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A Woodstove Compendium

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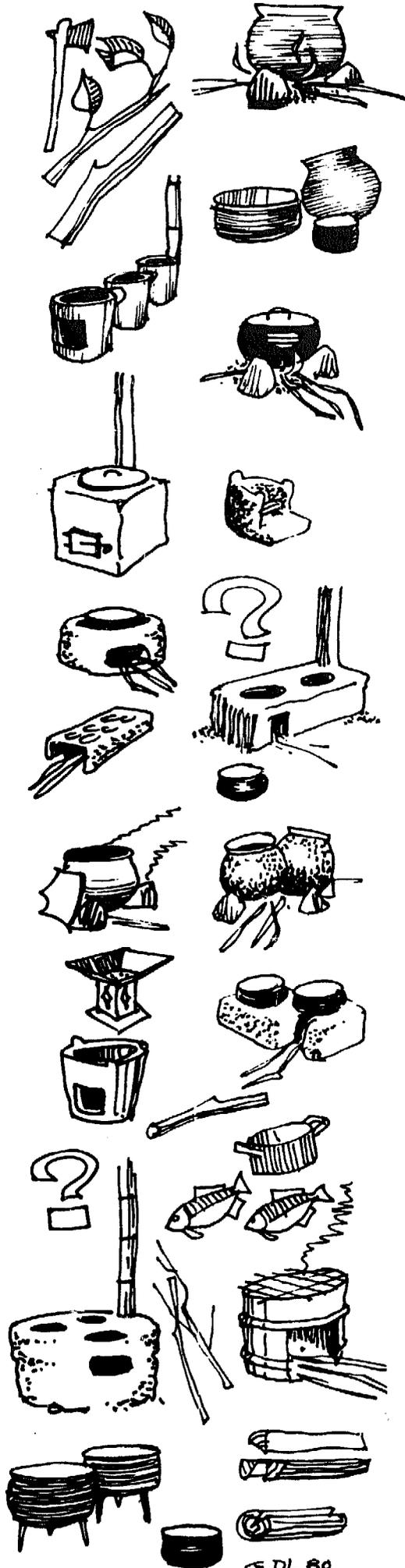
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by
G. De Lepeleire
K. Krishna Prasad
P. Verhaart
P. Visser

prepared for the technical panel
 on fuel wood and charcoal on the
 U.N. Conference on new and
 renewable sources of energy
 Nairobi
 Aug. 81

a publication from the wood-burning
 stove group, the Netherlands.

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Preface

To live, man must eat. To be edible, food must be cooked. For more than half the world's population, living in the rural areas or the cities of the third world, fuelwood and its derivative, charcoal, are as essential to survival as food itself.

The problem of fuelwood is more menacing than is usually realized. Unless adequate measures are taken, the fuelwood supply for some 1000 million people will be so critical by the year 2000 that they are no longer able to cook their food adequately. A further 2000 million or more will then be facing similar critical shortages within one or two decades. As more wood is cut, deserts will spread. We may be heading for a famine worse than any known famine in history.

For the large majority of the populations involved, there is no alternative to using wood, charcoal or agricultural waste: in the current international economic order, imported fossil fuels are too expensive, and the infrastructure to ensure their availability is lacking. Increasing the supply of the biomass fuels, and using

them more efficiently, will be vital tasks in the coming decades.

It is not widely known that in developing countries roughly three times as much fuel per person is used for the cooking process as in the industrialized nations. The main reason is the poor fuel efficiency of the traditional stoves. Many proposals for better stoves have been made, but up to the present few have shown proven performance or have received widespread acceptance. There is no doubt, however, that much improved fuel use is possible.

In the coming decades, many people all over the world will be working on designing, manufacturing and introducing improved cooking stoves. In asking for this compendium to be prepared, our Technical Panel has aimed at creating a tool that would be of use to all these workers, and to all those who have the responsibility for initiating, funding, managing and evaluating projects in this field. For this task, we were fortunate to be able to call on the expertise of a number of scientists closely associated with the Woodstove Group at the Eindhoven University of Technology. It is largely due to their initiative that this compendium has been expanded from a simple survey of existing literature to the present form, which evaluates both the present state of our scientific understanding and the still considerable gaps in our knowledge.

The subject of cooking stoves is entering a period of rapid development. One can expect that, within a few years, the transition from 'art' to 'science' and 'idea' to 'practice' will have proceeded far enough for some future compendium to be able to present what at this moment is still lacking: explicit guidelines for stove design, and explicit recommendations of proven designs.

This compendium has been prepared for the Technical Panel on Fuelwood and Charcoal, one of the eight Technical Panels of the United Nations Conference on New and Renewable Sources of

Energy (UNERG), to be held in Nairobi in August 1981. The preparation, publishing and dissemination of this compendium was made possible by the financial support of the Netherlands government, to whom we express our thanks. We are also grateful for the constant support given to this publication by the Forestry Department of F.A.O., which supplied the technical secretariat for our panel.

Eindhoven, June 1981

Eric T. Ferguson

Member of the Technical Panel on Fuelwood and Charcoal.

Acknowledgements

Fifteen stove designs, together with relevant data were contributed by Mr. Stephen Joseph of ITDG, London. Sound practical advice from her experience as a field worker was given by Ms. Margo Bulk. Mr. Joan A. Boer contributed many useful suggestions from his experience as a Netherlands Volunteer. The authors think back with pleasure on the hours spent in fruitful discussion with these persons. We owe a special debt of gratitude to Mr. J.D.L. Harrison of the Energy Technology Support Unit at AERE Harwell for critically reviewing an earlier draft of the work.

Our thanks go to Mr. J.J. Arts of the library of the Department of Architecture THE for doing the Bibliography, to Ms. Noor van Gerwen and Ms. Els van der Steen for the large amount of typing they did for this compendium and to Ms. Christine C. Schermey and Mr. Peter D. de Graaf for transforming sketches into decent drawings of stoves.

A word of thanks too, to the printer of this compendium, Mr. Th. M. van Stiphout who kept assuring us that it would be finished on

time and did this so convincingly that we found the peace of mind to get the manuscript ready. In the same breath we must mention the enthusiastic help of the computer wizards of the Mechanical Engineering Department, Messrs. Jos Banens, Erhan Dukul and Lambert van Beukering who made it possible to transfer the contents of this compendium by telephone line to the printer's word processor.

The authors want to express their thanks to the Forestry Department of FAO and in particular to Mr. M.C. de Montalembert, who as Technical Secretary to the Panel made the arrangements to have this compendium prepared and actively stimulated our task by his constant interest.

The infectuous enthusiasm for wood stoves, the neat balance required between our engineering daydreaming and the stark field realism, and the occasional harassment to finish the work on time - these and many patient hours of his time were supplied with an abundant measure of goodwill by Dr. E.T. Ferguson. A mere thanks is not compensation enough for his contributions to the work.

Three of us (KKP and the two PV's) look back with affection on the alacrity with which Guido De Lepeleire produced the many sketches that adorn this book, very much like a magician pulling rabbits out of a hat. Special mention must be made of our wives and colleagues for tolerating with cheer and forbearance our preoccupation with this work, much to their disadvantage.

This work has taken a long time to come to fruition. Many friends and wellwishers have helped us in keeping our noses to the grindwheel with cries of 'when will it be ready?'. Our thanks for their enthusiasm.

Eindhoven, 30 june 1981.

Errata

We regret that many errors have crept into the text. These errata sheets provide corrections to only those that are likely to cause confusion. The authors.

page no.	line/no.	text	should read as
7	12	Ms. Noor van Gerwen	Ms. Noor van Gemert
20	15	analyzing	analyzes
20	20	nog	not
23	18	attenton	attention
24	4, 5	(VITA 1980 and Appro- vecho Institute 1980)	(VITA/ITDG 1980 and Acott et al 1980)
38	20	possible for example	possible. For example
49	8	GATE (1980)	Acott et al (1980)
53	22	overleaf	previous page
54	23	in the sketch below	in the sketch on page 55
56	8, 9	Shelton and Shapiro 1978	Shelton and Shapiro 1976
96	dimension	3720	372
133	3	This pot van have	This pot can have
159	24	Simon, Soli 1976	Simon and Solis 1976
209	29	Garberson	Garberson (1979)
255	21	An examination of figure 4.5.	An examination of figure 4.2.
257	2	$Q_r = F_{12} A_1 (T_1^4 - T_2^4)$	$Q_r = \tau F_{12} A_1 (T_1^4 - T_2^4)$
257	5	is the Stefan-	τ is the Stefan-
257	23	is a property of	λ is a property of
259	20	for for different	for different
263	6	Z_{\max} is	Z_{\max} (see figure 4.5) is
265	6	The table below	Table 4.1
266	4	(Krishna Prasad, 1981)	(Krishna Prasad, 1981 b)
266	12	$(8 < a < 16)$	$(8 < a < 20)$
268	11	= 18.900 kJ/kg.	= 18.700 kJ/kg.

page no.	line/no.	text	should read as
270	9	The figure has	Figure 4.8 has
270	10	1 m.s. ⁰⁸⁻¹	1 m.s. ⁻¹
273	17	(see figure 4.6)	(see figure 4.11)
299	3	the following table	table 4.3
309	23, 24	τ	T
309	26	than e few	than a few
316	9	friction factor f	friction factor λ
318	13	v^l	v'
318	20	is the density	ρ is the density
319	9	f is the pressure	f_1 is the pressure
321	9	heat input from table 4.	heat input from table 4.3.
327	14	square root of 2	square root of $\frac{1}{2}$
327	26	$A_g = \frac{12 \times 10^{-3}}{29,5} = 406 \text{ cm}^2$	$A_g = \frac{12 \times 10^3}{29,5} = 406 \text{ cm}^2$
354	20	of 5)	of 6)
Table 6.1			
356		k 10^{-3}	k 10^3
		M 10^{-6}	M 10^6
		G 10^{-9}	G 10^9
Table 6.2			
357	Mass	ton (short) $9,072 \times 10^{-2}$	ton (short) $9,072 \times 10^2$
	Time	clay	day
358	Volume	cu. inch $1,639 \times 10^{-6}$	cu. inch $1,639 \times 10^{-5}$
		gallon (Brit.) $4,546 \times$	gallon (Brit.) $4,546 \times 10^{-3}$
		gallon (U.S.) $3,785 \times$	gallon (U.S.) $3,785 \times 10^{-3}$
	Velocity	ft/min $5,08 \times$	ft/min $5,08 \times 10^{-3}$
	Sp. mass	lb(cu. in.)	lb/cu. in.
	Sp. Volume	cu.ft./lb. $6,243 \times 10^1$	cu. ft./lb. $6,243 \times 10^{-2}$

page no.	line/no.	text	should read as
Table 6.2			
359	Heating value	Btu/lb. 2,324 x cal/g 4,186 x	Btu/lb. 2,324 x 10 ³ cal/g 4,186 x 10 ³
	Specific heat	Btu/lb. F 4,186 x 10 kcal/kg C 4,186 x 10	Btu/(lb.F) 4,186 x 10 ³ kcal/(kg C) 4,186 x 10 ³
360	Mass flow	kg/min 1,667 x lb/min 7,56 x 10	kg/min 1,667 x 10 ⁻² lb/min 7,56 x 10 ⁻³
	Heat flux	Btu (m.sq.ft)	Btu/(h.sq.ft.)
	Heat conductivity	Btu. in/(sq.ft.h.F) 1,441 x kcal/(m.h.)	Btu. in/(sq.ft.h.F.) 1,441 x 10 ⁻¹ kcal/(m.h. °C)
360	9	$K = \frac{5}{9} F + 255,37$	$K = \frac{5}{9} F + 255,37$
365	7	Ahuja, S.B.C.	Ahuja, S.B.D.
365	15	Home Information Series	Home Science series
366	11	Sahel Iran zone	Sahelian zone
366	16	Anon (1978)	Shelton, J.W., Black, T., Chaffee, M. and Schwartz, M. (1978)
366	17	Preliminairy	preliminary
366	19	Anon (1979) (a)	Saubolle, B.R. (1979)
368	22	Aton, C., Brown, M. and Mc Gowan, T.	Aton, C.L., Brown, M.L. and Mc Gowan, T.F.
370	7	Corlett	Corlett, R.C.
371	1	Eckert and Drake	Eckert, E.R.G. and Drake, R.M.
371	4	Emmons	Emmons, H.W.
371	10, 13, 16	Evans, J.	Evans, I.
374	1	Kämmer, K.K.H.	Kämmer, K.K.H. (1980)

page no.	line/no.	text	should read as
376	9	Saubolle, B.	Saubolle, B.R.
377	7	Silva, D. da,	Silva, D. de,
378	1	Vandele, L.	Vandaele, L.
378	16	Williams	Williams, F.
378	17	"Condenset....	"Condensed....

Additions to the bibliography:

Eckholm, E.P. (1973)

"Losing ground: Environmental stress and world food prospects. W.W. Norton & co., New York.

Bussmann, P.J.T. (1981)

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VITA/ITDG (1980)

Wood conserving cookstoves. pp. 111. VITA (Volunteers in Technical Assistance), Mt. Rainier, Maryland.

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Summary

The compendium is divided into seven chapters:

1. Introduction;
2. A common sense guide to stove technology;
3. Design descriptions;
4. A Technical guide to stove technology;
5. Testing of stoves;
6. A Glossary;
7. Bibliography.

This summary provides a brief outline of the material in the book. It is hoped that this will enable the interested reader to pick what he wants to read in greater detail.

1. Introduction

The theme of the present work is that the design of a 'good' stove is an engineering task. Unfortunately stoves at present are being

built by almost everybody except engineers. Thus it becomes mandatory to explain the choice of material included in the work and the manner of its organization. This is done at some length in this section. Some attention is paid to the readership who would benefit from the work.

2. A common sense guide to the stove Technology

2.1. A brief discussion on the utilization of heat in different cooking tasks provides the basic background for defining the functions of a stove.

2.2. This section is a simplified guide to the working of a stove. At the outset a distinction is made between the burning properties of thin and thick pieces of wood. A description of combustion in an open fire is presented next, indicating the rationale behind the choice of the pan position with respect to the fire.

A description of the wind effects on the open fire naturally leads to the concept of shielded fires. The behaviour of a thin metallic shield is compared with that of a heavy shield. The role of chimney draught on combustion and heat transfer to the pans is discussed. The need for sinking the pans in the stove body to increase heat transfer to them in such designs is pointed out. The section ends with some comments on: grates; moisture content in wood and its influence on stove performance; the output control of stoves with dampers.

2.3. The final section of this chapter serves as an introduction to the next chapter. It gives some useful hints on the factors that are to be considered before embarking on the difficult road to introducing stoves.

3. Design Descriptions

This chapter in some sense represents the genesis of the present work and still forms its core. Over 100 designs - some traditional and others of recent origin - have been listed.

3.1. A table provides the highlights of each design - overall dimensions, fuel used, materials of construction and the name under which the design is commonly known - according to a system of classification that generally follows the description in 2.2.

3.2. This is the largest section in the book and assembles data sheets for each of the designs. They include drawings, pictorial representations, constructional details and test results wherever they are available, with appropriate bibliographic citations.

3.3. A possible method of converting the information in the data sheets into usable hardware is indicated through an example. In particular attention is drawn to available information. This is usually inadequate for successful implementation of the designs. A few comments are made on estimating material requirements and costs for the example design. At this point, some digression would be not out of place. The intention of using more than half the book in giving the design descriptions is five-fold. Firstly, it represents a storehouse of ideas that have been used in this class of stoves. Secondly, it makes it possible to check any 'new' designs against this list and obtain a first guess on their merits. Thirdly, it provides in an accessible manner a means by which one can narrow down choices according to circumstances like cooking practices and availability of fuels, materials and skills prevailing in a community. Fourthly, it provides for easy comparisons among the different designs by assembling the information in a uniform style. Finally, it brings out clearly the facts that are not known (or if known not documented) about these designs. For example, none of

the designs provide satisfactory answers (if they provide any at all) to the following questions which are vital from the user's point of view:

- (a) How long does it take to bring a given quantity of water to boil?
- (b) How much wood (of a given quality) does it use to achieve the above task?
- (c) Does it cater to the rather low power output needs of simmering operations?

One can assemble more questions of this sort. This should do for a start.

4. A Technical Guide to stove Technology

This chapter returns to the theme that was presented earlier - developing a stove design is an engineering task. It has been relegated to the latter part of the book because it is somewhat tougher reading for someone who is not used to engineering literature. It is to be emphasized that the material does not use very much more than high school physics.

4.1. Some background information on the physical processes in a stove is presented first.

4.2. This section runs more or less parallel to section 2.2, but the descriptions are more detailed. It is clearly established that we are able to provide very detailed descriptions of combustion, fluid flow and heat transfer processes in a stove in a qualitative sense, certain quantitative estimates of heat transfer to the pan from the fire can

serve as good first guesses for design evolution. By and large the main limitation at the present moment is one of converting the qualitative information into quantitative data that can be used in reliable design practice. In general it can be stated with confidence that careful laboratory experimentation coupled with the existing ability in engineering computations should be able to overcome this situation.

4.3. This section is design oriented. It adopts the viewpoint that since we do not have quantitative data on wood stoves, we might as well use for a start the available information on gas ranges and boiler furnace practice. The information assembled would not only be useful as design guidelines but also serves a notice on the researchers and designers of stoves as to the kind of information they ought to be providing for their designs. An example is given as to how to use the information for designing stoves.

5. Testing of Stoves

The work envisaged in section 4.2 is research laboratory oriented. There obviously exist considerable differences between the idealized laboratory conditions and the real life kitchen. Hence testing stoves under field conditions is essential. Suggestions for testing procedures are detailed in this section and recommendations are made for recording the information in a systematic manner . A word of caution should be introduced here. If the information from testing is to have any practical value, it has to be carried out with care and all observations recorded. An eye for detail is vital in this class of work. Testing has the twin purposes of verifying claims about a design and providing information to narrow the gap between laboratory and field situations. The editors of this compendium strongly urge those who are contemplating to

introduce 50 stoves or more to spend the time and effort to read the chapters 4 and 5 carefully.

6. Glossary

This explains some of the technical terms employed in the work. In addition it provides conversion factors for changing the SI system of units (which is the version used in the main body of the work) to other units.

7. Bibliography

The original literature sources and some additional reading material are listed in this bibliography.

1

Introduction

According to the shorter Oxford Dictionary a compendium is: "An abridgement of a larger work or treatise giving the sense and substance within smaller compass". At present no treatise covering the subject of wood stoves for use by the third world poor is available. What is available, however, is a considerable body of work describing different types of stoves. Unfortunately this work is scattered among mimeographed notes and reports of diverse development agencies. The original purpose of this compendium was simply to compile all the known designs according to a set of predetermined norms.

The authors soon realized that the norms mentioned above are not easy to come by. The main difficulty in this connection lies in the fact that information available on many of the designs is scanty. In addition, whatever is available, is in a form that does not permit easy comparisons so that one could assess the 'quality' and suitability of a given design in a specific situation. Under such conditions the choice of norms would perforce be arbitrary. Thus it

seems unwise to pass any judgement on the quality of the designs. Instead, we have opted for an orderly presentation of information as it was available at the moment of this writing.

Clearly there is a danger in forcing order on a rather chaotic field of work. It lends to the subject an aura of elegance and superficial simplicity that is not characteristic of the original. This is explicitly highlighted in some notes appended to the design data sheets.

Leaving the work in this untidy state appeared quite unsatisfactory to our engineering minds. It is our contention that a wood stove, in spite of its apparent simplicity, is not a trivial piece of engineering. Thus it seemed worthwhile adding a chapter giving an engineering description of the wood stove processes. It starts by outlining the principles underlying the phenomena as they occur in wood stoves - the phenomena of combustion, heat transfer and fluid flow. This is followed by a section that analyzing the behaviour of three distinctive designs. Though these sections are quite involved in their technical content, they are still in the realm of qualitative descriptions. However they serve the purpose of creating an insight into the complexity of the problem. Further they provide a basis not only for judging the existing designs but also for carrying out improvements on them.

Since the descriptions mentioned above are not yet accessible to quantification, they can not be put in the form of a codified design practice. Notwithstanding this, we do not subscribe to the present haphazard cut-and-try approaches to the design of stoves. We believe the cause is not as hopeless as it appears and have tried to use our background as students, teachers and research workers in engineering to put together a methodology for arriving at stove designs. We have borrowed heavily from the practice that is commonly adopted in gas ranges and steam boilers. We fully realize that many numbers given in this section are quite suspect.

They at best serve as a starting point for arriving at designs to match the needs of a specific application. Nevertheless the procedure can save much needless experimentation to reinvent the wheel as it were. For example chimney heights require to be different in hilly areas from those in plains for a given design. We hope as time progresses it will be possible to substitute the present numbers with more authentic data on wood stoves.

The foregoing discussion brings out three deficiencies in the current state of art.

- (a) The existing designs are not capable of being tabulated according to a merit order list for lack of adequate informaton.
- (b) The technical descriptions can not be quantified yet.
- (c) The design methodology is based on intelligent guesses rather than hard data.

It is possible that sustained R and D effort will overcome these deficiencies in due course. But the problem of wood stoves is here now and can not wait for this neat course of action to bear fruit. In our opinion the answer is field testing. Such field testing will also help in the evolution of a mature technology. Thus a whole chapter devotes its attention to the methods of field testing. The chapter has been conceived to fulfil two purposes.

The immediate problem of the selection of the most suitable stove for a given situation from among a set of prospective candidates is an obvious first need.

The second reason for testing is more subtle, but vital. There is reason to believe that, in the years to come, many stove progammes will be initiated and executed with varying degrees of

success. If one has to learn from success stories, it is not just sufficient to record the amount of wood used to cook a given meal. It is essential to record additional data pertaining to the circumstances (like geographic, resource base and socio-cultural circumstances) under which the information on wood use was collected. Such a procedure would also take us further along on the road to the promised land of 'the perfect stove'. This is the reason why considerable attention has been paid in this chapter to the task of information collection on the nature of the community in which testing is carried out.

Finally, the testing procedure suggested explicitly takes into account the non-availability of specialised instruments to carry out such tests. Many simple improvisations from locally available resources are recommended.

To our dismay, we find the current stove scene to be dominated by almost everybody except engineers. The treatment described in the preceding paragraphs completely misses this point. In order to cater for this part of our audience, a chapter has been added to provide a 'popular' account of what cooking of food is about and how stoves work. These sections are copiously illustrated to assist the readers. Moreover the chapter specifically tackles the question: "which stove?" The original intention was to make this section some sort of a 'consumer's guide' for selecting a stove. Because of the difficulties of rating stoves, we satisfy ourselves with a general outline of the factors that need to be considered before choosing a stove for introduction.

We have reordered the material described in the foregoing paragraphs taking specifically into account that mostly non-engineers are involved in the business of planning for, and actually introducing stoves. The chapter that follows this introduction presents the popular account of stoves. Chapter 3 concerns the

design descriptions. The technical descriptions and testing have been relegated to Chapters 4 and 5. There is an inevitable overlap between Chapters 2 and 4 - this is the only way we could reconcile our view that stove designing is an engineering task and the present fact that tends to ignore this view. We hope that the policy maker will go through Chapter 2 and persuade engineers to take up the task of reading Chapter 4, modify it were necessary and design stoves for specific applications.

We have the utmost sympathy for field workers who are involved in the difficult task of introducing stoves. Our suggestion to them is to take the time and effort to go through Chapters 4 and 5 carefully. We believe that this study will yield handsome dividends in that they would be able to reduce the number of painful iterations that are inevitable to convert the drawings of Chapter 3 into usable hardware. To lighten the task of reading we have provided a glossary in Chapter 6 to explain some of the technical terms.

We should like to end this introduction by drawing attention to a few important omissions. We have not explicitly described the nature of the wood fuel crisis. Others have done so more eloquently (see for example, Eckholm 1976). In our opinion the ecological or world energy arguments will carry little weight with the daily users of wood stoves or open fires. The decision for accepting designs deviating from the traditional will come about through arguments much closer to the user's ken, such as increased comfort, obvious fuel economy and of course the cost of the stove.

We have not touched upon the all-important question of manufacturing. Our attitude here has been: anything goes. If in a certain locality there is metalworking skill available, we don't insist that the stove be made of clay. Of course, the design should have taken into account the particular properties of metal as a stove

material. But the manufacturing process should suit the locality and we hesitate to prescribe the details of its execution. For building stoves of clay, some descriptions of material preparation and design implementation are available elsewhere (VITA 1980 and Approvecho Institute 1980). While we do not completely agree with the general philosophy behind these publications, we are not in a position to recommend anything better at this moment. Thus people engaged in the construction of clay stoves would do well to consult these publications. They should serve as a starting point for construction of clay stoves.

The authors feel certain that this compendium is by no means the final word on the wood stove problem. Indeed serious research seems to have hardly begun. Our effort will not have been in vain if at the minimum it stimulates serious research and a responsible attitude towards designing stoves and claims made thereon.

2

A common sense stove guide

2.1 The use of heat in preparing food

By P. Verhaart

2.1.1 Introduction

With the exception of a few items (some fruits, soft plant leaves and stalks, some seafood like herring and oysters and some insect larvae like Witchety grubs) most vegetable and animal products need the application of heat in order to become fit for human consumption. The manner in which heat is applied varies for the different kinds of food, as does the amount of heat needed for the process. These points will be further worked out in the following paragraphs.

2.1.2 Boiling

This is the method most generally used to prepare food. The raw

food is placed in a vessel with water and minor amounts of additives such as salt and spices. The vessel is then placed on the stove to raise the temperature of the vessel's contents to the boiling point. Usually after the boiling point is reached, the heat output of the stove is diminished where possible so that the contents of the cooking vessel remain at boiling point but as little steam generation as possible takes place. The boiling process takes a certain amount of time depending on the food and on the cooking habits. It can take up to several hours. The process time can be shortened by boiling at elevated temperatures. In the affluent parts of the world so-called pressure cookers are used; closed vessels in which a certain overpressure of steam is maintained. Cooking time is shortened by a factor of 4 to 6 depending on the type of food cooked. Needless to say, the pressure cooker is currently used as a time saving device rather than to save energy. Let us note that boiling is unique among the cooking processes in being a uniform temperature process. The temperature is essentially constant throughout the contents of the pan. As cooking processes need very little heat for the chemical reactions it is usually sufficient to heat the pan with its contents to boiling point and then take it off the stove and leave it for the required length of time wrapped in straw or paper or blankets. A more elaborate utensil to do this job is known in several civilisations as a haybox. The haybox will probably save far more fuel than any improvement in woodstoves.

2.1.3 Frying

In frying the heat is transferred to the food particles by hot fat or oil. The temperature of the fat or oil is markedly above the boiling point of water, typically between 150 and 190 C. It is very much a non-uniform temperature process: it is essential for the end product that the outside surface of the food particles consist of material partially thermally decomposed. The bulk of the food

particles does not reach a temperature above the boiling point due to the presence of water. In frying there is an essential need for continuous heat input during the whole process, herein it differs sharply from boiling.

2.1.4 Grilling

Can be done in two ways. One way is exposing the food to thermal radiation, the other is placing the food on a hot flat horizontal surface. The heat transfer in the latter case is by conduction. Here also some thermal decomposition of the outer layer of the food particles is essential, therefore a continuous supply of heat is necessary. For grilling by radiation a charcoal fire can be used.

2.1.5 Baking

In baking the food to be baked is placed in a space where there is a high temperature. The transfer of heat is both by radiation and by convection. It is a slow process and the heat is required at a high (higher than the boiling point) temperature. Some thermal decomposition of the baked food is essential.

2.2 Understanding woodfires and stoves

By G. De Lepeleire

When we cook on a traditional open fire we use three stones or something similar to set the cooking pot at a suitable height over the fire. The fire is watched and adapted to the needs at all times. What happens? Let's start a wood fire.

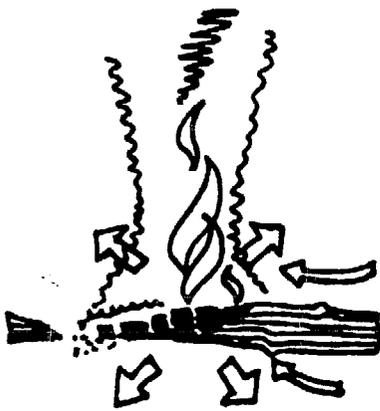
Thick wood burns slowly.

For easy lighting, and to get sufficient power from the fire, thick wood is often split, so that it burns faster. The wood is stacked in such a way that air can come freely into the fire to sustain the combustion; it should be just enough, not too much: excessive air intake cools the fire and results in poor combustion. So experienced woodfire users build up a suitable fire structure by putting the sticks of wood somewhat crosswise. If the heat output is to be reduced, this can be done rapidly by withdrawing some or all of the wood. Where wood is scarce, people watch the fire with care and feed wood frequently in small portions. By doing so they get a more constant burning rate, closely adapted to the output required. They avoid waste, and are saving wood. When wood is scarce, other vegetable matter is also burnt, for example millet stalks. This thin material might burn too fast. People have learnt to moisten it slightly.

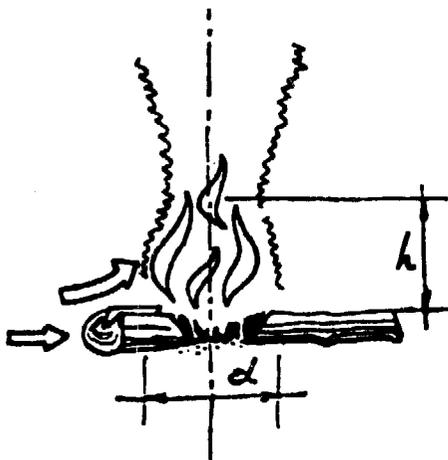




Whereas the combustion of moist fuel in principle gives less heat, fuel can be saved in this case as the combustion is slowed down and non usable (waste) heat output is limited.



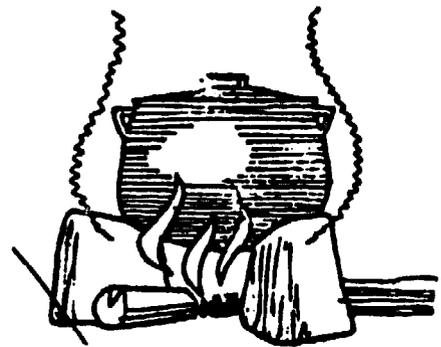
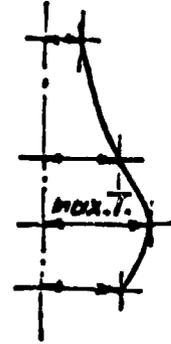
The fire is on. Wood combustion is a complex phenomenon as wood itself is a complex material. Roughly speaking, wood decomposes at high temperature and volatiles come out. Mixed at high temperature with air, they burn as flames. If there is no space for good mixing with air, and/or the temperature is too low, the combustion is incomplete. You then get smoke. Apart from volatiles wood contains charcoal. This burns without flames, simply glowing. The rest is fine ash.



Volatiles and charcoal burn in sequence. However, in a woodfire volatiles and charcoal are often burning at the same time, in different spots. A woodfire gives off radiation (you can see and feel it) and a plume of hot combustion gases (this you can see as well), which gradually cools down by mixing with ambient air. Now, a cooking pot is set over the fire at an appropriate height, which is a compromise. Let's see how.

The burning woodfire (glowing

charcoal, light and flames) radiates both light and heat in all directions, just as does a candle. One can see that only a fraction of the light and heat goes to the pot bottom, a fraction goes to the three stones and the soil, the remainder is lost in the far environment. At the same time the flames and the hot combustion gases (with some smoke) lick and flow around the cooking pot body, which thus gets additional heat input by convection from all sides if there is no wind. Now, if the pot is put closer to the fire, it gets more radiant heat, and perhaps more convective heat too. But if the pot is too close the flames cannot develop, the mixing of volatiles and combustion air is poor and the fire may even go out. Obviously the best thing is to put the pot at an appropriate height to get fair combustion together with a reasonable heat transfer. Of course when the cooking pot rises in temperature, it also radiates heat, to the environment.



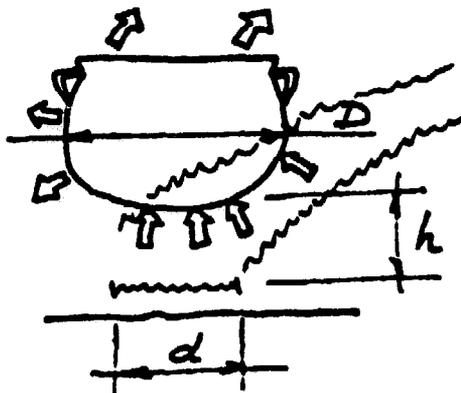
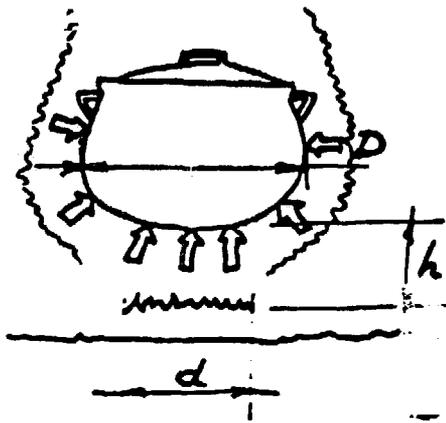
Note that the size (diameter) of the fire should be adapted to the pot diameter. If the fire size is too small you don't get enough power. If it is too large, the excessive power output is poorly transferred to the pot and wasted. At all times the heat output should be adapted to the need.





Simmering for example needs only low heat. A higher heat input than necessary is wasted causing excessive evaporation. This can be limited by a lid on top of the pot.

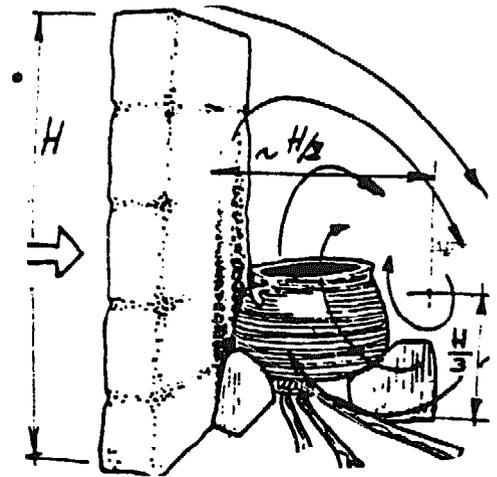
After all, a three stones open fire is a cooking device which has been used for millennia. It is a very low cost equipment, easy to observe and to control. However there are drawbacks too. Wood is running out in some places. Moreover, the open fire offers a risk for children playing around, and the smoke is an irritating and unhealthy thing. Finally, in windy conditions the open fire suffers a lot. In general the wind blowing through the fire activates the combustion and increases the heat output. This however is blown away from the pot, which instead of convective heat input now shows heat losses on the upwind side. As a consequence the open fire, even when watched with care, shows rather high wood consumption.



A well known trick against this is shielding. One can use very simple means, for example pieces of broken pottery set around the fire, taking into account the wind direction. Where the wind blows most of the time from the same side, the fire can be built behind a protecting wall. In this case the wind

does not blow through the fire, but rather upward, due to the whirl behind the wall. So the convective flow pattern survives.

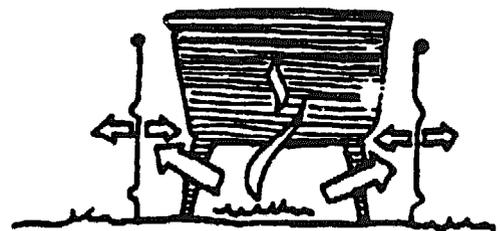
Other people have found that you can make a shield all around for example in pottery, in steel sheet or even in a clay-sand mix. If sufficient air intake is guaranteed, for example with the help of a grate, this has been found very satisfactory. The all-around shield obviously supports the convective flow pattern around the pot. In addition, the radiation output is partly recovered and the cooling of flue gas through mixing is reduced.

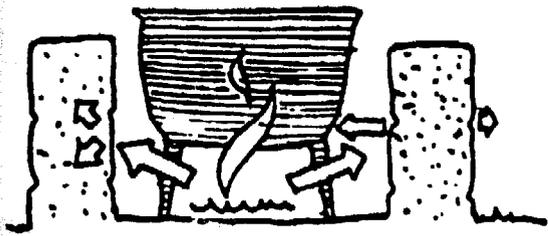


Note the different reactions of a thin (light) shield and a thick shield. A thin shield (steel sheet for example) has low heat resistance and capacity. It heats up rapidly, inside and outside temperatures are very close to each other.

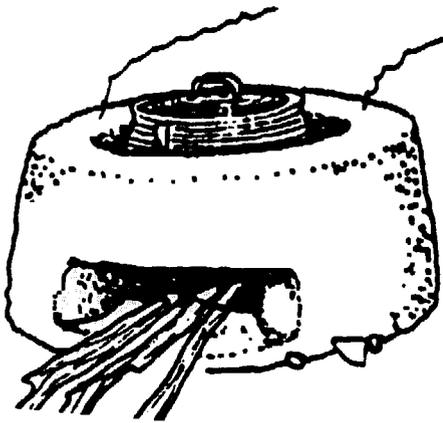
A thick shield has appreciable heat resistance and capacity. So, when the fire is lit this shield heats up slowly due to its heat capacity. However, after some time, due to its heat flow resistance, the inside gets pretty hot whereas the outside is only warm.

Therefore, the thin shield will, very rapidly, reradiate some heat into the fire and to the pot but also loose heat to

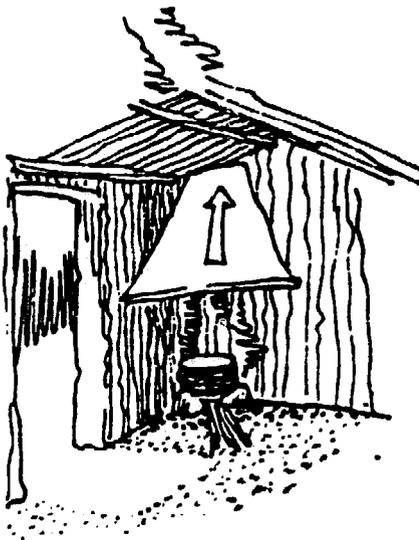




the surroundings. The thick shield after some time will recover more heat and lose less. So the thin shield is expected to be better for short operations, the thick one for long lasting cooking.



In general a shielded fire performs better than a simple open fire as to wood consumption, because less heat is lost and the fire burns hotter and better. Moreover, the safety around the fire is increased. It is not too difficult to control. The smoke however is still there. You can try to burn wood without smoke: it is really difficult. But you can get rid of its effects. When, cooking inside the house, you use some inverted hopper over the fire place with a smoke outlet through the roof. In former days this was common practice in Europe for example. Of course, one has to look for sufficiently fire resisting material.



Another way out is a closed fire with a chimney, an option that has got widespread publicity lately. But be careful: a stove with a chimney can handle the smoke problem, but its wood consumption can be better or can be worse than with an open fire. Designing an appropriate stove is a difficult thing. Small changes can have dramatic consequences. Let's go through it and

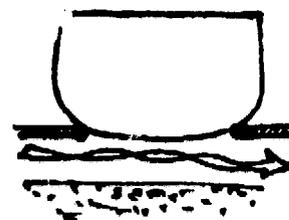
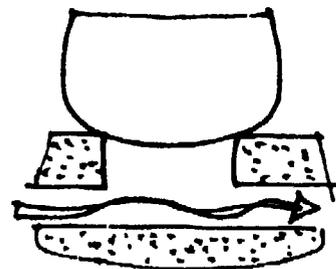
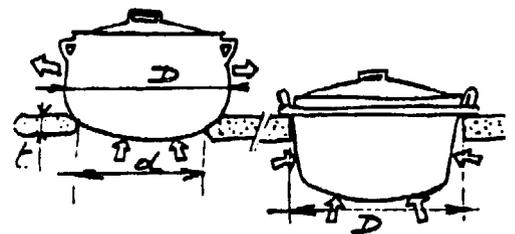
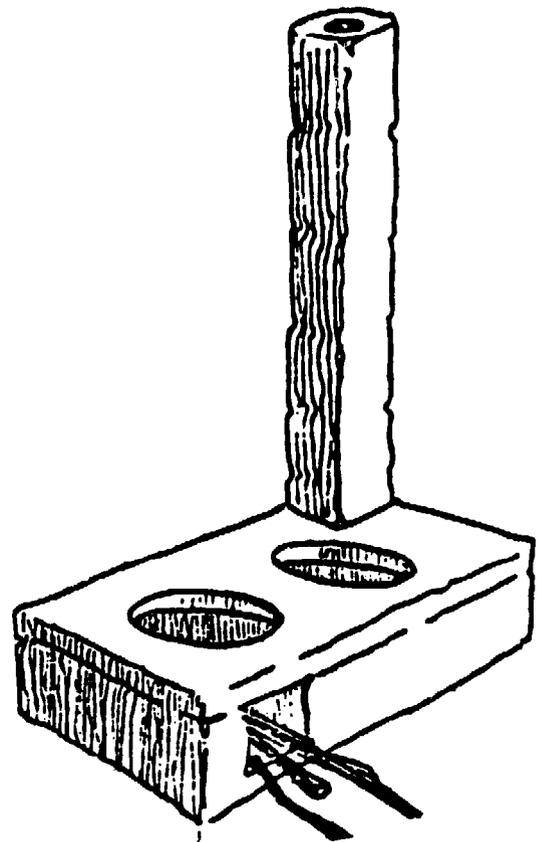
see what happens. A closed woodstove essentially consists of a stove body. The fire is lit inside a firebox. Wood is fed through the firebox entrance, the hot gases go through a flue to the chimney. Cooking pots fit in holes over the firebox and the gas flue.

Note that a chimney is necessary to pull sufficient air through the system, which indeed shows gas flow resistances well over those of an open or shielded fire.

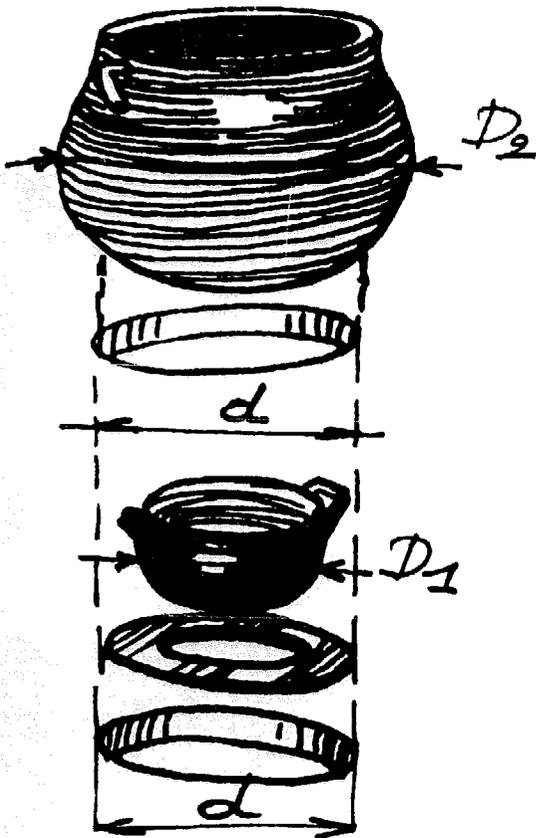
A striking thing is that the cooking pots get heat input only through the bottom. The side surfaces no longer get heat but only lose it to the environment. On the other hand, more pots can be used on one fire. The stove body acts as a shield around the fire.

The holes on top of the stove body have a diameter smaller than the pot diameter. If a curved bottom is used on too large a hole, the pot on heating up can get stuck in the hole by thermal expansion and may damage the stove.

Obviously it would be fine if more of the pot's surface could get heat input and less of its surface be exposed to losses. One can achieve this by sinking the pot in the stove body. To avoid the pot getting stuck and air leakage, you



need a pot with a rim all around, perhaps an expensive innovation. On the other hand it is clear that the top cover thickness should be kept as small as possible. Too thick a top cover is bad for radiant and convective heat transfer to the pot bottom. However, if a stove is to be built from sand-clay mixes, you cannot make very thin walls because of poor mechanical strength of the material.



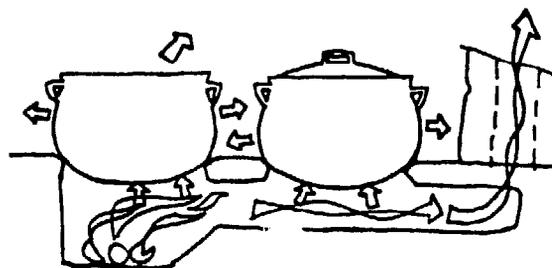
A metallic top cover plate would be a good but more expensive way out. Another problem of holes is the use of different pot diameters: this is difficult unless adapter rings are used. These again should be preferably made out of metal. Pottery breaks easily. As in any cooking process, lids on the pots are highly desirable to limit the evaporation losses.

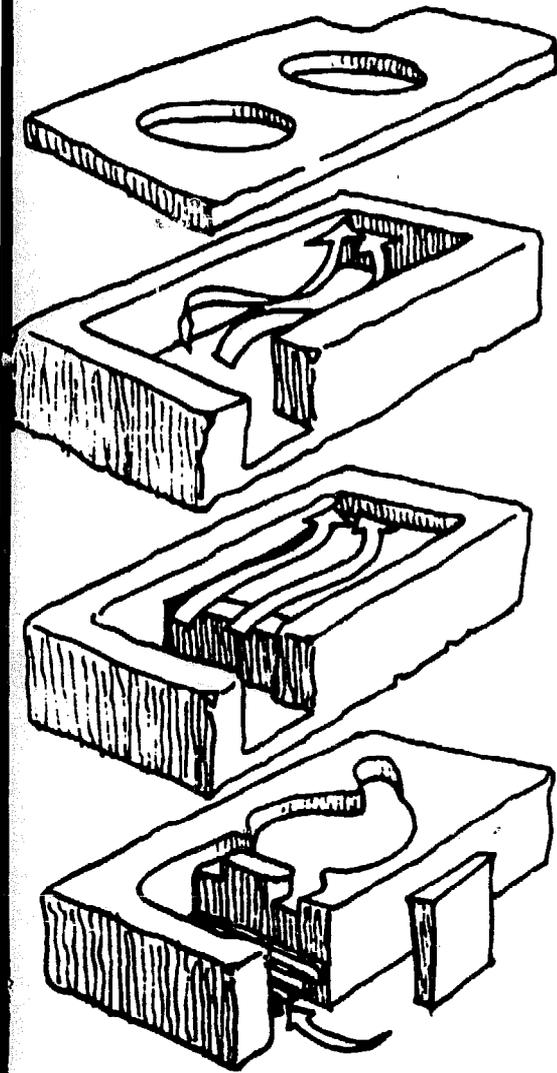
Let's now Look at the firebox. Don't make it too large. The firewood within the box cannot be positioned in detail as can be done in an open fire.

Normally it will spread over the entire available surface. So, keep it small, not larger than the best size of an open fire and this certainly smaller than the pot diameter. As to the height, the compromise situation of the open fire persists. The free height between pot bottom and the top of the firebed

should be about one hand. The firebox entrance (or front loading door) should be large enough to feed the wood, and to position it to some extent to get a good fire structure. On the other hand it should not be too large, to avoid excessive radiation losses from the fire to the environment. Note that the stove body acts as a shield around the fire.

When a fire is lit in the firebox, flames, hot gases and smoke move through the horizontal flue, and out through the vertical chimney. Obviously the gas flow in the firebox, under the first cooking pot looks somewhat like an open fire under wind, as flames go away horizontally. If the draught is too strong this 'wind' effect is strong too. The combustion rate will be high but the heat transfer to the first pot rather poor. We come back to this point when we discuss the chimney. To increase the heat transfer to the first pot, the fire can be set somewhat 'upstream' from the pot. Now, if the flue is large as to cross section the flow velocities and pressure drops are low and a short chimney is good enough. However, low flow velocities give low convective heat transfer to the pot bottoms over the flue. This can be improved with baffles, that means some built-in obstructions which force the gases to flow along the





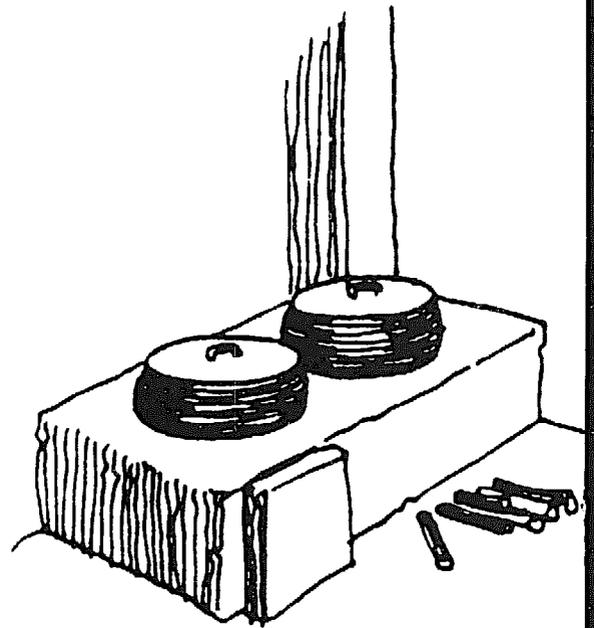
pot bottoms with high velocity, good heat transfer and ... higher pressure drop. In principle, for highest heat transfer, the baffles should be closely adapted to the pot bottoms. However, if different pot sizes are used on the same hole, one can get into trouble. All potsizes should sink over the same depth into the stove body, and have similar shapes. If not, the flow should be regulated with a damper.

As appears from the foregoing, the chimney should be dimensioned in close correlation with the stove body design. Moreover, the flow resistance of the chimney should be adaptable with an air damper when different pot sizes are used on a baffled stove. If too much air is pulled through the system, the combustion rate and specific wood consumption go up. If the draught is too low, the power is low too, and moreover smoke might come out from the stove body through air leakage paths around the pots or even through the front loading door. Note that pressure drops associated with high velocities under the pan bottoms increase the heat transfer whereas other pressure drops in bends, dampers and the chimney do not. Therefore, so far as possible, all pressure drops should be concentrated under the pan bottoms.

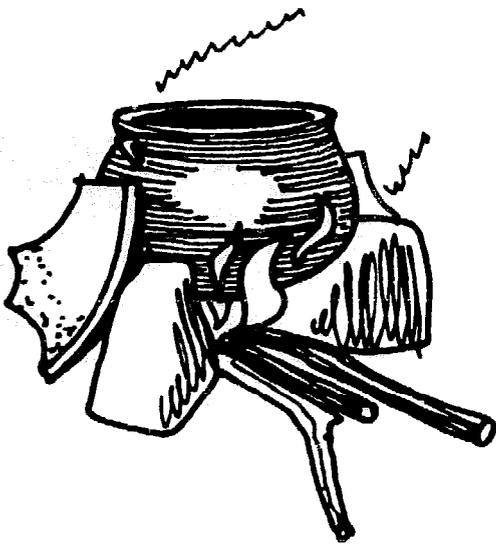
The gasflow generated by a chimney increases with increasing height and cross section. Remember that a chimney progressively clogs up with soot, and that it needs periodical cleaning.

Most people prefer to burn long wood, as cutting wood is a demanding job. Beyond this, long wood together with an open front loading door seems to be easier to handle: you can observe the fire, and regulate by moving the wood as in an open fire. On the other hand, if one used short wood, the front door could be used to regulate the air intake, at the same time it acts as an extra shield with the known advantages. In any case even when long wood is burnt, obviously with an open front door, it is good practice to have the door closed whenever possible for example when cooking goes on at a low rate with remaining charcoal and after cooking. In this way the stove body is kept warm and can give other services like hot water, baking, house heating, etc...

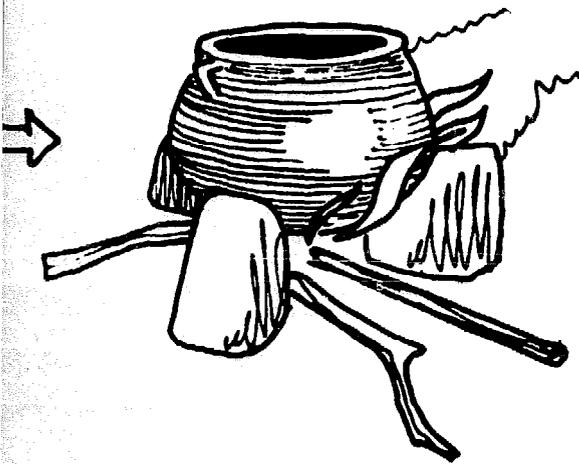
In fact regulation of the power output of the fire is important. It has already been stressed that excessive power for simmering is simply wasted. So a good cooking stove should be able to give low as well as high power, both in a stable manner. Moreover the transition is



important. Now for this the open fire with long wood is excellent. Burning wood can be removed and extinguished for rapid and efficient reduction of the power output, as already pointed out. In a closed stove burning short wood this is not feasible, but there the combustion air can be controlled. It should be stressed that power reduction by means of air dampers is rather slow. In fact, when an air damper is closed, the combustion of volatiles is interfered with, they continue to be evolved for some time until the temperature of the fire as a whole has decreased. There will therefore be a transition period of incomplete combustion. To shorten this the wood should be charged continuously.



As in an open or shielded fire, a grate can help the air intake and mixing process and this improves the combustion. In operating a stove, ashes should be removed regularly to maintain the air flow paths.



A problem is the choice of materials. Cast iron is good but expensive. Hard pottery is breakable. One might use thin bricks, set with a gap in between.

When rice husks or similar densely packed material is to be burnt, a grate will be needed. When for example a

perforated steel sheet is used, set at a steep angle, the husks can slide down and be fed automatically as the combustion proceeds.

Charcoal combustion is a different matter again. In this case there are no volatiles to be burnt so the necessary combustion volumes are smaller. We get all the burning in the charcoal bed. As charcoal is brittle and small in size it adapts closely to any shape of grate and pan bottom. The latter can therefore be very close to the fire so that the heat transfer by radiation can be very intense. To improve the performance of charcoal fires is mainly a matter of reducing losses to the environment.

As can be seen from the foregoing story, the stove performance depends on shapes and material qualities. Optimum design is a matter of compromises linked together. On the other hand, the choice of materials and designs is limited by local availability and skills. Here again a compromise has to be made.

2.3 Choosing a stove

to the prospective introducer

By G. De Lepeleire.

The present booklet is not a catalogue where you can simply select readily available answers to your problems. It is quite often incomplete information on stove designs as tried by others. If you are looking for an appropriate stove design, remember that performance and success depend on a lot of circumstances such as cooking programs, social structures, fuels, skills and availability of tools, local convictions, economic potentials etc.

Before pushing innovation, be informed on how things are done today and why. Do not believe that you can make final decisions; let people, let women decide.

Let's look at some points of interest.

The cooking program is essential and can be quite different from one place to another. Simmering is not like frying and needs different equipment. Note that the local kitchen is often conditioned by local agricultural potentials which in turn depend on soil and climatic conditions and these you have to accept. The social structure too is important. For example where large families live together, the cooking vessels will be dimensioned accordingly. Often rural social habits differ considerably from the urban way of life.

Traditional cooking vessels have various shapes and sizes: try to understand why. In any case the stove design must be compatible with the cooking vessels, this really is a must. If new vessels, together with new stove designs are considered, remember the

higher cost involved and make sure that the new vessels are acceptable. Ask the women.

Obviously the wood fuel availability is important. This has to do not only with quality and quantity but also with available means and skills for preparation of it before firing. Often wood is fired in great lengths: it is the easy way with a traditional open fire. Before considering a stove design with an air inlet damper, be sure that the users are prepared to cut the wood in short pieces (a demanding extra job), as necessary for this type of stove.

Local materials and skills are to be considered; for obvious economic reasons local manufacture is preferable. Check local artisan potentials: they are often underestimated. Check local social and commercial structures. The introduction of wood stoves requires less and more concentrated instruction effort if it goes with the help of local artisans (blacksmiths, bricklayers, metal founders etc.) Note that for good performance a stove should be not only well built but also well used. Be sure that the necessary instruction can be given to the end users. Look for cooperation with existing structures such as women's associations etc. A new stove design may be splendid in theory but ineffective in practice if it is not readily accepted by the population. In general the first argument for acceptance of new ideas is the immediate increase in comfort and the associated investment; the second is the long term advantage to the user, for example fuel saving. Ecological arguments will seldom sway the users: they can not afford it.

Lifetime of equipment is important but often not identified as such at the beginning. Progressive improvement of stove designs for example, through selection of better (and more expensive) materials might be a good approach.

Do not believe a simple claim about the efficiency or performance

of a stove design without evidence. In many instances no evidence is given. It happens that laboratory tests are advocated: remember that so far no lab testing procedures exist to simulate in detail the practical use. Moreover it is not clear what efficiency means. In other cases, field experience is reported. Check if operating conditions are reported in detail and whether they are similar or different from your own conditions. After all, the right way is to gather your own field experience and let the cooking women decide (*).

Be aware of functional aspects of a stove design on one hand, construction and maintenance on the other. This is more important than the names that are mentioned or propaganda.

Functional aspects have to do with sizes and ratios, heat flow resistance and heat capacity of walls. Note that slight changes or mistakes may have drastic consequences. Cooking stoves of apparent similarity may therefore differ dramatically in performance. Learn what is important and what is not.

Construction is rather a matter of materials selection and manufacturing processes. One has to search for an optimum.

A stove can be built by the owner from freely available materials; the investment is low but mostly the lifetime is low too. Often the repairs necessary for good performance will not be done on time.

A stove can be built and sold by an artisan. As more adequate material can be used, a higher lifetime and better performance are possible but at a higher initial cost. Intermediate solutions are possible where main components such as grates, dampers and chimney elements are made and sold by professionals and integrated in a home built stove. A progressive change from user built to artisan built equipment is quite common.

(* In chapter 5 you will find suggestions on how to do this.

3

Design descriptions

by P. Visser

This chapter is an attempt to assemble information on a large variety of cookstove designs that are meant more or less exclusively for use in the third world countries. The information is presented according to an order chosen to assist the reader in assessing the 'quality' of the stoves.

The following quotation from Penner & Icerman (1974) illustrates the dilemmas of compendium writers on subject matters of the present type.

"It is reasonable to expect that people, who are unable to verify demand, resource, or economic estimates on the basis of their own knowledge, should quote the evaluations of experts with care and indicate proper credits for the source in order to avoid making false impressions on unsuspecting readers.

This obvious requirement is not always satisfied in energy-related evaluations. We shall try to be careful with statements of data and qualifications concerning the available factual data. Nevertheless, the reader would do well to adopt a highly skeptical attitude from the beginning and to insist on using his own best judgment and his own factual verification of important matters. We shall on occasion deliberately quote contradictory or incompatible evaluations in order to emphasize uncertainties in the data base."

The quotation is taken from the author's preface to a 3-volume work on energy in the United States of America. The subject of this compendium exhibits many more heterogeneities than the one tackled by Penner and Icerman. Thus it should not be surprising that neither the content nor the quality of information are anywhere near where one would like them to be. The following is offered in the spirit that one should start somewhere rather than as definitive statements about the designs.

The first step in any effort to codify designs should obviously be their classification. Classification in this work has been done at two levels - an overall classification of stoves and an internal classification of information about each design. We shall present a framework for these classifications in the next two sections before giving the design data for the stoves.

3.1 Overall classification of stoves

The overall classification follows the general description provided in section 2.2. The classification is done according to a 3-symbol code of two letters followed by a number. The first letter is either O, S, or C signifying open, shielded or closed stoves. The difference between a shielded and closed stove lies in the fact that the latter

has a chimney. The second letter is L or H, signifying light or heavy weight stoves. The former includes both sheet metal and ceramic stoves and the latter can be constructed out of clay, bricks, concrete or a combination thereof. The last symbol, the number, signifies the number of pans/pots that the design can accommodate. Thus SH3 stands for a shielded, heavyweight stove that can accommodate 3 pans.

All the stove designs that we have come across have been collected in Table 3.1 according to the classification described above. The table summarizes some general information on the overall dimensions of the stoves, the materials of construction, the fuel it burns and the name under which it is commonly known. The last column gives the page number on which more details about the design can be found. A missing entry in this column means that the information available on the design was inadequate for the preparation of a data sheet at the time of this writing.

The table thus gives a quick overall impression about the competing designs on the 'market'. A prospective stove introducer is advised as a first step to carefully study this table to narrow down choices for detailed considerations that inevitably have to follow.

3.2 Design data sheets

We now turn to the descriptions of designs listed in table 3.1. They include drawings, pictorial representations, details of design features and other information available on the design. The information on the designs has been assembled according to a numerical code described in a fold-out sheet placed at the end of the data sheets. A missing entry of a code number again implies

missing information on that particular aspect. The presentation of the material in the data sheets follows the pattern of drawings on the left page and the pictorial representation along with the stove data on the right page. The recommended method of reading the data sheets is illustrated in a figure placed immediately in front of the data sheets.

Apart from the properties of stoves listed in the data sheets, there are a few other general aspects of building and maintaining stoves that are useful to know. These are discussed in the rest of this section.

Tools and Skills

In general it is not advisable to expect a user to build her/his own stove. We believe that building a stove is the task of a skilled person. A ceramic or a metal stove is best built by a potter or a blacksmith. Even a clay stove requires a potter since this is the person most knowledgeable about clays, mixes and curing procedures to obtain a reliable final product. Building a good clay stove is not an easy job. Cracking is a malady that almost every clay stove suffers from, unless carefully constructed. Moreover some tools and a certain number of measuring devices, however rudimentary they may be, would be needed. The latter in particular would be essential for achieving a reasonable level of dimensional fidelity so that the promised performance could be realized from the design. Moreover, once the dimensional fidelity of the design is guaranteed, the task of diagnosis for nonuniform performance of a given design in different households is considerably simplified. Finally, such a procedure lends itself to continuous modifications in design and constructional methods as time progresses.

In principle these skills could be acquired by any person willing to put in the required effort. However, it is reasonable to assume that

an owner is unlikely to build more than a handful of stoves in her/his lifetime. Under such conditions, it is hard to justify the effort involved. In addition, an owner will not be able to bring to the task the experience of a skilled artisan who can be expected to build scores of stoves every year. These are the reasons why this compendium does not stress the constructional aspects of the stoves. However, the interested reader might wish to consult the publications of ITDG/VITA (1980) and GATE (1980) for more detailed information on the subject.

Lifetime

The lifetime of a stove is difficult to predict because it is dependent on many factors such as material, maintenance, number of hours per day that it is used, climate, fuel and so on. Further, most of the stoves described here have not been used in sufficient numbers for sufficient period of time to arrive at reliable figures for the lifetime (at least according to documented information). A clay stove, as was pointed out earlier, is so strongly dependent for its durability on the quality of the mix. A sheet metal stove in humid climatic zones will wear out quite fast. Thus one can provide at best some guesses on the lifetime of the stoves and the following table is just that:

clay stoves	: 1...2 years
ceramic stoves	: 2...4 years
sheet iron stoves	: 1...2 years
cast iron stoves	: 5...10 years

Safety

There are three aspects to safety of stoves.

- 1) In general burn injuries pose a serious hazard to young children. The heavy stoves are the safest from this point of view as their outside surfaces get barely warm. The ceramic stoves get quite hot and the metal stoves run very hot. In

particular when the latter are of the closed type the benefit of visibility of an open fire as an educating influence on children is removed and alternative instruction is required.

- 2) The way the pans are seated on the stoves can be another source of serious danger. Stoves that are designed for at least partial sinking of the pans will considerably reduce this. Of course such stoves will also facilitate stirring.
- 3) Finally the stability of the stove itself is also a very important factor. Again the heavy stoves with their broad base score on this point.

Of course much of the risk to children could be eliminated if the stove is located high enough. But this requires a rather drastic change in cooking postures used in many societies and thus the suggestion is likely to be viewed with disfavour.

Space heating

All stoves give off some heat to the environment during their operation. This could be thought of as a secondary benefit from stoves, particularly during the cold season. After the fire is extinguished the lightweight stove gives off its heat rapidly. The heavyweight stove, due to its superior heat storage properties is capable of giving off heat over a long period of time, up to the entire night (particularly when it is used to cook an evening meal) when the space heating is required most. In addition, if the stoves supply hot water, the water will remain warm for long periods of time after the fire is extinguished. It is to be remembered that the chimney should remain closed for deriving maximum benefits in this mode of space heating.

If however, one were to assume that people are warm enough under blankets during the night, metal stoves if used during the early hours of the morning and the late hours of the evening,

would start providing warmth almost from the start of its operation.

Cleaning and Maintenance

Stoves require cleaning and maintenance on a regular basis. This is very vital for the closed stoves burning wood and other organic matter. The volatiles from such fuels have a tendency to deposit on the cold surfaces of gas passages and chimney. The consequences of these deposits are twofold:

(1) they can restrict the air-breathing capacity of the stoves, resulting in a loss of combustion efficiency and:

(2) they constitute a fire hazard.

In order to prevent these, it is essential to clean the gas passages and chimneys frequently, twice a week at least.

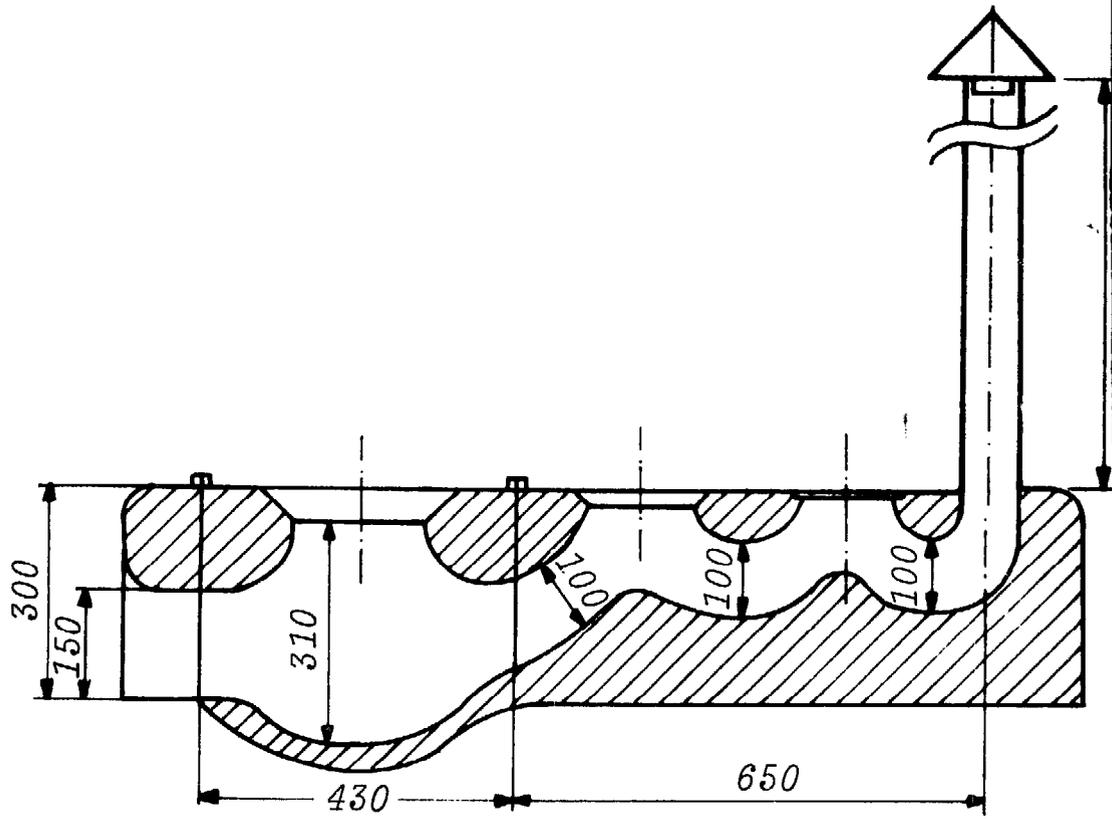
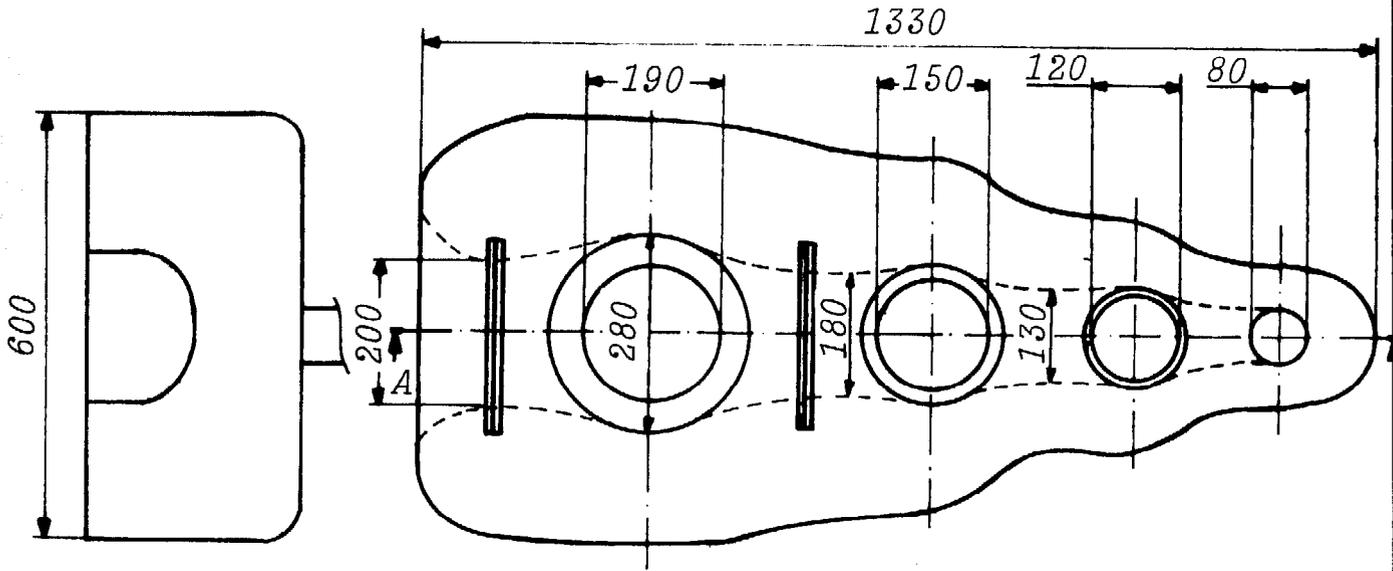
Clay stoves are prone to cracking resulting in unintended air leaks. Such cracks require immediate patching up. Good maintenance can improve the performance of a stove and give a longer lifetime.

Efficiencies

In the following table a classification of efficiency ranges is made.

Low	0...10	%
Medium	10...15	%
Good	15...20	%
High	20...30	%
Very high	30 % and higher	

CH3-11



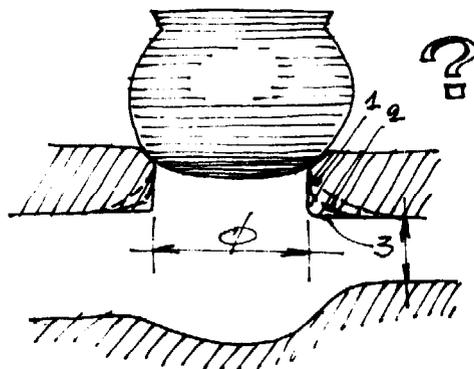
section A-A



3.3 Conversion of data sheets to hardware

The main source of information for building a stove are the drawings. It is unfortunate that the state of the art of stove designing is such that the drawings in many cases are inadequate for conversion to usable hardware. Thus it is advisable to redraw the drawings in the data sheets preferably to full scale (if not, at least to half scale). This will help in getting an appreciation of what the stove looks like internally as well as externally in real life. In addition it will identify the missing dimensions without ambiguity. Some of these can be derived from the scale factor provided on the data sheets and others require judgement on the part of the builder. This first step is well worth the effort for situations where the introduction of a substantial number of units is being contemplated.

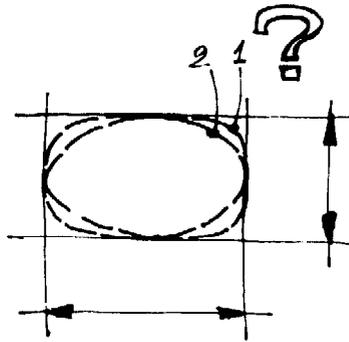
The problem of ill-defined dimensions is particularly severe with clay stoves, because clay gives the impression of a material that can be moulded to any shape. Such a facility is not as easily realized with bricks for example. However, this facility afforded by clay is its strength as well as its weakness. We will illustrate the problems encountered during the construction of a clay stove by considering a specific example, the Lorena Guitar (CH3-11). For ease of reference the drawing is reproduced overleaf.



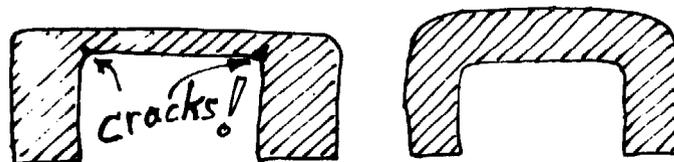
The cross-sectional view in the drawing shows many roundings. The drawing available to the author did not specify the radii of these roundings. These presumably have to be supplied by the builder. Assuming that the builder supplies these at the drafting stage, the actual implementation of these roundings in the construction will have considerable influence on the stove performance. For instance let us consider the shapes near the pan holes. The radii of the roundings in these regions are to be determined as a compromise between mechanical strength and the exposure of the pan bottom to the flames. Line 2 is the recommended version. If line 1 is realized in practice, the exposure of the pan bottom to the fire is larger but there is the risk of the pothole edges crumbling in a short time. Repairing these edges can tend to be a perennial task. Line 3 on the other hand will provide excellent mechanical strength.

However, heat transfer is likely to be impaired due to the formation of a stagnant layer under the pan bottom. Similar arguments apply to the other parts of the gas passage.

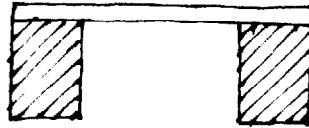
A second point that requires attention is the cross section of the flue passage. As can be seen from the drawing of the Lorena Guitar only the width and height are specified. But these do not determine the passage shape adequately since sharp edges are not easily realizable in clay stoves. Realization 1 in the sketch below is close to the design, but realization 2 is quite off the mark. The method of providing dimensions in many a stove design might lead to the alternative realizations of the gas flue near the pot holes, leading to quite different performances of the stove. Here also realisation 1 will give better performance than realization 2. These can cause considerable trouble for designs that incorporate damper controls. Such controls will be rendered less effective because unintended narrowing of passages for gas flow will shift the point of principal resistance to flow from the damper location to



somewhere else in the gas flow path. (For additional details see section 4.2.). A third complication with clay stoves is their propensity to crack during drying and in use. As pointed out in section 3.2., the danger due to this can be minimized by using a proper mix. In spite of this, if cracks appear other possibilities of reducing crack formation should be considered. Cracks appear during drying due to the fact that clays shrink as moisture is driven out. When one part of a stove dries faster than another part, the shrinkage is nonuniform resulting in internal stresses that ultimately lead to cracks. Thus it is necessary to avoid uneven drying. This can be accomplished by applying wet rags over parts that are expected to dry too fast. A second approach lies in designing the stove to avoid sudden changes in wall thicknesses, which usually represent an important source of trouble. As shown in the sketches below design 1 is prone to cracks while design 2 will show less tendency to do so.



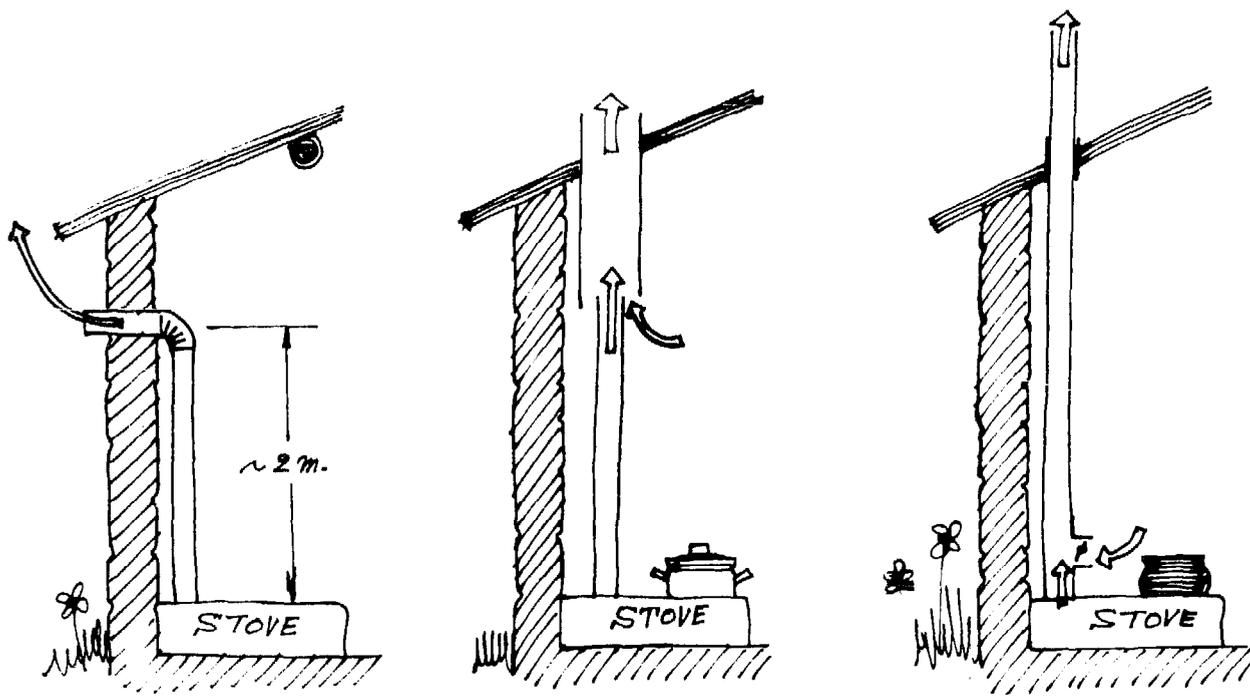
Yet another method of avoiding cracks is to construct the stove from different parts that can be made crackfree as shown in the sketch overleaf.



By far the stickiest problem of the closed type stove is the chimney. Chimneys are meant to serve the twin purposes of providing the necessary draught for combustion air and for removing the smoke from the kitchen environment. One has to pay a stiff price for these advantages. The chimney probably represents the largest cost in a clay stove. Much wisdom on the construction and installation of chimneys is available in books concerning home heating fire places (see for example Self 1977, Vivian 1978, Shelton and Shapiro 1978). Some help on the design of chimneys is available in the next chapter. Here we restrict ourselves to the implications of a chimney for the construction of the stove.

The Lorena Guitar specifies a chimney of 80 mm diameter and about 2 m height. Many other designs provide similar specifications. The assumption is that such tubes are commercially available. When this assumption fails (as it is likely to in a majority of the rural areas in the third world) one needs to improvise. In principle chimneys can be constructed with pottery tubes or bricks in which case the skills of a potter or a mason are required. Whatever is done, it is imperative to maintain the cross-sectional area and the height of the chimney according to design specifications. Changing these at will 'to suit local conditions' (to borrow a popular phrase from appropriate technologists) is an invitation to disaster. Experimentation is possible; however it is to be realised that this is a painful and laborious task with pottery and brick chimneys.

The major question that remains then is: what if the roof is taller than 2 m? This requires thought and care on the part of the builder. One approach is to provide a bend and lead the gases out



through the side wall. A second approach is to mount a tube of larger diameter surrounding the top of the design chimney and leading up through the roof, with the annular space between the two tubes left open. It is expected in this design that the cold air rushing through the annular space will maintain the chimney draught at approximately the design value. The third approach -probably the most attractive one- is to provide a T-section with a damper in it at the chimney bottom to give a controlled cold air leak into the chimney.

Any of these modifications introduced at the time of installation will inevitably affect the design draught and hence the stove performance. In order to realize the design performance, changes will be needed. For example in case 1 the chimney height below the bend might have to be larger than 2 m while in case 2 it will have to be smaller than 2 m. Case 3 will alter the controllability of the fire output. Information on the extent of these influences in the class of stoves considered here is scant. Thus experimentation on site seems to be the only answer in the immediate future. Thus, back to square one.

Finally the chimneys that are led outdoors require special constructional features to minimize the wind effects at the chimney exit and rainwater passing into the stove. More information on these problems is available in the references cited earlier.

Whatever happens to the design performance, one consequence of these modifications is indisputable; all these ideas will push the cost upwards.

A few words about the cost of a stove. General estimates on this aspect are probably worthless as they are largely determined by local conditions. An orderly method of estimating the cost can be indicated. For the Lorena Guitar, the volume of clay required can be estimated by the overall dimensions given in table 3.1. Not all this volume of clay is required since the interior is hollow. $\frac{2}{3}$ of the volume calculated above should be sufficient. This turns out to be 89 litres. To this should be added the cost of chimney and damper. Finally the labour costs need to be accounted for either in terms of time of the builder (if he/she is the owner) or in terms of payment to a professional stove builder.

The discussion in this section is meant to show the many difficulties (not all of them are included) that one encounters while converting the drawings into hardware that works. The reason for insisting on care during construction is to ensure that the designers' intentions are realized in practice. This care is also indispensable if one attempts to improve on the performance and constructional methods of a stove. Such improvements can be brought about only by a thorough understanding of the processes that take place in a stove. In the next two chapters an attempt is made to provide a beginning for such understanding. Further, these chapters also provide a means of converting such an understanding into standard design and testing practice that can lead to improved stoves as far as that is feasible at this moment.

Readers who contemplate introducing a large number of units of a particular design in a given community are strongly urged to take the time and effort to go through these chapters with care. The minimum benefit that can be expected out of such an effort is the formulation of a set of questions that need to be asked before accepting a design as satisfactory.

Abbreviations

In some of the design descriptions on the pages that follow, recurring long names of institutions and anonymous literature have been abbreviated as follows.

ATRRU	Appropriate Technology for Renewable Resource Utilisation.
CETA	Centro de Experimentation en Tecnologia Appropriada. Guatemala.
ITDG	Intermediate Technology Development Group Ltd. London - U.K.
PRAI	Planning Research and Action Institute, Lucknow. India.
RCASTTU	Research Centre for Applied Science and Technology of Tribhuvan University, Kathmandu, Nepal.

Table 3.1 Classification of Stoves

Number	Size (mm) Length x Width x Height or Diam. x Height	Material					Fuel			Name	Page
		Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other		

Stove Class OL1: open lightweight stoves., 1 pot

Number	Size (mm)	Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other	Name	Page
1						x	x			Open fire	67
2		x			x	x	x	x		Open fire with grate	69

Stove Class SL1: Shielded lightweight Stoves, 1 pot

Number	Size (mm)	Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other	Name	Page
1	200 x 250			x			x			Single Country Stove	71
2	590 x 300 x 230			x	x		x			India Chula	73
3	590 x 300 x 300	x		x	x		x			India Chula with grate	75
4	260 x 160			x			x			Keren	77
5	260 x 190	x		x			x			New Keren	79
6					x		x			\$ 1.50 Woodburning Stove	81
7		x		x			x	x		Kamado Cooker	83
8		x		x	x		x	x		5 Gallon Paint Can Stove	85
9	300 x 365	x			x		x			De Lepeleire 1	87
10		x			x			x		Micuta Jiko 1	89
11	250 x 150	x			x			x		E. Afr. Metal charcoal stove	91
12	230 x 190	x		x				x		Indonesia Charcoal Stove	93
13	230 x 240	x		x				x		Da Silva Charcoal Stove	95
14	230 x 245	x			x			x		Brace Institute Metal Stove	97
15	235 x 215	x		x				x		Ceramic Inst. of Bandung St.	99
16		x			x			x		I.D.C. Stove	101
17	250 x 250	x			x	x		x		Indonesia Cement Stove	103
18		x			x			x		Malagasi Stove	105
19		x			x			x		Rumford Stove	107
20	270 x 360	x	x		x			x		Angheti	109
21	310 x 280	x		x	x			x		Thai Bucket	111

Stove Class SL2: Shielded lightweight Stoves, 2 potholes

Number	Size (mm)	Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other	Name	Page
1				x			x			Biscated Country Stove	113
2	650 x 350 x 240			x			x			Tungku Muntilan	115
3	510 x 260 x 330			x			x			Teri-ITDG Stove	117
4	750 x 300 x 350	x		x			x	x		Tandoor Stove	119
5	570 x 260 x 250	x		x			x		x	Tungku Sae	121

Number	Size (mm) Length x Width x Height or Diam. x Height	Material					Fuel			Name	Page
		Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other		

Stove Class SH1: Shielded heavyweight Stoves, 1 pothole

1						x	x			Bangladesh Chula	123
2		x				x	x			Improved Bangladesh Chula	125
3	640 x 400 x 280			x	x		x			Economical Chula	127
4	640 x 400 x 280	x		x	x		x			Economical Chula with grate	129
5	700 x 300		x				x			Louga	131
6	770 x 700 x 660		x				x			Evans M3	133
7	540 x 600			x					x	Pail-type Stove	135
8	840 x 600	x		x					x	Improved Pail-type Stove	137

Stove Class SH2: Shielded heavyweight Stoves, 2 potholes

1			x				x			Two hole Stove	139
2			x				x			Heavy Biseated Country Stove	
3	350 x 500 x 280		x				x			Indonesia two hole Stove	141
4	300 x 380 x 250		x				x			Tungku Lowon	143
5	1520 x 460 x 760	x				x			x	Bhavnagar Stove	145

Stove Class SH3: Shielded heavyweight Stoves, 3 potholes

1			x				x			Three hole Stove	147
2	1200 x 500 x 350		x				x			Indonesia three hole Stove	149
3	1640 x 600 x 760	x				x			x	G.E. Shillong type 1	151
4	1360 x 540 x 400		x						x	Egyptian Rural Stove	153

Stove Class CL1: Closed lightweight Stoves, 1 pothole

1	230 x 180				x		x			Micuta Jiko 2	155
2					x		x			Micuta Jiko 3	157
3	230 x 230 x 440				x				x	Sawdust burner	159

Stove Class CL2: Closed lightweight Stoves, 2 potholes

1	720 x 300 x 300	x			x		x			De Leppeleire/Vandaele Stove	161
2	600 x 250 x 225	x			x		x	x	x	Family Cooker	163
3	830 x 300 x 320	x			x		x	x		Kali Cooker	165

Number	Size (mm) Length x Width x Height or Diam. x Height	Material					Fuel			Name	Page
		Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other		

Stove Class CH1: Closed heavyweight Stoves, 1 pothole

1	800 x 720 x 280		x				x			Ban Ak Suf 2	167
2	1150 x 780 x 360		x				x			Ban Ak Suf 3	169
3	1150 x 1000 x 450		x				x			Evans M2	171
4		x			x	x		x		Improved Family Cooker	173
5	620 x 330 x 362	x		x	x			x		Economical Angheti	175
6	1000 x 460 x 1070	x			x	x			x	D.G.W. Type Stove	177
7	2400 x 1500 x 1050	x			x	x			x	Java Rice Husk Stove	179

Stove Class CH2: Closed heavyweight Stoves, 2 potholes

1	1700 x 530 x 560		x	x					x	Imp. Egyptian Rural Stove	181
2	810 x 600 x 850		x				x			Nigerian Stove	183
3	1400 x 700 x 300					x	x			Nouna Stove	185
4	1030 x 1100 x 450	x	x				x	x		Evans M1	187
5			x				x			Gayan Saga	
6	1100 x 650 x 850		x		x		x			Karai Stove	189
7	480 x 480 x 190		x				x		x	PRAI Improved Chula	191
8	520 x 430 x 220		x				x		x	PRAI Improved Chula	193
9	520 x 300 x 300					x	x			I.D.B. Stove	195
10	1070 x 500 x 375	x			x	x	x			Pogbi	197
11	820 x 220 x 580	x	x	x	x				x	IPA-Stove	199
12	770 x 900 x 750	x			x	x			x	Banerjee Type Stove	201
13	1666 x 650 x 1390	x			x	x			x	Army HQ Type Stove	203
14	1080 x 760 x 760	x			x	x			x	Shillong Improved Type Stove	205
15	900 x 700 x 760	x			x	x			x	Bhavnagar Improved Type Stove	207

Number	Size (mm) Length x Width x Height or Diam. x Height	Material					Fuel			Name	Page
		Grate	Mud	Ceramic	Metal	Other	Wood	Charcoal	Other		

Stove Class CH3: Closed heavyweight Stoves, 3 potholes

1	1210 x 480 x 700				x	x	x			Singer Stove	209
2	1000 x 1000 x 800		x				x			Lorena Mud Stove	211
3	910 x 690 x 150		x				x			Junagadh Chula	213
4	900 x 220 x 230	x		x			x	x		Portable Magan Chula	215
5	1695 x 1000 x 750		x		x		x			Ghana Stove	217
6	762 x 586 x 200	x	x		x		x	x		Magan Chula	219
7			x				x			Smokeless Fogones	
8	1000 x 950 x 280	x	x				x			New Nepali Chulo	221
9						x	x			Kubota Stove	
10		x					x			CISIR-Stove	
11	1330 x 600 x 300		x				x		x	Lorena Guitar	223
12	1000 x 480 x 250	x			x	x	x		x	CETA-Stove	225
13			x				x			Improved HERL-Chula	227
14	2080 x 600 x 440	x			x	x			x	Gula Jawa Stove	229

Stove Class CH4: Closed heavyweight Stoves, 4 potholes

1	1270 x 660 x 150		x				x			HERL Chula	231
2	1410 x 660 x 200		x				x			Moradabad Chula	233
3			x				x			Horse-shoe Shaped Chula	

Stove Class CH5: Closed heavyweight Stoves, 5 potholes

1	1460 x 600 x 450	x			x	x		x		C.W.E. Cochin Type Stove	235
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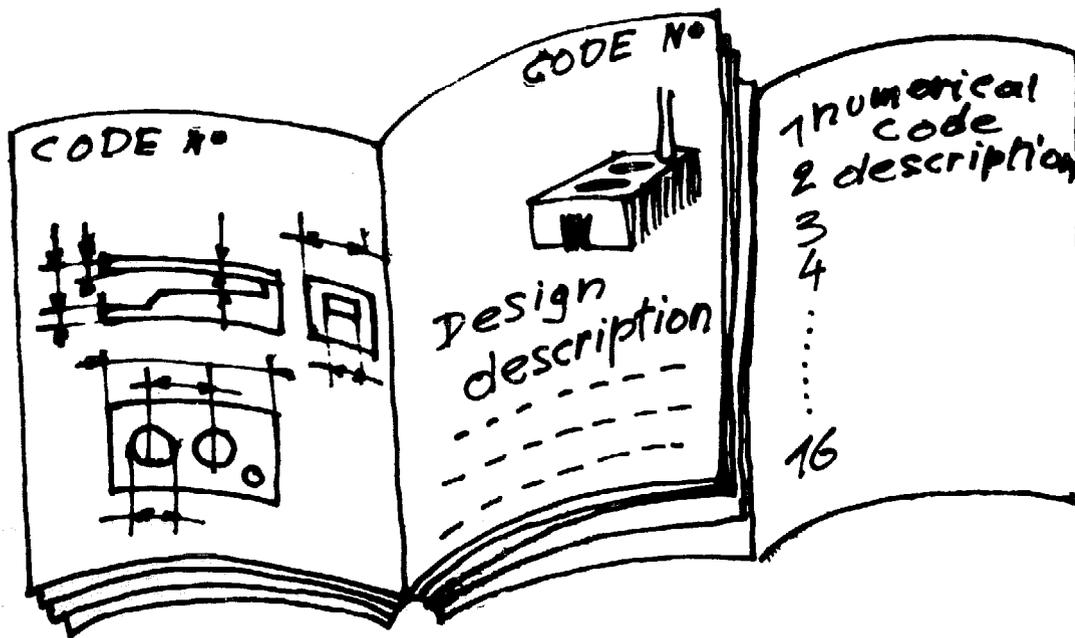
Ovens

1	405 x 580				x		x			Pat Howdens Oven	237
2	1800 x 1800 x 1400				x	x	x			Woodburning Oven	239
3	2200 x 1000 x 425				x	x	x			Oil Drum Oven	241
4										Fiji Stove	
5	1200 x 1400					x	x			Outdoor Oven	243

Others

1						x				Haybox	245
2	160 x 405				x		x			Thermette	247
3					x		x	x		Hot Water Stove	249

3.4 Data sheets

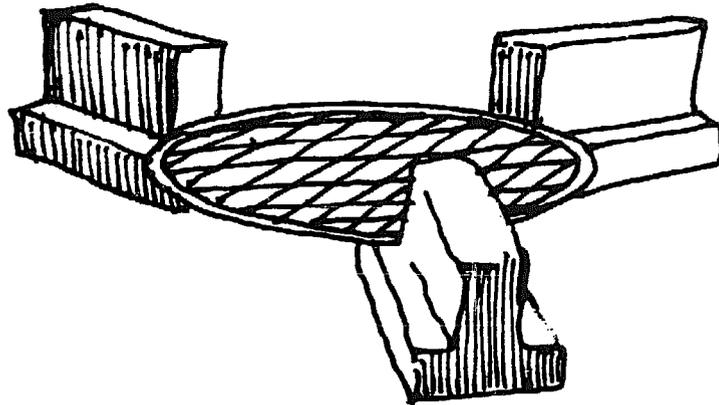


OL1-1



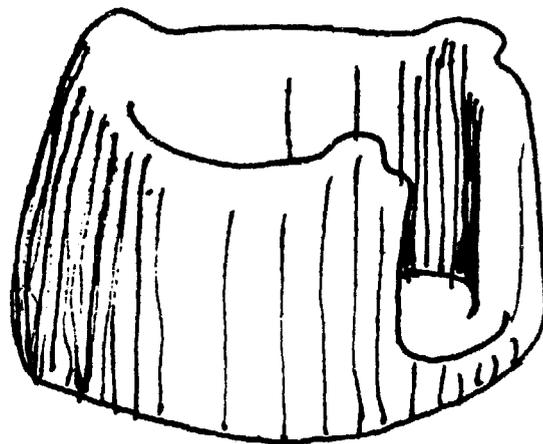
- 1) *OL1-1*
- 2) *No technical drawings*
- 3) *A portable stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn long wood.*
- 5) *Three stones or bricks or any support for the pot.*
- 7) *Wood, straw, cornstalks.*
- 8) *For the sake of fuel-efficiency it is advisable to cut up big pieces.*
- 11) *Three-stone open fire.*
- 12) *The three-stone open fire is widely used all over the world to cook food.*
- 13) *Water boiling tests at the Eindhoven University of Technology. Small pieces of firewood in a wind-free environment showed good efficiency. Water boiling tests at the K.U. Leuven, Belgium, showed poor efficiency.*
- 15) *Meal cooking test at the University of the South Pacific, Fiji, showed medium efficiency. Water boiling tests at Ouagadougou showed medium efficiency.*
- 16) *Krishna Prasad 1980. Garberson 1979. Visser 1981. Siwatibau 1978 Vandaele 1978*

OL1-2



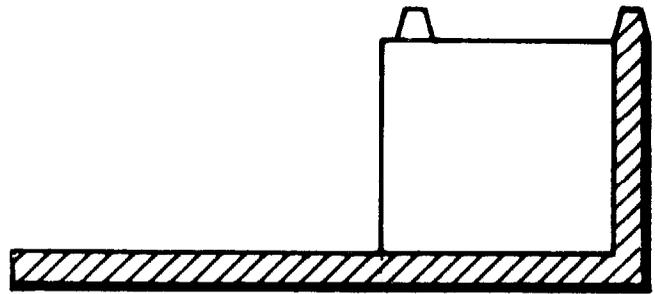
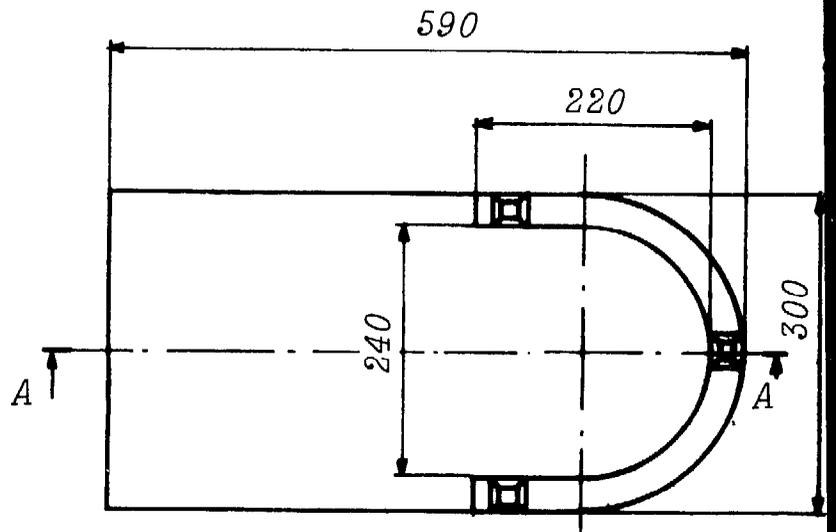
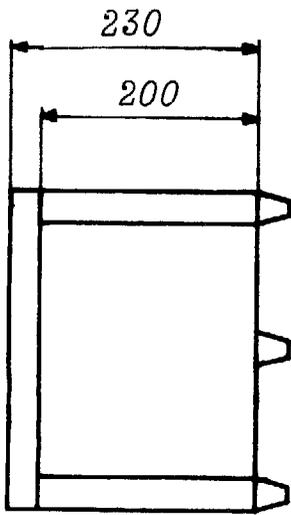
- 1) *OL1-2*
- 2) *No technical drawings.*
- 3) *A portable stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn long wood and it has a grate.*
- 5) *Three-stones or bricks or any support for the grate and the pot.*
- 7) *Wood, charcoal.*
- 8) *For the sake of fuel-efficiency it is advisable to cut up big pieces.*
- 11) *The three-stone open fire with grate.*
- 13) *Waterboiling tests at the Eindhoven University of Technology, the Netherlands. Small pieces of firewood in a wind-free environment showed good efficiency.*
- 14) *No field tests known.*
- 16) *Krishna Prasad 1980. Visser 1981.*

SL1-1



- 1) *SL1-1*
- 2) *No technical drawings.*
- 3) *A portable ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provision for secondary air.*
- 5) *The stove is completely made of ceramic.*
- 6) *3 kg.*
- 7) *Wood.*
- 8) *Any length. No dimensions known. Refuelling without lifting the pan.*
- 11) *Single country stove .*
- 12) *India. A traditional model.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Kallupatti. 1955.*

SL1-2

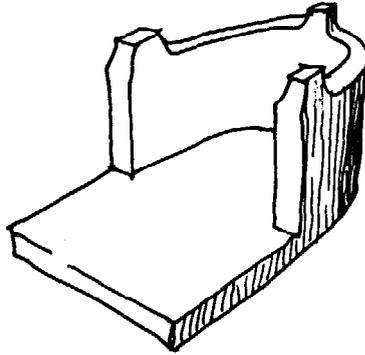


section A-A



1) SL1-2

3) *A portable ceramic and metal stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,3 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



5) *The outside of the stove is metal sheet with a layer of clay on the inside. With good clay the metal sheet is optional. For a non-portable alternative the outside can be made of bricks.*

6) 15 kg.

7) Wood.

8) *Any length. 0,24 x 0,20 m. Refuelling can be done without lifting the pan.*

11) India chula

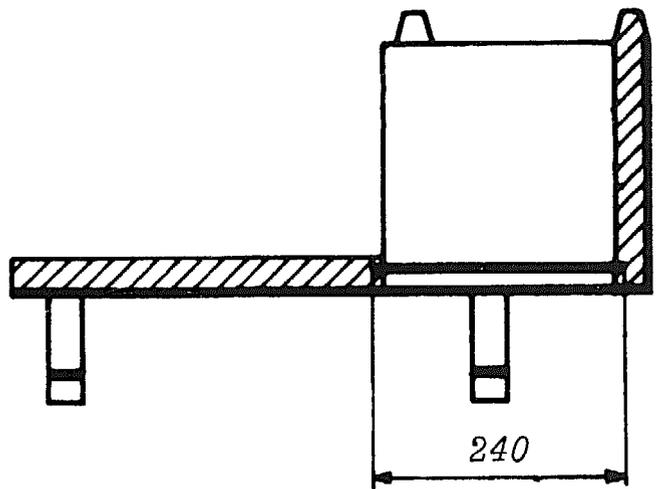
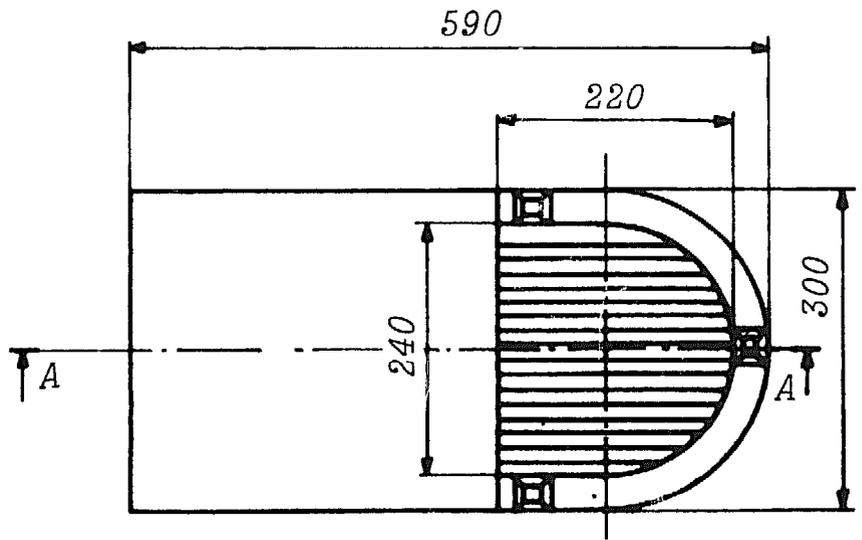
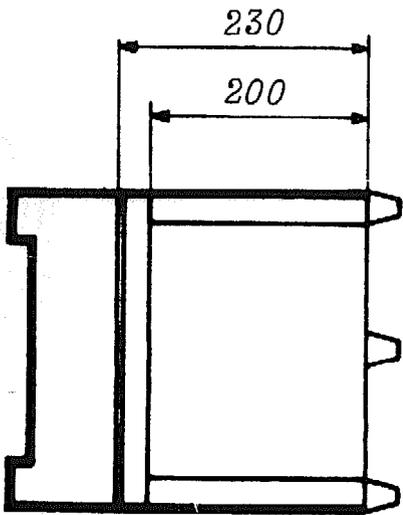
12) *Indian traditional stove in rural areas.*

13) *Water boiling tests by Salariya showed medium efficiency.*

14) *No field tests known.*

16) *Salariya 1978.*

SL1-3

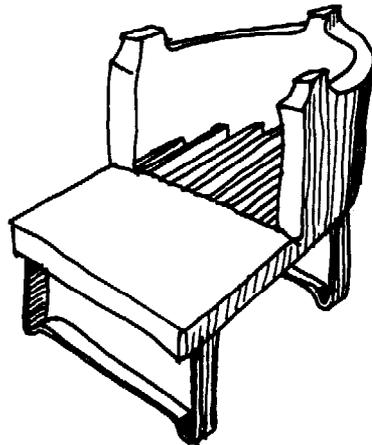


section A-A



1) *SL1-3*

3) *A portable ceramic and metal stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,3 m. It will burn long wood. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The outside of the stove is made of metal sheet with a layer of clay inside and a grate of steel bars. With good clay the metal sheet is optional and the grate can also be made of ceramics. For a non-portable alternative the outside can be made of bricks.*

6) *15 kg.*

7) *Wood.*

8) *Any length. 0,24 x 0,20 m. Refuelling can be done without lifting the pan.*

11) *India chula with grate.*

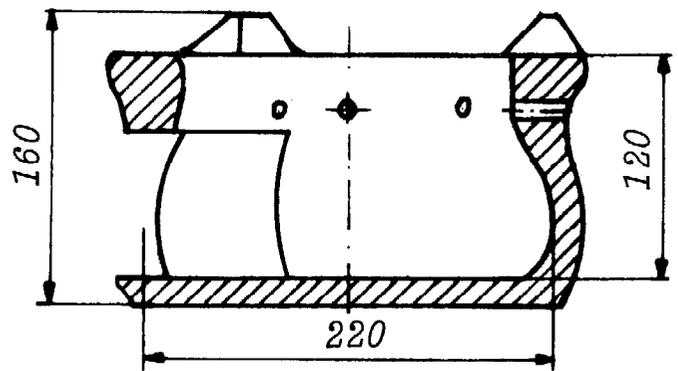
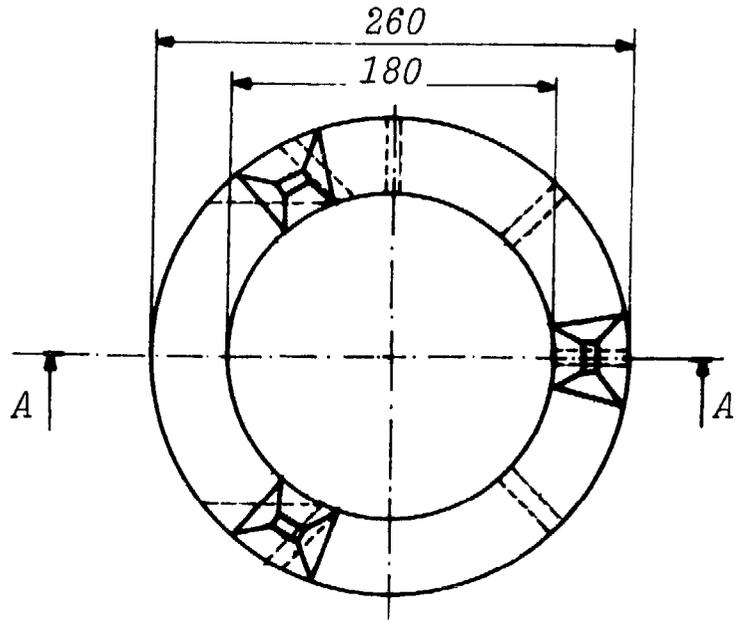
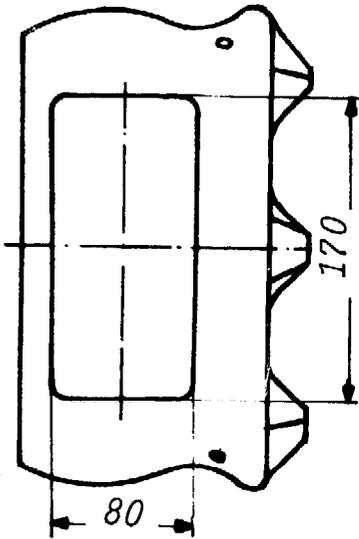
12) *Developed as an improved version of the traditional India chula (SL1-2) at Punjab Agricultural University in India.*

13) *Water boiling tests by Salariya showed an improvement on the India chula. Good efficiency figures.*

14) *No field tests known.*

16) *Salariya 1978.*

SL1-4

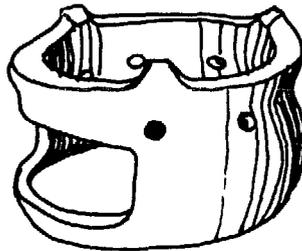


section A-A



1) *SL1-4*

3) *A portable ceramic stove which can accommodate 1 pot of spherical or cylindrical shape. This pot can have a diameter of 0,26 m. It will burn long wood, with no limitations to the length. It has no chimney, no dampers, no baffles and no grate.*



4) *This stove has holes for secondary air in the wall of the combustion chamber.*

5) *Stove is completely made of ceramic.*

6) *3 kg.*

7) *Wood.*

8) *Any length. 0,17 x 0,08 m. The stove can be refuelled without lifting the pan.*

11) *Keren.*

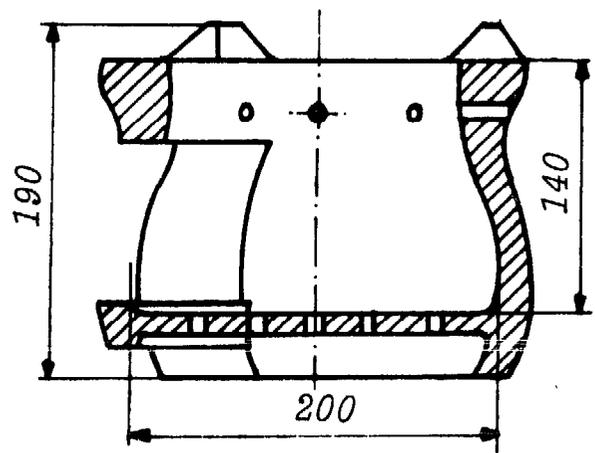
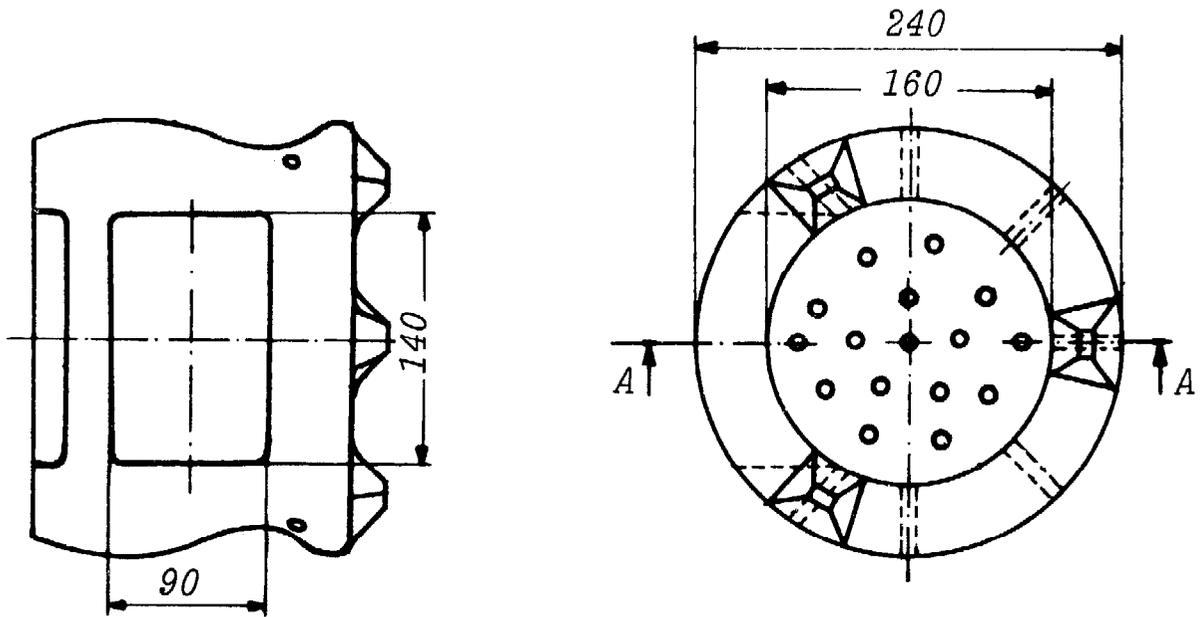
12) *Central Java, Indonesia.*

13) *Water boiling tests at Dian Desa, Indonesia. 2 l of water were brought to the boil in an aluminium pot of 0,22 m, covered with a lid. The average wood consumption was 230 g in pieces of 1 x 1 x 20 cm in 12 minutes.*

14) *No field tests known.*

16) *Joseph, Shanahan, Bialy 1980.*

SL1-5



section A-A



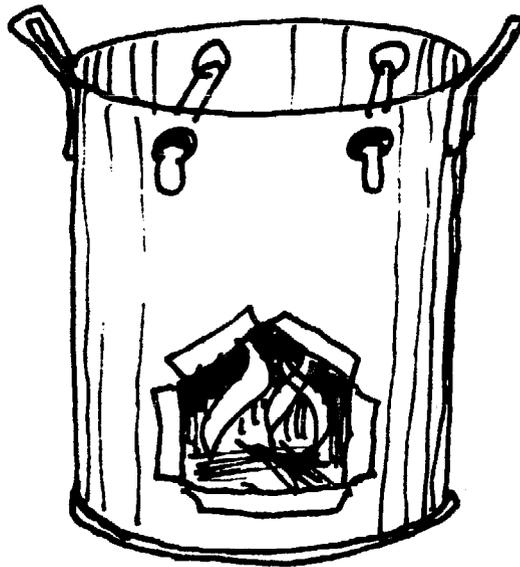
1) *SL1-5*

3. *A portable ceramic stove which can accommodate 1 pot of spherical or cylindrical shape. This pot can have a diameter of 0,24 m. It will burn long wood. It has no chimney, no dampers, no baffles. It has a grate and a provision for secondary air.*



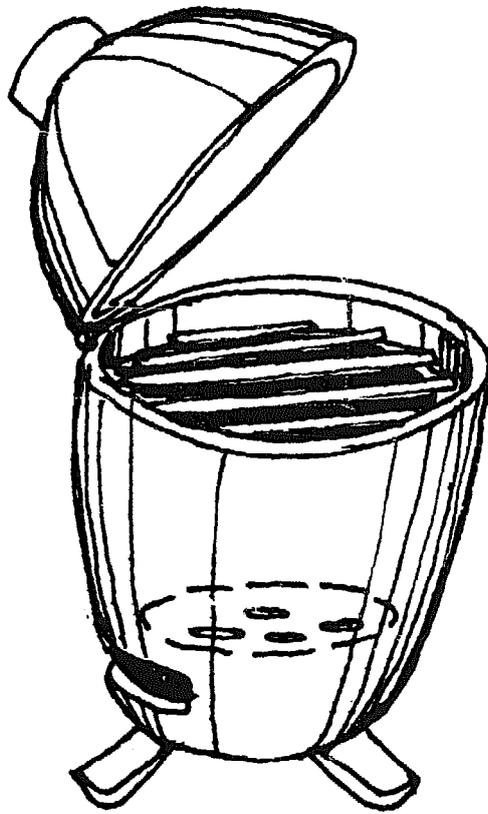
4. *This stove has holes for secondary air in the wall of the combustion chamber.*
- 5) *Stove is completely made of ceramic.*
- 6) *3 kg.*
- 8) *Any length. 0,14 x 0,09 m. The stove can be refuelled without lifting the pan.*
- 11) *New Keren.*
- 12) *Indonesia, Dian Desa, 1980.*
- 13) *Water boiling tests at Dian Desa. Comparative tests showed no improvement on the original Keren.*
- 14) *No field tests known.*
- 16) *Joseph, Shanahan, Bialy 1980.*

SL1-6



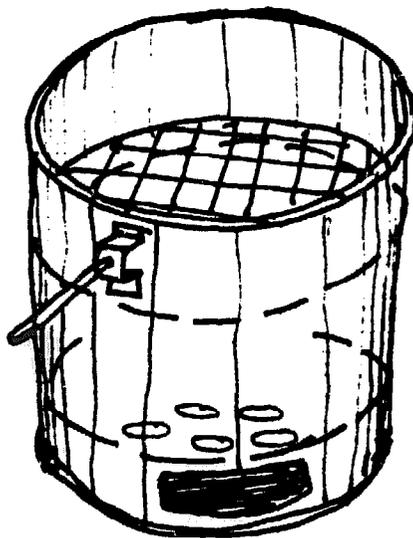
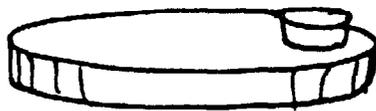
- 1) *SL1-6*
- 2) *No technical drawings.*
- 3) *A portable metal stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*
- 5) *The stove is made of a paint can or a small oil drum.*
- 6) *2 kg.*
- 7) *Wood.*
- 8) *Any length. No dimensions known. Refuelling without lifting the pan.*
- 11) *The \$ 1.50 woodburning stove.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 15) *Conserves 50 % of the fuelwood compared to the open fire.*
- 16) *Darrow (undated).*

SL1-7



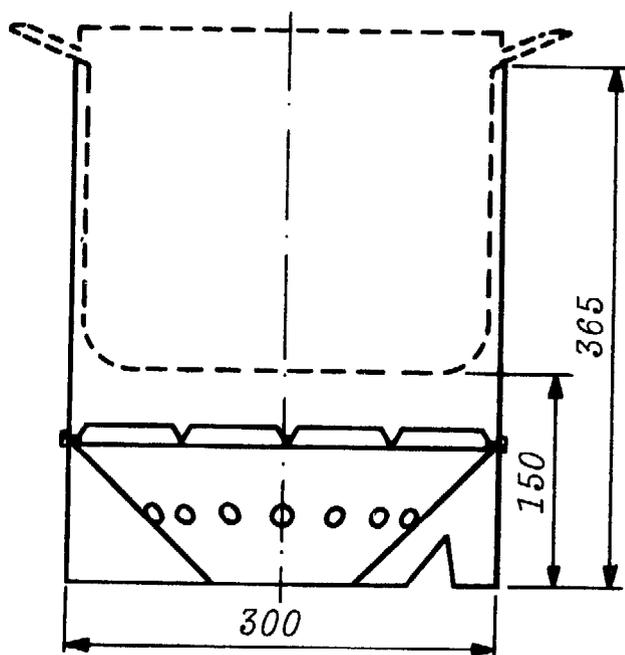
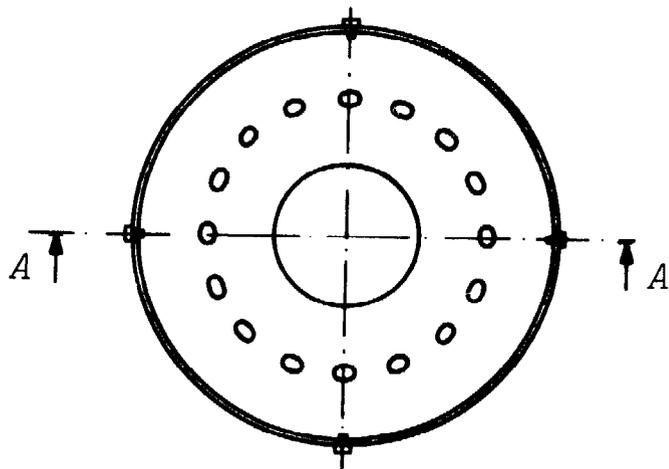
- 1) *SL1-7*
- 2) *No technical drawings.*
- 3) *A portable ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn short wood or charcoal. It has no chimney, a damper for combustion gases and a damper for combustion air, a metal grate and no provisions for secondary air. It can be used as a small oven.*
- 4) *Dampers for combustion air and combustion gases. By closing these dampers the stove can be completely shut off for extinction of the fire.*
- 5) *The stove is completely made of ceramic with an optional metal grate for grilling.*
- 6) *10 kg.*
- 7) *Wood, charcoal.*
- 8) *The stove will only accept small pieces of fuel. The pan must be lifted for refuelling.*
- 9) *By closing the top cover the stove can be used as an oven.*
- 11) *Kamado cooker.*
- 12) *Japan. A traditional Japanese stove design.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 15) *Potential fuel savings of 50% compared to the open fire.*
- 16) *Bomar, Roy, Walton 1978.*

SL1-8



- 1) *SL1-8*
- 2) *No technical drawings.*
- 3) *A portable metal or ceramic stove which can accommodate 1 pot of cylindrical shape. It will burn short wood. It has no chimney, no damper for combustion air, a damper for combustion gases, a grate and no provisions for secondary air.*
- 4) *Fire control by a damper for the combustion gases.*
- 5) *The inner cylinder is made of ceramic, the outer cylinder is made of a five gallon paint-can, but can also be made of ceramic. The optional grate for grilling is made of metal.*
- 6) *5 kg.*
- 7) *Wood, charcoal.*
- 8) *The stove will only accept small pieces of fuel. No dimensions known. Pan must be lifted from the stove for refuelling.*
- 11) *Five gallon paint can stove.*
- 12) *This stove was developed at the Georgia Institute of Technology in 1978. Modification of Kamado cooker.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Anon 1980 b. Krishna Prasad, Nieuwvelt, Verhaart 1979. Bomar, Roy, Walton 1978.*

SL1-9

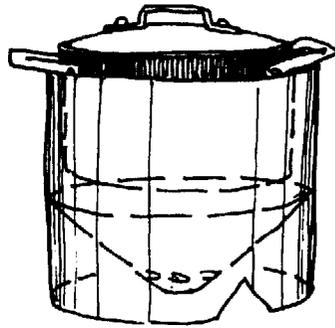


section A-A



1) *SL1-9*

3) *A portable metal stove which can accommodate 1 pot of cylindrical shape. This pot can have a diameter of 0,25 m. It will burn short wood. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove is completely built of metal sheet.*

6) *8 kg.*

7) *Wood*

8) *Refuelling through the pothole of 0,29 m, when the pan is removed.*

11) *De Lepeleire 1.*

12) *Developed at K.U. Leuven by De Lepeleire 1978.*

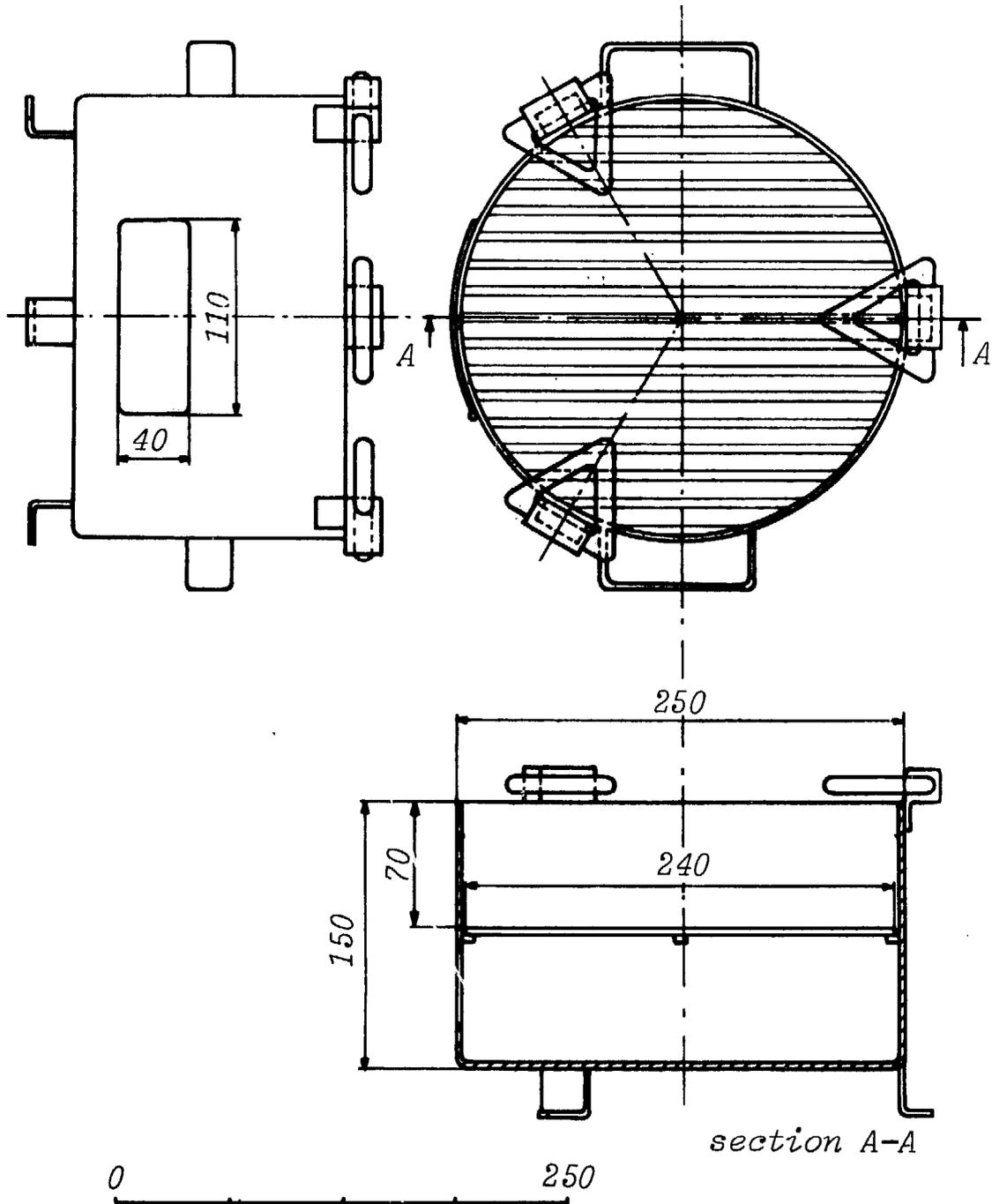
13) *Water boiling tests at K.U. Leuven showed very high efficiency.*

14) *No field tests known.*

16) *Vandaele, 1978. Joseph (undated).*

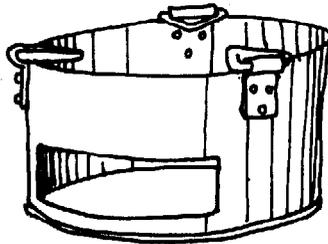
- 1) *SL1-10*
- 2) *No drawings.*
- 3) *A portable metal stove which can accommodate 1 pot of cylindrical shape. It will burn charcoal. It has no chimney, no damper for combustion gases, a damper for combustion air, no baffles, a grate and no provisions for secondary air.*
- 4) *Fire control by a door for the air entrance hole.*
- 5) *The stove is completely made of metal sheet.*
- 6) *8 kg.*
- 7) *Charcoal.*
- 8) *Refuelling through the pothole. No dimensions known. Pan must be lifted for refueling.*
- 11) *Micuta Jiko 1.*
- 12) *Developed by Micuta of the Bellerive Foundation in Geneva as an improvement on the East African metal charcoal stove (SL1-11).*
- 16) *Juma 1980, Micuta 1980.*

SL1-11



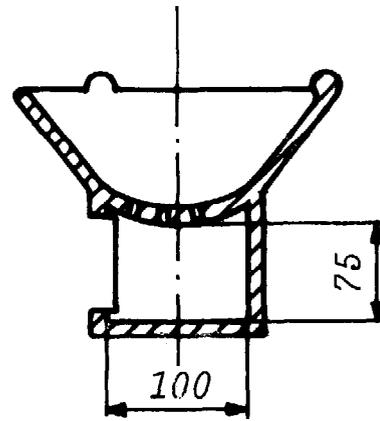
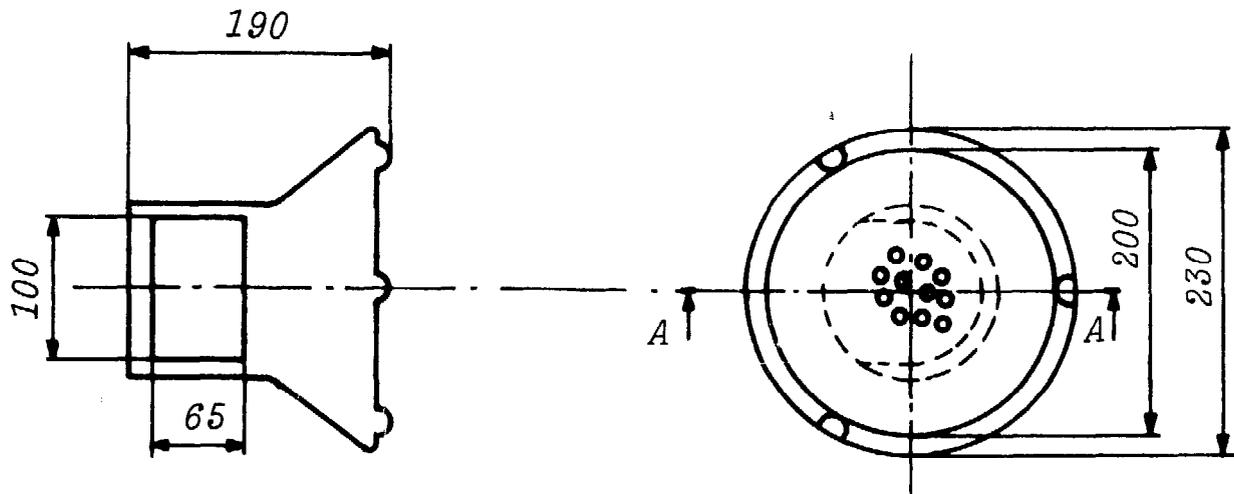
1) *SL1-11*

- 3) *A portable stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,25 m. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



- 4) *Inlet air control by the woodcharging door.*
- 5) *The stove is completely made of sheet steel.*
- 7) *Charcoal.*
- 8) *Refuelling through the pothole for which the pan must be lifted from the stove.*
- 11) *East Africa Metal Charcoal Stove.*
- 12) *This stove is widely used in East Africa, and sold on markets.*
- 13) *Water boiling test by Dobler showed high efficiency.*
- 14) *Water boiling tests at Morogoro, Tanzania, showed poor efficiency.*
- 16) *Dobler 1980. Openshaw 1979. Anon 1980 b. Singer 1961. Joseph (undated). Jagadish 1980. Micuta 1980.*

SL1-12



section A-A



1) *SL1-12*

3) *A portable ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,25 m. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove is completely made of ceramic.*

6) *3 kg.*

7) *Charcoal.*

8) *The pan must be lifted from the stove for refuelling.*

11) *Indonesia charcoal stove.*

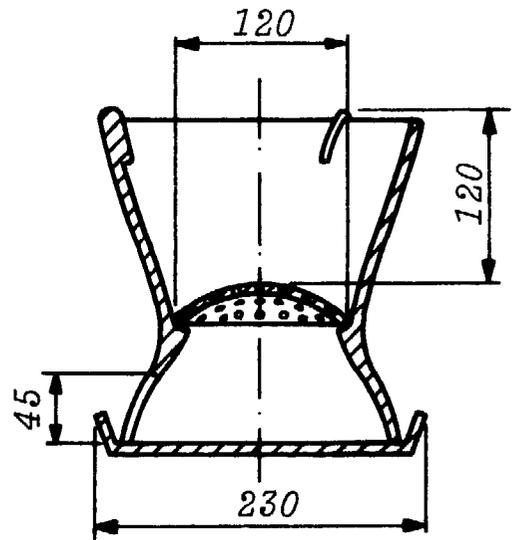
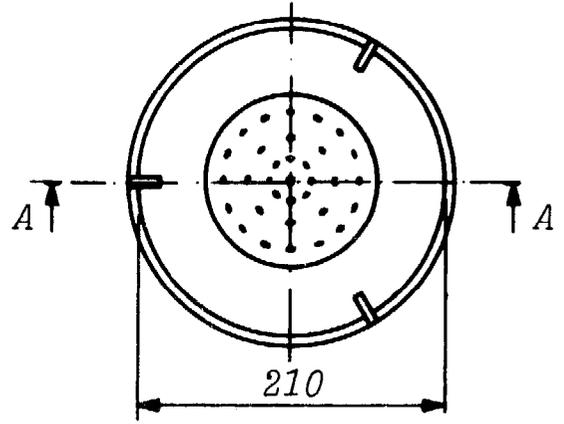
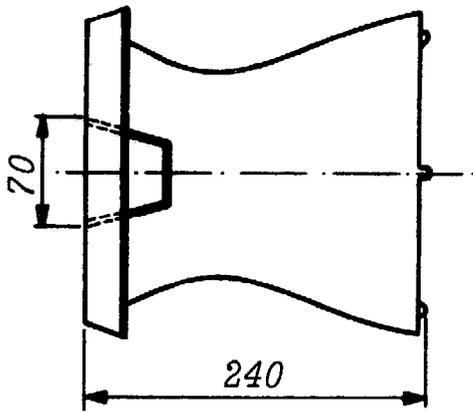
12) *A traditional Indonesian design that is found nearly everywhere in Indonesia.*

13) *Singer has measured very high efficiencies with this stove.*

14) *No field tests known.*

16) *Singer 1961. Anon 1980 b. Acott et al 1980.*

SL1-13

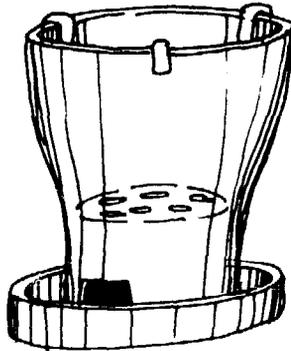


section A-A



1) *SL1-13.*

3) *A portable ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,25 m. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove is completely made of ceramic.*

6) *4 kg.*

7) *Charcoal.*

8) *Pot must be lifted from the stove for refuelling.*

11) *Da Silva charcoal stove.*

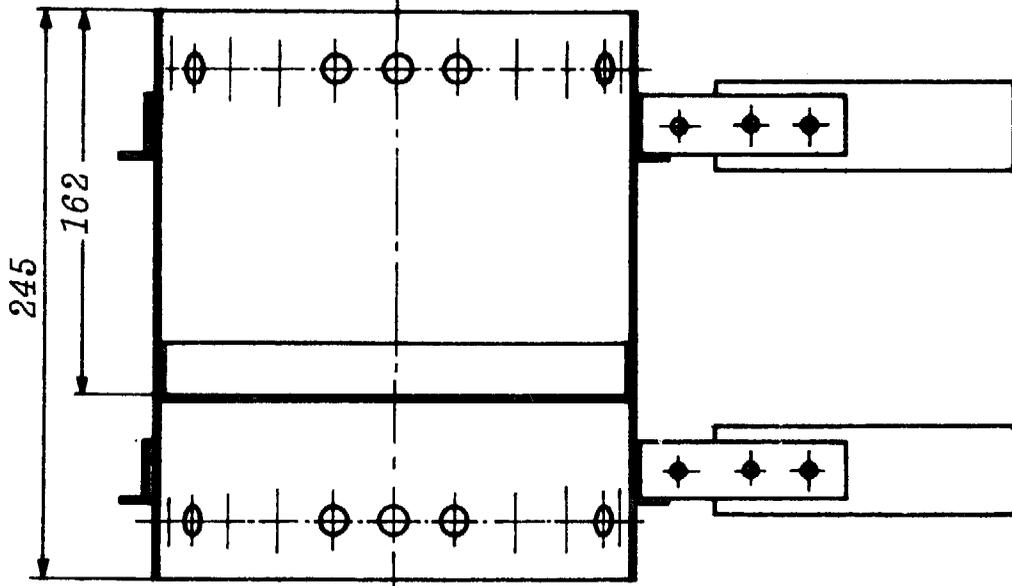
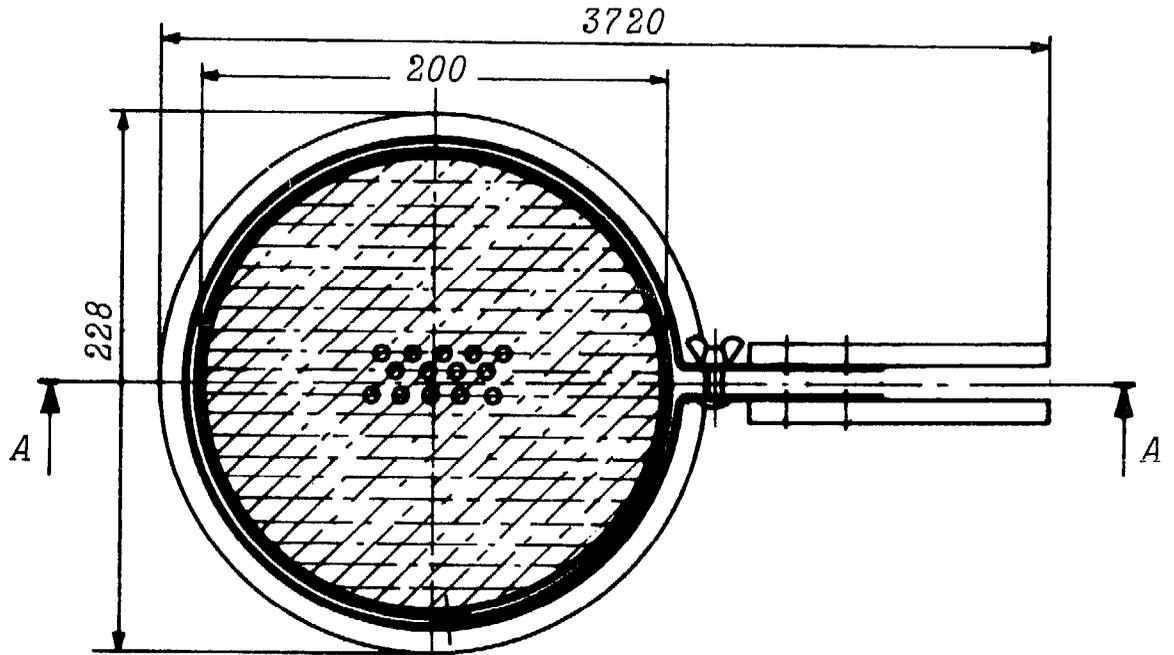
12) *This stove was developed in Sri Lanka at the Ceylon Institute of Scientific and Industrial Research in 1980.*

13) *Water boiling tests by Da Silva showed high to very high efficiency.*

14) *No field tests known.*

16) *Da Silva 1980.*

SL1-14

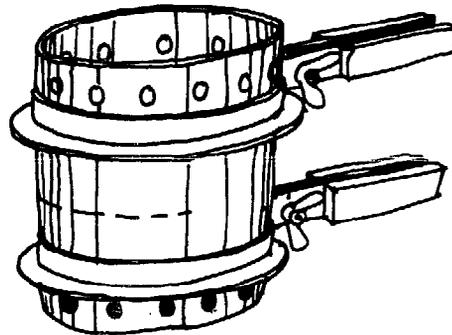


section A-A



1) *SL1-14*

3) *A portable, sheet metal stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 22 cm. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove is completely made of sheet steel.*

6) *4 kg.*

7) *Charcoal.*

8) *0,15 m. Refuelling through the pothole, for which the pot must be lifted.*

11) *Brace Institute metal stove. Simple fuel burning cooking stove.*

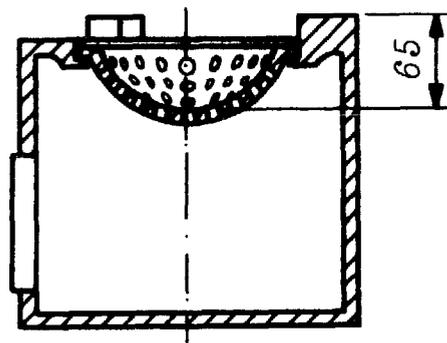
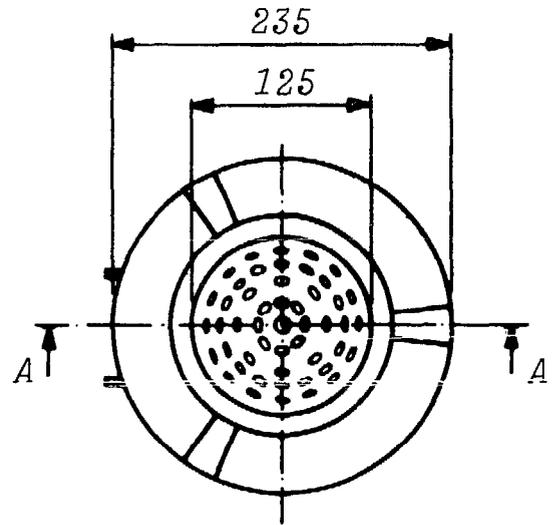
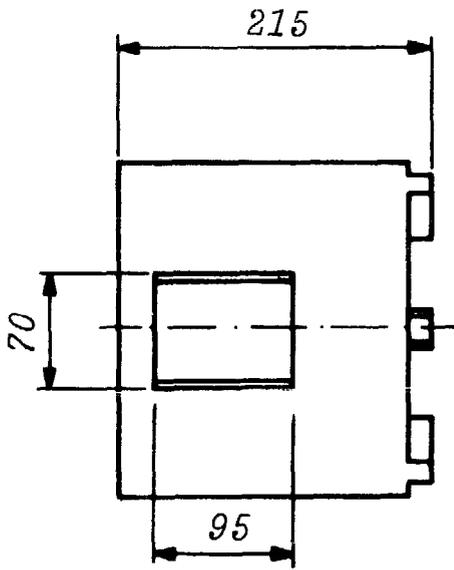
12) *This stove was developed at the Brace Research Institute in Canada, 1977.*

13) *No laboratory tests known.*

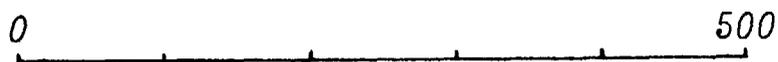
14) *No field tests known.*

16) *Anon 1977.*

SL1-15

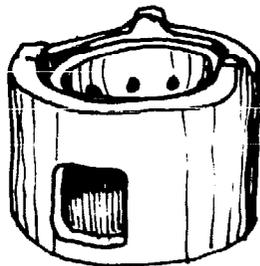


section A-A



1) SL1-15

3) *A portable ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,24 m. The stove will burn charcoal. It has no chimney, a damper for combustion air, no damper for combustion gases, no baffles, a grate and no provisions for secondary air.*



4) *The fire is controlled by a small combustion air damper at the air intake opening.*

5) *The stove is made of ceramic and has a metal damper.*

6) *4 kg.*

7) *Charcoal.*

8) *For refuelling the pan must be lifted from the stove.*

11) *Ceramic Institute of Bandung Stove.*

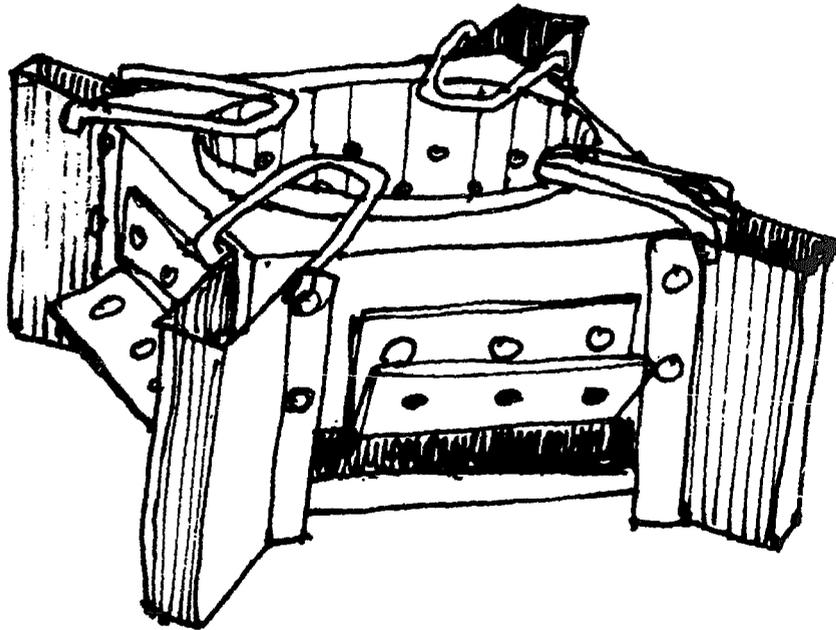
12) *This stove was developed at the Ceramic Institute of Bandung in the late fifties.*

13) *Water boiling tests by Singer showed very high efficiencies.*

14) *No field tests known.*

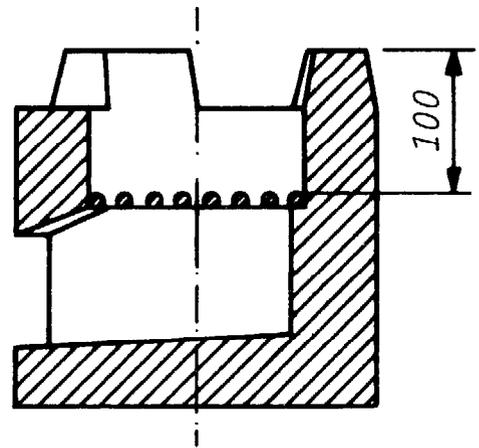
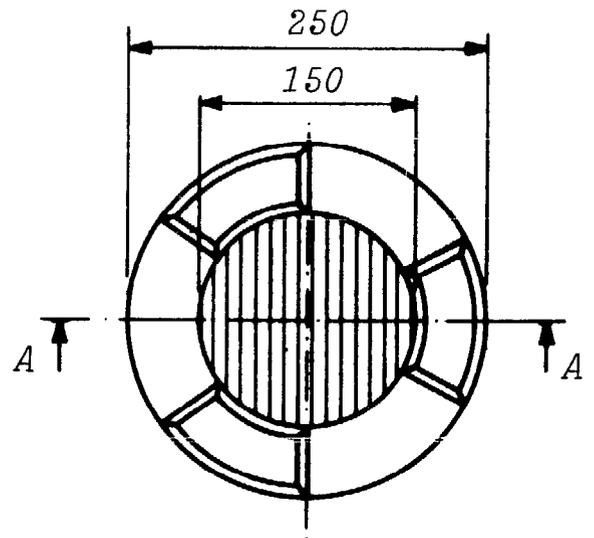
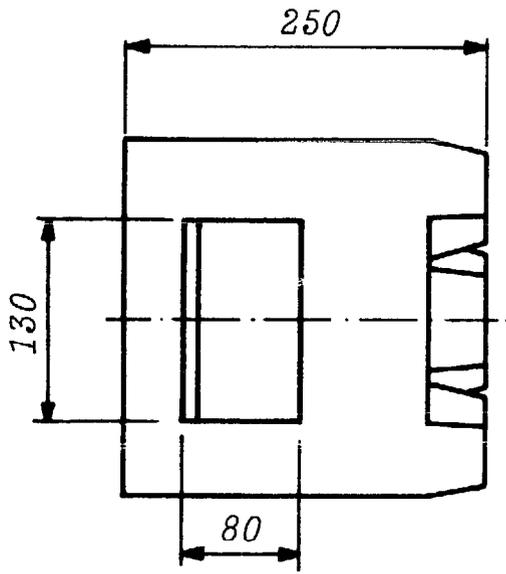
16) *Singer 1961.*

SL1-16



- 1) *SL1-16*
- 2) *No technical drawings.*
- 3) *A portable metal stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn coal or charcoal. It has no chimney, dampers for combustion air, no dampers for combustion gases, no baffles, a grate and provisions for secondary air.*
- 4) *The stove has four dampers for combustion air at the four sides. In the side wall of the combustion chamber are holes for secondary air.*
- 5) *The stove is completely built of sheet metal with metal bars for the grate.*
- 6) *6 kg.*
- 7) *Coal. Charcoal.*
- 8) *Refuelling through the pothole. For refuelling the pot must be lifted from the stove. No dimensions known.*
- 11) *IDC-stove (Industrial Design Centre).*
- 12) *This stove was developed at the Indian Institute of Technology, Bombay, by Rao, Jagadish and Rahan in 1980. It was designed for burning coal with high volatile content.*
- 13) *Waterboiling tests at the Indian Institute of Technology, Bombay showed good efficiency.*
- 14) *No field tests known.*
- 16) *Jagadish 1980.*

SL1-17

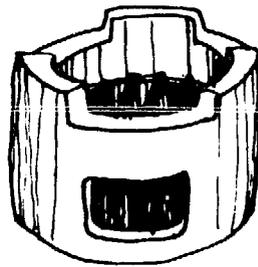


section A-A



1) *SL1-17*

3) *A portable cement and steel stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0.25 m. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove is made of cement with an outside wall of sheet steel. The grate is made of steel bars or perforated sheet steel.*

6) *10 kg.*

7) *Charcoal*

8) *Refuelling through the pothole, for which the pan must be lifted from the fire.*

11) *Indonesia cement stove.*

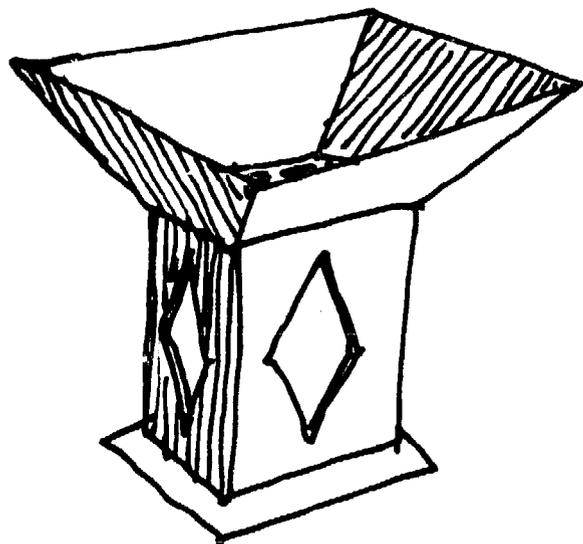
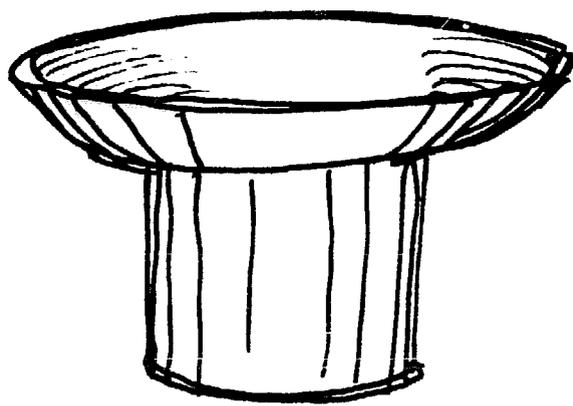
12) *A model that is widely used in Indonesia.*

13) *Waterboiling tests by Singer showed high to very high efficiency with the grate of perforated sheet steel.*

14) *No field tests known.*

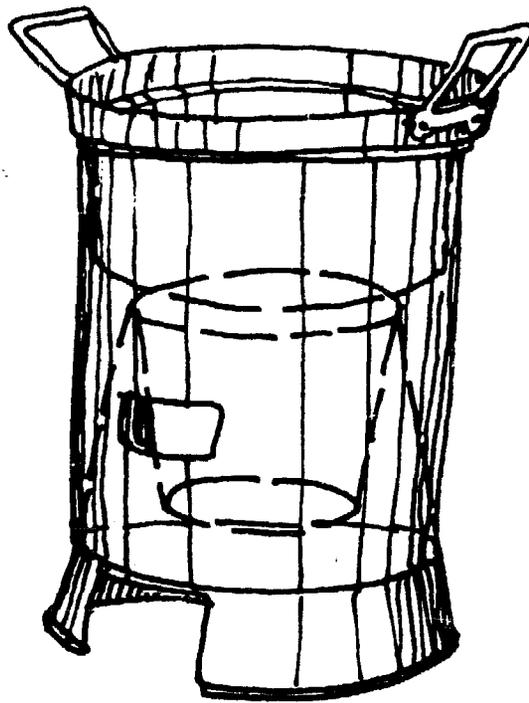
16) *Singer 1961.*

SL1-18



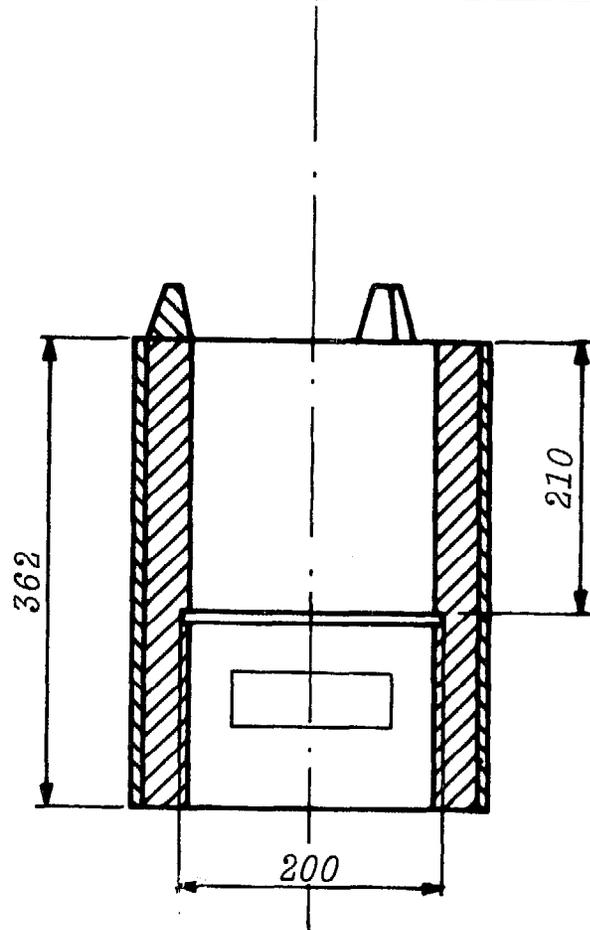
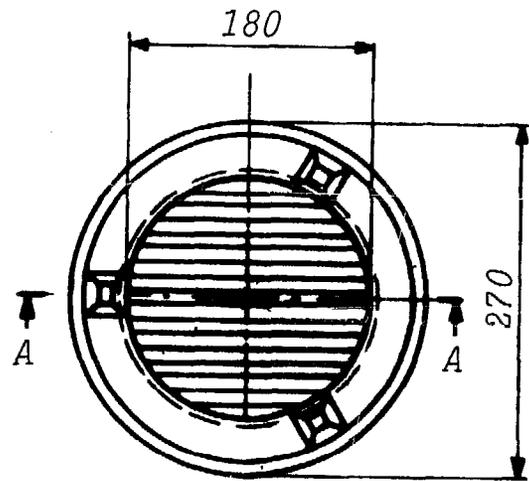
- 1) *SL1-18*
- 2) *No technical drawings.*
- 3) *A portable metal stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*
- 5) *The stove is completely built of sheet steel.*
- 6) *4 kg.*
- 7) *Charcoal.*
- 8) *Refuelling through the pothole, for which the pot must be lifted from the fire. No dimensions known.*
- 11) *Malagasi stove.*
- 12) *This stove is widely used in West-Africa and sold on markets in various sizes, in round and square shape.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Acott et al 1980.*

SL1-19



- 1) *SL1-19*
- 2) *No technical drawings.*
- 3) *A portable metal stove which can accommodate 1 pot of cylindrical shape. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*
- 5) *The stove is completely made of sheet steel.*
- 6) *5 kg.*
- 7) *Charcoal.*
- 8) *Refuelling through the pothole for which the pan must be lifted from the fire. No dimensions known.*
- 11) *Rumford Stove.*
- 12) *This stove was developed by Benjamin Thompson, Count Rumford, early in the 18th Century. Based on the same ideas he also built bigger stoves.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Bomar 1978.*

SL1-20

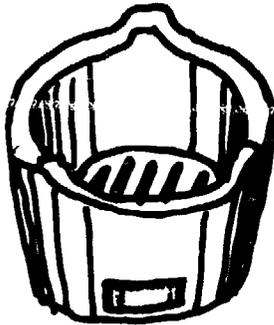


section A-A



1) SL1-20

3) *A portable metal and ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,25 m. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove consists of a sheet steel cylinder, with a clay lining on the inside. In this cylinder a metal grate is situated. a ceramic grate should also be possible.*

6) *10 kg.*

7) *Charcoal, Coal.*

8) *Refuelling through the pothole with a diameter of 0,18, for which the pan must be lifted. Small pieces of fuel can be added without lifting the pan.*

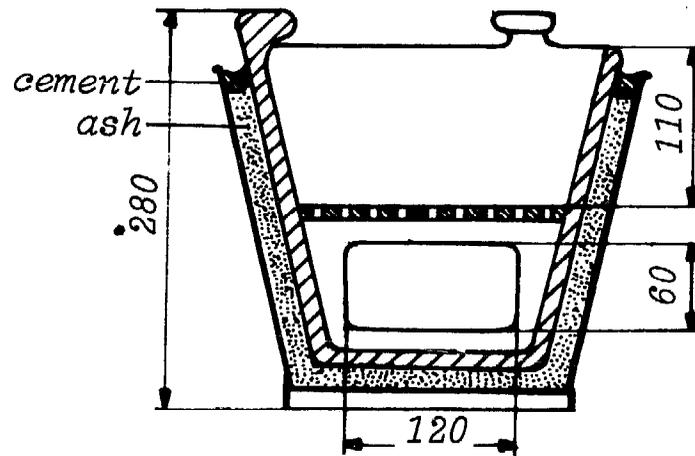
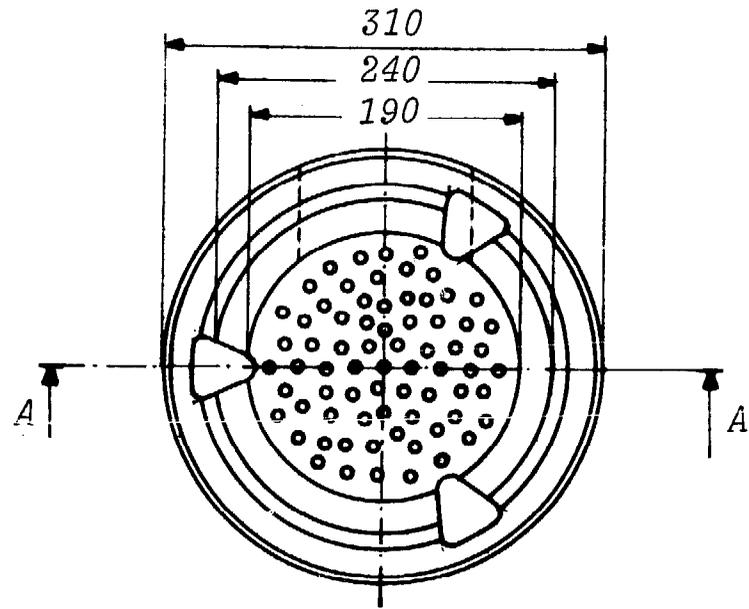
11) *Angethi.*

13) *Water boiling tests by Salariya showed low efficiency.*

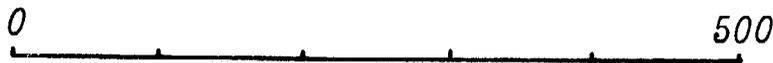
14) *No field tests known.*

16) *Salariya 1978. Krishna Prasad 1979.*

SL1-21

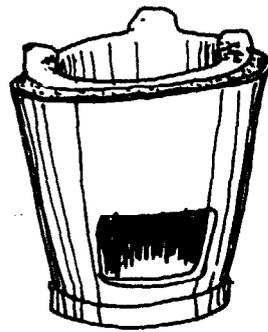


section A-A



1) *SL1-21*

3) *A portable metal and ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,28 m. It will burn charcoal. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The outside of the stove is a metal bucket, the inside a ceramic pot with a ceramic grate. Inside and outside walls are separated by an insulating layer of ash. This ash layer is sealed with cement.*

6) *10 kg.*

7) *Charcoal, wood or coal.*

8) *0,2 m. Refuelling through the pothole with lifting of the pan. Small pieces of fuel can be added to the fire without lifting the pan.*

11) *Thai bucket.*

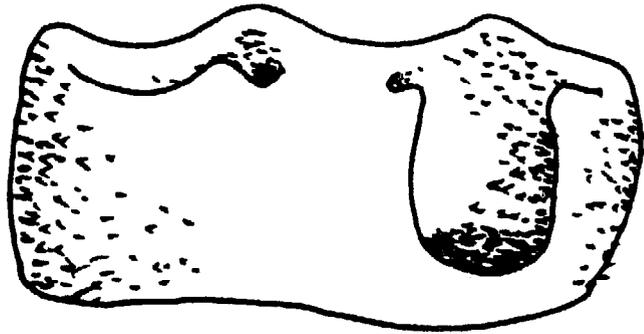
12) *Developed in Thailand about 1920. It is a traditional model that is used all over Thailand.*

13) *Water boiling tests by Openshaw showed medium efficiency. Water boiling tests by I T D G London showed good efficiency. Water boiling tests by Jagadish showed good efficiency.*

14) *No field tests known.*

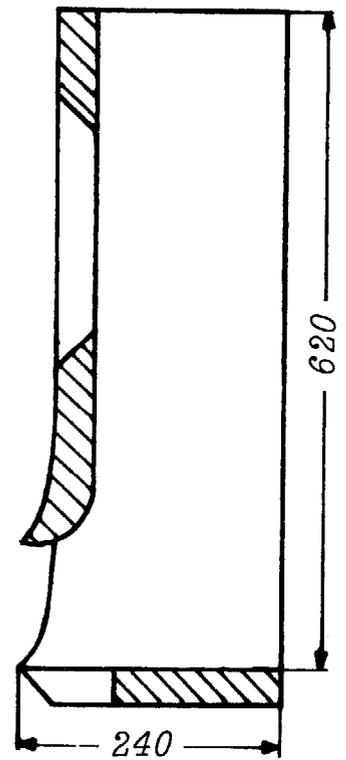
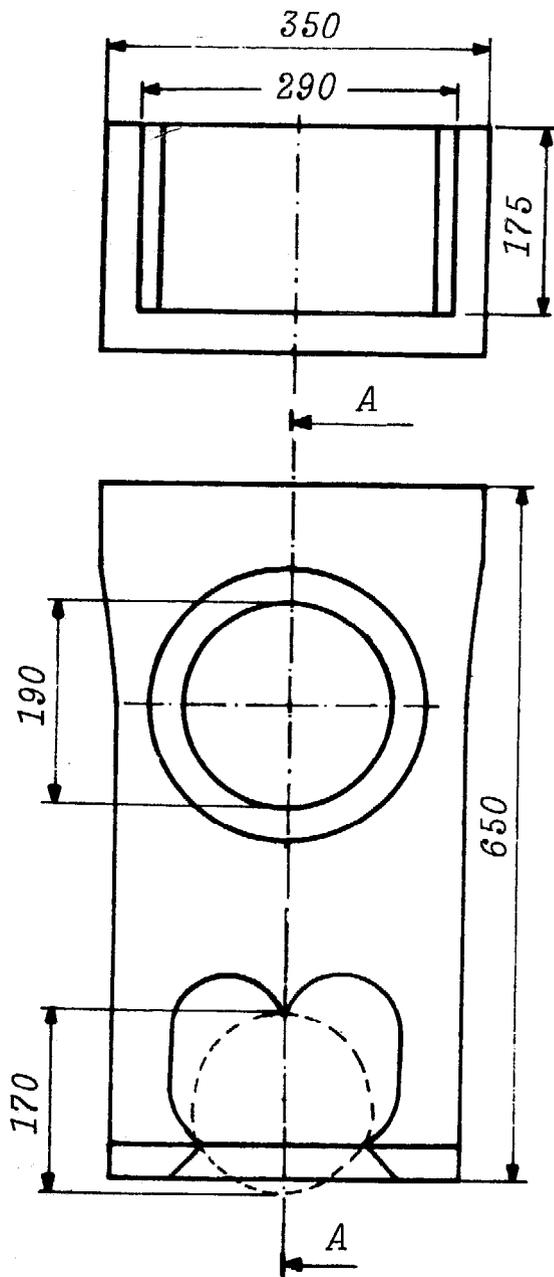
16) *Openshaw 1979. Jagadish 1980. Anon 1980 b. Joseph Shanahan, Bialy 1980. Acott et al 1980.*

SL2-1

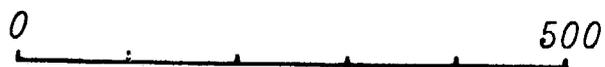
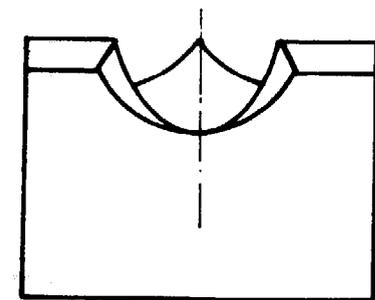


- 1) *SL2-1*
- 2) *No technical drawings.*
- 3) *A portable ceramic stove which can accommodate 2 pots of cylindrical or spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*
- 5) *The stove is completely made of ceramic.*
- 6) *6 kg.*
- 7) *Wood*
- 8) *Any length. No dimensions known. Refuelling without lifting the pan.*
- 11) *Biseated country stove.*
- 12) *Traditional Indian stove.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Kallupatti 1955.*

SL2-2

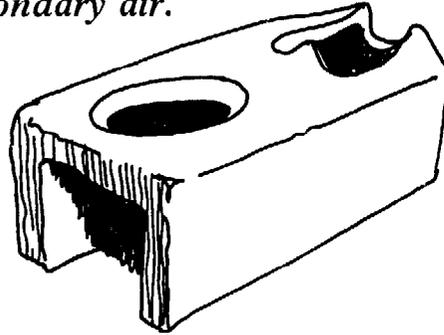


section A-A



1) SL2-2

3) *A portable ceramic stove which can accommodate 2 pots of spherical shape. These pots can have diameters of 0,26 and 0,2 m. It will burn long wood with no limitations on the length. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



5) *The stove is completely built of ceramic.*

6) *20 kg.*

7) *Wood.*

8) *Any length, 0,29 x 0,15 m. The fuel can be added without lifting the pan.*

11) *Tungku Muntilan.*

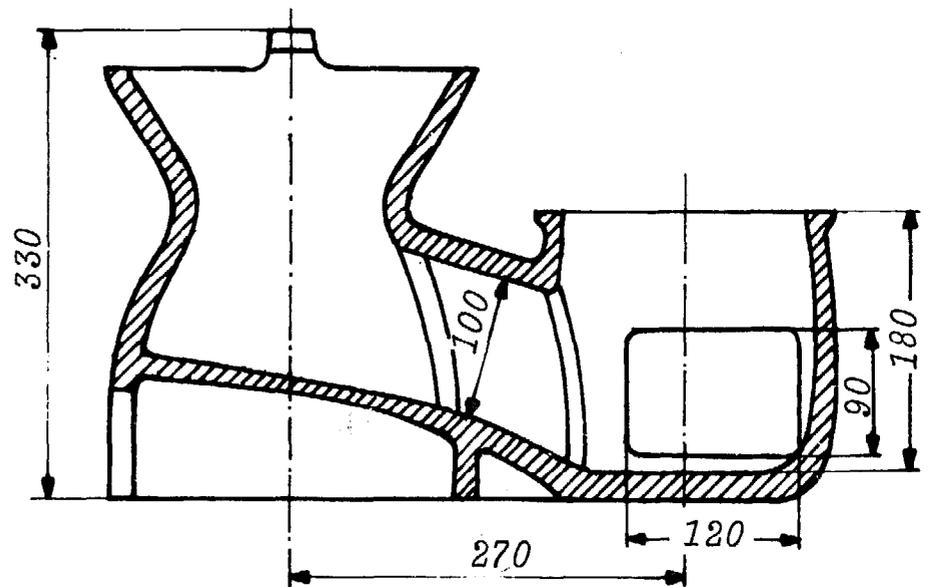
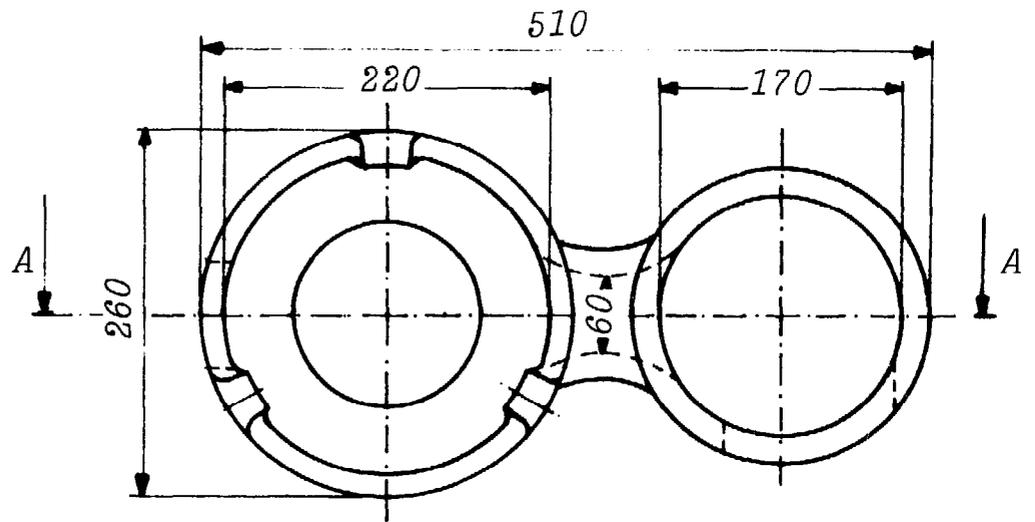
12) *Central Java, Indonesia. It is a traditional design. These stoves are made in different sizes for domestic cooking as well as for use in restaurants.*

13) *Water boiling tests at Dian Desa by Aryanto Soedjarwo, Don Flickinger and Stephen Joseph (ITDG London). Two aluminium pots of 0,22 m, containing 2 l of water each were used. When the water in the first pot has come to the boil, the pots change positions. When the water in the second pot has come to the boil, both pots are kept simmering for 30 min. Average time to bring the water in the first pot to the boil was 15 min. Total use of fuel wood was 450 g. Both pots were covered with a lid.*

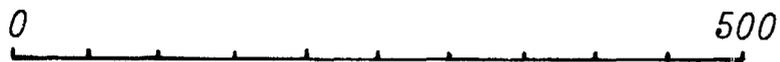
14) *No field tests known.*

16) *Joseph, Shanahan, Bialy 1980.*

SL2-3

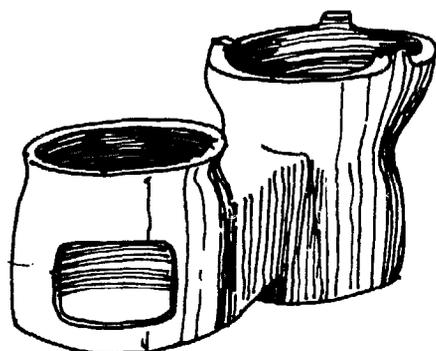


section A-A



1) SL2-3

3) *A portable ceramic stove which can accommodate 2 pots of cylindrical or spherical shape. These pots can have diameters of 0,23 and 0,30 m. On the second pothole also smaller pots can be used to a minimum diameter of 0,15 m. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



5) *The stove is completely built of ceramic.*

6) *12 kg.*

7) *Wood.*

8) *Any length. 0,09 x 0,12 m. Refuelling without lifting the pan.*

11) *TERI-ITDG stove.*

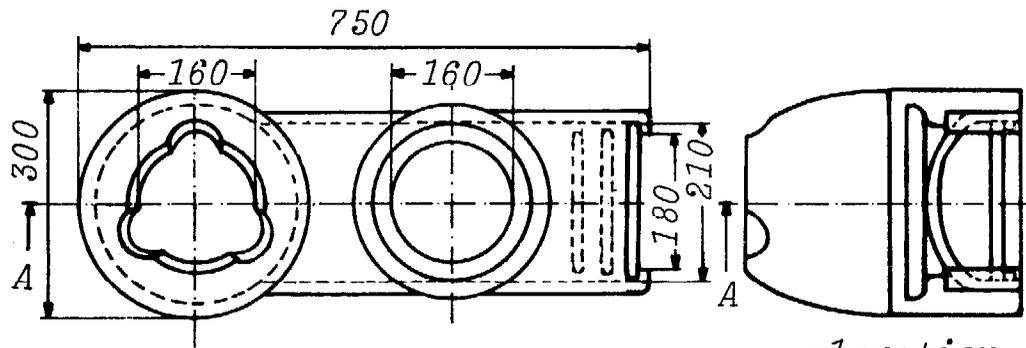
12) *This stove is a modification by ITDG of the TERI-stove designed in 1980 by Rao and Gupta of the Tata Energy Research Institute in India.*

13) *Water boiling tests by ITDG showed good efficiency. Water boiling tests by Geller showed good efficiency.*

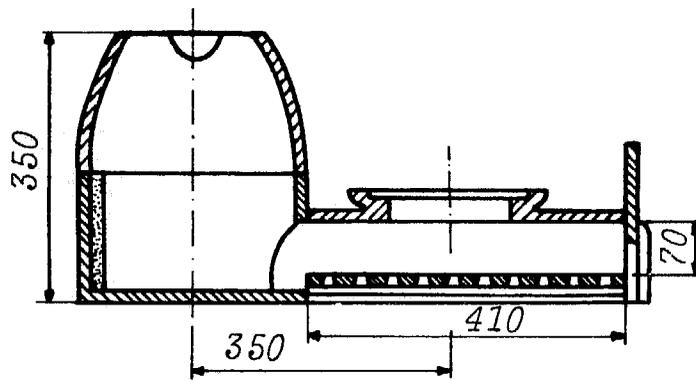
14) *No field tests known.*

16) *Joseph, Shanahan, Bialy, 1980. Geller 1981 c.*

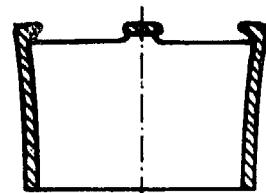
SL2-4



*elevation
without door*



section A-A

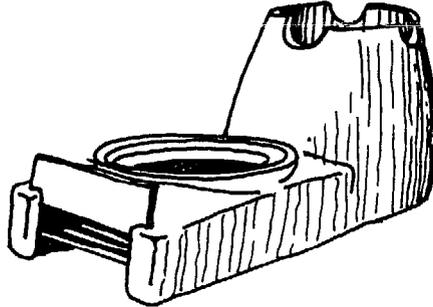


alternative top



1) SL2-4

3) *A portable ceramic stove which can accommodate 2 pots of cylindrical or spherical shape. These pots can have diameters of 0,2 m. With an alternative top the second pot can have a diameter of 0,35 m. It has no chimney, a damper for combustion air, no damper for combustion gases, no baffles, a grate and no provisions for secondary air. It can be used as an oven.*



4) *With a door in the front of the stove the combustion air can be controlled.*

5) *The stove is completely made out of ceramic with a sheet metal shield at the backside of the stove which can function as an oven. Between this metal shield and the ceramic wall is an insulating layer of ash.*

6) *30 kg.*

7) *Wood. Charcoal.*

8) *Maximum length: 0,4 m. 0,07 x 0,15 m. Refuelling without lifting the pan.*

9) *When both potholes are closed, the space under the second pothole can be used as an oven.*

11) *Tandoor stove.*

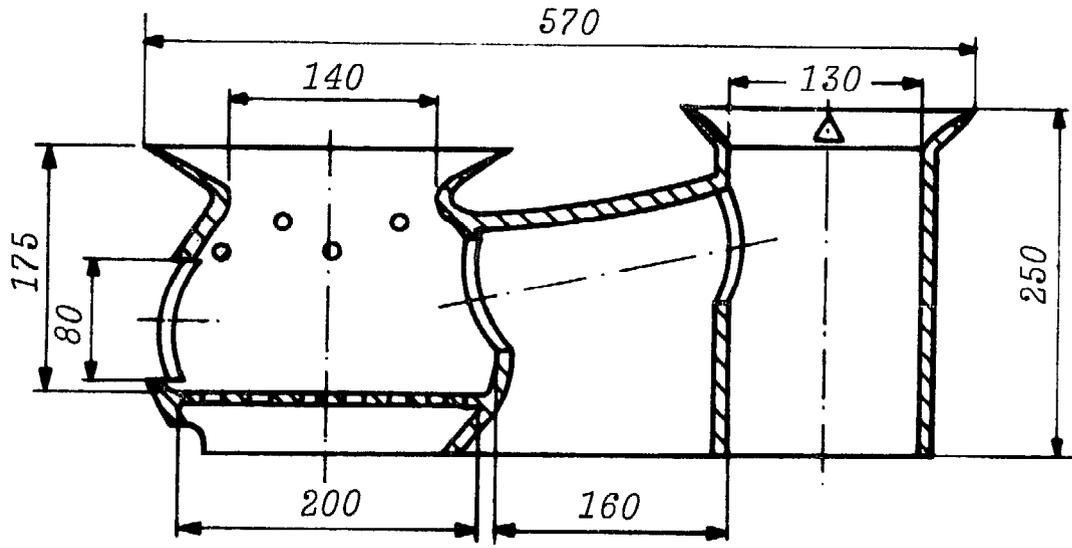
12) *This stove was designed by S. Joseph of I.T.D.G. in 1978.*

13) *Water boiling tests on the stove with the oven-top at I.T.D.G. showed medium efficiency.*

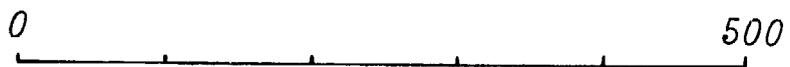
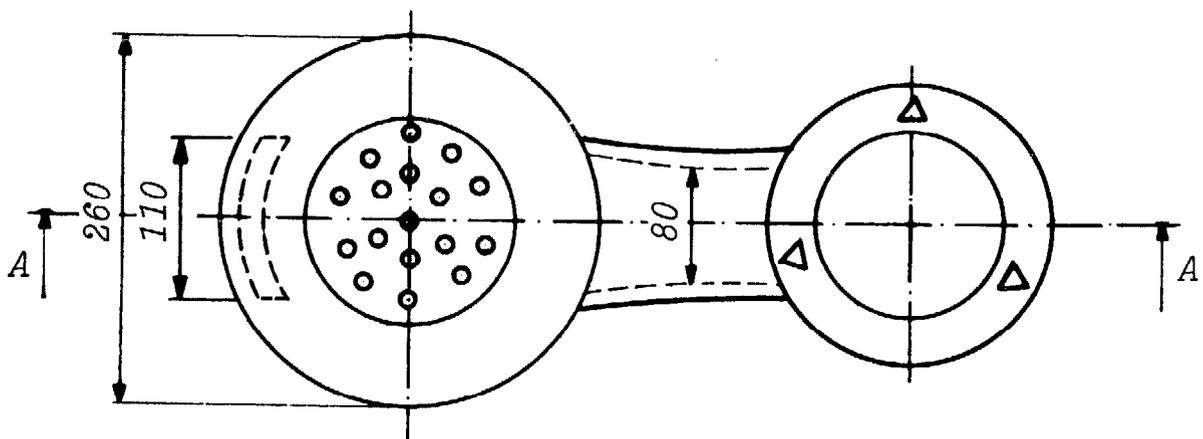
14) *No field tests known.*

16) *Joseph, Shanahan, Bialy 1980.*

SL2-5

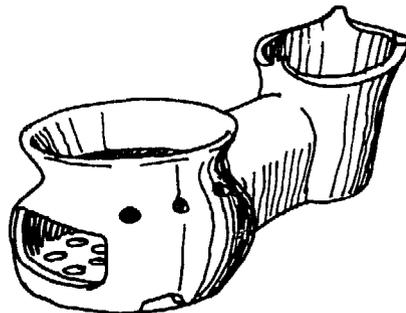


section A-A



1) SL2-5

3) *A portable ceramic stove which can accommodate 2 pots of cylindrical or spherical shape. These pots can have a diameter of 0,2 m. It will burn long wood. It has no chimney, no dampers, no baffles, a grate and a provision for secondary air.*



4) *This stove is provided with holes in the combustion chamber for secondary air.*

5) *Stove is completely made of ceramic.*

6) *8 kg.*

7) *Wood. Agricultural waste, corn stalks, straw.*

8) *Any length of the firewood. 0,11 x 0,08 m. The fuel can be added to the fire without lifting the pan*

11) *Tungku Sae.*

12) *Indonesia, Urban areas 1980.*

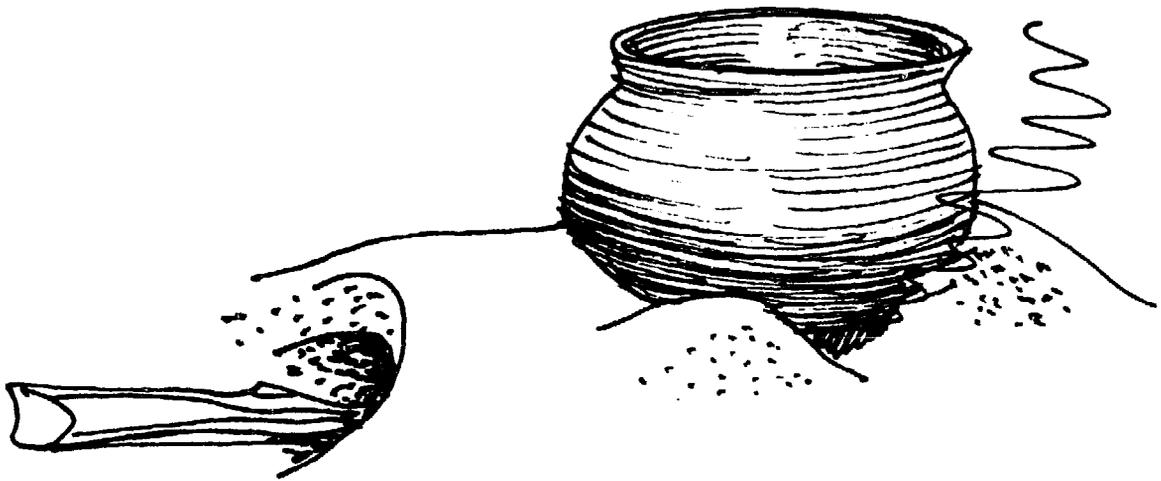
13) *Water boiling tests at Dian Desa by Aryanto Soedjarwo, Don Flickinger and Stephen Joseph (ITDG London). Two aluminium pots of 23 cm, containing 2 l of water each were used. The average amount of wood needed to bring the water in both pots to the boil was 500 g.*

14) *No field tests known.*

15) *A woman who has used this stove for three weeks claims that it is easier to use, cleaner, quicker and saves more wood than the Keren-stove (SL1-4).*

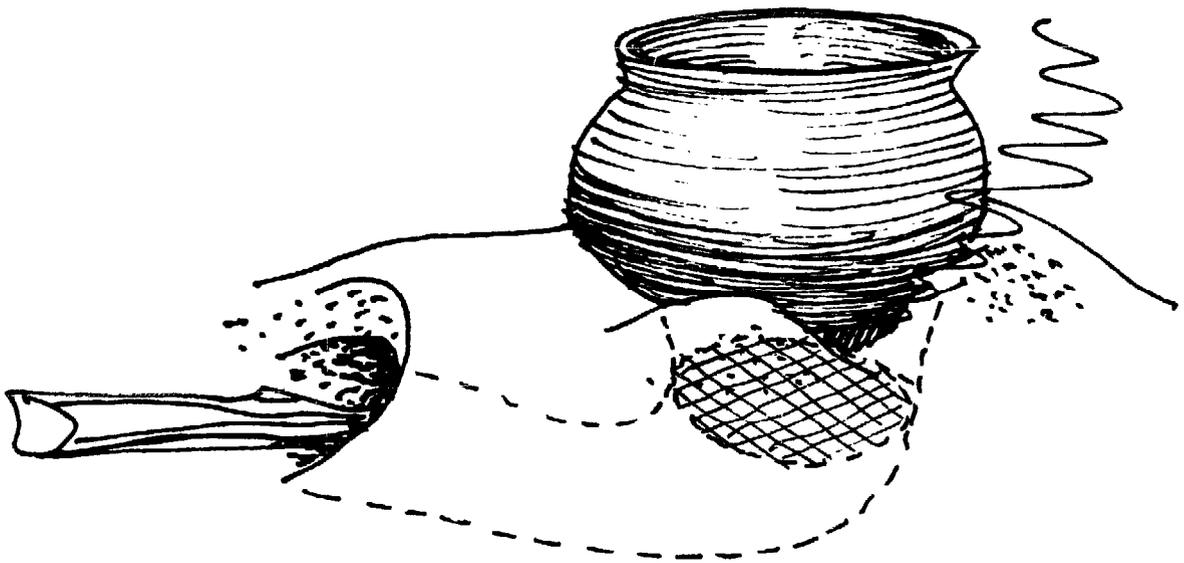
16) *Joseph, Shanahan, Bialy 1980.*

SH1-1



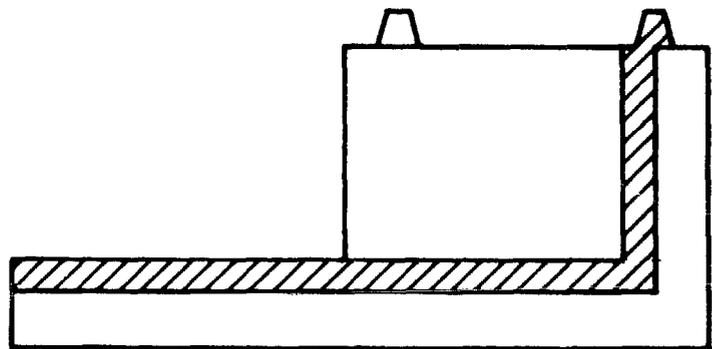
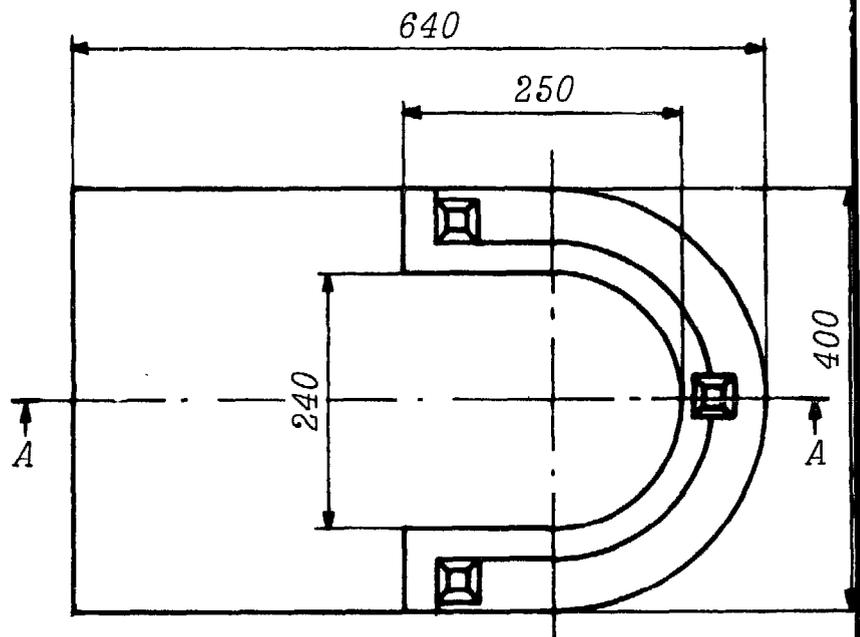
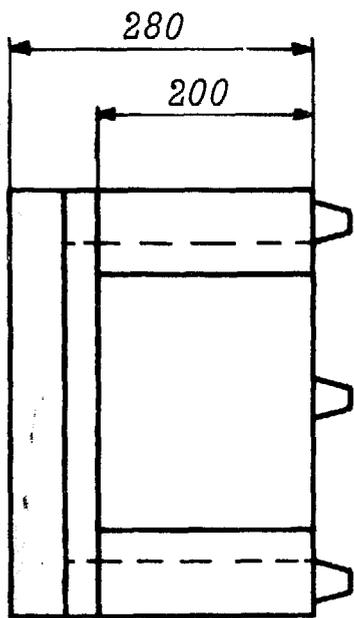
- 1) *SH1-1*
- 2) *No technical drawings.*
- 3) *A fixed stove that can accommodate 1 pot of cylindrical or spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*
- 5) *The stove consists of a tunnel, dug out in the ground. At one end of the tunnel the pot is seated, through the other end the wood is fed to the fire that is burning under the pot.*
- 7) *Wood.*
- 8) *Any length. No fixed dimensions. Refuelling without lifting the pan.*
- 11) *Bangladesh Chula.*
- 12) *This is an traditional Indian stove. Based on the same principle a stove for more pots can be built. An example is the Roti Stove.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Joseph (undated).*

SH1-2



- 1) *SH1-2*
- 2) *No technical drawings.*
- 3) *A fixed stove which can accommodate 1 pot of cylindrical or spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.*
- 5) *The stove is basically a tunnel dug out in the ground. At one end of the tunnel the pot is seated. In the tunnel is placed a ceramic grate on which the fire burns. The wood is fed to the fire through the other end of the tunnel.*
- 7) *Wood.*
- 8) *Any length. No fixed dimensions. Refuelling without lifting the pan.*
- 11) *Improved Bangladesh chula.*
- 12) *This modification of the Bangladesh chula was developed by Dr. Narruzaman of BSCIR.*
- 15) *The amount of wood to boil a quantity of food was considerably reduced, compared to the original Bangladesh chula.*
- 16) *Joseph (undated).*

SH1-3

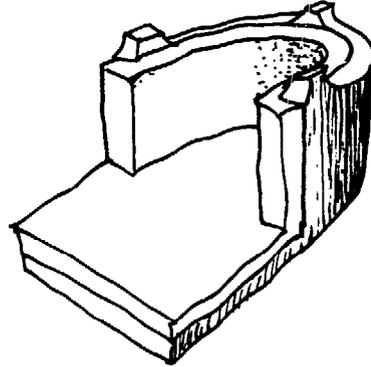


section A-A



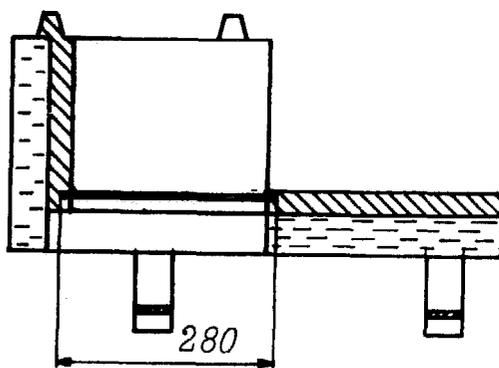
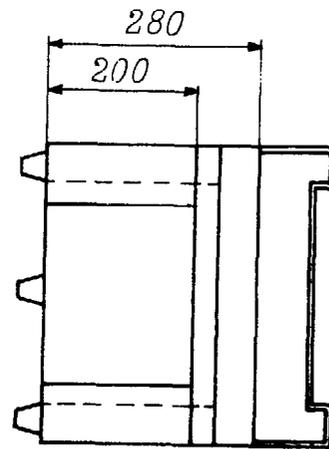
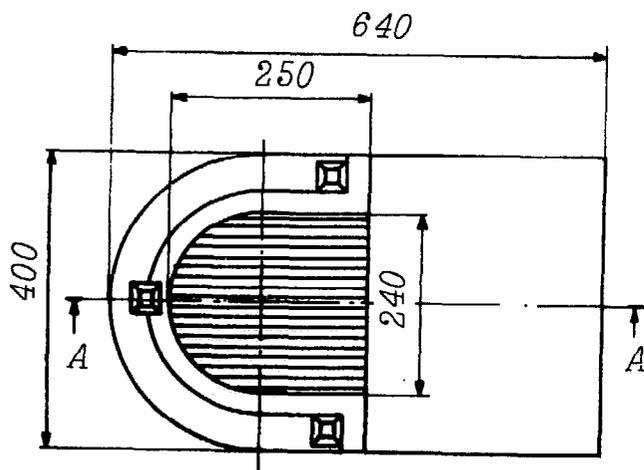
1) SH1-3

3) *A portable ceramic and metal stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,3 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



- 5) *The stove consists of a water tank made of sheet steel, with a lining of clay on the inside and bottom.*
- 6) *20 kg (with empty water tank) 40 kg (with filled water tank)*
- 7) *Wood.*
- 8) *No limitations on the length. 0,2 x 0,24 m. Refuelling without lifting the pan.*
- 10) *The water tank has a volume of 20 l. No figures on achievable temperatures.*
- 11) *Economical chula.*
- 12) *Developed as an improved version of the traditional India chula (SL1-2) at Punjab Agricultural University in India.*
- 13) *Water boiling tests by Salariya showed medium efficiency without and good efficiency with taking into account the heat absorbed by the water in the water jacket.*
- 14) *No field tests known.*
- 16) *Salariya 1978.*

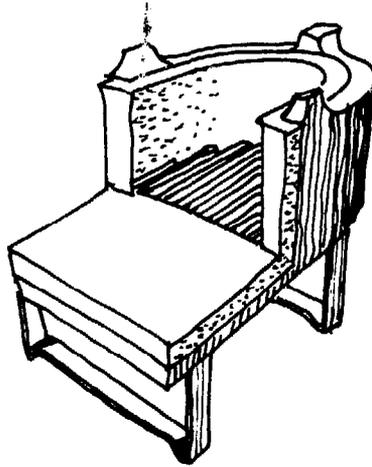
SH1-4



section A-A 0 500

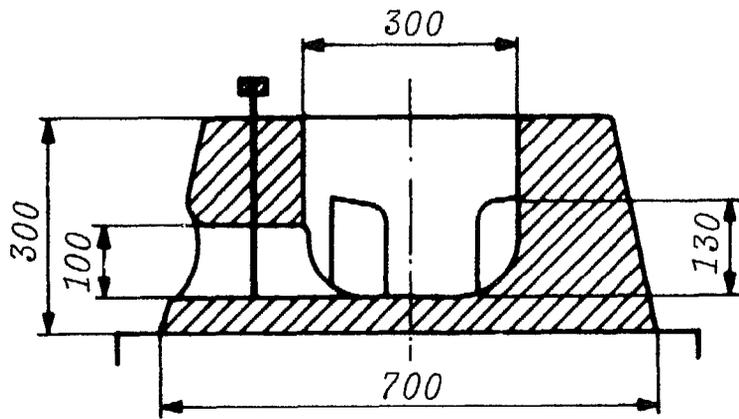
1) SH1-4

3) A portable ceramic and metal stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,3 m. It will burn long wood. It has no chimney, no dampers, no baffles, a grate and no provisions for secondary air.

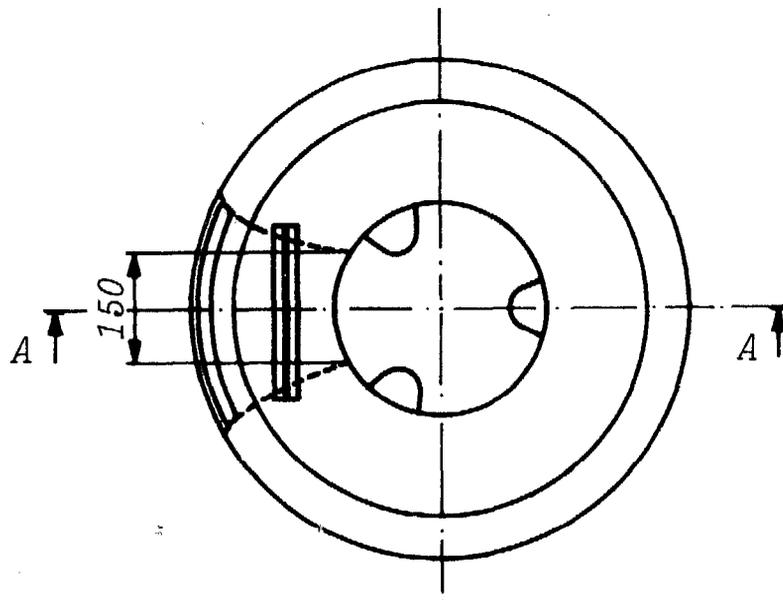


- 5) The stove consists of a water tank of sheet steel with a lining of clay on the inside and the front part of the bottom. The back part of the bottom is a ceramic grate.
- 6) 20 kg (with empty water tank) 40 kg (with filled water tank)
- 7) Wood.
- 8) Any length. 0,2 x 0,24 m. Refuelling without lifting the pan.
- 10) The water tank has a volume of 20 l. No figures on achievable temperatures.
- 11) Economical chula with grate.
- 12) Developed as an improved version of the traditional India chula (SL1-2) at Punjab Agricultural University in India.
- 13) Water boiling tests by Salariya showed medium efficiency without and good efficiency with taking into account the heat absorbed by the water in the water jacket.
- 14) No field tests known.
- 16) Salariya 1978.

SH1-5

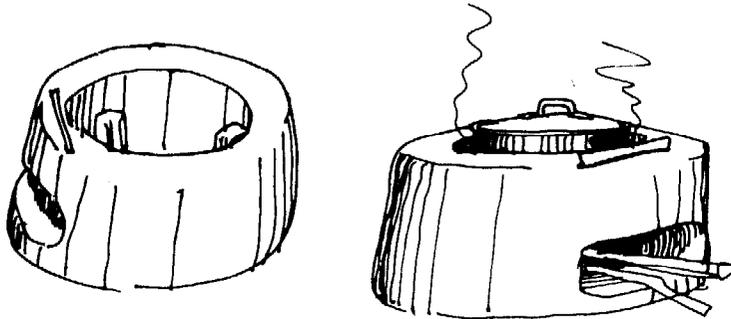


section A-A



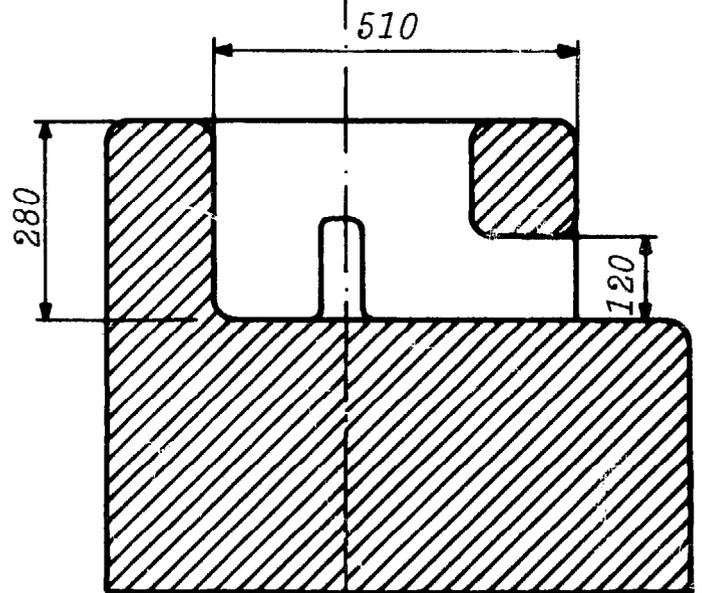
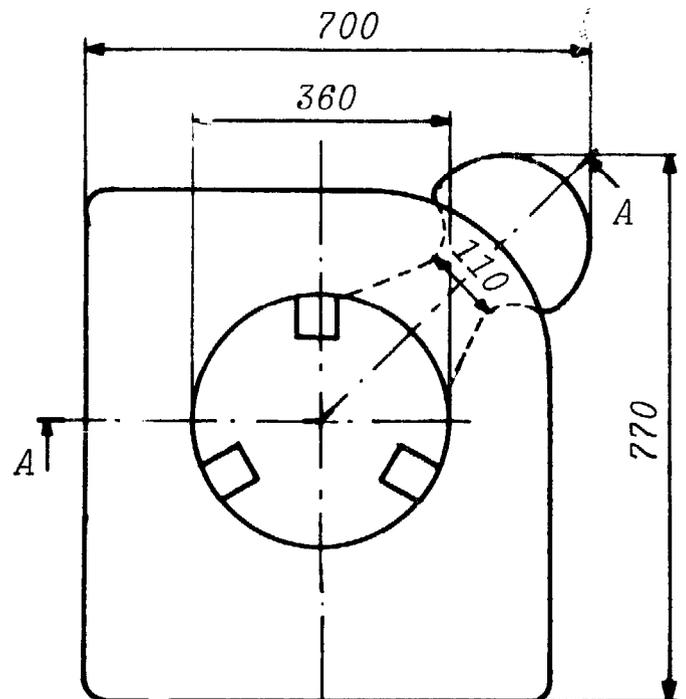
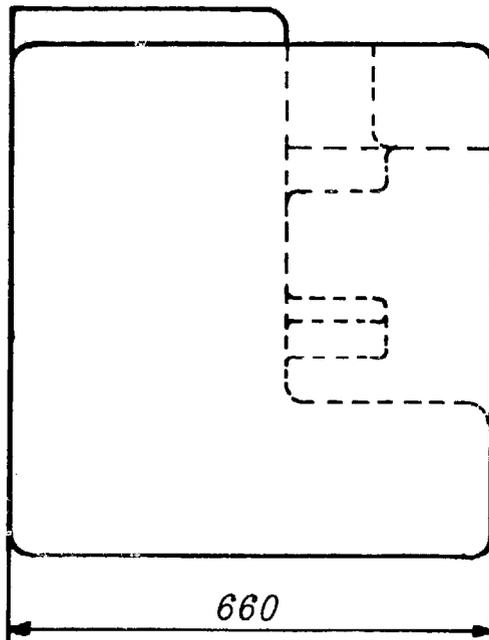
1) SH1-5

3) *A fixed mud stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,26 m. It will burn long wood. It has no chimney, a damper for combustion air, no damper for combustion gases, no grate and no provisions for secondary air.*

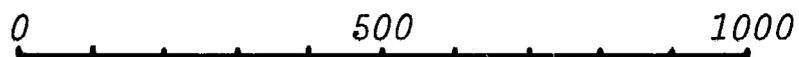


- 4) *The stove has an inlet air damper which can completely shut off the entrance opening.*
- 5) *The stove is completely made of mud with a damper of sheet steel.*
- 6) *100 kg.*
- 7) *Wood.*
- 8) *0,4 m with closed damper, otherwise no limitations to the length 0,1 x 0,15 m. Refuelling without lifting the pan.*
- 11) *Louga stove.*
- 12) *This stove was developed in 1980 in the northern part of Senegal.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 15) *Fuel savings from 40...60% compared to the open fire.*
- 16) *Evans, Gern, Jacobs 1980.*

SH1-6

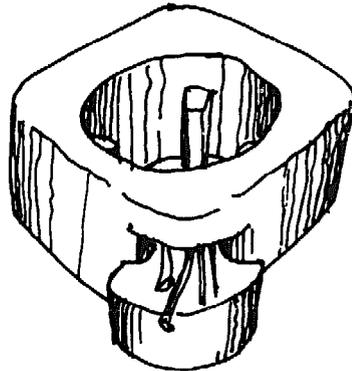


section A-A



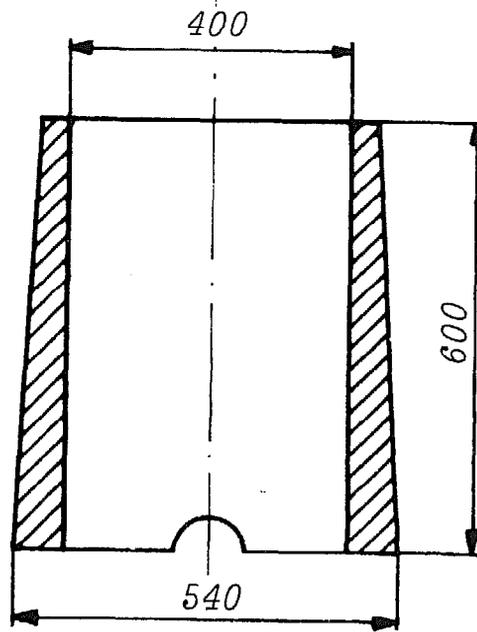
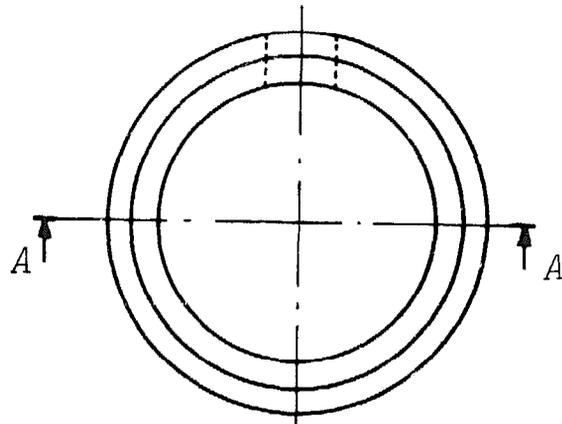
1) SH1-6

3) *A fixed mud stove which can accommodate 1 pot of cylindrical shape. This pot can have a diameter of 0,32 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*

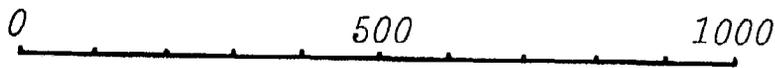


- 5) *The stove is completely made out of mud. Bricks can be used to build the base.*
- 6) *550 kg.*
- 7) *Wood.*
- 8) *Any length. 0,11 x 0,12 m. Refuelling without lifting the pan.*
- 11) *Evans M3.*
- 12) *Stove was built in Africa in 1980.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Evans, Gern, Jacobs 1980.*

SH1-7

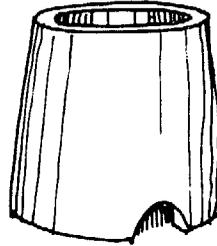


section A-A



1) SH1-7

3) *A fixed ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,45 m. It will burn rice husks. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



5) *The stove is completely made of ceramic. As an alternative material bricks could be used.*

6) *80 kg.*

7) *Rice husks, possibly sawdust.*

8) *The amount of fuel needed must be fed to the stove before lighting it. Refuelling while the stove is burning is not possible. The rice husks are pressed into the stove, while leaving open a central hole. This can be done by using a stick. There must also be a connection between this central hole and the draught hole at the bottom of the stove. The rice-husks must be lighted at the bottom of the central hole.*

11) *Pail-type stove.*

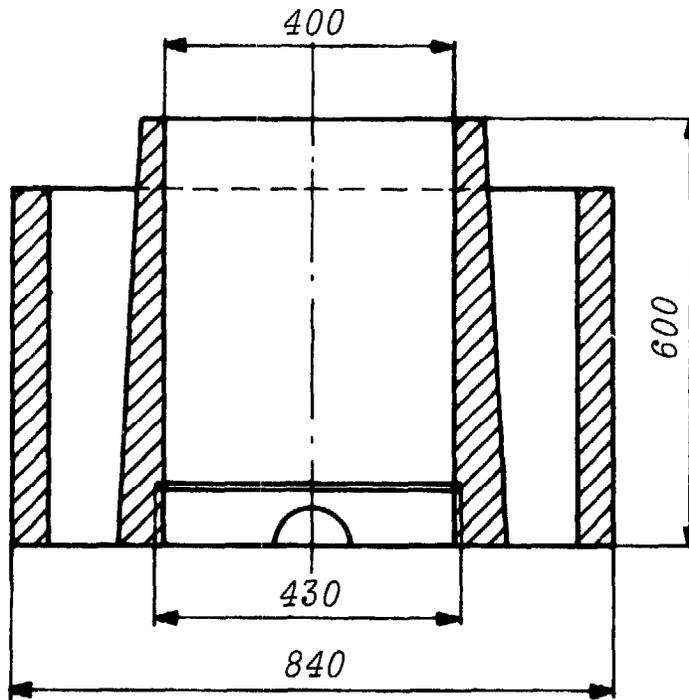
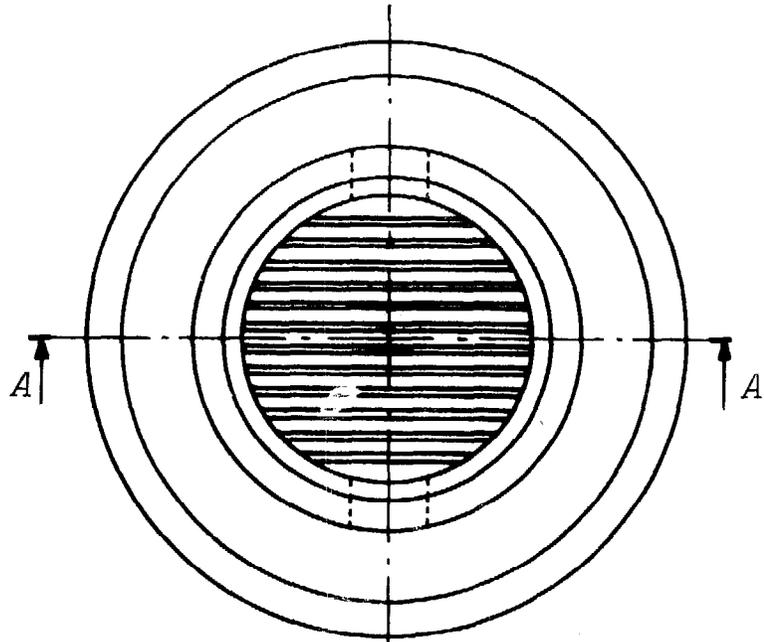
12) *This stove was developed at General Soerdirman University in Central Java.*

13) *Water boiling tests showed very high efficiency.*

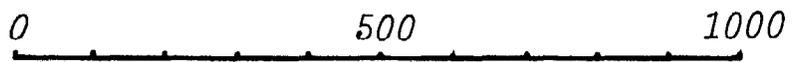
14) *No field tests known.*

16) *Huynink, Sapardi, Hartono 1979.*

SH1-8

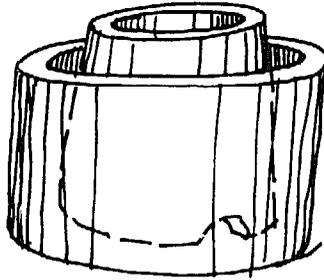


section A-A



1) SH1-8

3) *A fixed ceramic stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,45 m. It will burn rice husks. It has no chimney, no dampers, no baffles, a grate and no provision for secondary air.*



5) *The stove is made out of ceramic. As an alternative material bricks could be used.*

6) *150 kg.*

7) *Rice husks, possibly sawdust.*

8) *The stove must be charged with the amount of fuel needed before lighting it, because refuelling is impossible while the stove is burning. The rice husks are pressed into the stove while leaving open a central hole. The rice husks must be lighted at the bottom of the central hole.*

11) *Improved Pail-type stove.*

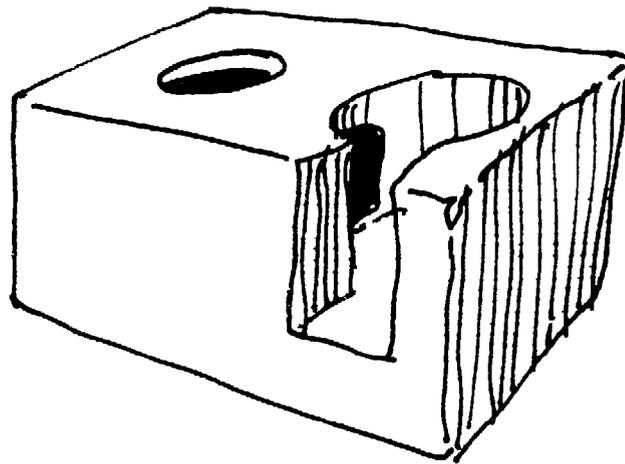
12) *The stove was developed at General Soedirman University in Central Java.*

13) *No laboratory tests known.*

14) *No field tests known.*

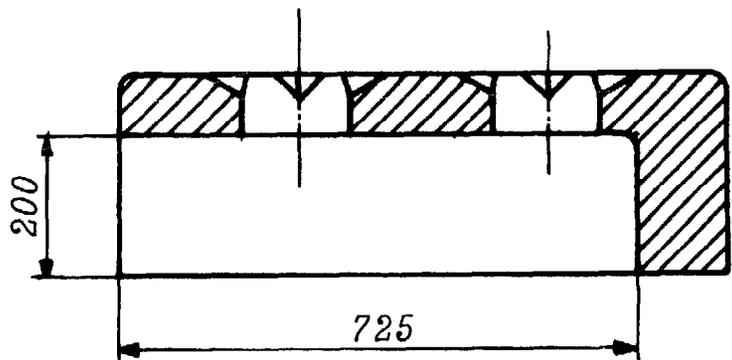
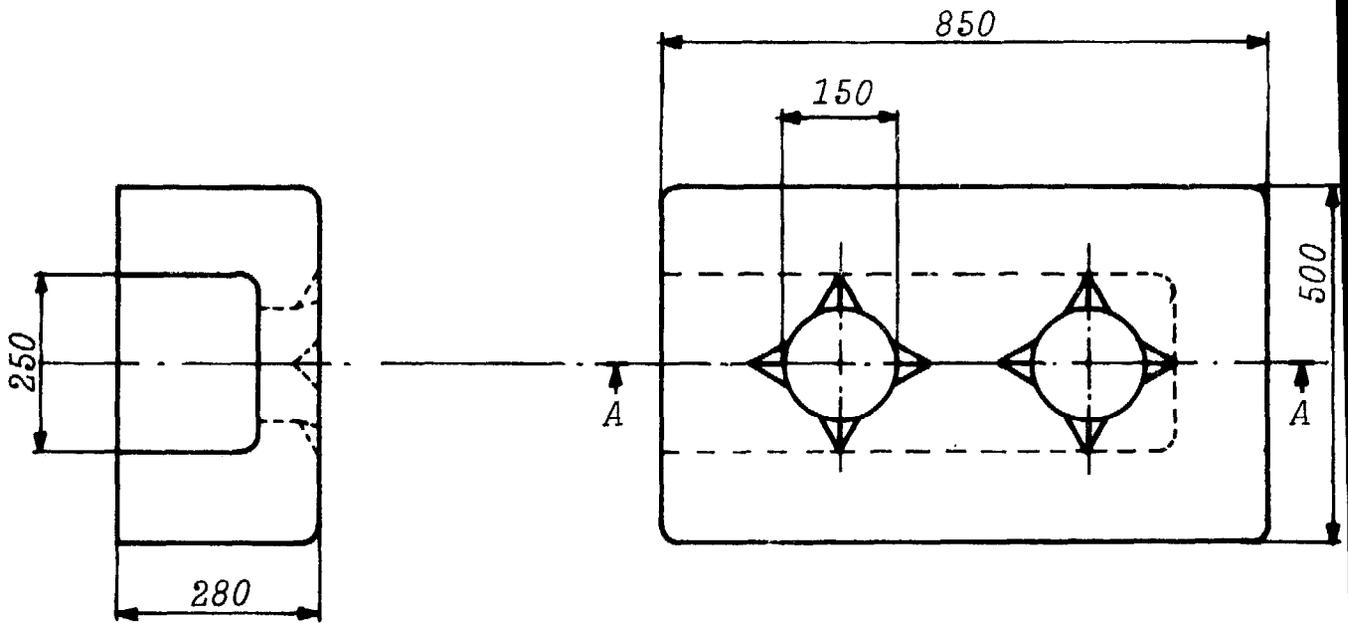
16) *Huynink, Sapardi, Hartono 1979.*

SH2-1

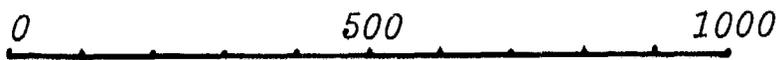


- 1) *SH2-1*
- 2) *No technical drawings.*
- 3) *A fixed mud stove which can accommodate 2 pots of spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*
- 5) *The stove is completely made out of mud.*
- 6) *No dimensions known.*
- 7) *Wood*
- 8) *Any length. No dimensions known.*
- 11) *Two hole stove.*
- 12) *Traditional Indian model*
- 13) *This stove was tested by Dutt, but his testing was different from the normal waterboiling tests, and he does not give efficiency figures.*
- 14) *No field tests known.*
- 16) *Dutt 1978.*

SH2-3

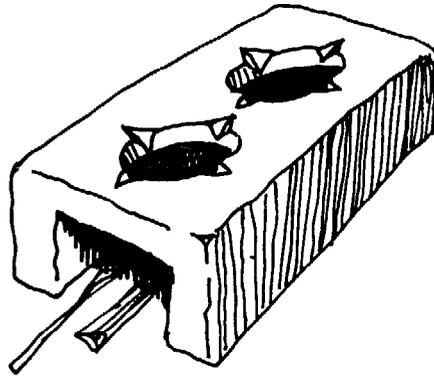


section A-A



1) SH2-3

3) *A fixed mud stove which can accommodate 2 pots of spherical shape. These pots can have diameters of 0,2 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



5) *The stove is completely made of mud but can also be constructed of bricks or fired clay.*

6) *150 kg.*

7) *Wood.*

8) *Any length. 0,25 x 0,2 m. Refuelling without lifting the pan.*

11) *Indonesia two hole stove.*

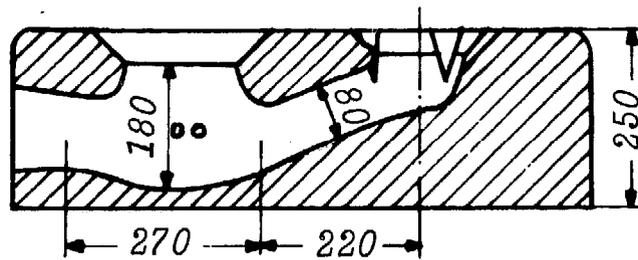
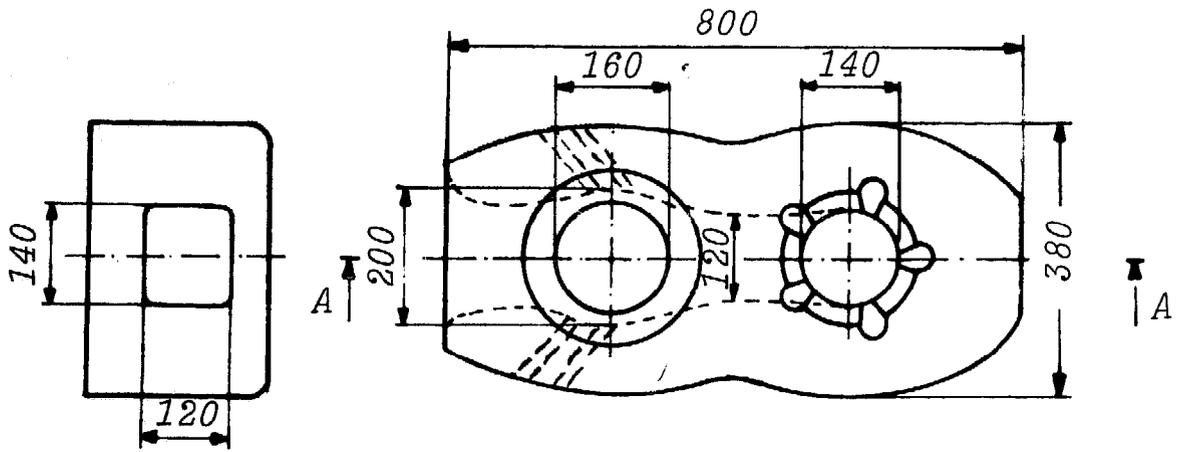
12) *This stove is a general form of many traditional two hole stoves in Indonesia, built by Singer to do tests.*

13) *Water boiling tests by Singer showed low efficiency.*

14) *No field tests known.*

16) *Singer 1961.*

SH2-4

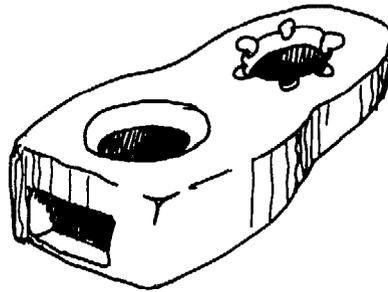


section A-A



1) SH2-4

3) *A fixed mud stove which can accommodate 2 pots of cylindrical or spherical shape. These pots can have diameters of 0,25 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and a provision for secondary air.*



4) *The stove is provided with holes in the side walls of the combustion chamber for secondary air.*

5) *The stove is completely made out of mud.*

6) *80 kg.*

7) *Wood.*

8) *Any length. 0,14 x 0,12 m. Refueling without lifting the pan.*

11) *Tungku Lowon.*

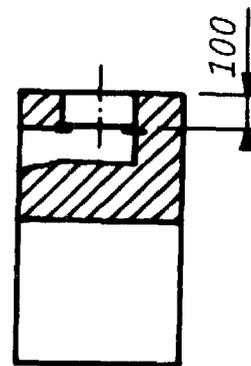
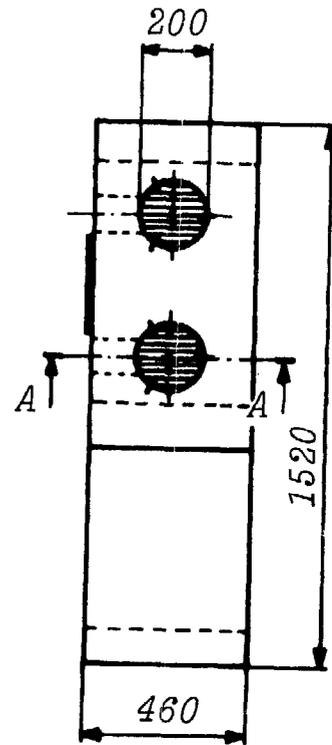
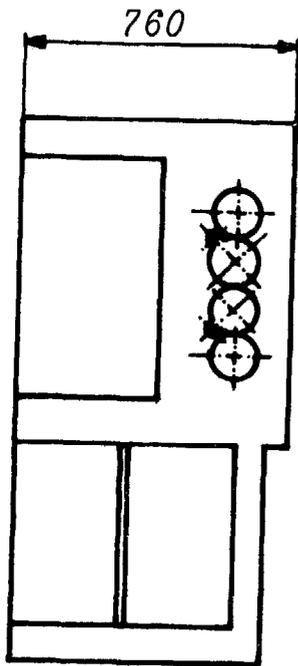
12) *This stove was designed and tested at Dian Desa in Indonesia in 1979.*

13) *Water boiling tests by Joseph, Flickinger and Soedjarwo at Dian Desa showed high efficiency.*

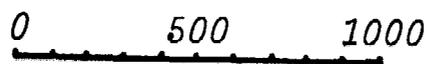
14) *No field tests known.*

16) *Joseph, Shanahan, Bialy 1980.*

SH2-5

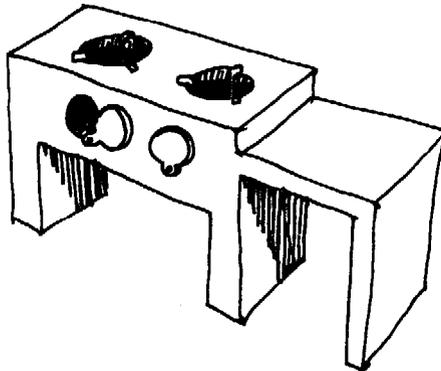


section A-A



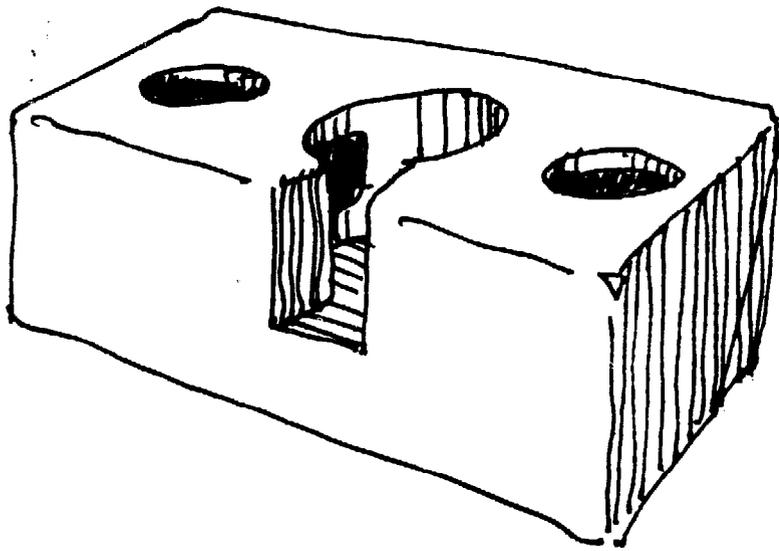
1) SH2-5

3) *A fixed brick stove which can accommodate 2 pots of spherical shape. These pots can have diameters of 0,25 m. It will burn soft coke. It has no chimney, dampers for combustion air, no dampers for combustion gases, no baffles, grates and no provision for secondary air.*



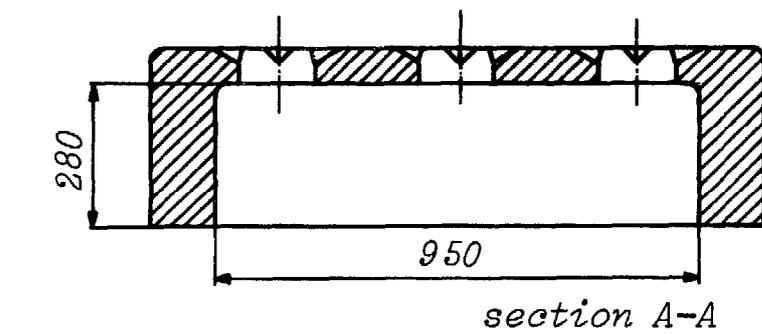
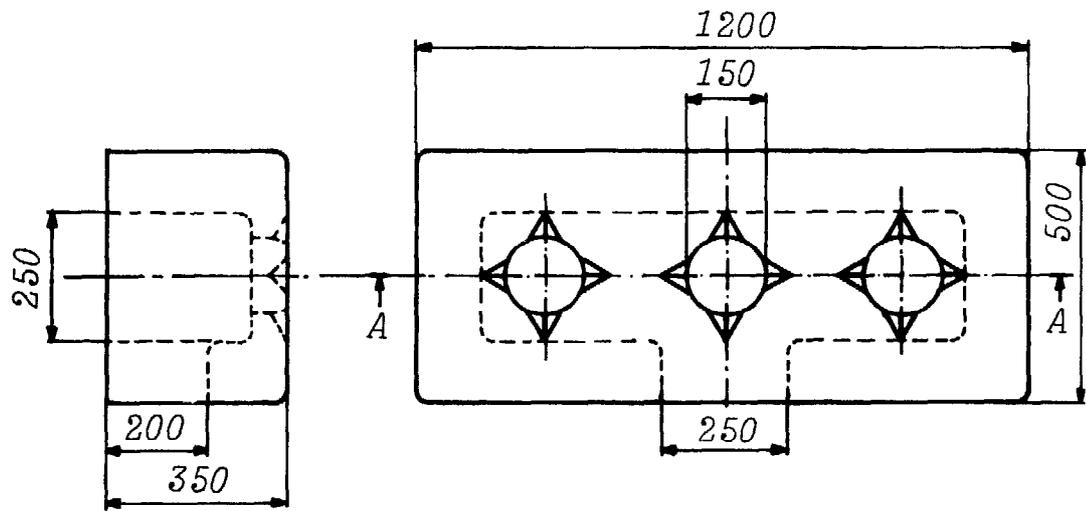
- 4) *The inlet air can be controlled by inlet air dampers that swing over the front opening of the stove.*
- 5) *The stove is built of bricks with sheet metal for the air dampers and metal bars for the grates.*
- 6) *450 kg.*
- 7) *Soft coke.*
- 8) *Refuelling through the pot holes of 0,2 m, for which the pan must be lifted.*
- 11) *Bhavnagar stove.*
- 13) *Water boiling tests by National Building Organisation and the UN Regional Housing Centre ESCAFE at PRAI showed good efficiency. Food cooking tests in the same research programme showed low fuel consumption compared to the water boiling tests.*
- 14) *No field tests known.*
- 16) *Ahuja 1969.*

SH3-1



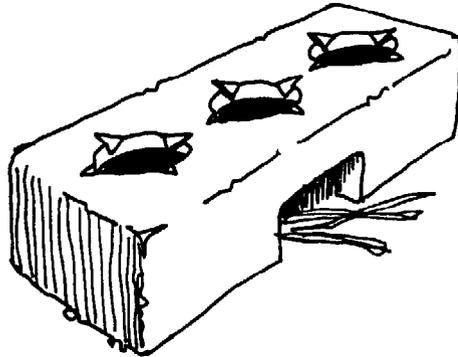
- 1) *SH3-1*
- 2) *No technical drawings.*
- 3) *A fixed mud stove which can accommodate 3 pots of spherical shape. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*
- 5) *The stove is completely made of mud.*
- 6) *No dimensions known.*
- 7) *Wood.*
- 8) *Any length. No dimensions known.*
- 11) *Three hole stove.*
- 12) *Traditional Indian model.*
- 13) *This stove was tested by Dutt, but his testing was different from the normal waterboiling tests and he does not give efficiency figures. Waterboiling tests by Geller showed medium efficiency.*
- 14) *No field tests known.*
- 16) *Dutt 1978. Geller 1981 a.*

SH3-2



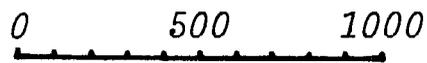
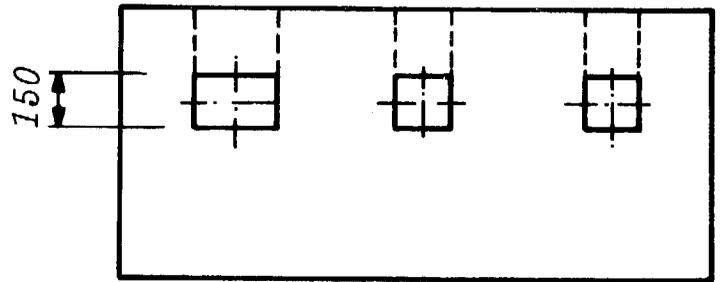
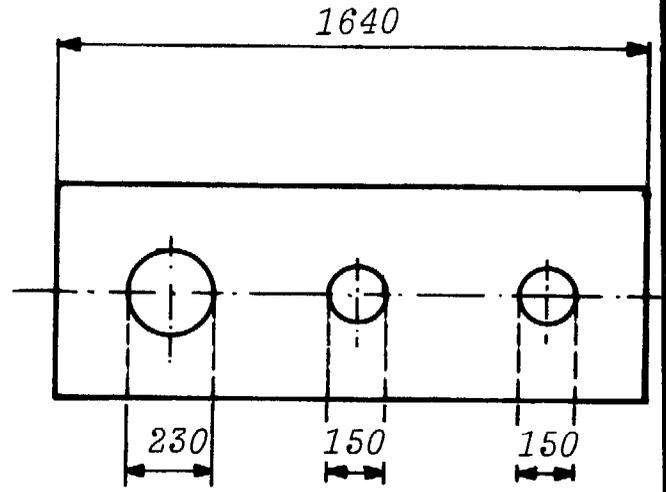
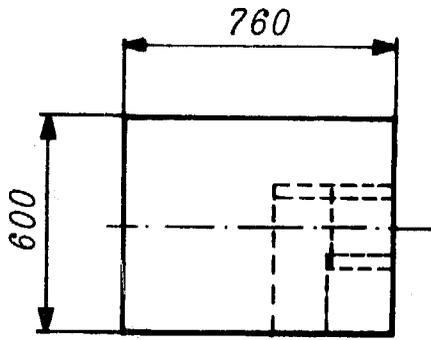
1) SH3-2

3) *A fixed mud stove which can accommodate 3 pots of spherical shape. These pots can have a diameter of 0,2 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



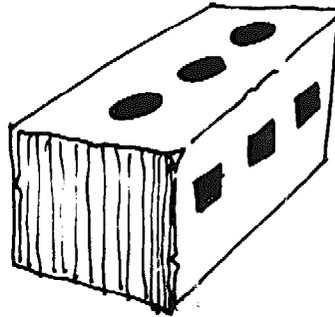
- 5) *The stove is completely made of mud but can also be constructed of bricks or of fired clay.*
- 6) *200 kg.*
- 7) *Wood.*
- 8) *Any length. 0,25 x 0,2 m. Refuelling without lifting the pan.*
- 11) *Indonesia three hole stove.*
- 12) *This stove is a general form of many traditional three hole stoves in Indonesia built by Singer for testing purposes.*
- 13) *Water boiling tests by Singer showed low efficiency.*
- 14) *No field tests known.*
- 16) *Singer 1961.*

SH3-3



1) SH3-3

3) *A fixed brick and concrete stove which can accommodate 3 pots of cylindrical or spherical shape. These pots can have diameters of 0,28, 0,19 and 0,19 m. It will burn soft coke. It has no chimney, no dampers, no baffles, grates and no provisions for secondary air.*



5) *The stove is built of bricks, with fire bricks around the combustion chamber and a concrete slab on the top. The grates are made of steel bars.*

6) 1400 kg.

7) Soft coke.

8) *Refuelling through the potholes, for which the pans must be lifted from the fire.*

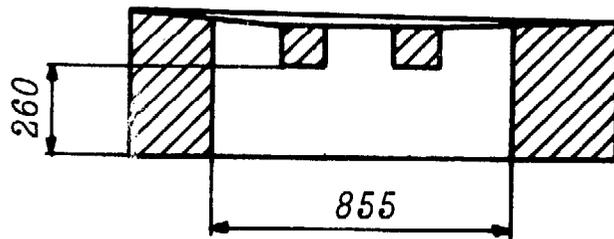
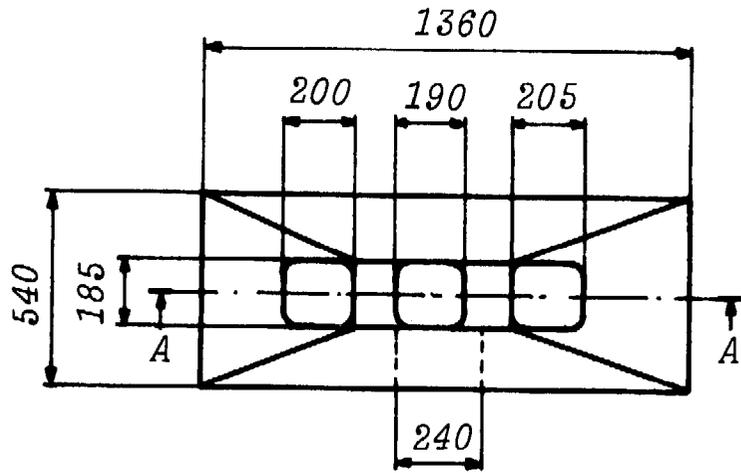
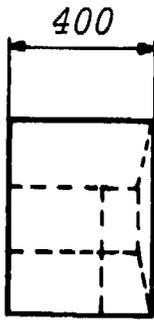
11) G.E. Shillong Type 1.

12) *Waterboiling tests by National Building Organisation and the U.N. Regional Housing Centre ESCAFE at PRAI showed high efficiency. Food cooking tests at the same institute showed a much lower efficiency.*

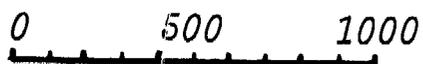
14) No field tests known.

16) Ahuja 1969.

SH3-4

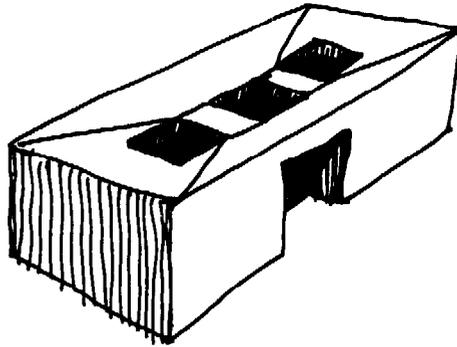


section A-A



1) SH3-4

3) *A fixed mud stove which can accommodate 3 pots of spherical shape. These pots can have a diameter of 0,25 m. It will burn long wood. It has no chimney, no dampers, no baffles, no grate and no provisions for secondary air.*



5) *The stove is made of mudbricks plastered with mud.*

6) *125 kg.*

7) *Corn stalks and corn husks.*

8) *Any length. 0,24 x 0,26 m. Refuelling without lifting the pan.*

11) *Egyptian Rural stove.*

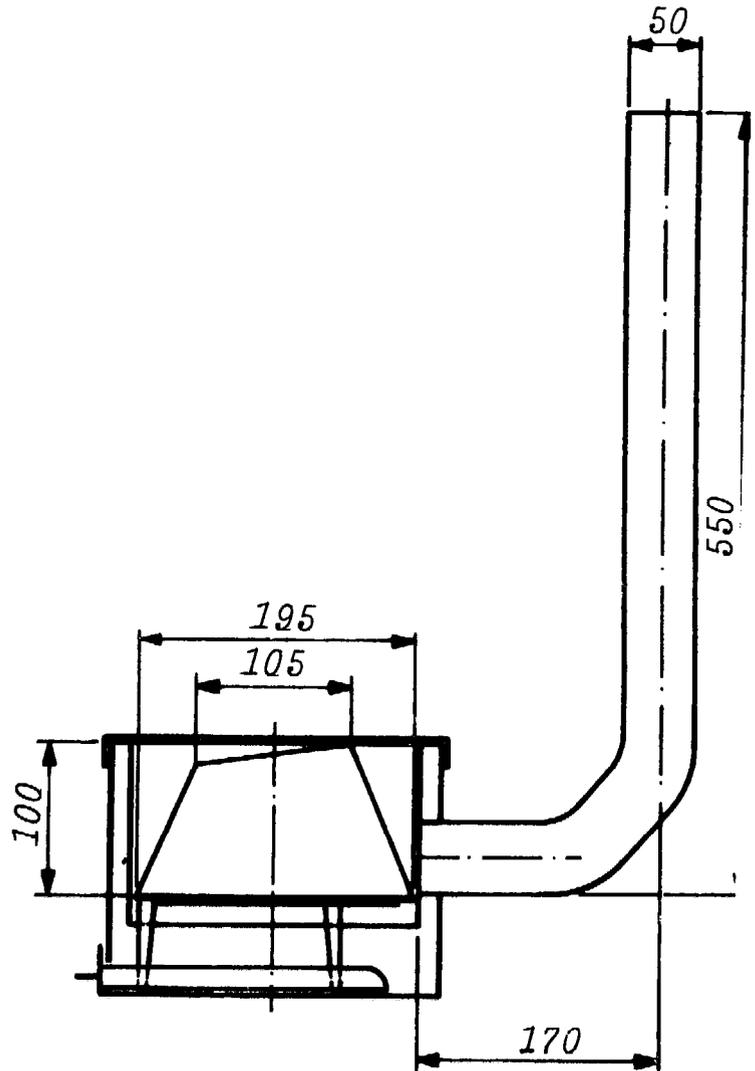
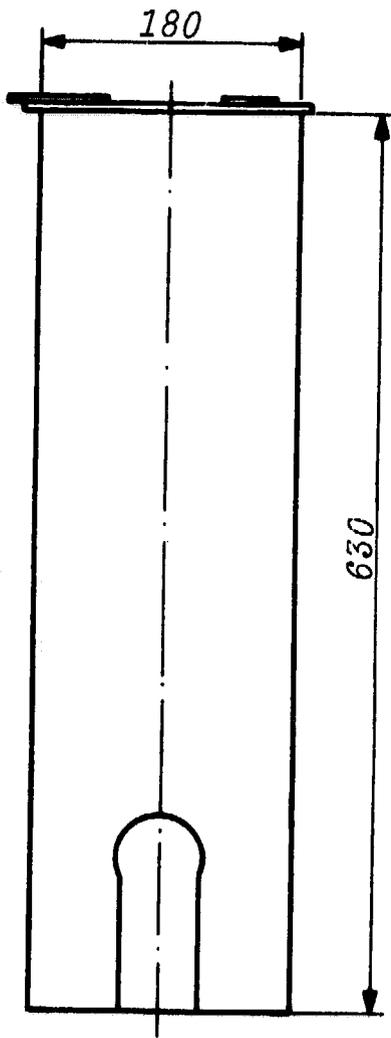
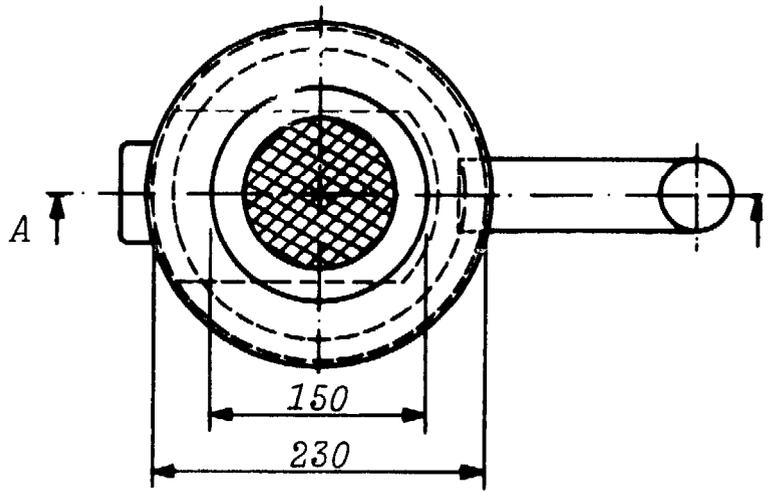
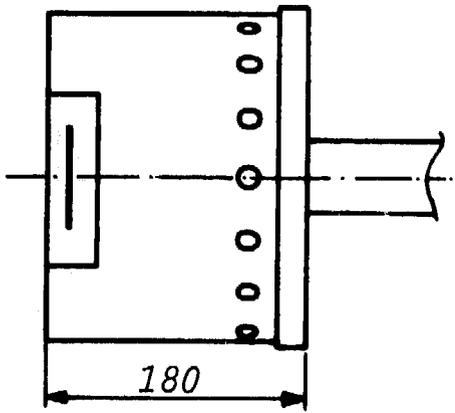
12) *This is a typical example of a traditional rural stove in Egypt.*

13) *Water boiling tests by Theodorovic. He compared this basic Egyptian rural stove with an improved model (CH2-1) and found that it uses considerably more fuel than the improved model.*

14) *No field tests known.*

16) *Theodorovic 1953.*

CL1-1

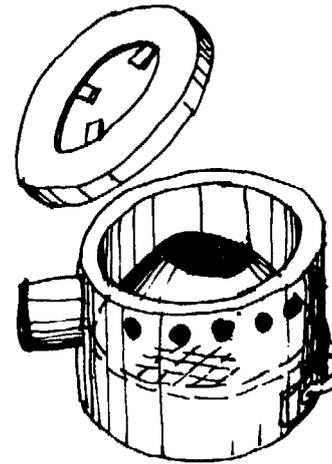


section A-A



1) *CL1-1*

3) *A portable metal stove which can accommodate 1 pot of cylindrical shape. This pot can have a diameter of 0,2 m. It will burn short wood. It has a chimney, no dampers, no grate, a baffle and no provisions for secondary air.*



5) *The stove is completely made of sheet steel.*

6) *20 kg.*

7) *Wood.*

8) *Refuelling through the hole in the baffle of 0,105 m. The pan must be lifted for refueling.*

11) *Micuta Jiko 2.*

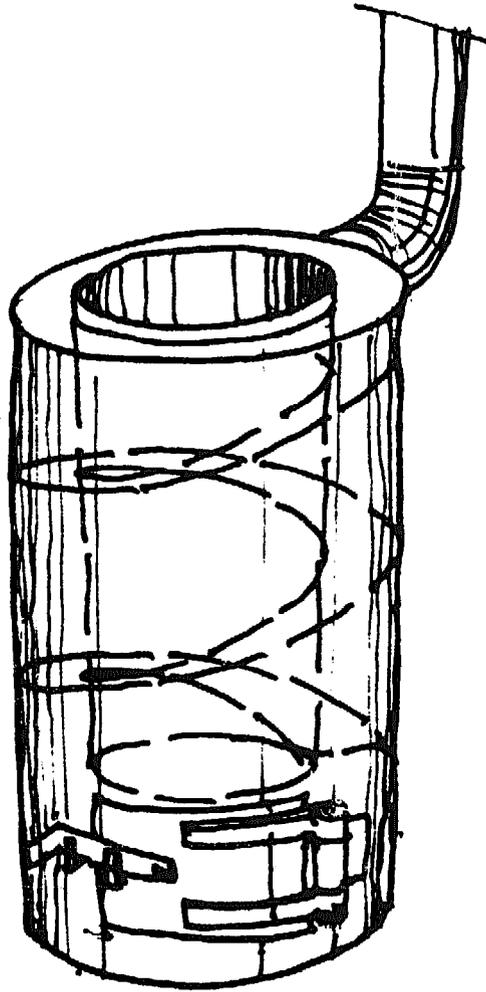
12) *This stove was developed by Micuta of the Bellerive Foundation in Geneva in 1980.*

13) *Water boiling tests by Dobler showed a very high efficiency. For these tests charcoal was used and the chimney was covered with a cylinder of larger diameter on which a second pan was placed. The very high efficiency is obtained by including the heat absorbed by this second pan.*

14) *No field tests known.*

16) *Micuta 1980. Dobler 1980.*

CL1-2



1) *CL1-2*

2) *No technical drawings.*

3) *A portable metal stove which can accommodate 1 pot of cylindrical shape. This pot must be made to fit the stove. It will burn short wood. It has a chimney, a damper for combustion air, no damper for combustion gases, no baffles, no grate and no provision for secondary air.*

4) *There is a combustion air damper in the door at the bottom of the stove.*

5) *The stove is completely made of sheet metal.*

6) *25 kg.*

7) *Wood.*

8) *No dimensions known. Refuelling without lifting the pot.*

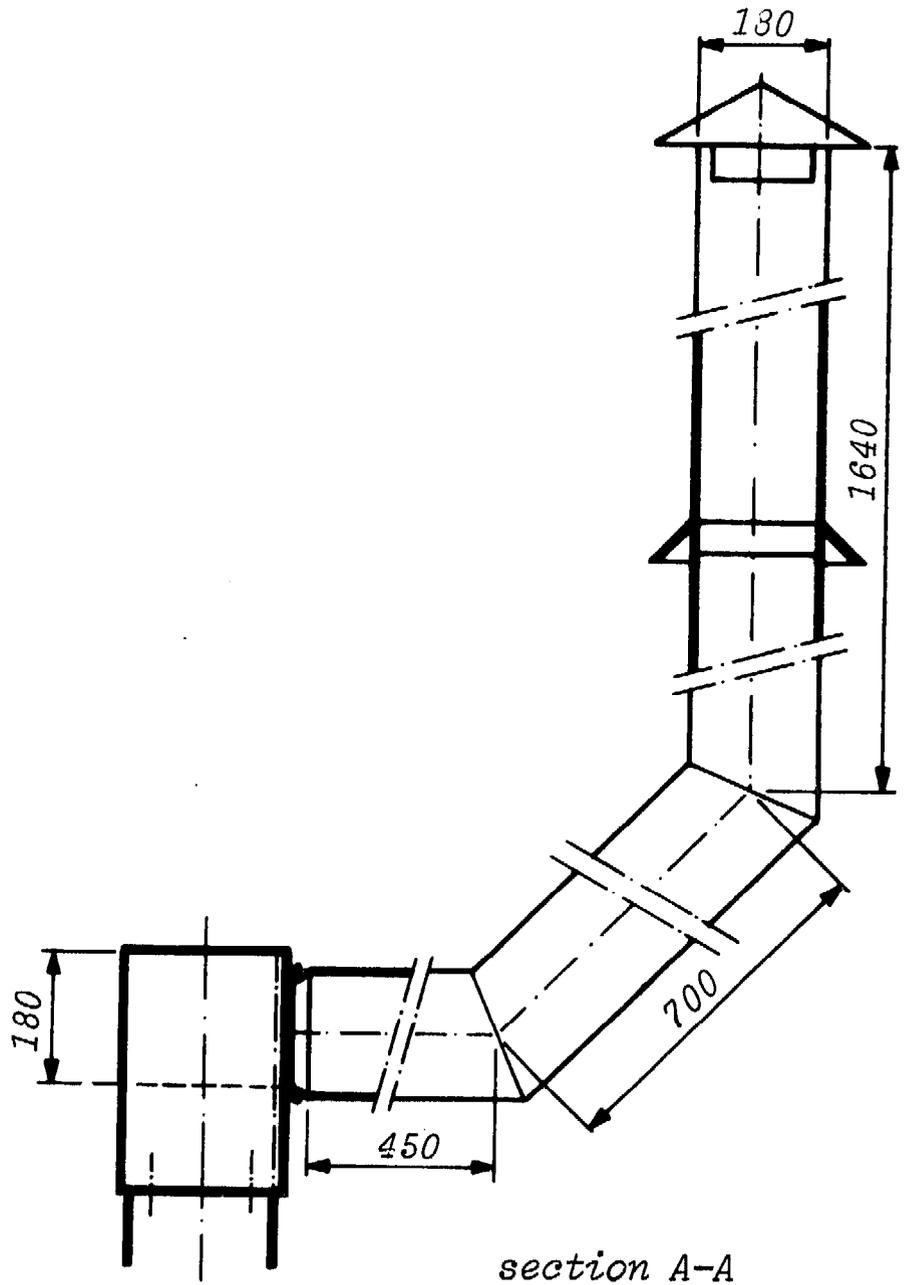
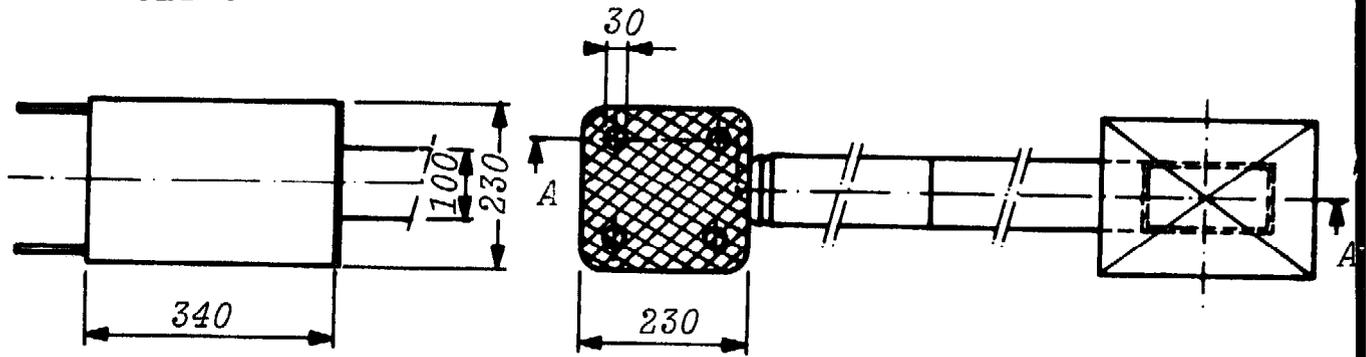
11) *Micuta Jiko 3*

13) *No laboratory tests known.*

14) *No field tests known.*

16) *Micuta 1980.*

CL1-3

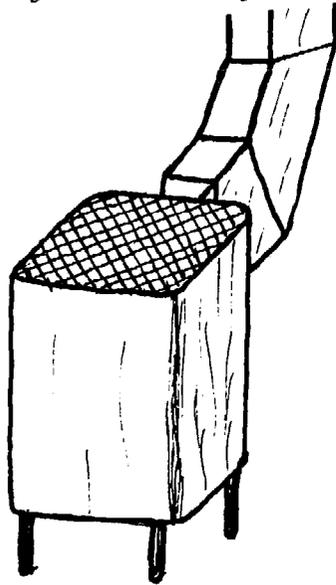


section A-A



1) *CLI-3*

3) *A portable metal stove which can accommodate 1 pot of cylindrical shape. This pot can have a diameter of 0,25 m. It will burn sawdust. It has a chimney, no dampers, no baffles, no grate and no provision for secondary air.*



5) *The stove is completely made of sheet metal. For the stove body a paint can of suitable size can be used.*

6) *5 kg.*

7) *Sawdust. It will burn rice husks as well.*

8) *The stove must be charged with the right amount of fuel before lighting it because refuelling is impossible while the stove is burning. The filling procedure is as follows. Four sticks are placed in the holes in the bottom of the stove when the stove is charged with sawdust. This sawdust must be tamped down regularly to get a tight filling. The maximum level to which the stove can be charged is to the bottom of the exhaust opening. Then the sticks are withdrawn and the sawdust can be lit at the bottom of each hole. To start combustion it might be necessary to sprinkle some oil or kerosine on the sawdust.*

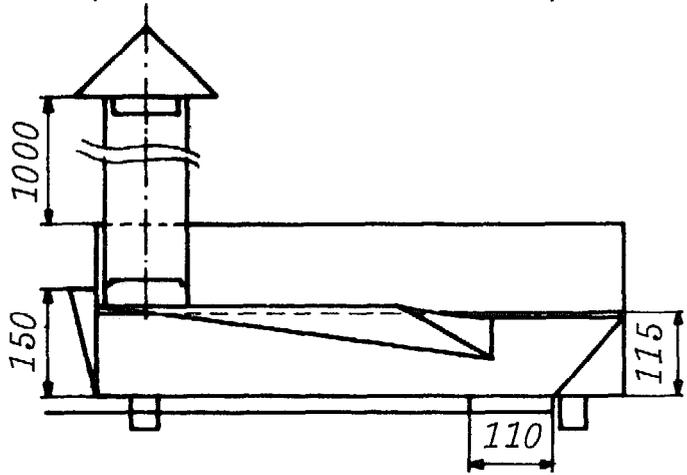
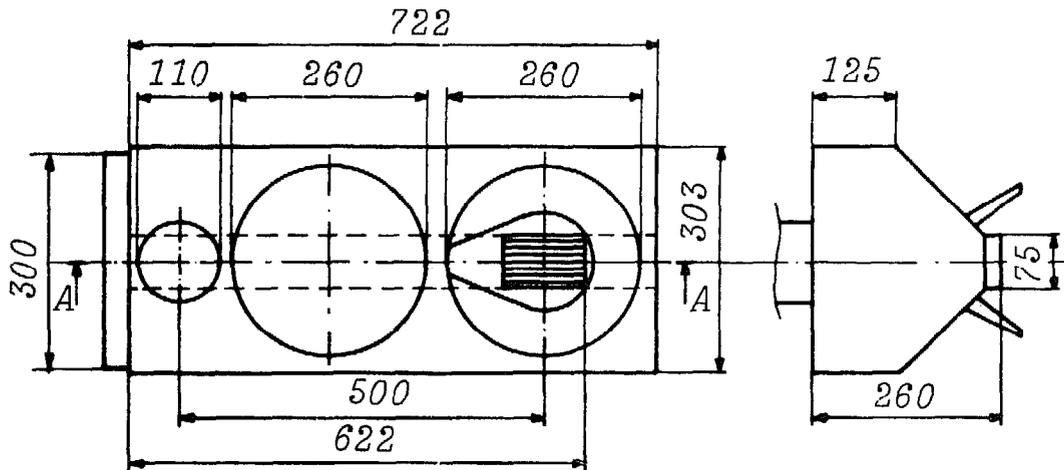
11) *Sawdust burner.*

13) *No laboratory tests known.*

14) *No field tests known.*

16) *Simon, Soli 1976. Simon, Solis 1977.*

CL2-1

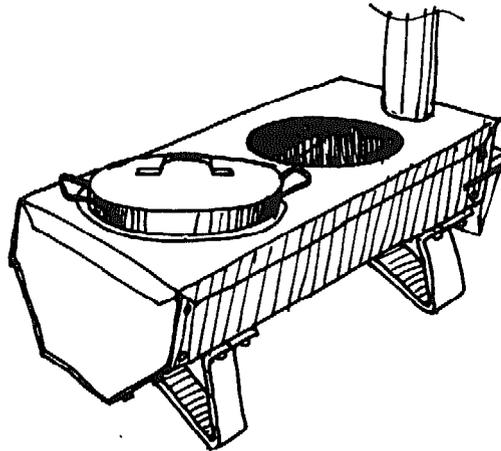


section A-A



1) CL2-1

3) *A portable metal stove which can accommodate 2 pots of cylindrical shape. The pots must have a diameter of 0,26 m. It will burn long wood. It has a chimney, a damper for combustion air, no damper for combustion gases, no baffles, a grate and no provision for secondary air.*



4) *Combustion air is controlled by a perforated slide under the grate. This slide is manipulated by a rod from the front of the stove.*

5) *The stove is completely made of sheet metal.*

6) *15 kg.*

7) *Wood.*

8) *0,60 x 0,3 x 0,15 m. Refuelling without lifting the pan.*

11) *De Lepeleire/Vandaelen stove.*

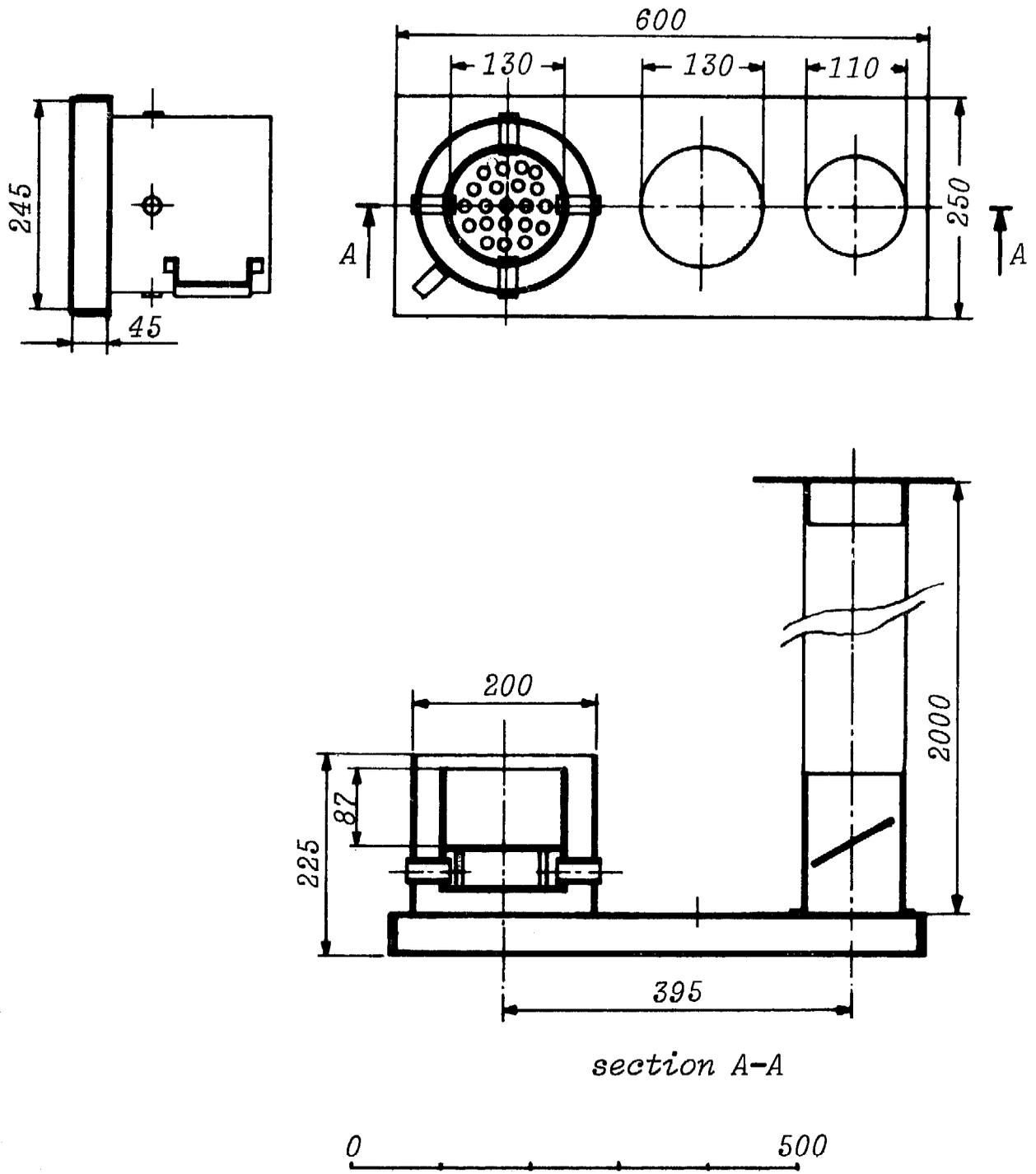
12) *This stove was developed in 1978 at the K.U. Leuven in an effort to construct a closed stove that could burn long wood.*

13) *Water boiling tests by Woodstove Group of the Eindhoven University of Technology showed high efficiencies.*

14) *No field tests known.*

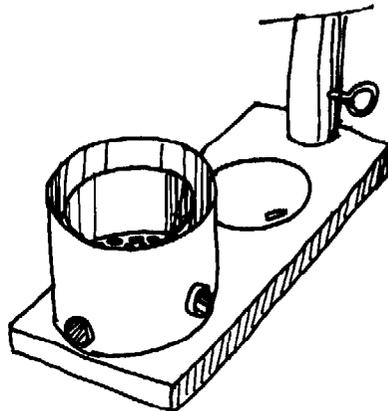
16) *Vandaele 1978. Nievergeld et al 1981.*

CL2-2



1) CL2-2

3) *A portable metal stove which can accommodate 2 pots, of cylindrical or spherical shape. These pots can have diameters of 0,24 and 0,18 m. It will burn short fuel. It has a chimney, no damper for combustion air, a damper for combustion gases, no baffles, a grate and no provisions for secondary air.*



5) *The stove is completely made of metal sheet.*

6) *15 kg.*

7) *Charcoal, wood, agricultural waste.*

8) *For refueling the pan must be lifted and the fuel put into the combustion chamber which has a diameter of 0,2 m.*

11) *Family cooker.*

12) *This stove was developed by Overhaart at the Eindhoven University of Technology in the seventies as an improvement on a stove that was used in the Netherlands during World War II.*

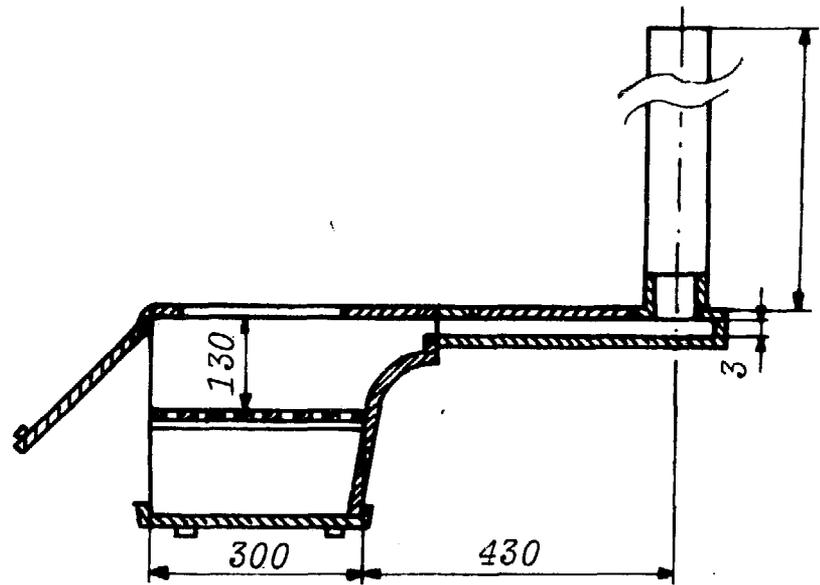
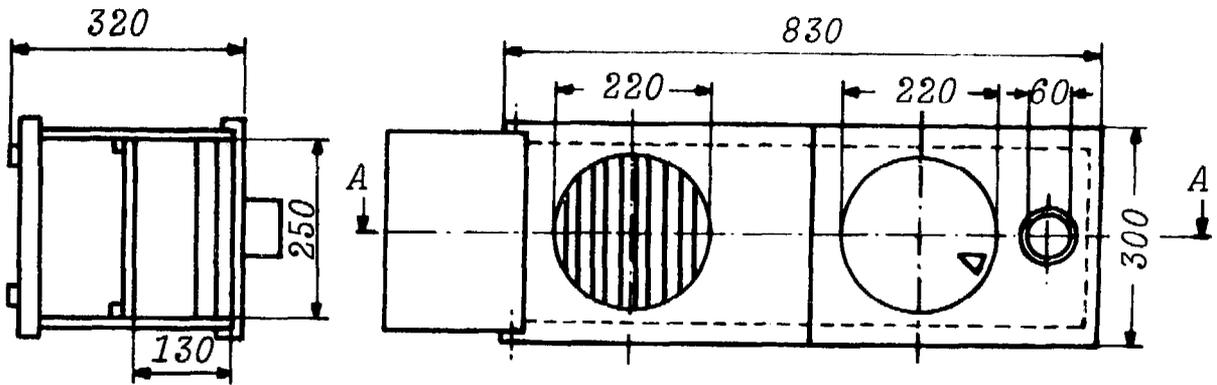
13) *Water boiling tests by the Woodstove group of Eindhoven University of Technology showed good to high efficiency for woodfuel and high to very high efficiency for charcoal.*

14) *No field tests known.*

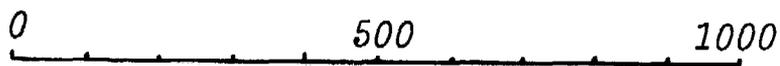
15) *Overhaart claims a fuel saving of 50% compared to the open fire.*

16) *Attwood 1980. Overhaart 1978. Krishna Prasad 1980, 1981.*

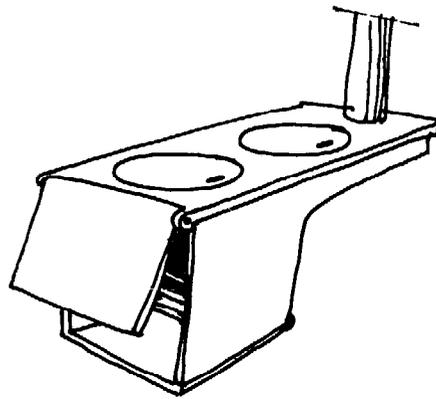
CL2-3



section A-A

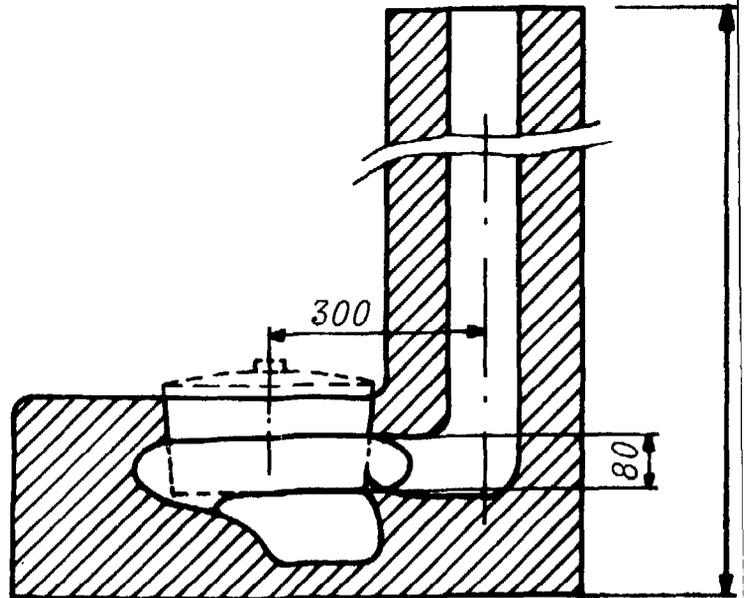
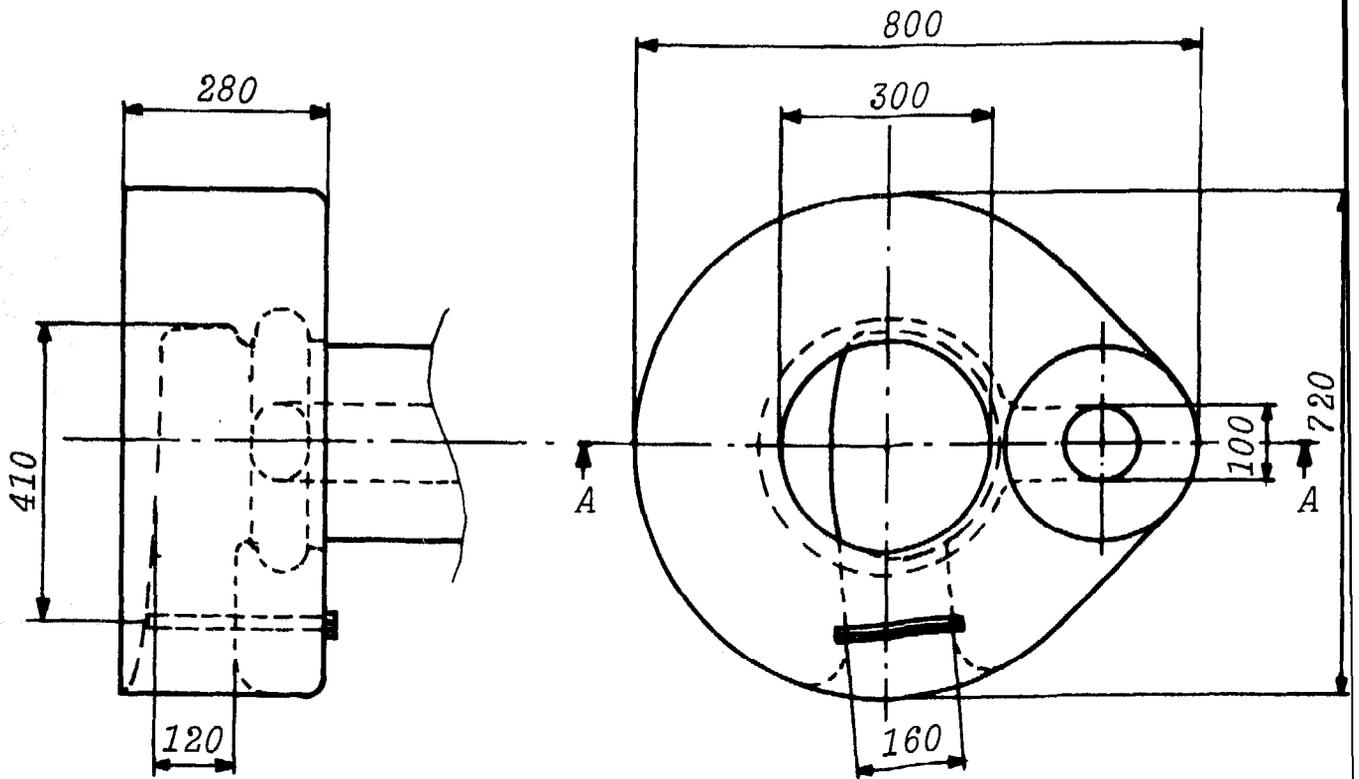


- 1) CL2-3
- 2) Chimney height not specified.
- 3) *A movable cast-iron stove which can accommodate 2 pots of cylindrical shape. The first pot may also be spherical. These pots can have diameters of 0,25 m. It will burn short wood and charcoal or coal. It has a chimney, a front door, no damper for combustion gases, no baffles, a grate and no provisions for secondary air.*

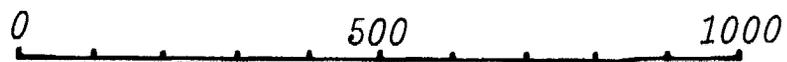


- 4) *Control by combustion air is not possible because the door does not fit well enough.*
- 5) *The stove is completely made of cast iron with a chimney.*
- 6) *The stove weighs about 42 kg.*
- 7) *Wood. Charcoal or coal.*
- 8) *0,3 m. 0,3 x 0,1 m. Refuelling without lifting the pan.*
- 11) *Kalie Cooker.*
- 12) *South-Africa 1946. Now still in production at Smith and Wellstood Ltd, Bonrybridge, Stirlingshire, England. They sell about 100 a year.*
- 13) *Boiling water test at ITDG, London, showed poor efficiency.*
- 14) *No field tests known.*
- 16) *Joseph, Shanahan, Bialy 1980.*

CH1-1



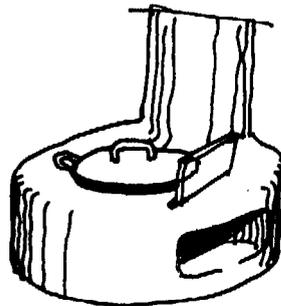
section A-A



1) *CH1-1*

2) *Chimney height not specified.*

3) *A fixed mud stove which can accommodate 1 pot of cylindrical shape. This pot must have a diameter of 0,30 m. It will burn long wood. It has a chimney, a damper for combustion air, no damper for combustion gases, no baffle, no grate and no provisions for secondary air.*



4) *Control of the fire by a sliding damper in the entrance tunnel of the stove.*

5) *The stove is made of mud with a damper of metal sheet.*

6) *350 kg.*

7) *Wood.*

8) *0,4 m. 0,12 x 0,16 m. Refueling without lifting the pan.*

11) *Ban Ag Suf 2.*

12) *Built in 1980 in Senegal.*

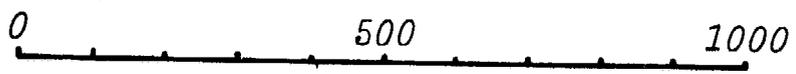
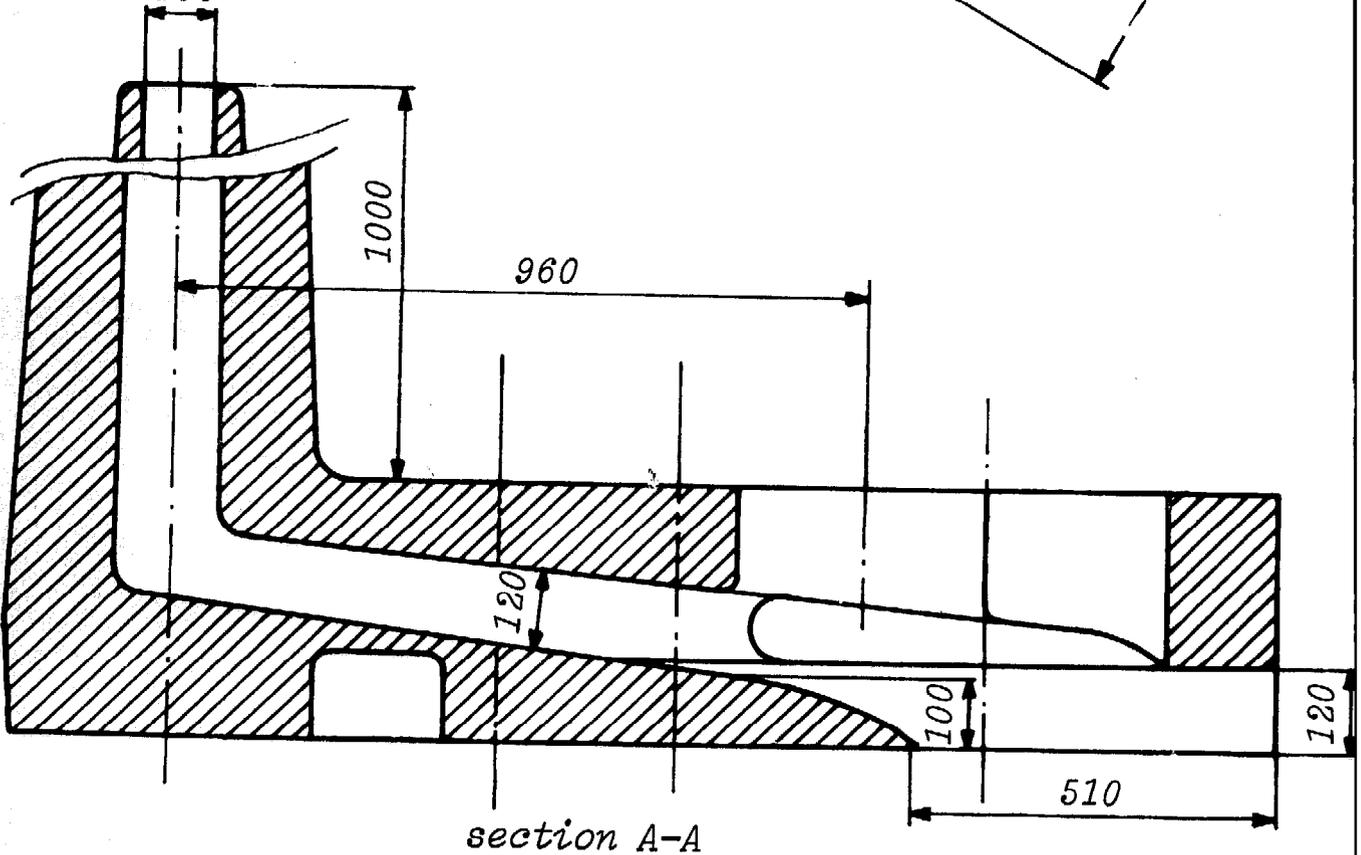
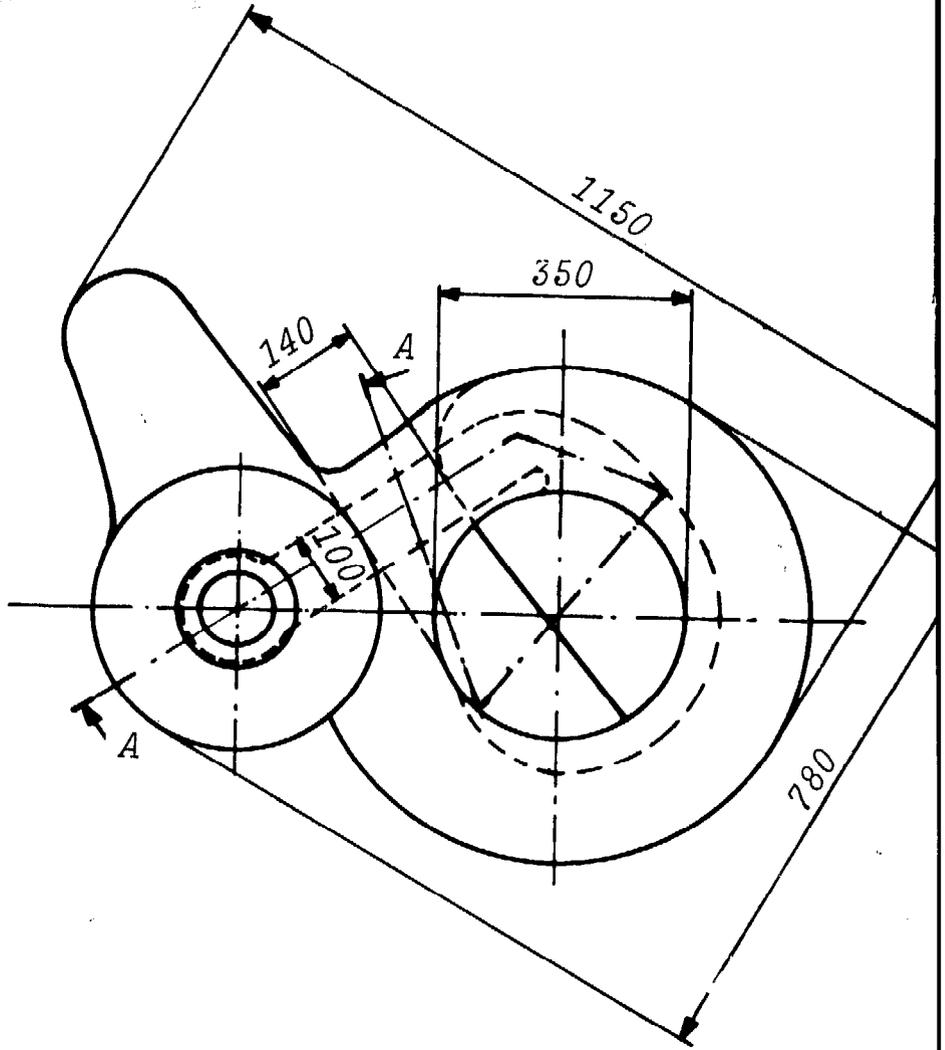
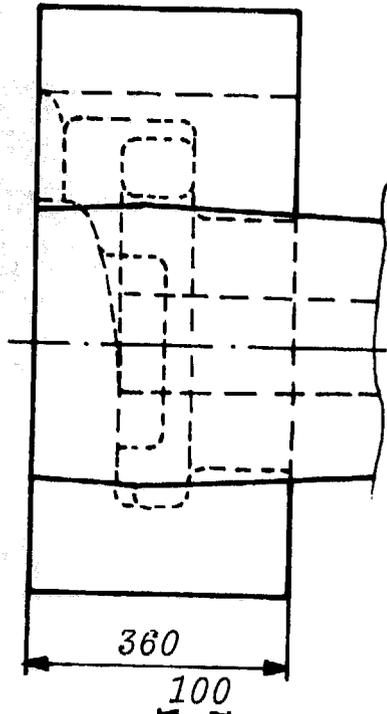
13) *No laboratory tests known.*

14) *No field tests known.*

15) *A wood saving of 50 % compared to open fires.*

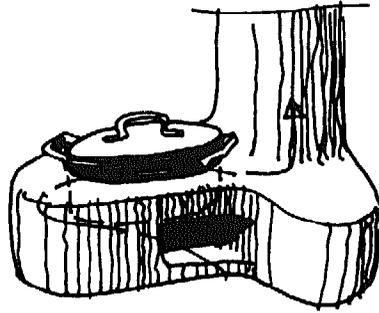
16) *Evans, Gern, Jacobs 1980. Cap-Impe 1980.*

CH1-2



1) CH1-2

3) *A fixed mud stove which can accommodate 1 pot of cylindrical shape. This pot must have a diameter of 0,35 m. It will burn long wood. It has a chimney, no dampers, no baffles, no grate and no provision for secondary air.*



5) *The stove is completely made of mud.*

6) *350 kg.*

7) *Wood.*

8) *Any length. 0,14 x 0,12 m. Refuelling without lifting the pan.*

11) *Ban Ag Suf 3.*

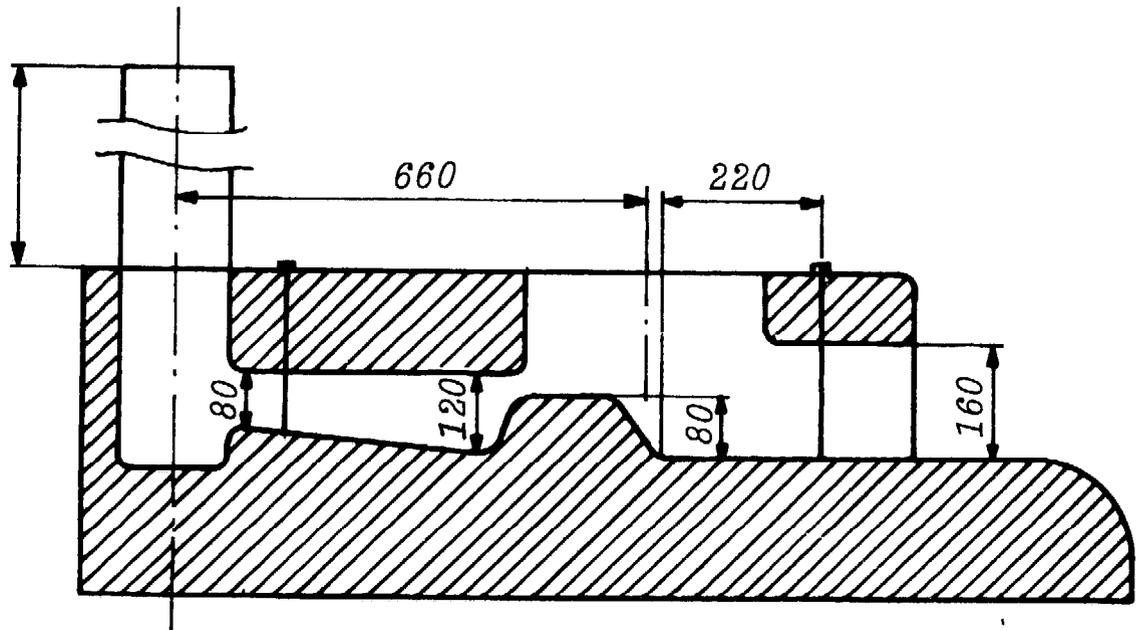
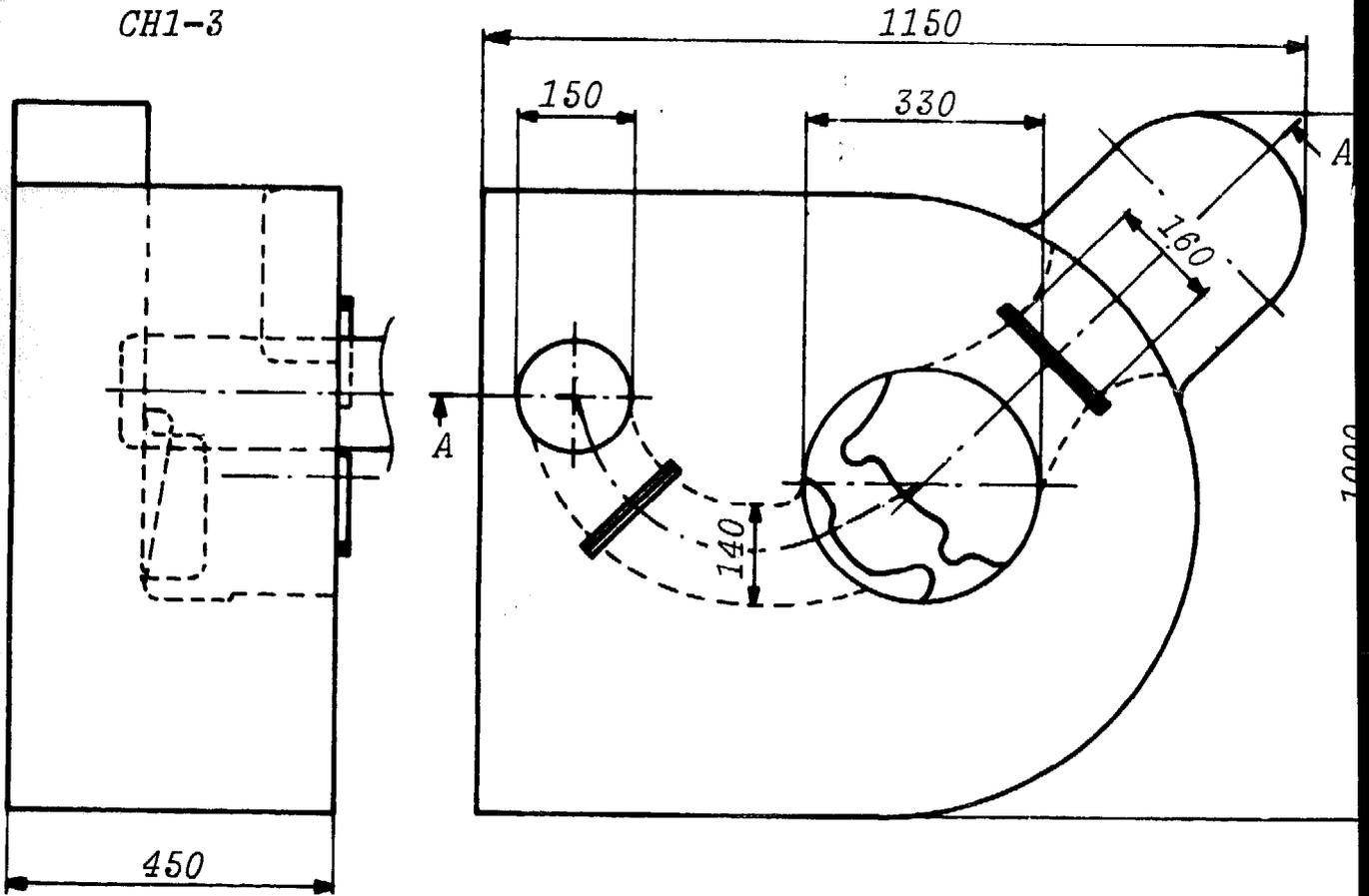
12) *Built in 1980 in Senegal.*

13) *No laboratory tests known.*

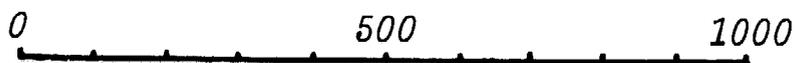
14) *No field tests known.*

15) *A fuel saving of 50% compared to open fires.*

16) *Evans, Gern, Jacobs 1980. Cap-Impe 1980.*



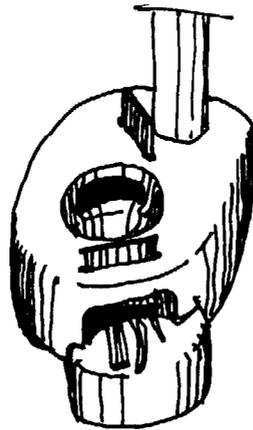
section A-A



1) *CH1-3*

2) *Chimney height not specified.*

3) *A fixed mud stove which can accommodate 1 pot of cylindrical shape. This pot must have a diameter of 0,33 m. It will burn short wood. It has a chimney, a damper for combustion gases, a damper for combustion air, a baffle, no grate and no provisions for secondary air.*



4) *Fire control by a sliding damper in the entrance tunnel of the stove and a sliding damper in the gas flue. By closing both dampers the fire is shut off from fresh air and will extinguish.*

5) *The stove is made of mud with a metal chimney.*

6) *250 kg.*

7) *Wood.*

8) *0,2 m. 0,16 x 0,16 m. Refuelling without lifting the pan.*

11) *Evans M2.*

12) *Built in 1980 in Senegal.*

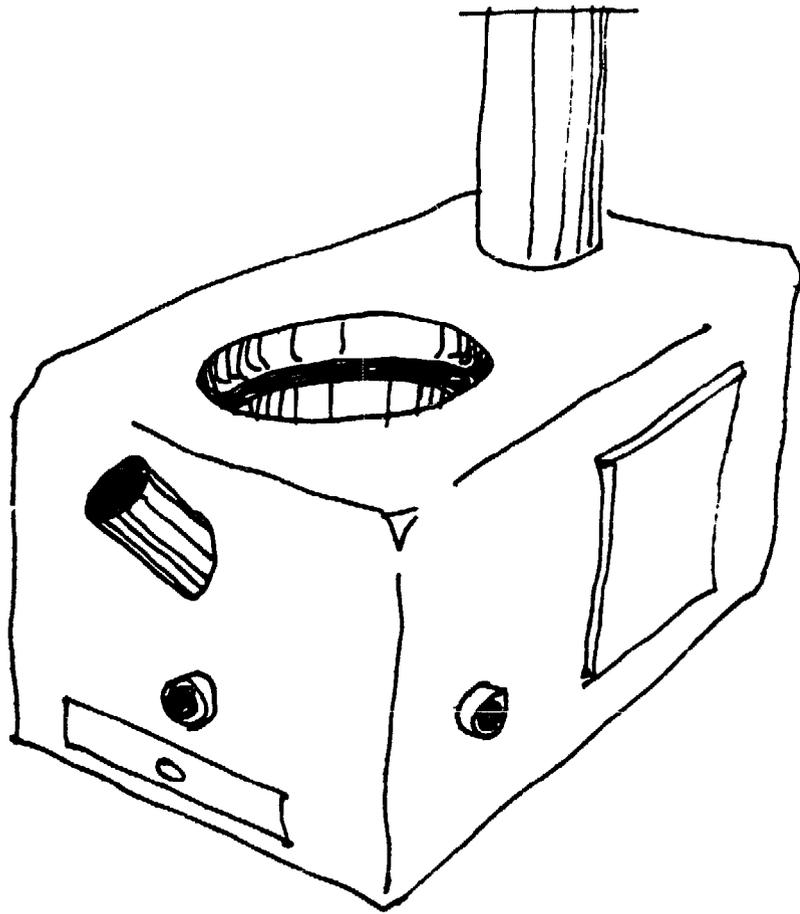
13) *No laboratory tests known.*

14) *No field tests known.*

15) *Regularly used, it works well.*

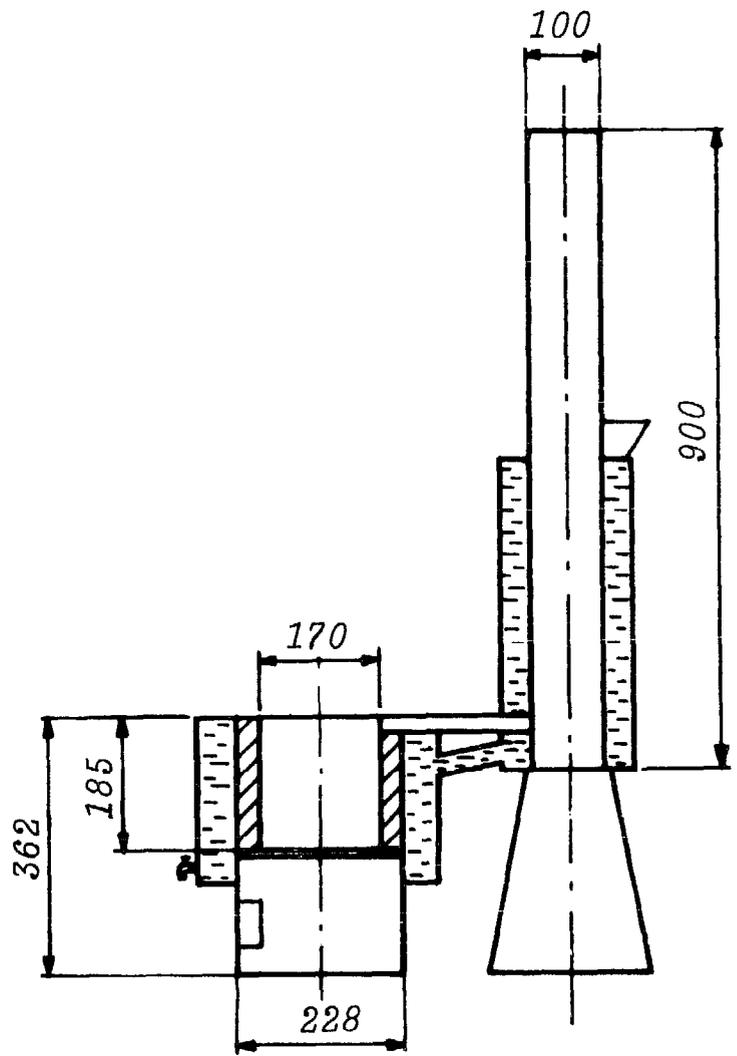
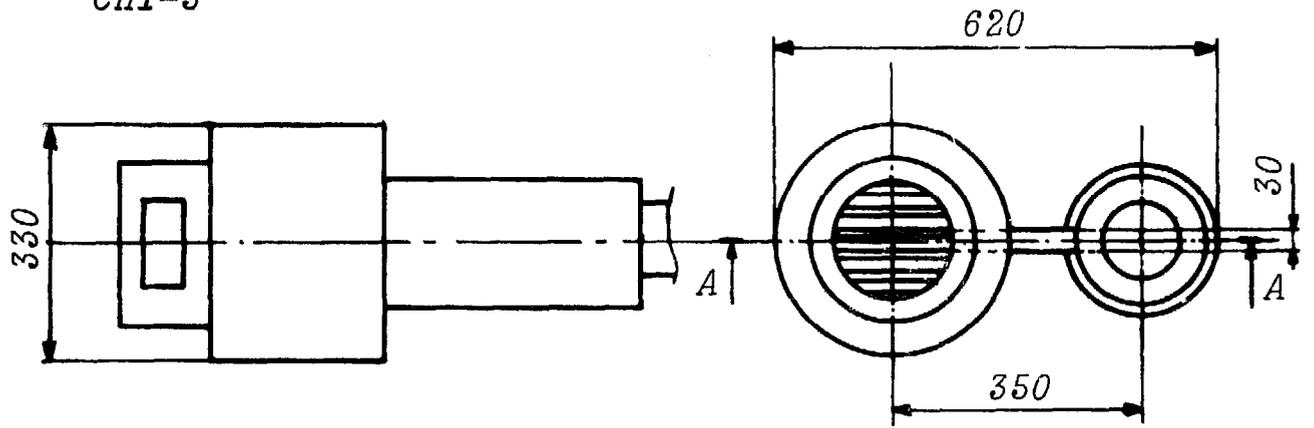
16) *Evans, Gern, Jacobs 1980. Cap-Impe 1980.*

CH1-4

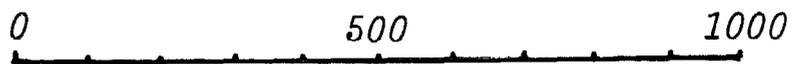


- 1) *CHI-4*
- 2) *No technical drawings.*
- 3) *A fixed stove of metal and insulating material, which can accommodate 1 pot of cylindrical or spherical shape. It will burn charcoal. It has a chimney, a damper for combustion air, no damper for combustion gases, no baffles, a grate and provisions for secondary air. It can be used as an oven.*
- 4) *The fire is controlled by two air inlet holes in the front of the ash-tray. The secondary air can be supplied to the fire by a hole in the fuel chute.*
- 5) *The stove is made of sheet metal with an insulating layer of clay, sawdust, ash or cement, sawdust, ash mixture.*
- 7) *Charcoal.*
- 8) *Refuelling through a special fuel chute without lifting the pan. No dimensions known.*
- 9) *The stove is equipped with an oven.*
- 11) *Improved Family Cooker.*
- 12) *Developed by Attwood as an improvement on the Overhaart Family Cooker, in 1980.*
- 13) *Testing was done by Attwood but with a different definition of the efficiency, so the results of this testing cannot be compared with the standard waterboiling test results.*
- 14) *No field tests known.*
- 16) *Attwood 1980.*

CH1-5

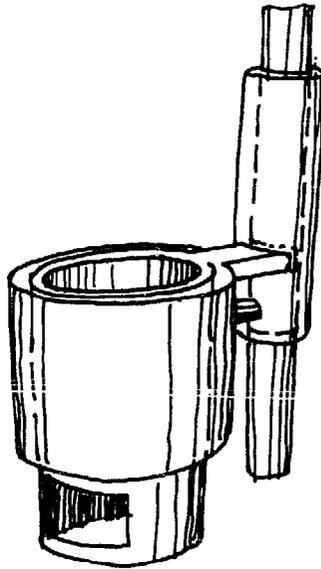


section A-A



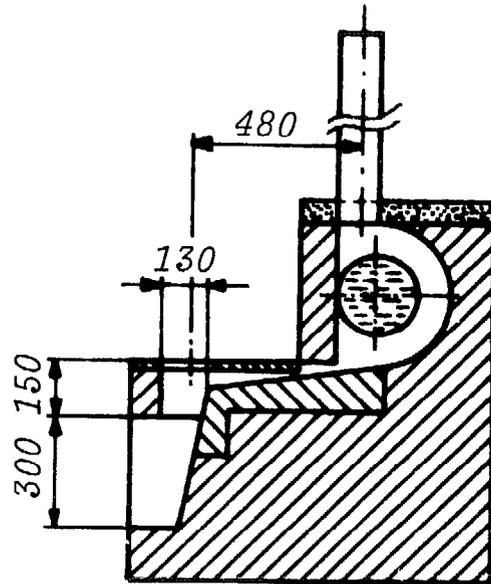
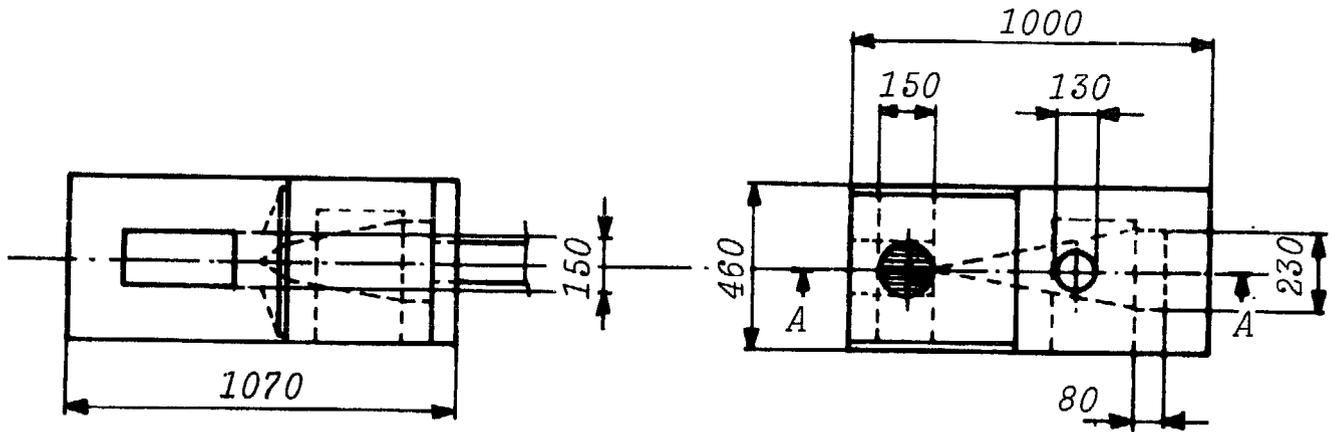
1) CH1-5

3) *Portable. Metal and ceramic. Takes 1 spherical or cylindrical 0,3 m diameter pot. Burns charcoal. Has a chimney and grate, no baffles, dampers or secondary air provision.*

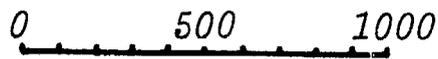


- 5) *Consists of a sheet steel annular water jacket, clay lined inside. Another connected water jacket partly covers the chimney.*
- 6) *25 kg empty, 47 kg water filled.*
- 7) *Charcoal. Coal.*
- 8) *Refuelling through 0,22 pothole, pan must be lifted.*
- 10) *Total volume of water jackets 22 l. No performance figures.*
- 11) *Economical Angethi (Smokeless chula).*
- 12) *Developed by Salariya of Punjab Agricultural University India, as an improvement on the traditional Angethi (SH1-7).*
- 13) *Salariya's water boiling tests showed good efficiency when counting warm water produced, low efficiency when otherwise.*
- 16) *Salariya 1978. Krishna Prasad, Nieuveld, Verhaart, 1979. Anon 1980, b.*

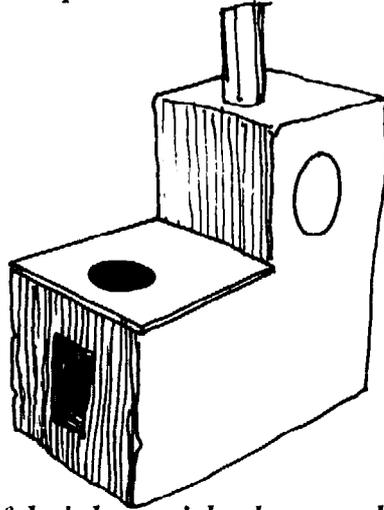
CH1-6



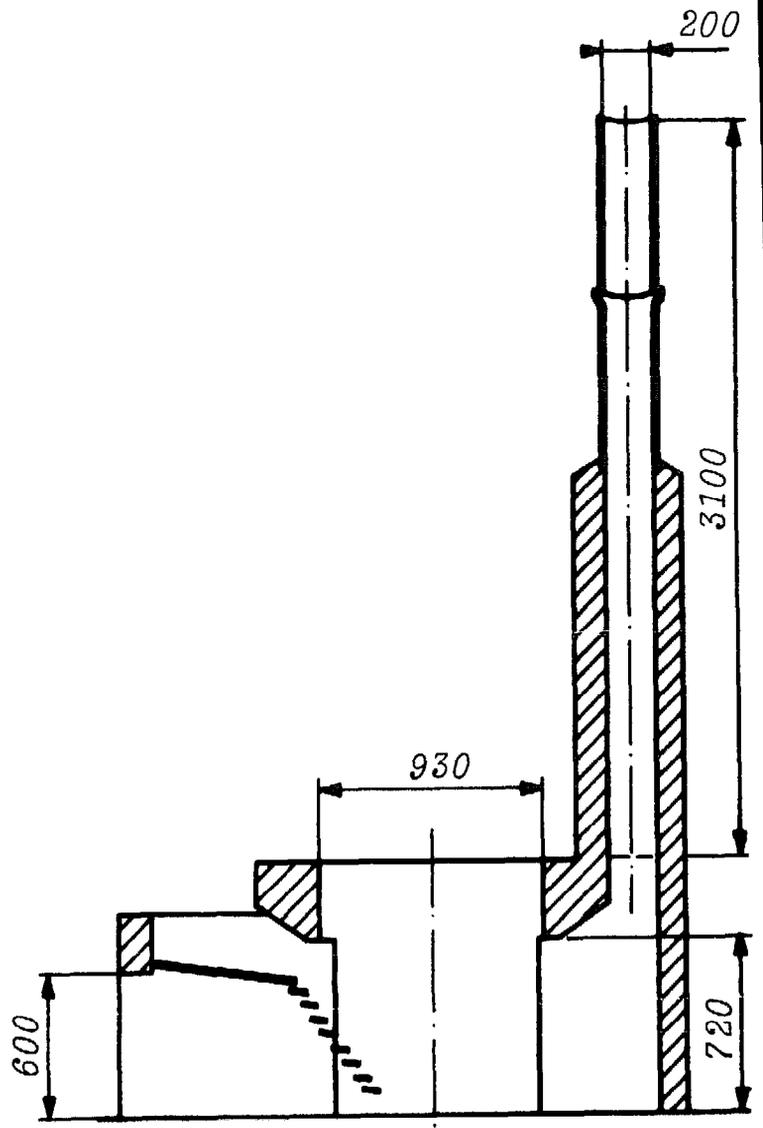
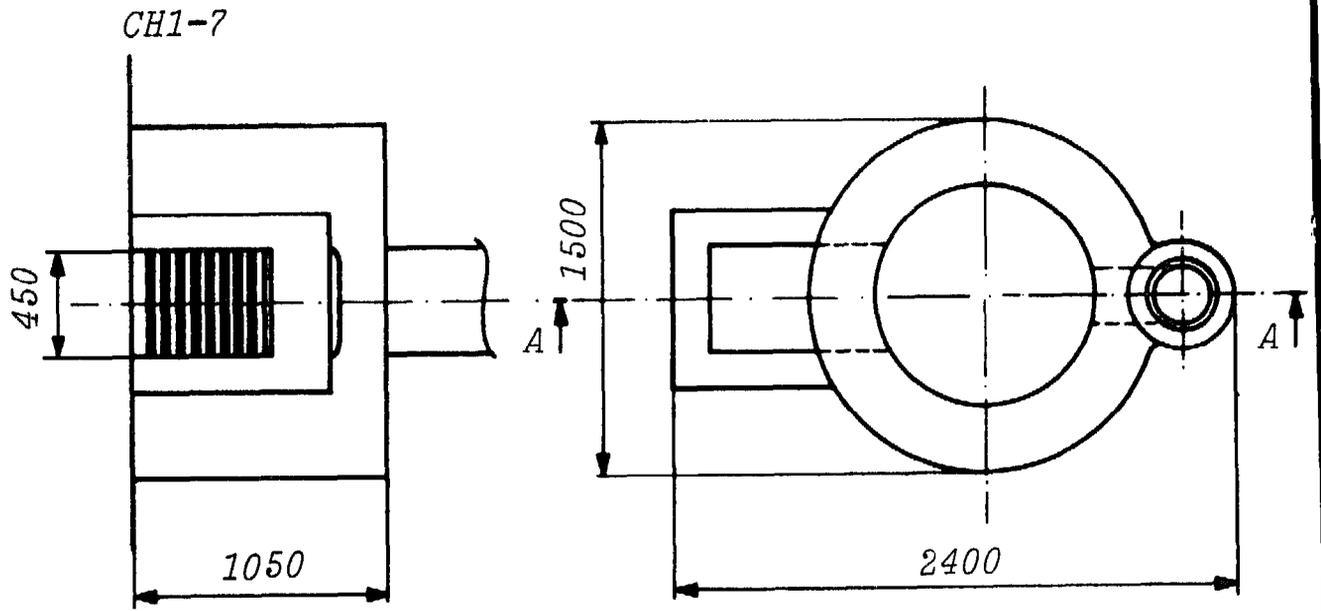
section A-A



- 1) CH1-6
- 2) Chimney height not specified.
- 3) A fixed brick and metal stove which can accommodate 1 pot of spherical shape. This pot can have a diameter of 0,20 m. It will burn soft coke. It has a chimney, no dampers, no baffles, a grate and no provisions for secondary air.



- 5) The stove is built of bricks, with the combustion chamber and gas flue in fire brick and fire clay. On top is a cast iron plate with the pothole. In the gas flue is a metal water tank. The grate is made of metal bars.
- 6) 600 kg.
- 7) Soft coke.
- 8) The stove must be refuelled through the pothole of 0,15 m. For refuelling the pot must be lifted from the stove.
- 10) Contents of the water tank is 15 l. No figures about achievable temperatures.
- 11) D.G.W. Type. (Director General Works).
- 12) This stove was developed in India.
- 13) Water boiling test at PRAI showed good efficiency. Food cooking tests at the same institute showed good efficiency.
- 14) No field tests known.
- 16) Ahuja 1969.

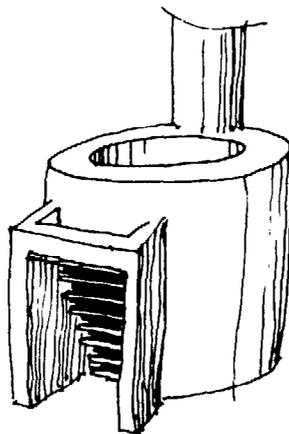


0 500 1000

section A-A

1) *CH1-7*

3) *A fixed brick and metal stove which can accommodate 1 pot of cylindrical or spherical shape. This pot can have a diameter of 0,93 m. It will burn rice-husks. It has a chimney, no dampers, no baffles, a grate and no provisions for secondary air.*



5) *The stove body is built of bricks, the storage bunker for the rice husks is made of sheet steel while the stepped grate is made from steel bars. The chimney is made of ceramic or steel.*

6) *900 kg.*

7) *Rice husks.*

8) *The fuel is charged into the fuel bunker from which it runs down to the grate where it is burnt. Refuelling without lifting the pan.*

9) *This stove was originally developed to make Tahu (soybean curd). It is used to boil the soy-milk in batches of 150 l.*

11) *Java rice-husk stove.*

12) *An Indonesian stove, commonly used in Jogjakarta and East Java to boil soy-milk.*

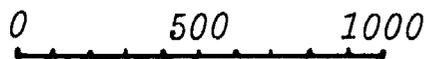
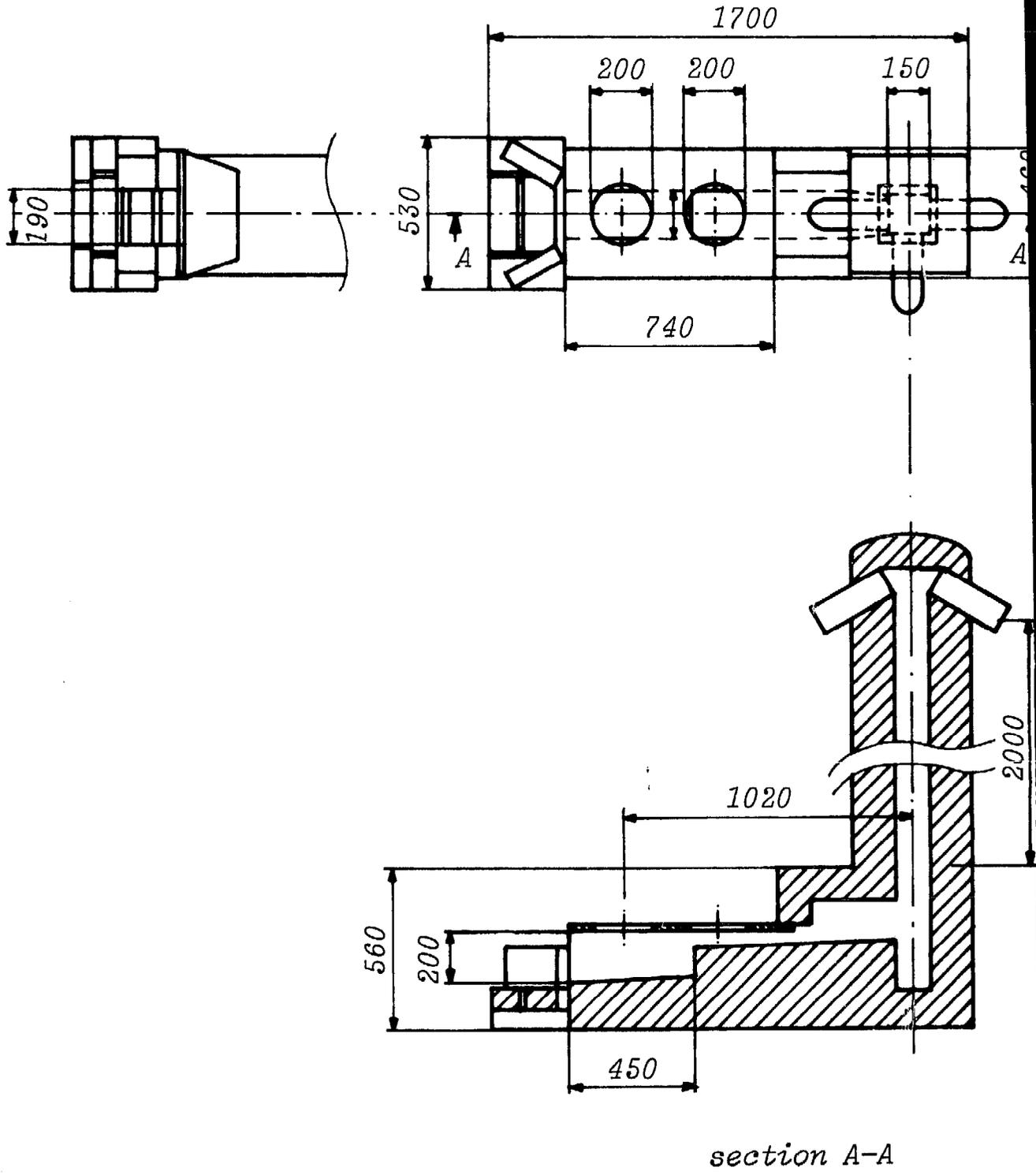
13) *No laboratory tests known.*

14) *No field tests known.*

15) *Boiling of 800-1400 l of soy-milk uses 125 kg rice husks.*

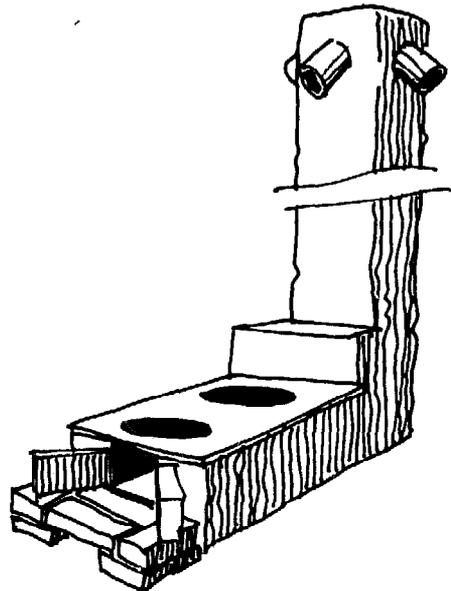
16) *Acott et al 1980. Anon 1980, b.*

CH2-1



1) CH2-1

3) *A fixed mud and ceramic stove which can accommodate 2 pots of spherical shape. These pots can have a diameter of 0,24 m. It will burn corn stalks and corn husks. It has a chimney, no dampers, a baffle under the second pot, no grate and no provisions for secondary air.*



5) *The stove is built of mud bricks and plastered with mud. The cover plates with the potholes are made of ceramic.*

6) *300 kg.*

7) *Corn stalks and corn husks.*

8) *Any length, 0,19 x 0,2 m. Refuelling without lifting the pan.*

11) *Improved Egyptian Rural stove.*

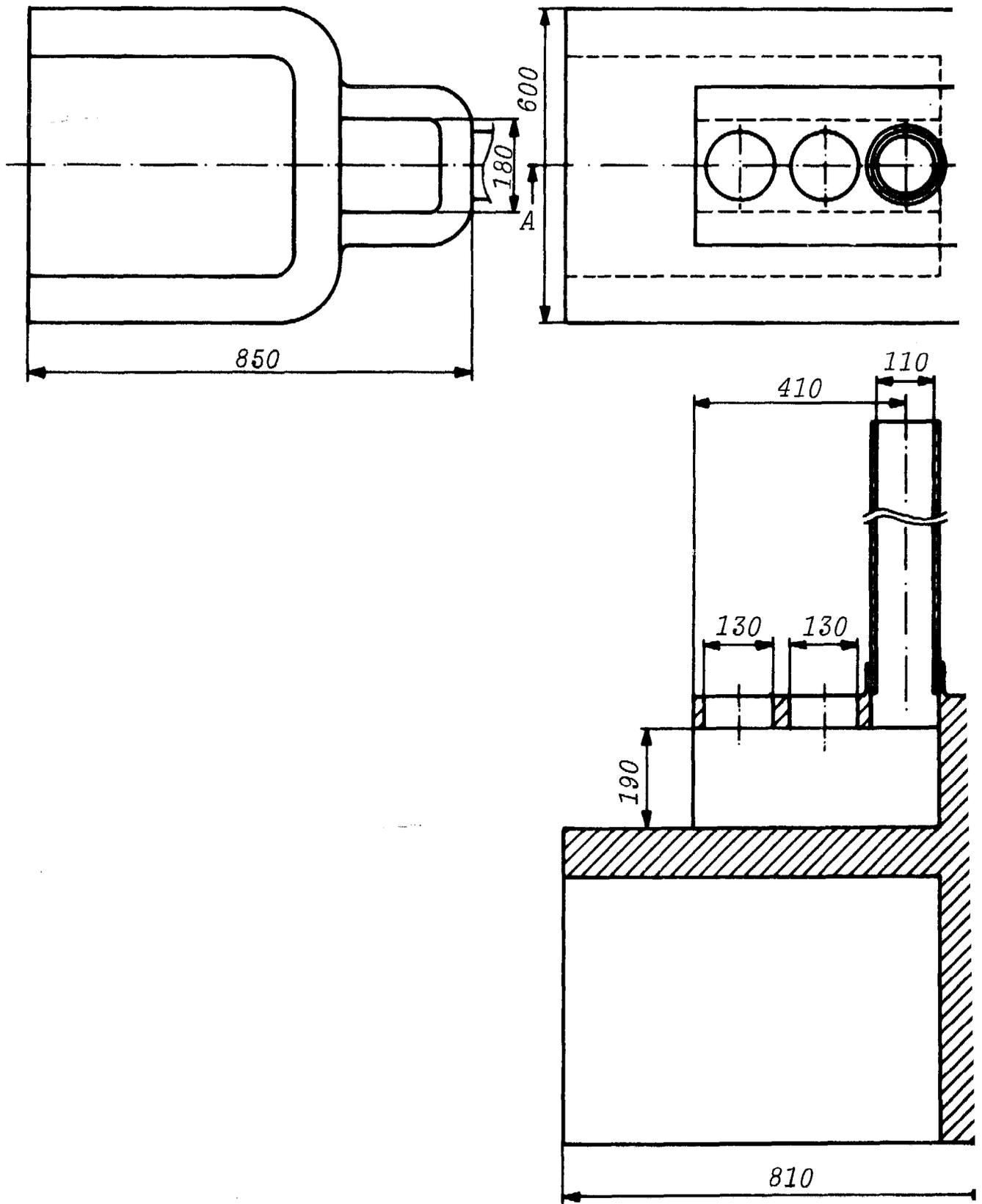
12) *This stove was developed at Arab States Fundamental Education Centre as an improvement on the traditional Egyptian Rural stove (SH3-4) in 1953.*

13) *Water boiling tests by Theodorovic showed an improvement compared to the basic stove of up to 28%.*

14) *No field test known.*

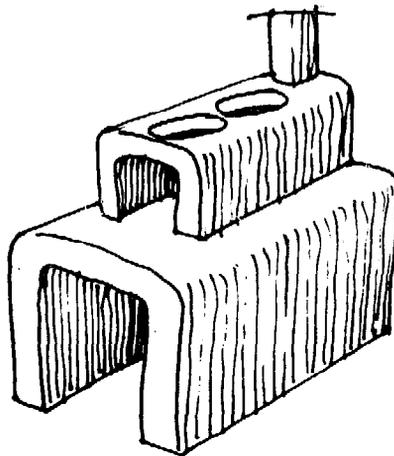
16) *Theodorovic 1953.*

CH2-2



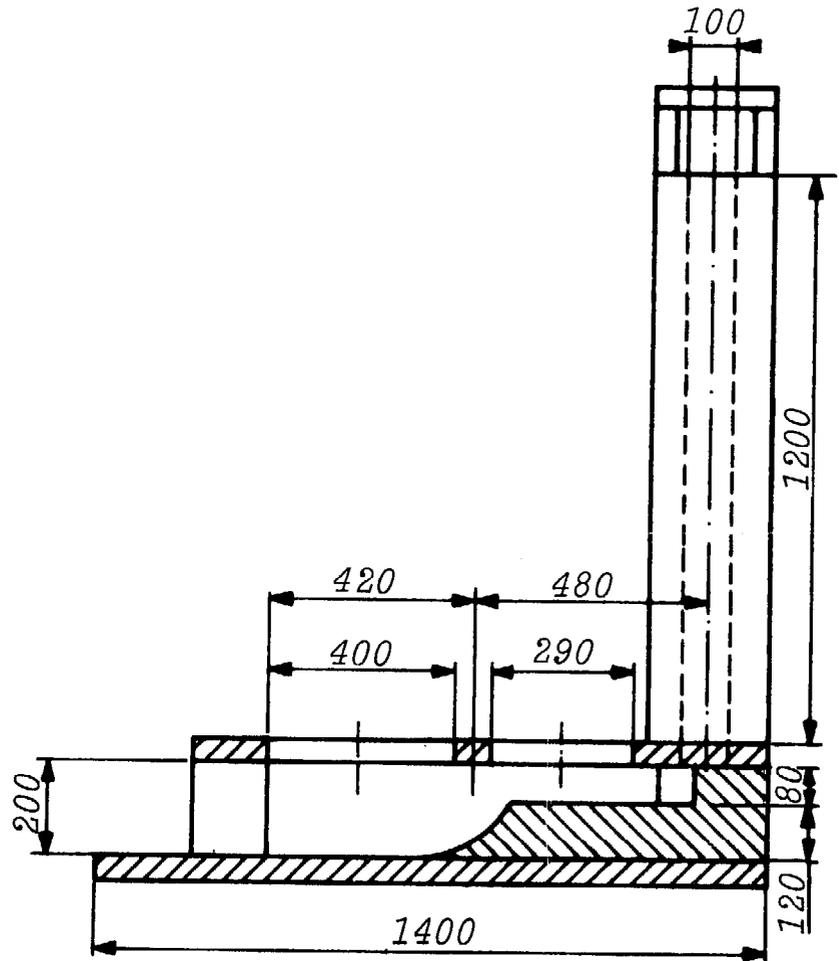
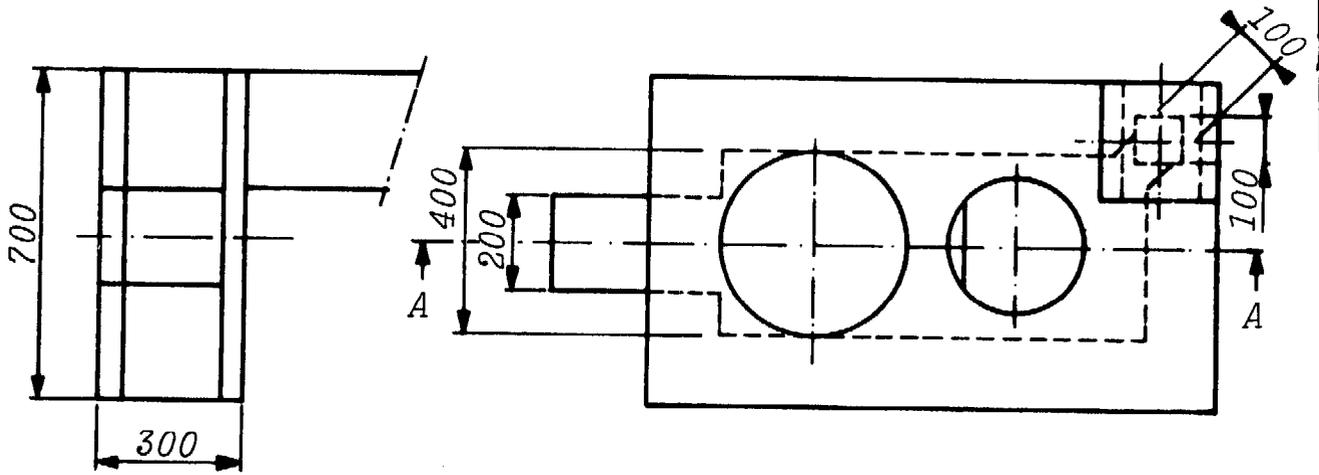
section A-A

- 1) CH2-2
- 2) Chimney height not specified.
- 3) A fixed mud stove which can accommodate 2 pots of spherical shape. These pots can have a diameter of 0,17 m. It will burn long wood. It has a chimney, no dampers, no baffles, no grate and no provisions for secondary air. With some changes it can be used as an oven.



- 5) The stove is completely made of mud. Alternatively the bottom of the fire-place can be made of metal sheet. By installing another metal sheet 0,2 m under the first, the space between can be used as an oven.
- 6) 350 kg.
- 7) Wood.
- 8) Any length. 0,18 x 0,19 m. Refuelling without lifting the pan.
- 9) In the alternative configuration the stove can be used as a baking oven.
- 11) Nigerian stove.
- 13) No laboratory tests known.
- 14) No field tests known.
- 16) Anon undated f.

CH2-3

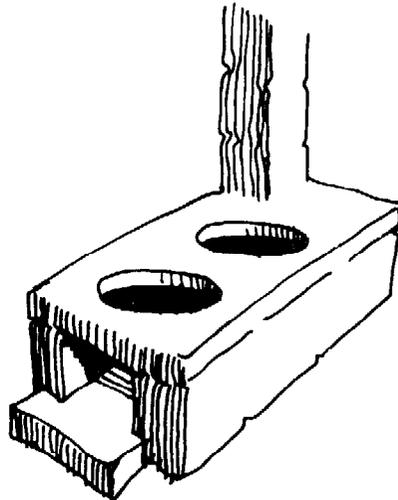


section A-A



1) CH2-3

3) *A fixed brick and concrete stove which can accommodate 2 pots of spherical shape. These pots can have diameters of 0,45 and 0,34 m. It will burn long wood. It has a chimney, no dampers, a baffle under the second pot, no grate and no provisions for secondary air.*



5) *The stove is made of bricks with a top plate of concrete, reinforced with metal.*

6) *400 kg.*

7) *Wood.*

8) *Any length. 0,2 x 0,2 m. Refuelling without lifting the pots.*

11) *Nouna-stove.*

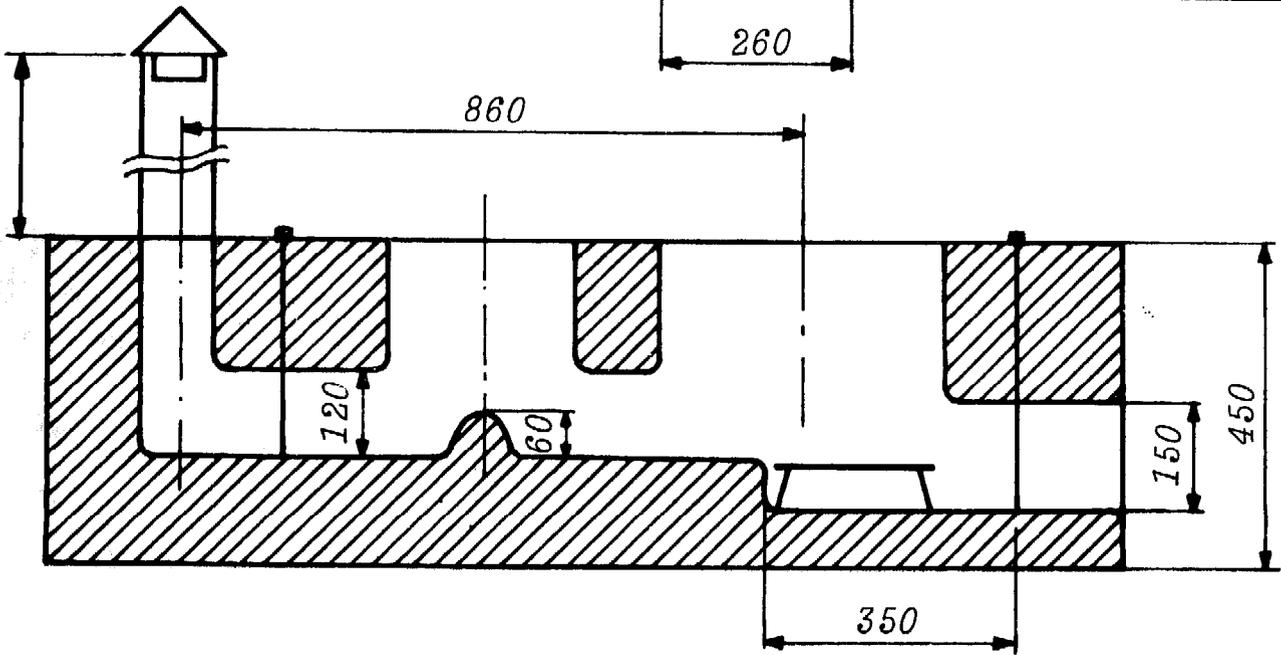
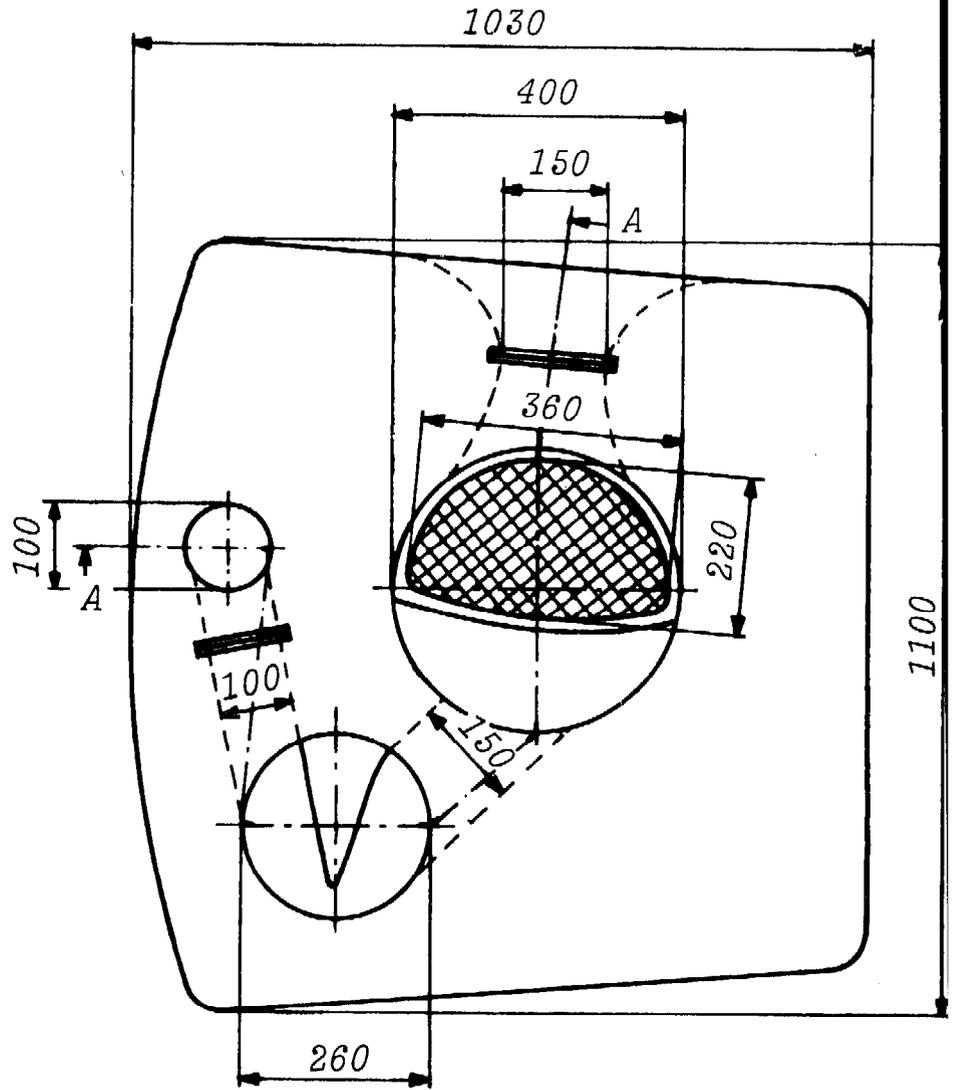
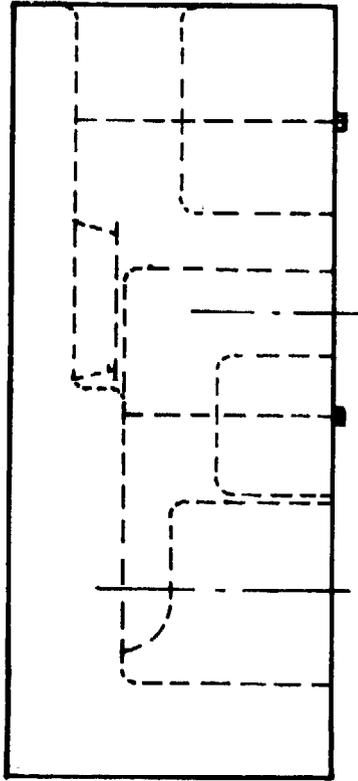
12) *These stoves were developed by Kempers in Nouna in the North-west of Upper-Volta.*

13) *No laboratory tests known.*

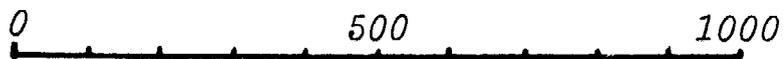
14) *No field tests known.*

16) *Acott et al 1980.*

CH2-4



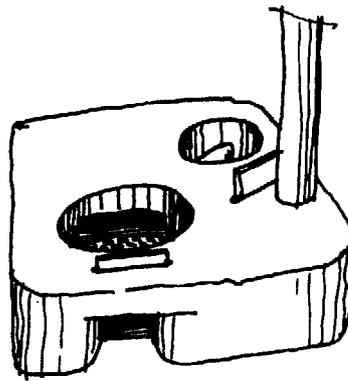
section A-A



1) CH2-4

2) Chimney height not specified.

3) A fixed mud stove which can accommodate 2 pots of spherical shape. These pots can have diameters of 0,45 and 0,3 m. It will burn short fuel. It has a chimney, a damper for combustion air, a damper for combustion gases, a baffle under the second pot, a grate and no provisions for secondary air.



4) Control of the fire by a sliding damper in the gas flue and one in the entrance tunnel to the fire. With both dampers closed the fire can be extinguished.

5) The stove body is built of mud, the two dampers are made of sheet steel, there is an optional steel grate for burning charcoal and a metal chimney.

6) 650 kg.

7) Wood. Charcoal with use of the grate.

8) 0,3 m. 0,15 x 0,15 m. Refuelling without lifting the pans.

11) Evans M1.

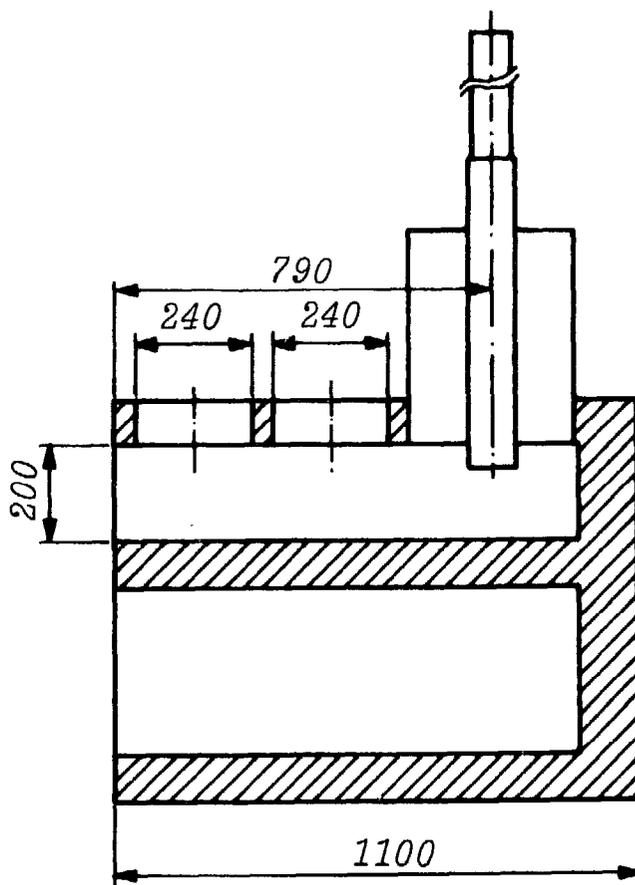
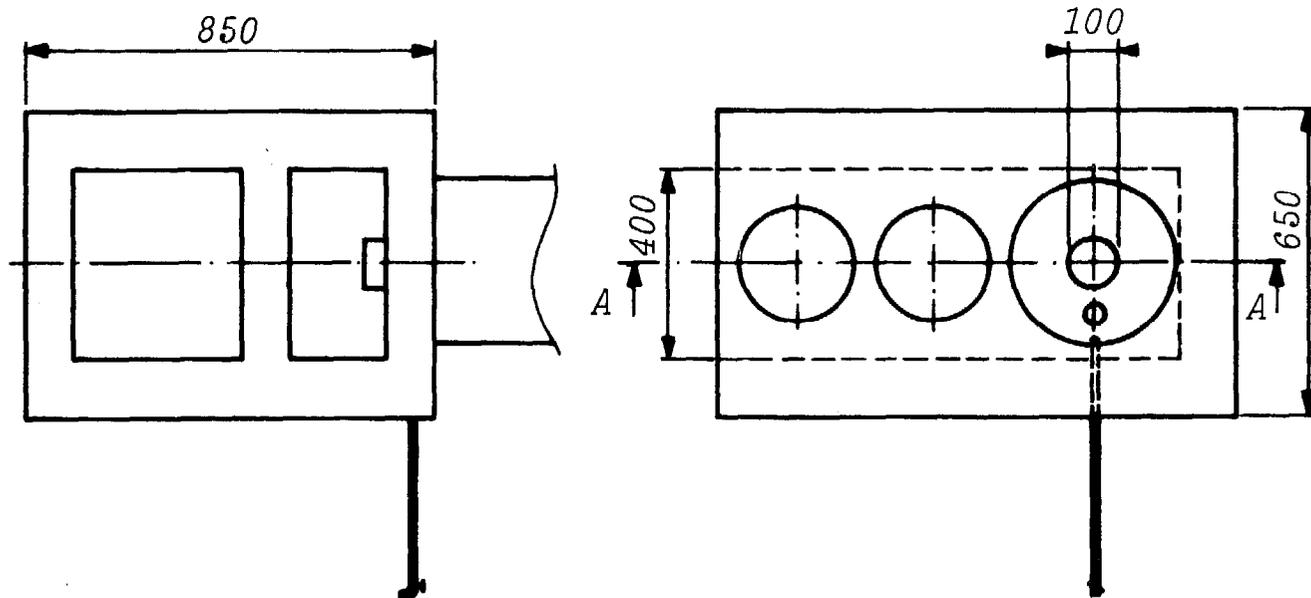
12) Built by Gern in Senegal in 1979.

13) No laboratory tests known.

14) No field tests known.

16) Evans, Gern, Jacobs 1980.

CH2-6



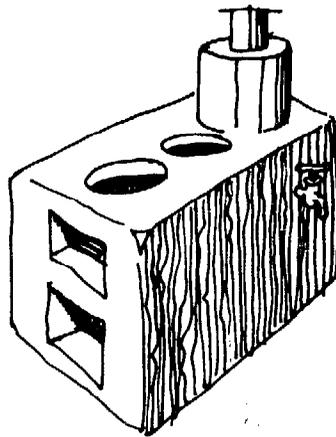
section A-A

0 500

1) CH2-6

2) Chimney height not specified.

3) A fixed mud and metal stove which can accommodate 2 pots of spherical shape. These pots can have a diameter of 0,28 m. It will burn long wood. It has a chimney, no dampers, no baffles, no grate and no provisions for secondary air.



5) The stove is made of mud with a metal water tank around the metal chimney.

6) 600 kg.

7) Wood.

8) Any length. 0,4 x 0,2 m. Refuelling without lifting the pans.

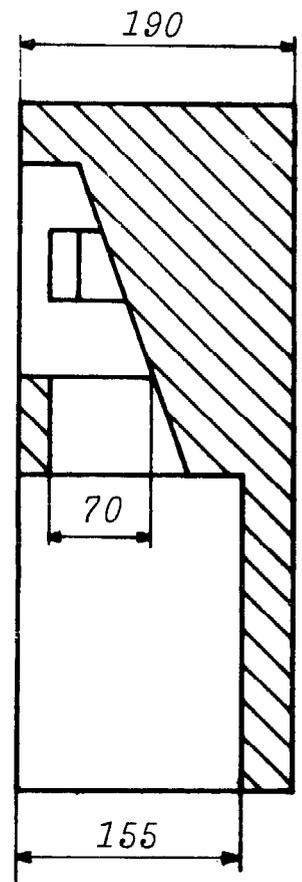
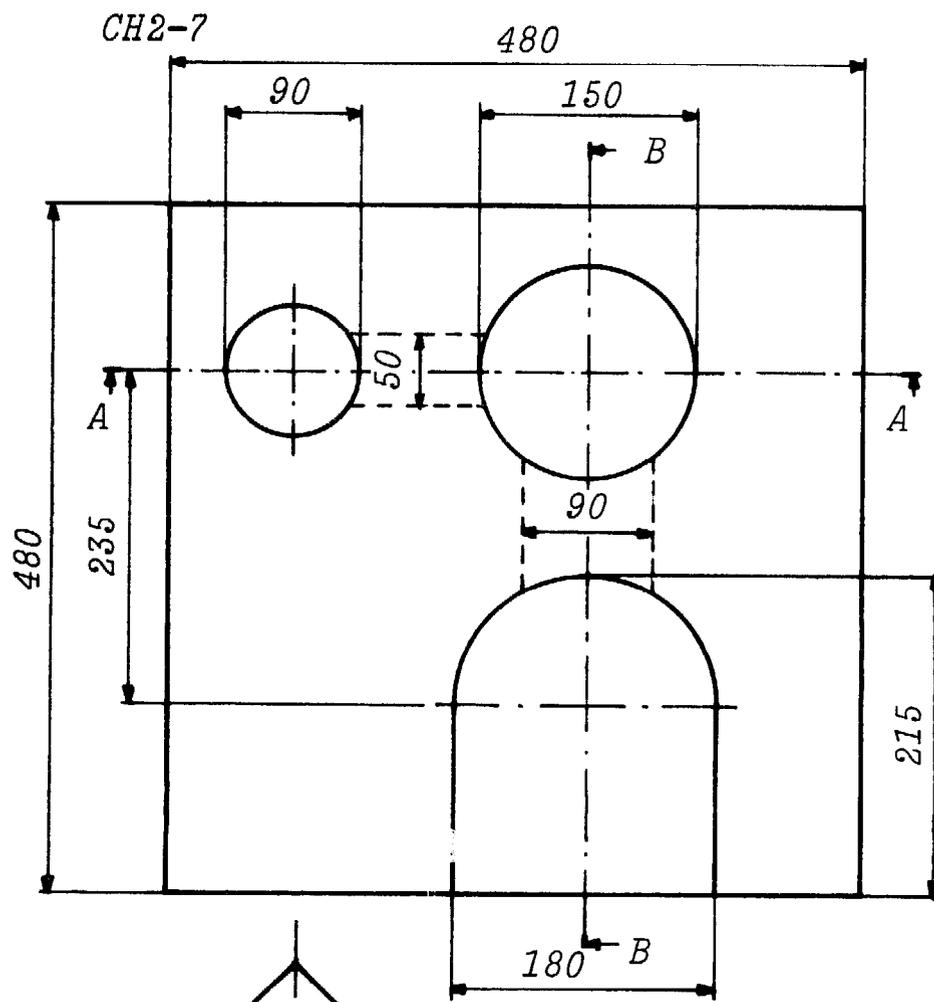
10) The content of the water tank is 40 l. According to Wolderufael the water temperature was 75 C after 1.50 h of firing.

11) Karai Stove.

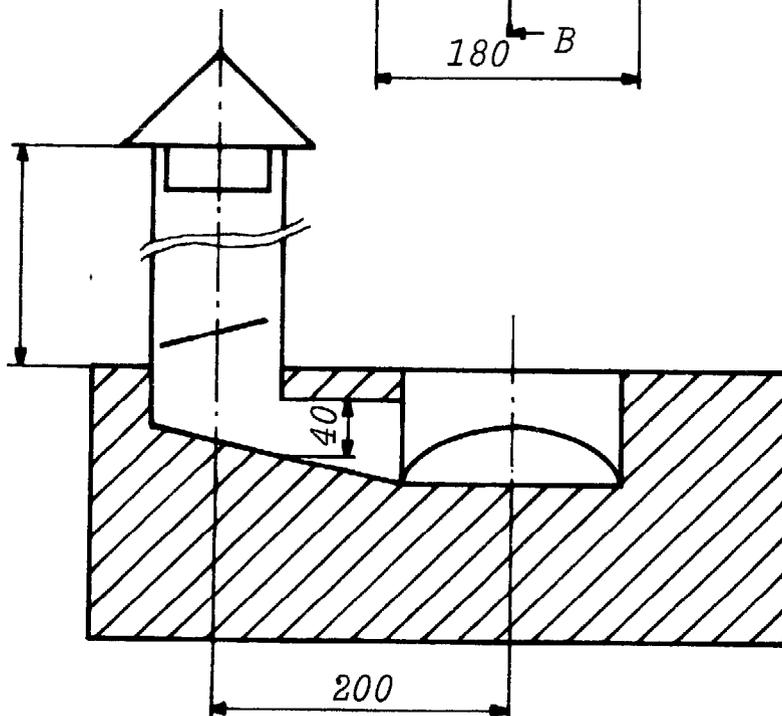
13) No laboratory tests known.

14) Food cooking tests by Wolderufael. No efficiency calculated.

16) Wolderufael 1980.



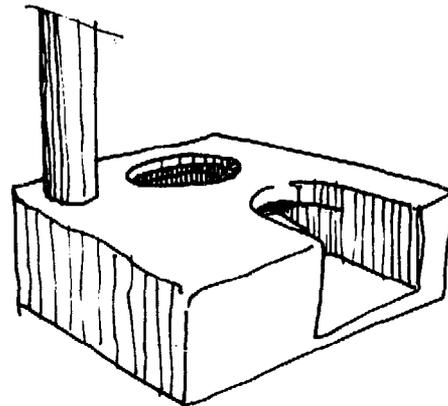
cross section B-B



section A-A

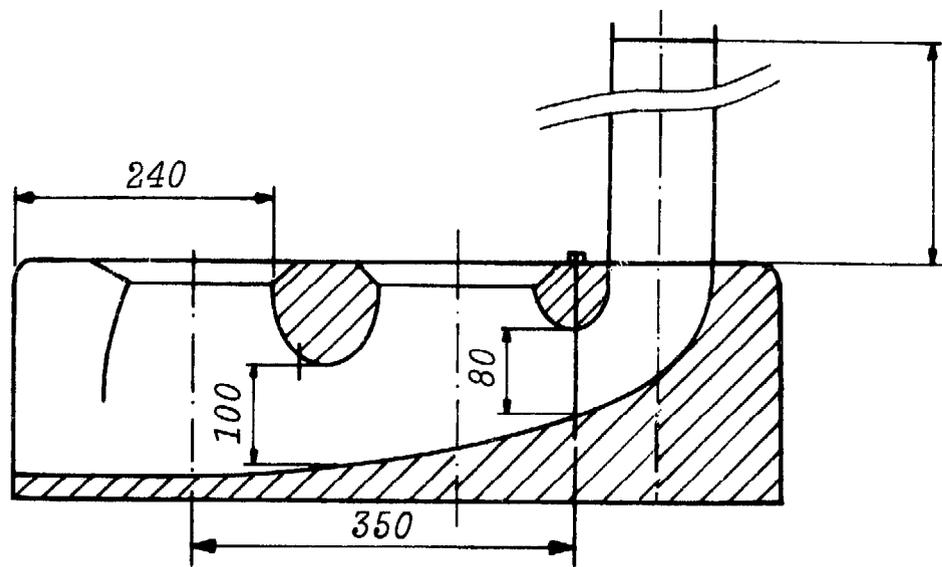
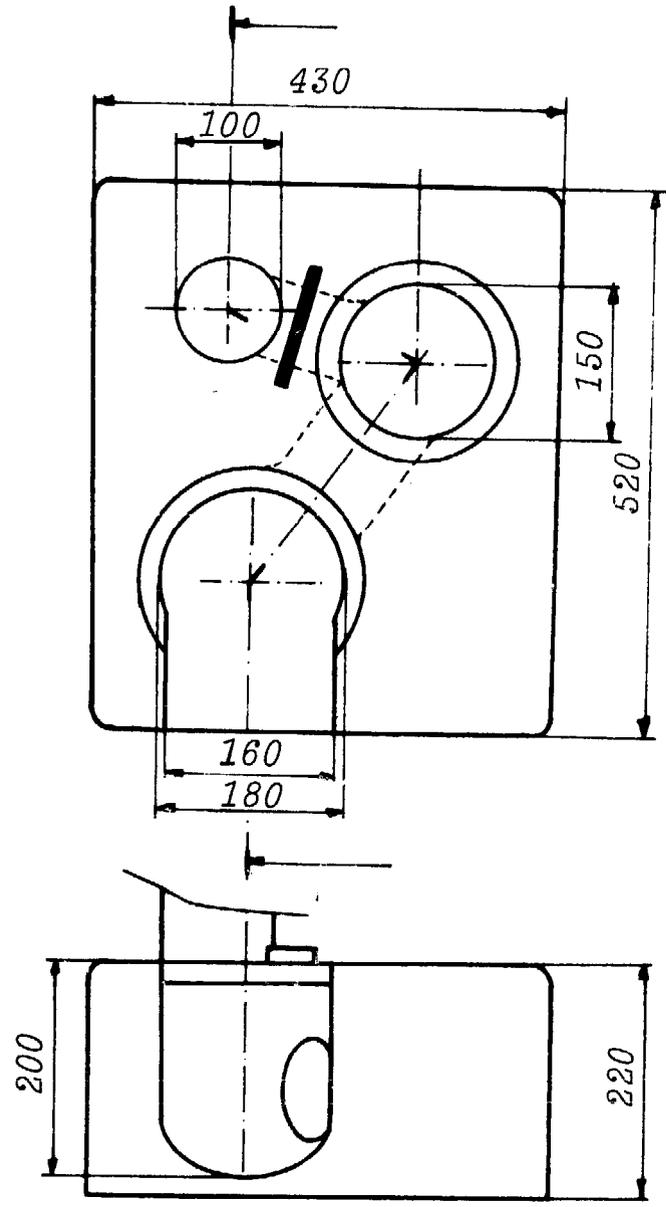


- 1) CH2-7
- 2) Chimney height not specified.
- 3) A fixed mud stove which can accommodate two pots of spherical shape. These pots can have diameters of 0,24 and 0,20 m. It will burn long wood, with no limitations to the length. It has a chimney, no damper for combustion air, a damper for combustion gases, no baffle, no grate and no provisions for secondary air.



- 4) Control by damper for the combustion gases.
- 5) The stove is made of mud with a chimney of metal or ceramic pipe and a damper of metal sheet.
- 6) Weight about 90 kg.
- 7) Wood, straw and rice-husks.
- 8) Any length. 0,15 x 0,18 m, charging without lifting the pan.
- 11) PRAI-Improved Chula.
- 12) India, Planning, Research and Action Institute at Lucknow. 1969.
- 13) National Building Organisation, India. Boiling water tests showed a high efficiency but the meaning of this efficiency figure is not made clear. PRAI-Rice cooking tests. ITDG-Water boiling tests.
- 14) Stoves of this type are widely used in Kerala, India. According to Gupta they are more efficient than an open fire for longer cooking times.
- 16) Ahuja 1969. Joseph, Shanahan, Bialy 1980.

CH2-8



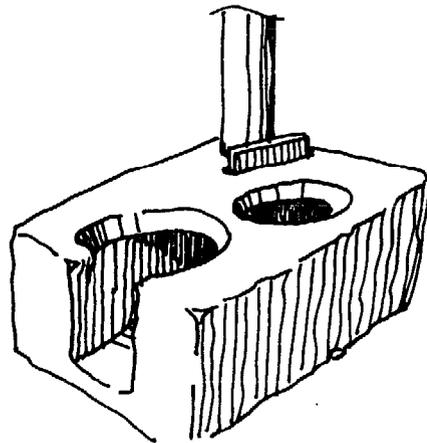
section A-A



1) CH2-8

2) Chimney height not specified.

3) This stove is a modification of CH2-7 by Joseph of ITDG and follows the same description.



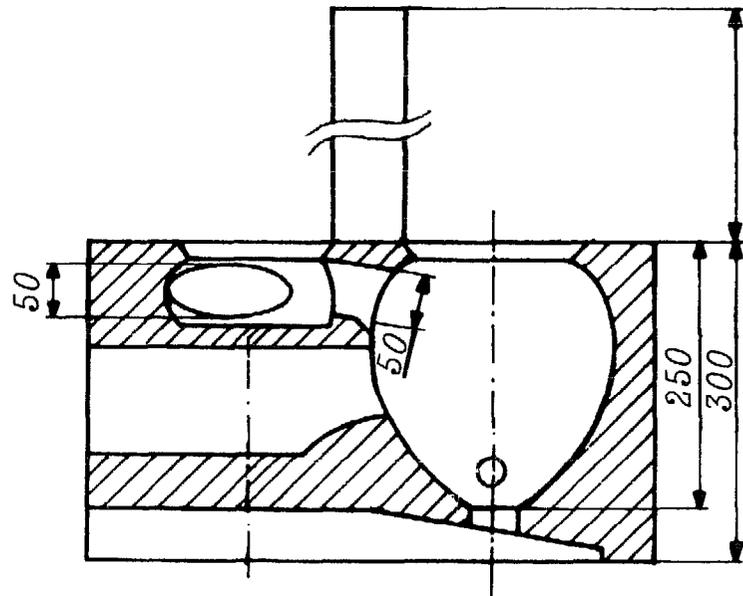
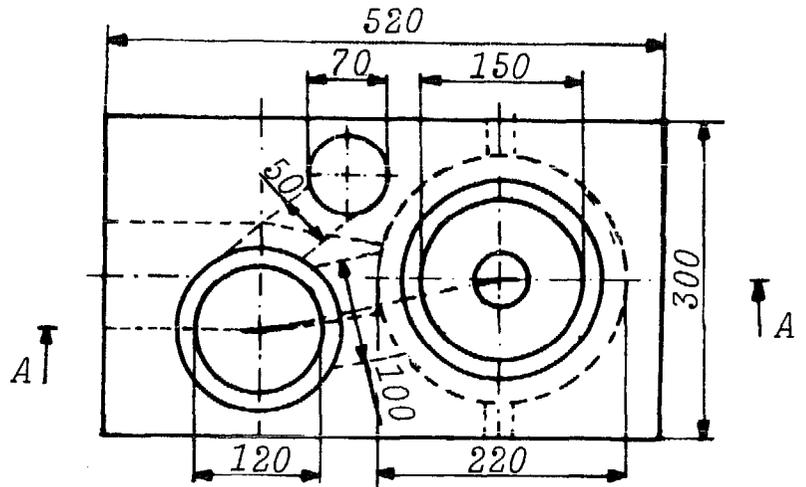
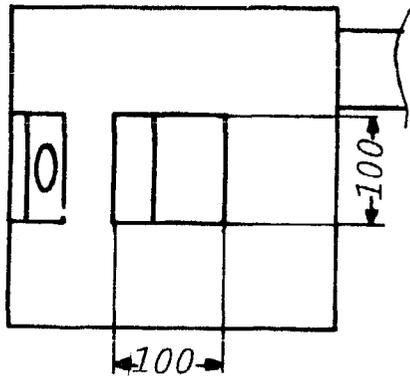
11) PRAI Improved Chula.

13) Water boiling tests at ITDG. Results of these tests available at ITDG

14) No field tests known.

16) Joseph, Shanahan, Bialy 1980.

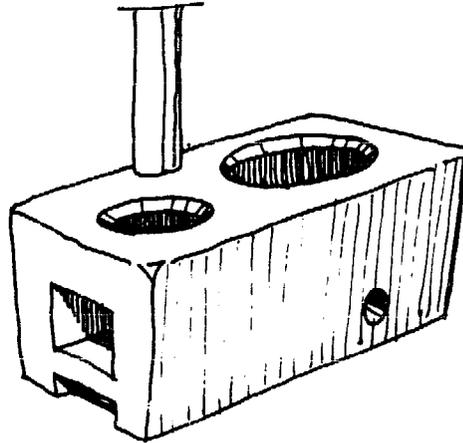
CH2-9



section A-A

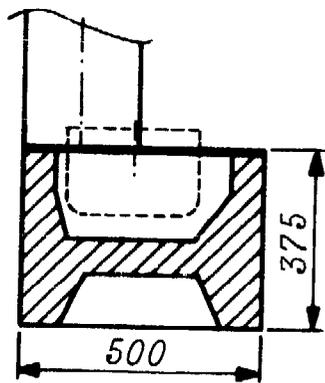
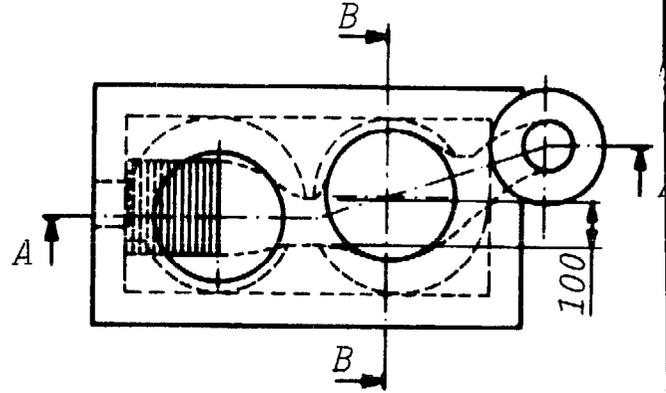
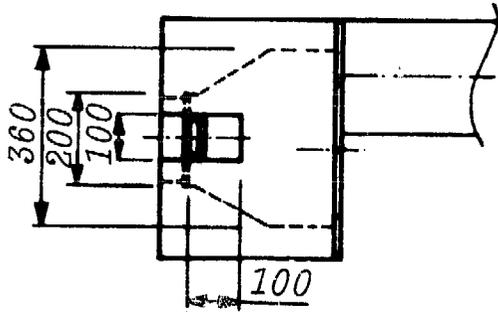


- 1) CH2-9
- 2) Chimney height not specified.
- 3) A fixed concrete stove which can accommodate 2 pots of spherical shape. These pots can have diameters of 0,22 and 0,19 m. It will burn long wood. It has a chimney, no dampers, no baffles, no grate and a provision for secondary air.

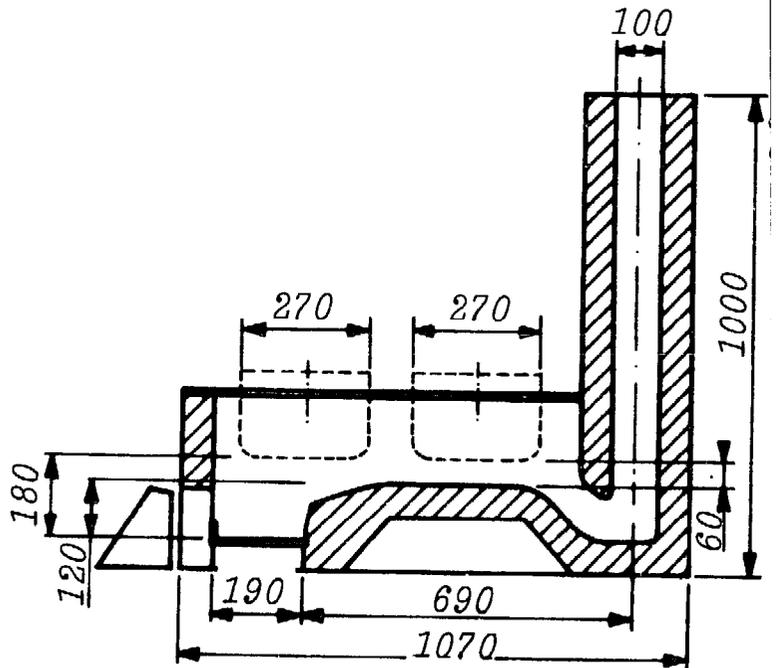


- 4) The stove is provided with holes in the side wall of the of the combustion chamber for secondary air.
- 5) The stove is completely built of concrete with the aid of a special wooden mould.
- 6) 80 kg.
- 7) Wood.
- 8) Any length. 0,1 x 0,1 m. Refuelling without lifting the pans.
- 11) IDB-stove.
- 12) This stove was developed by the Industrial Development Board of Sri Lanka in 1968. In 1979 fifty stoves were built and distributed throughout Sri Lanka. As far as is known, no further extension work has been undertaken.
- 13) Water boiling tests by Joseph showed medium efficiency. IDB-tests results are not available.
- 14) No field tests known.
- 16) Joseph, Shanahan, Bialy 1980.

CH2-10



section B-B

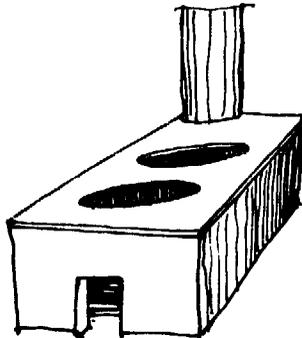


section A-A

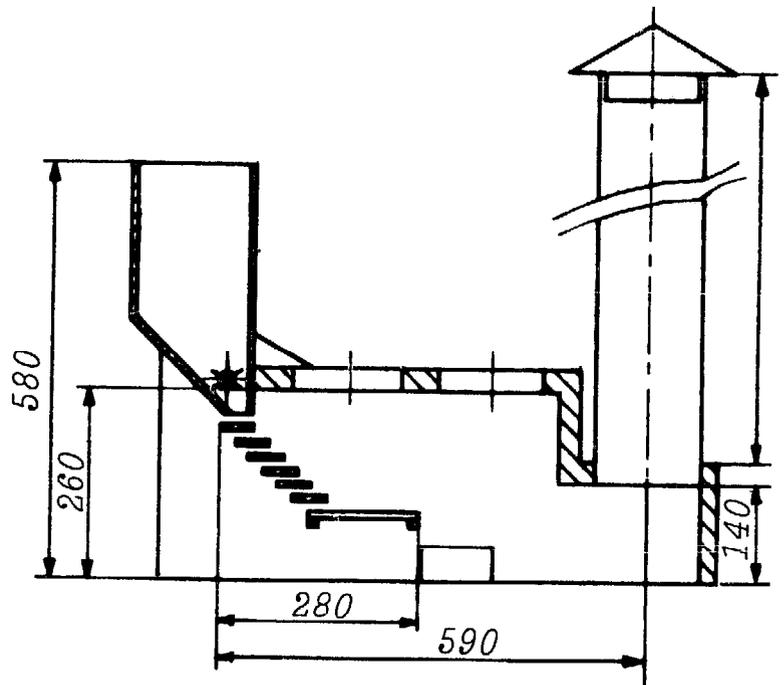
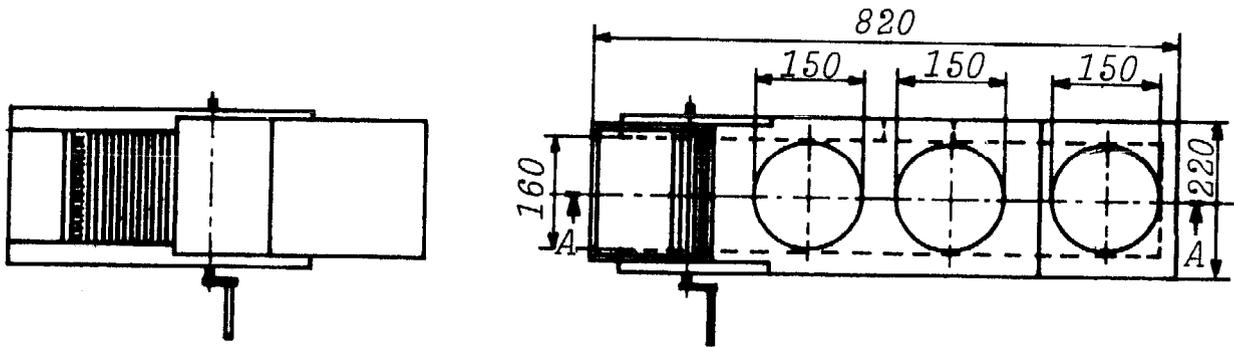


1) CH2-10

- 3) *A fixed metal and clay mixture stove which can accommodate 2 pots of cylindrical shape. The pots must have a diameter of 0,27 m. It will burn short wood. It has a chimney, a damper for combustion air, no damper for combustion gases, a baffle, a grate and a provision for secondary air.*



- 4) *Control of the fire by the door of the charging port. Secondary air is supplied to the fire by small holes in the wall of the combustion chamber.*
- 5) *The stove is built of a mixture of clay, crushed bricks and dry long grass. The top is covered with 2 cast iron plates. The grate is made of iron bars.*
- 6) *150 kg.*
- 7) *Wood.*
- 8) *0,18 m with damper closed. 0,1 x 0,1 m. Refuelling without lifting the pan.*
- 11) *Pogbi stove.*
- 13) *Waterboiling tests by Micuta showed high efficiency.*
- 14) *No field tests known.*
- 16) *Micuta 1980.*



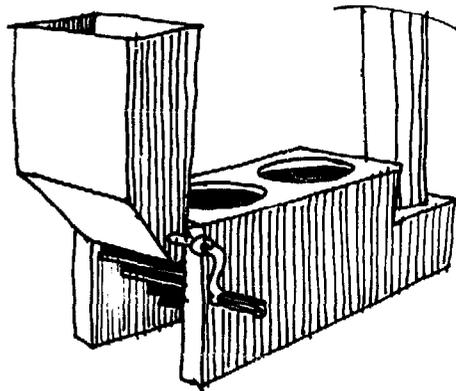
section A-A



1) CH2-11

2) Chimney height not specified.

3) Built of mud, ceramic and steel. Takes 2 spherical pots of 0,19 m diameter. Burns rice husks. Has a chimney and a grate, no dampers, baffles or secondary air facilities.



5) Body of mud or brickwork, metal or ceramic cover plate. A stepped steel bar grate. Sheet steel hopper and chimney.

6) 60 kg.

7) Rice-husks.

8) Fuel is hopper fed by rotating spreader.

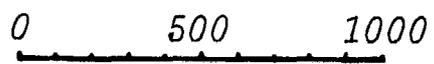
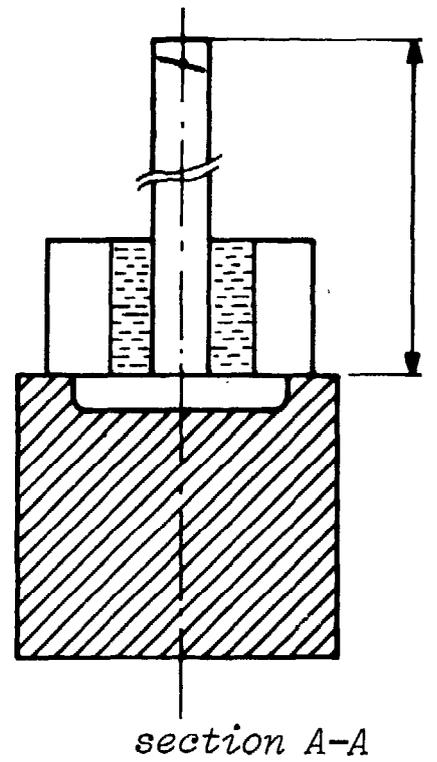
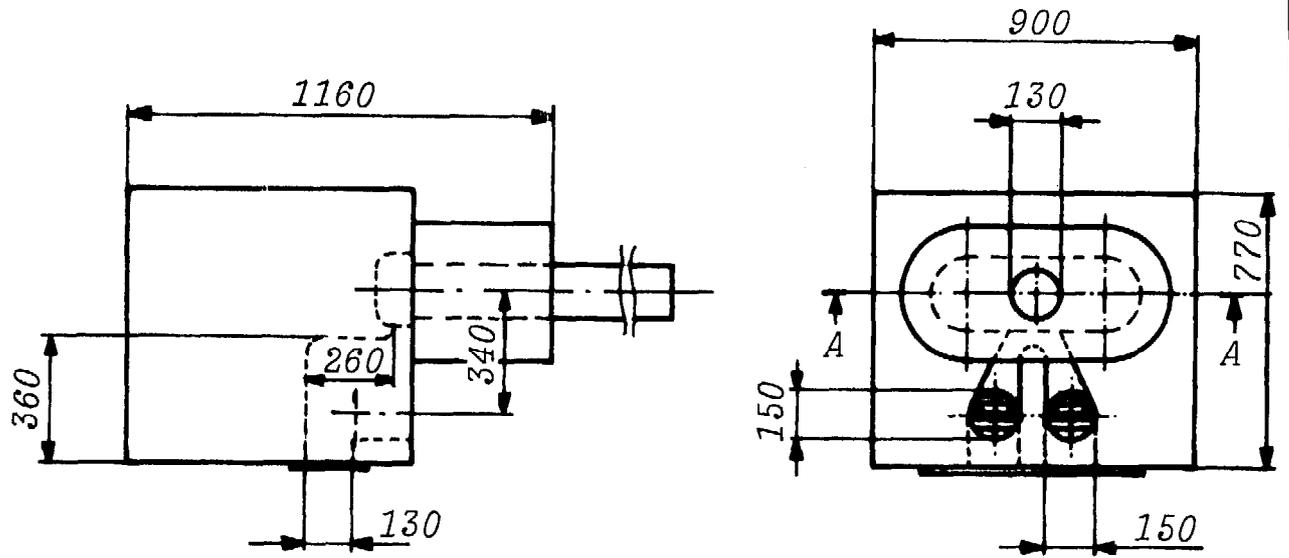
11) I.P.A.-stove.

12) Introduced in Asia early 20th century. Displaced in late fifties by cheap kerosene and electricity. Industrially made in Thailand, Philipines and Indonesia (see CH1-6 and CH3-13).

13) Water boiling tests at I.I.T.-Kharagpur showed good efficiency.

14) No field tests known.

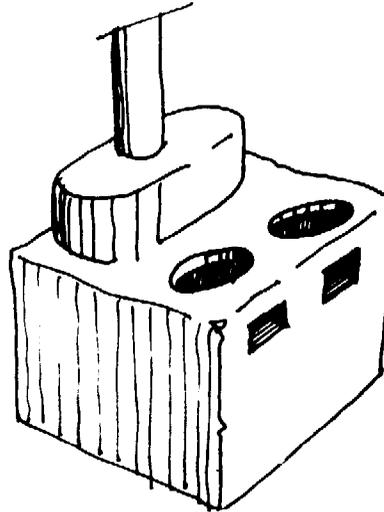
16) Joseph, Shanahan, Bialy 1980.



1) CH2-12

2) Chimney height not specified.

3) Built of brickwork and steel. Two fireplaces, one for each spherical pot of 0,17 m. Burns soft coke. Has grate, air damper, flue gas damper and no secondary air provisions.



4) Air- and chimney damper for each fireplace.

5) Brickwork stove. Metal coverplate has two potholes. Two grates and a water tank.

6) 1000 kg.

7) Soft coke.

8) Refuelling through potholes.

10) A 45 l hot water tank. No performance figures.

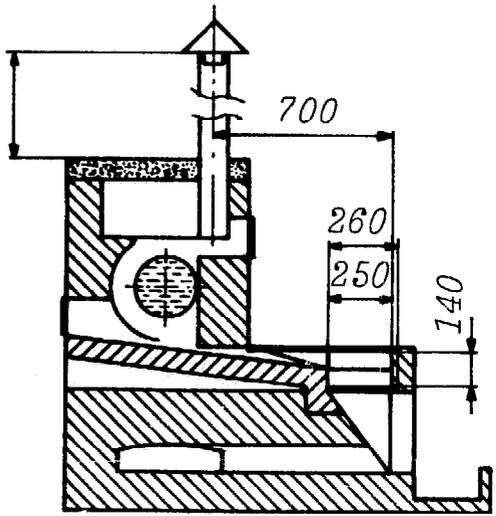
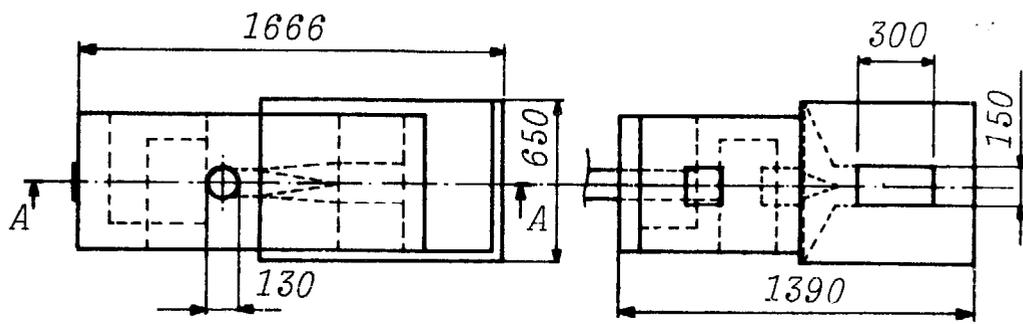
11) Banerjee type stove.

12) This stove originated in India.

13) Good efficiency for water boiling and food cooking tests at PRAI. Water tank heating probably disregarded.

14) No field tests known.

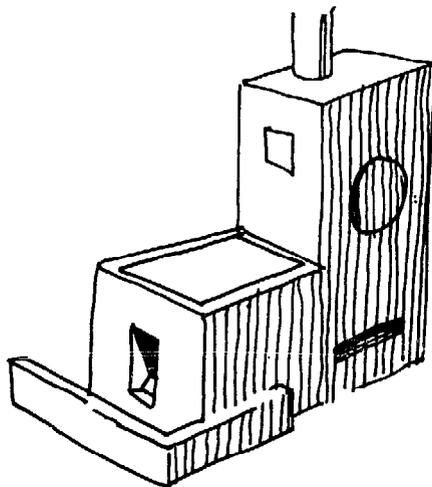
16) Ahuja 1969.



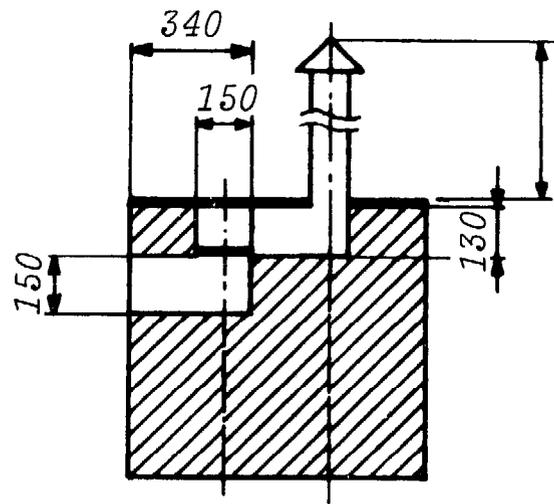
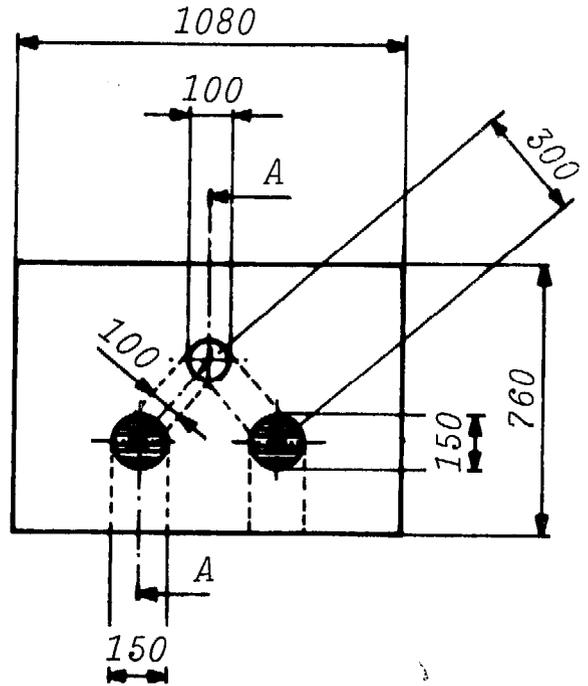
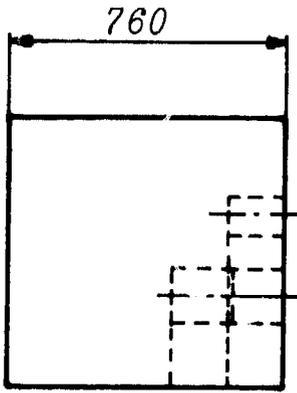
section A-A



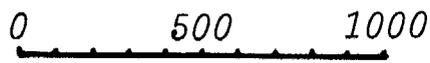
- 1) CH2-13
- 2) Chimney height not specified.
- 3) *A fixed, brick and metal stove which can accommodate 2 or more pots, with a flat bottom, on a hot plate of 0,53 x 0,54 m. in this plate is a pothole of 0,15 m. It will burn soft coke. It has a chimney, no dampers, no baffles and no provisions for secondary air. It has a metal grate, metal coverplate, metal watertank and a metal chimney.*



- 6) 1000 kg.
- 7) Soft coke.
- 8) *The fuel must be charged through the pothole of 0,15 m. For refuelling the pot must be lifted from the stove.*
- 10) *The hotwatertank contains 20 l. No figures about the achievable temperature.*
- 11) *Army H.Q. Type.*
- 12) *This stove is used in the Indian Army.*
- 13) *Water boiling tests at the PRAI showed medium efficiency, probably without taking into account the heat absorbed by the water heater. Food cooking tests at the same institute also showed good efficiency.*
- 14) *No field tests known.*
- 16) *Ahuja 1969.*



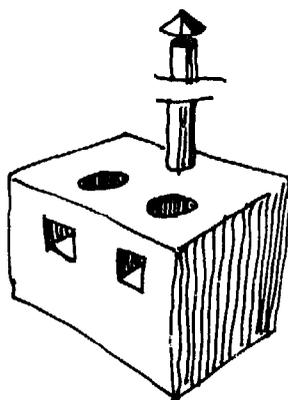
section A-A



1) CH2-14

2) Chimney height not specified.

3) A fixed brick and metal stove which can accommodate 2 pots of spherical or cylindrical shape with a fireplace for each pot. These pots can have a diameter of 0,19 m. It will burn soft coke. It has a chimney, no damper for combustion air, a damper for combustion gases, a grate, no baffles and no provisions for secondary air.



4) The fire can be controlled with a butterfly-valve in the chimney. This valve works for both fireplaces at the same time.

5) The stove is built of bricks with a grate of metal bars and a metal chimney.

6) 1200 kg.

7) Soft coke.

8) Refuelling through the potholes of 0,15 m. For refuelling the pots must be lifted from the stove.

11) G.E. Shillong Improved type stove.

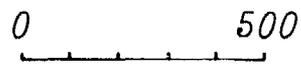
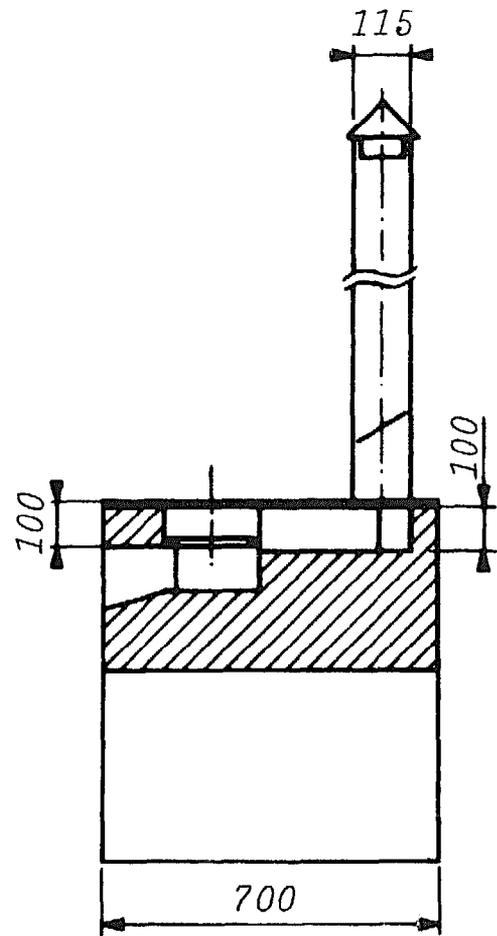
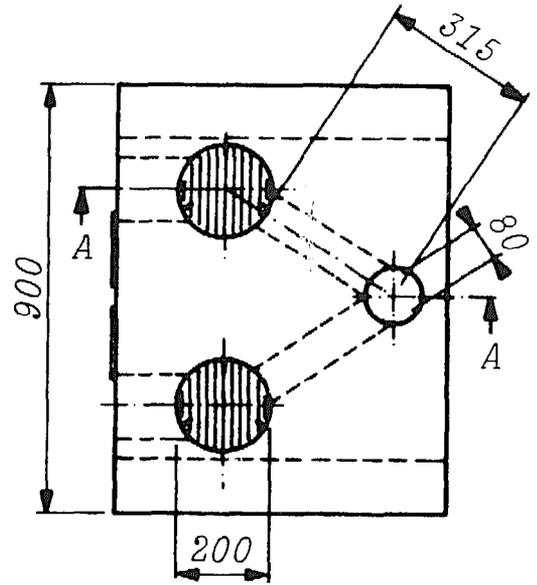
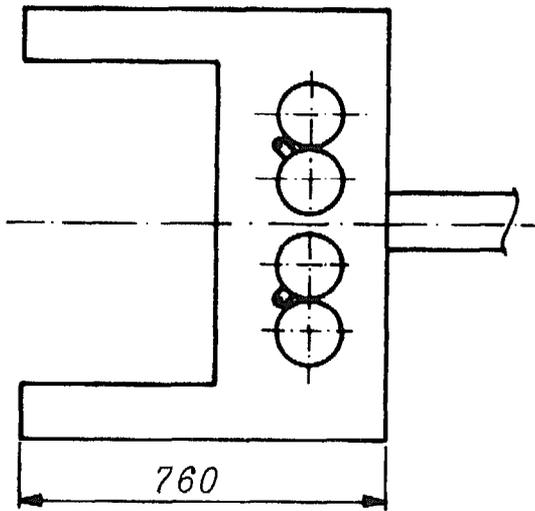
12) Developed at PRAI in 1964.

13) Water boiling tests at PRAI showed good efficiency.

14) No field tests known.

16) Ahuja 1969.

CH2-15

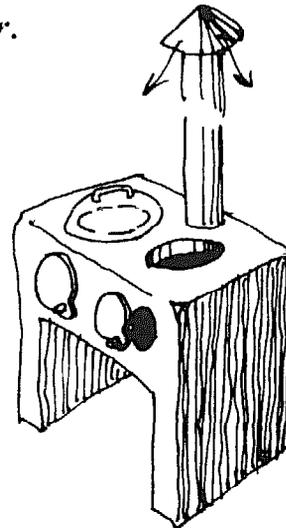


section A-A

1) CH2-15

2) Chimney height not specified.

3) A fixed brick and metal stove which can accommodate 2 pots of spherical or cylindrical shape with a fireplace for each pot. These pots can have a diameter of 0,24 m. It will burn soft coke. It has a chimney, dampers for combustion air, a damper for combustion gas, no baffles, a grate for each fireplace and no provisions for secondary air.



4) For each fireplace the combustion air can be controlled by a rotating damper. In the chimney is a butterfly-valve that controls the combustion gases for both fireplaces together.

5) The stove is built of bricks with a grate of metal bars, metal air dampers and a metal chimney.

6) 500 kg.

7) Soft coke.

8) Fuel must be charged through the potholes of 0,20 m. For refuelling the pot must be lifted from the stove.

11 Bhavnagar improved type stove.

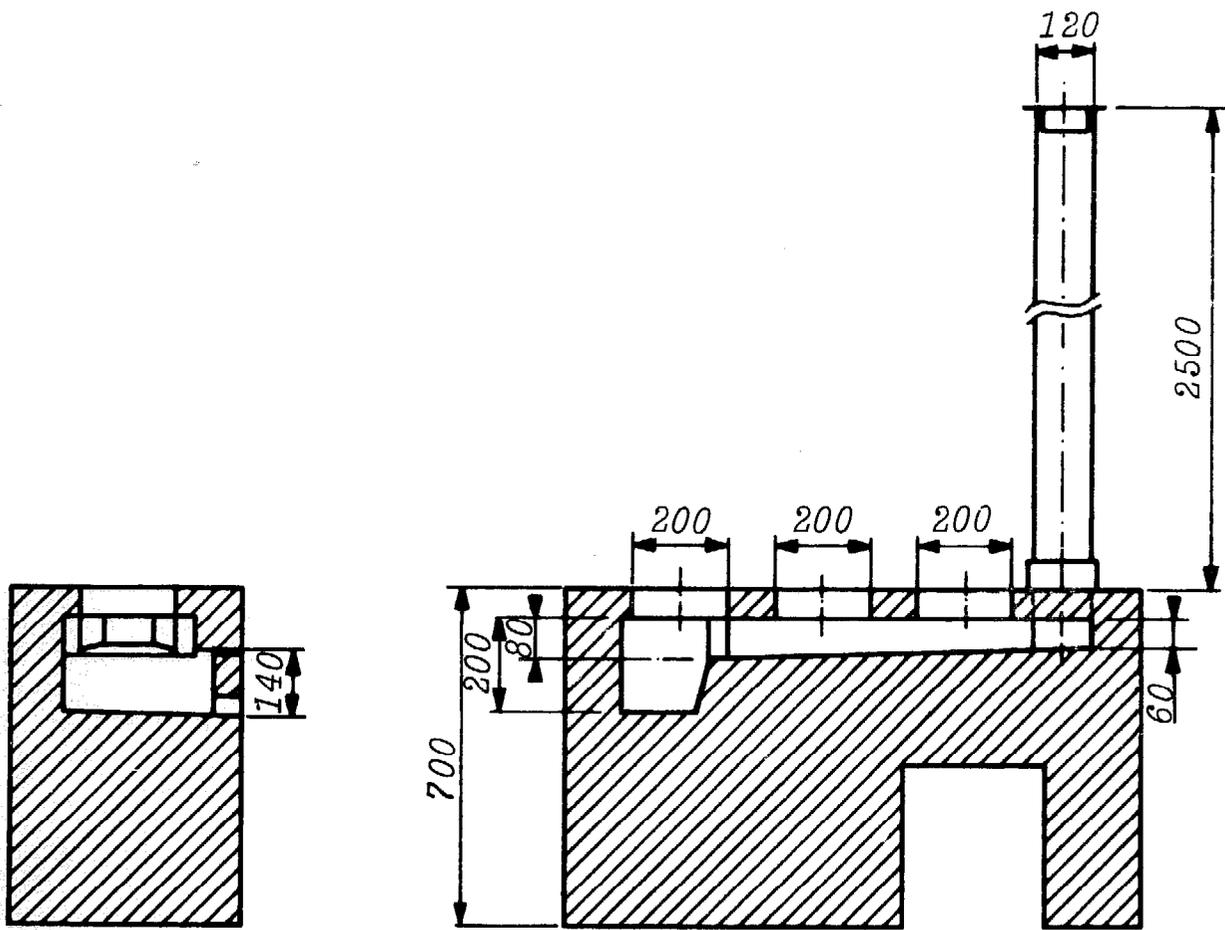
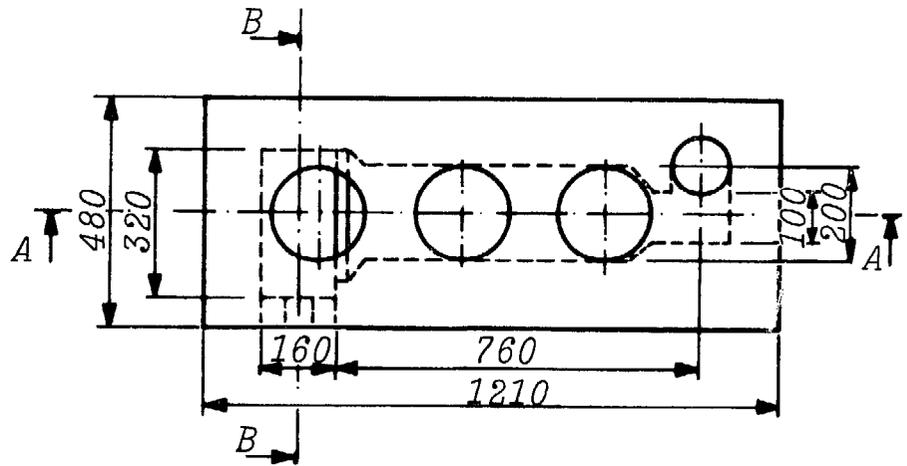
12) This stove was developed at PRAI in 1964.

13) Water boiling tests at PRAI showed good efficiency.

14) No field tests known.

16) Ahuja 1969.

CH3-1



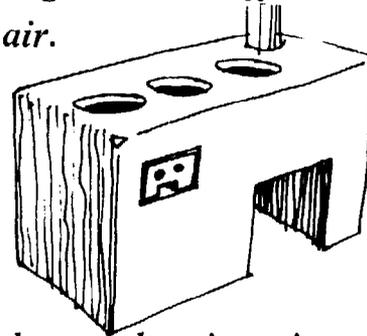
section B-B

section A-A



1) CH3-1

3) *A fixed brick and metal stove which can accommodate 3 pots of spherical shape. These pots can have a diameter of 0,24 m. It will burn short wood. It has a chimney, a damper for combustion air, no damper for combustion gases, no baffles, no grate and no provisions for secondary air.*



4) *The wood charging port, through which the combustion air enters, can be partially closed with a door to temper the fire.*

5) *The stove is built of fired bricks with a metal chimney. Alternative materials are sundried bricks or clay. Top plate is made of fired clay in three sections.*

6) 1000 kg.

7) Wood.

8) 0,27 m, with closed door. 0,16 x 0,14 m. Refuelling without lifting the pan.

11) Singer stove.

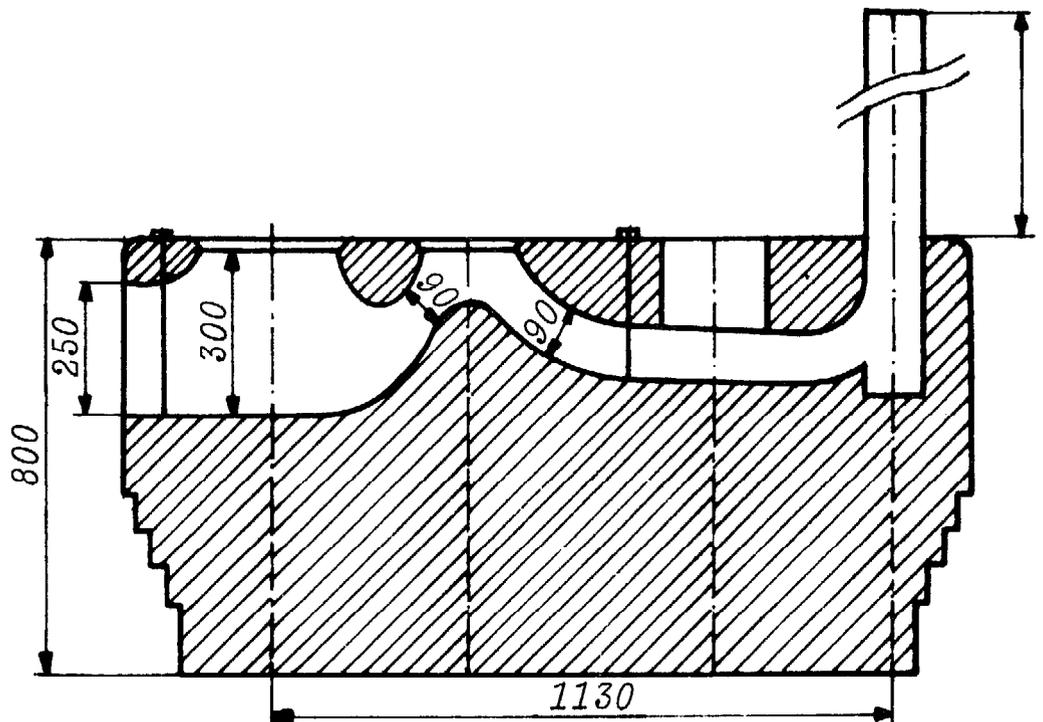
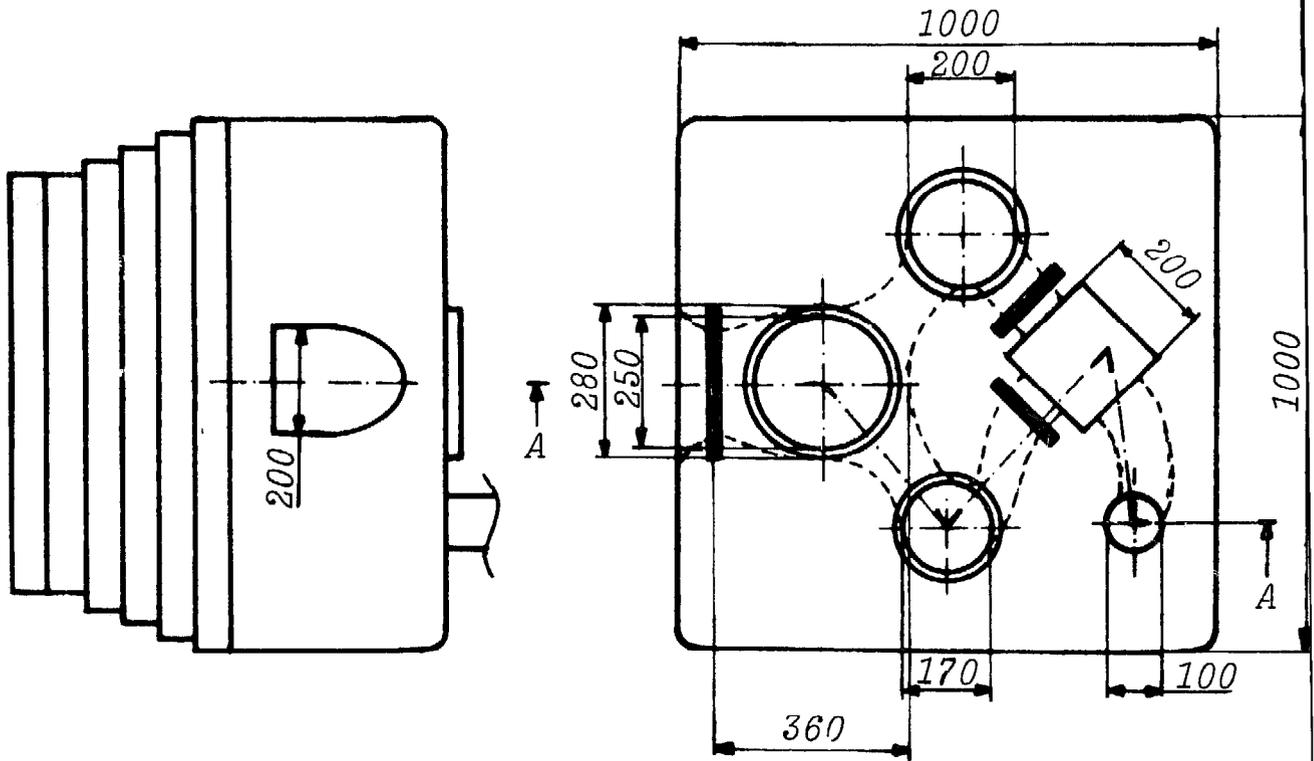
12) *This stove was developed by Singer in 1961 as part of a project to improve fuelwood cooking stoves. Singer developed more stoves, based on the same principles, for different circumstances.*

13) *Water boiling tests by Singer showed high efficiency. Food cooking tests by Singer showed an improvement in wood use compared to the traditional cooking stoves such as SH3-2. Water boiling tests by Garberson showed medium efficiency and he reports that the stove smokes badly. In these tests only two potholes were used, the third was covered.*

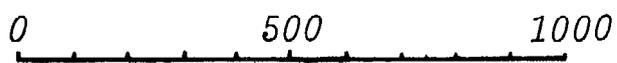
14) No field tests known.

16) *Singer 1961. Acott et al 1980. Krishna Prasad, Nieuwvelt, Verhaart 1979. Anon 1961, a.*

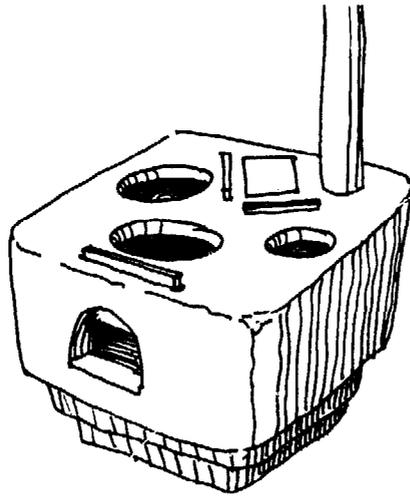
CH3-2



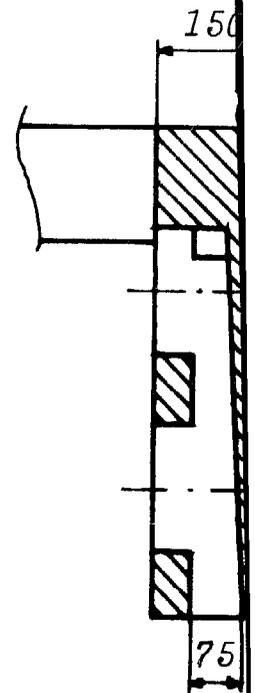
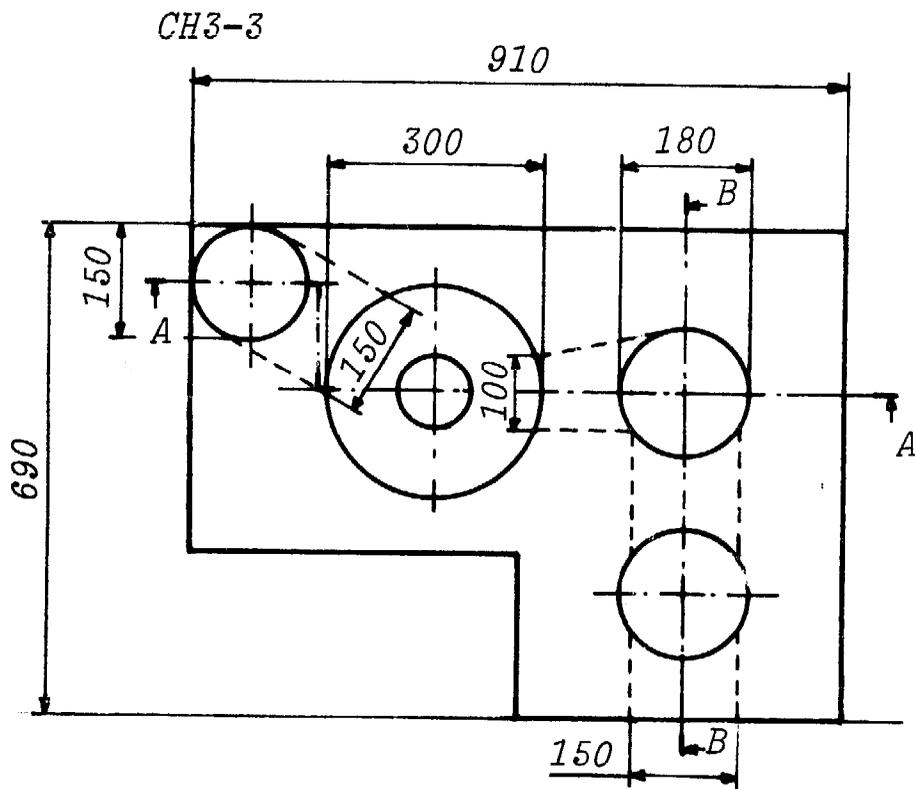
section A-A



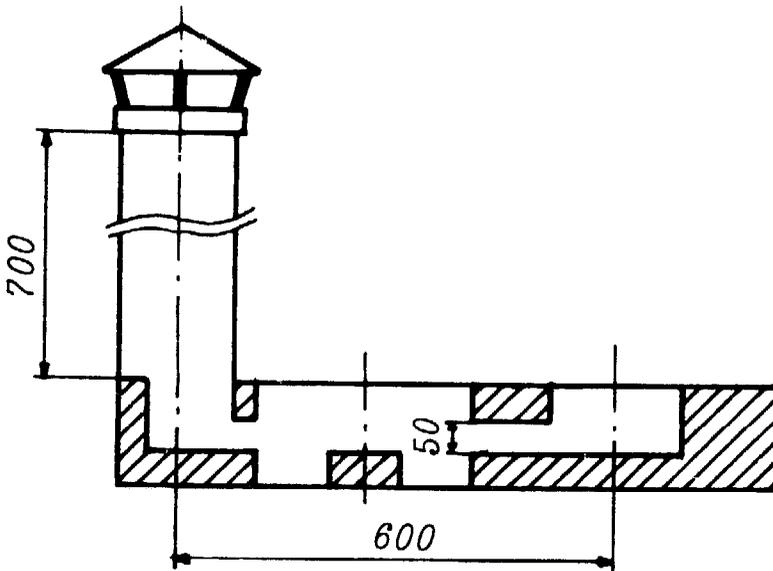
- 1) CH3-2
- 2) Chimney height not specified.
- 3) Fixed mud stove taking 3 spherical pots of 0,25; 0,21 and 0,20 diameter. Burns wood up to 0,25 m long. Has a chimney and dampers for air and flue gas; no baffles, grate or secondary air provisions. Can be used as oven.



- 4) Control by both dampers. Fire space can be shut off.
- 5) Mud. Metal or ceramic chimney. Sheet metal dampers.
- 6) 500 kg.
- 7) Wood.
- 8) 0,250 m. 0,15 x 0,12 m. Refuels with pans in place.
- 9) By closing the dampers the firebox can be used as an oven.
- 11) Lorena Mud stove.
- 12) Guatemala. Choqui Experimental Station 1977. Stove proved generally unacceptable in Java and Sri-Lanka according to ITDG.
- 13) Uses from half to double the amount of fuel in water boiling tests when compared to open fire.
- 14) Can operate satisfactorily if well built and maintained; when used for more than 3 hours per day and all holes are used.
- 16) Evans 1979. Shaller 1979. Anon 1980, a. Acost et al 1980.



section B-

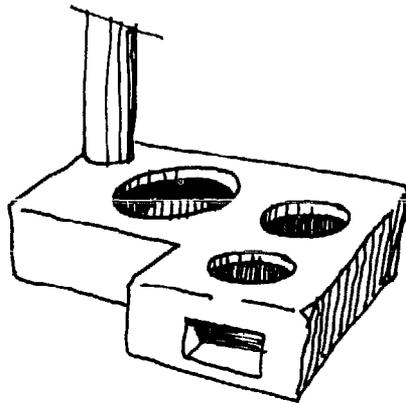


section A-A



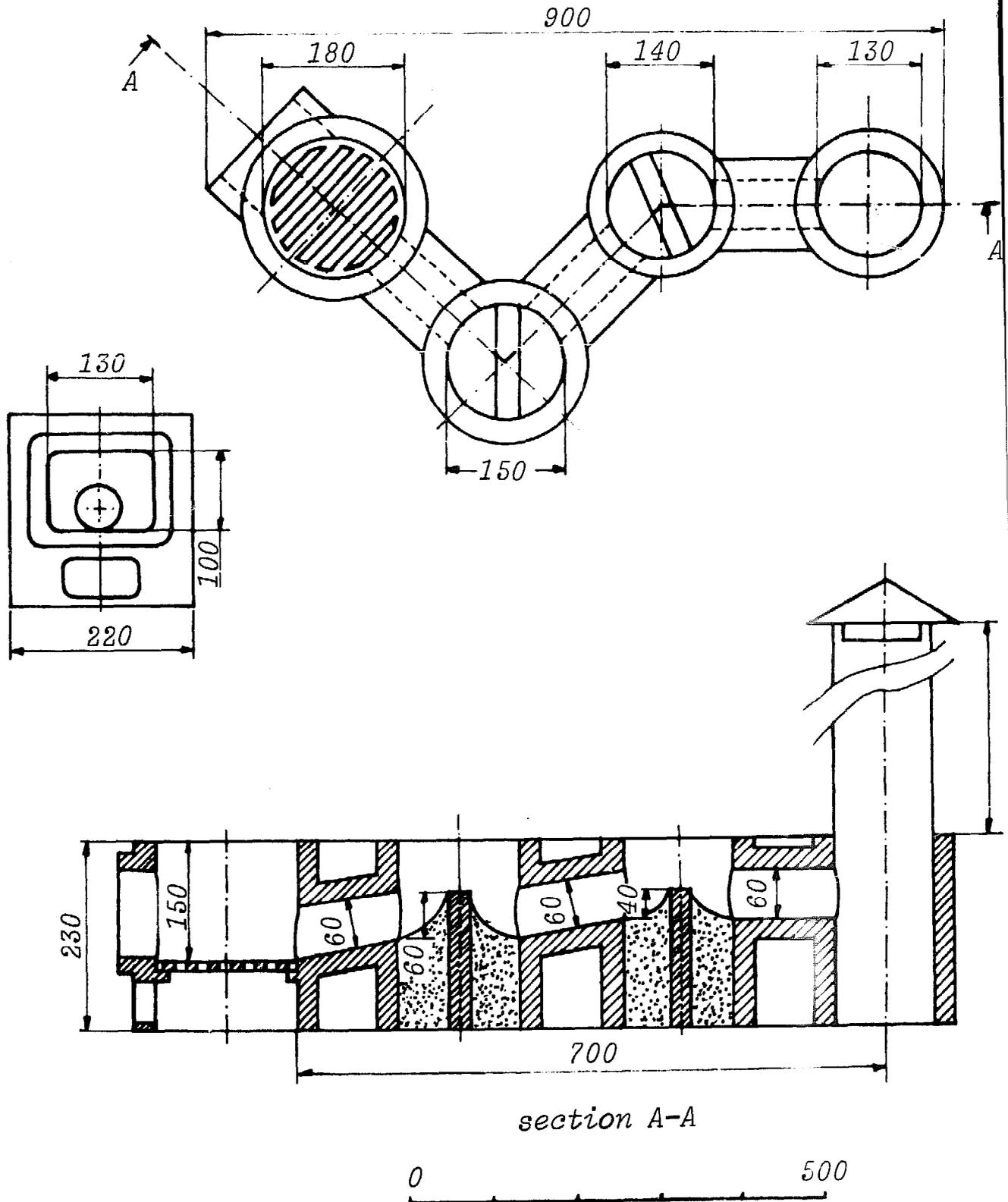
1) CH3-3

3) *A fixed mud stove which can accommodate 3 pots of spherical shape. These pots can have diameters of 0,24; 0,24 and 0,35 m. The biggest pot is meant for the preparation of hot water. It will burn long wood. It has a chimney, no dampers, no baffles, no grate and no provision for secondary air.*



- 5) *The stove is made of mud with a chimney of ceramic pipe.*
- 6) *250 kg.*
- 7) *Wood.*
- 8) *Any length. 0,15 x 0,07 m. Refuelling without lifting the pans.*
- 10) *The big pot contains 14 l. No figures on the achievable temperature.*
- 11) *Junagadh Chula.*
- 13) *Water boiling tests at PRAI showed high efficiency. Food cooking tests at the same Institute showed very high efficiency.*
- 14) *No field tests known.*
- 16) *Ahuja 1969.*

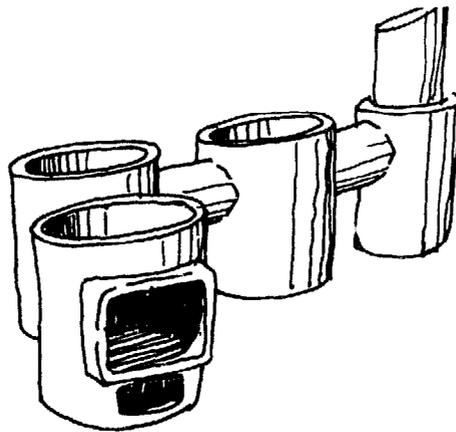
CH3-4



1) CH3-4

2) Chimney height not specified.

3) A portable ceramic stove which can accommodate 3 pots of spherical shape. These pots can have diameters of 0.2, 0.18 and 0.16 m. It will burn long wood with no limitations to the length. It has a chimney, no damper for combustion air, no damper for combustion gases, baffles under the second and third pot, a grate and no provisions for secondary air.



5) The stove is constructed of ceramic parts.

6) 25 kg.

7) Wood of any length, charcoal.

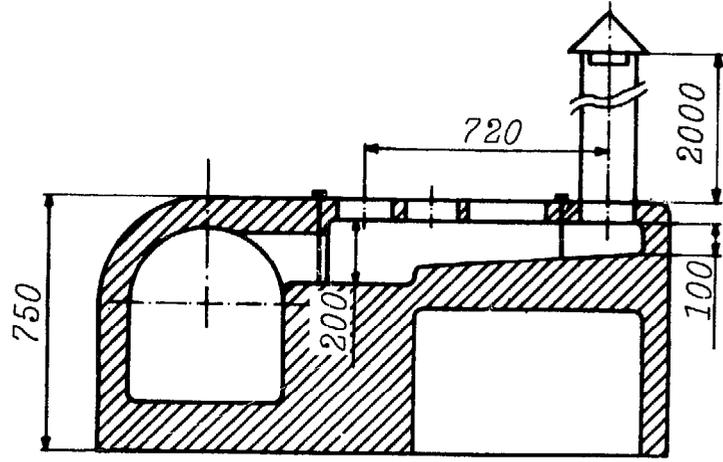
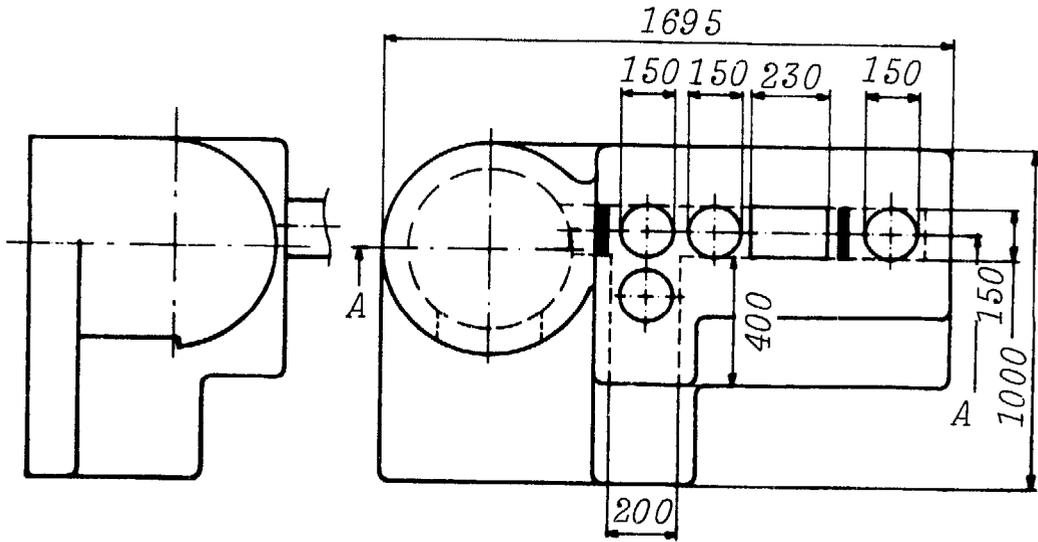
8) Any length. 0.13 x 0.1 m. The fuel can be charged without lifting the pan.

11) Portable Magan Chula.

12) India, Ashram, 1957, Nov. 1980, 2100 stoves a month are sold in Madurai, India.

13) Boiling water tests. 2l of water in an aluminium pot. Moderate efficiency.

16) Kallupatti 1955. Joseph, Shanahan, Bialy 1980.

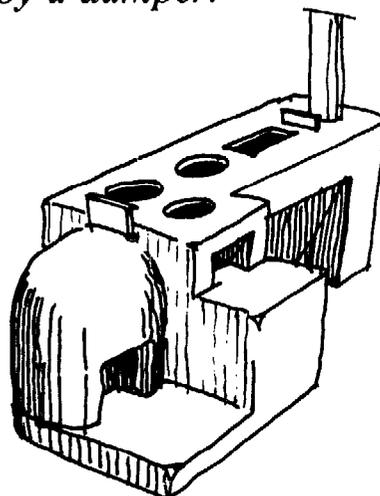


section A-A



1) CH3-5

3) *Fixed mud and metal stove. Accommodates 3 spherical pots of diameter 0,18 m. Has a hole of 0,15 x 0,23 m for hot water container. Burns long wood. Has a chimney, 2 flue gas dampers, no baffles, no secondary air provision. An oven is connected to the flue controlled by a damper.*



4) *Controlled by a sliding damper before the chimney. Oven controlled by second damper.*

5) *Built of mud with metal chimney.*

6) *1000 kg.*

7) *Wood.*

8) *Any length. 0,2 x 0,2 m. Refuels with pans on.*

9) *Has oven attached. Can be used for baking bread.*

10) *Holds a 10 l water container, no performance figures.*

11) *Ghana Stove.*

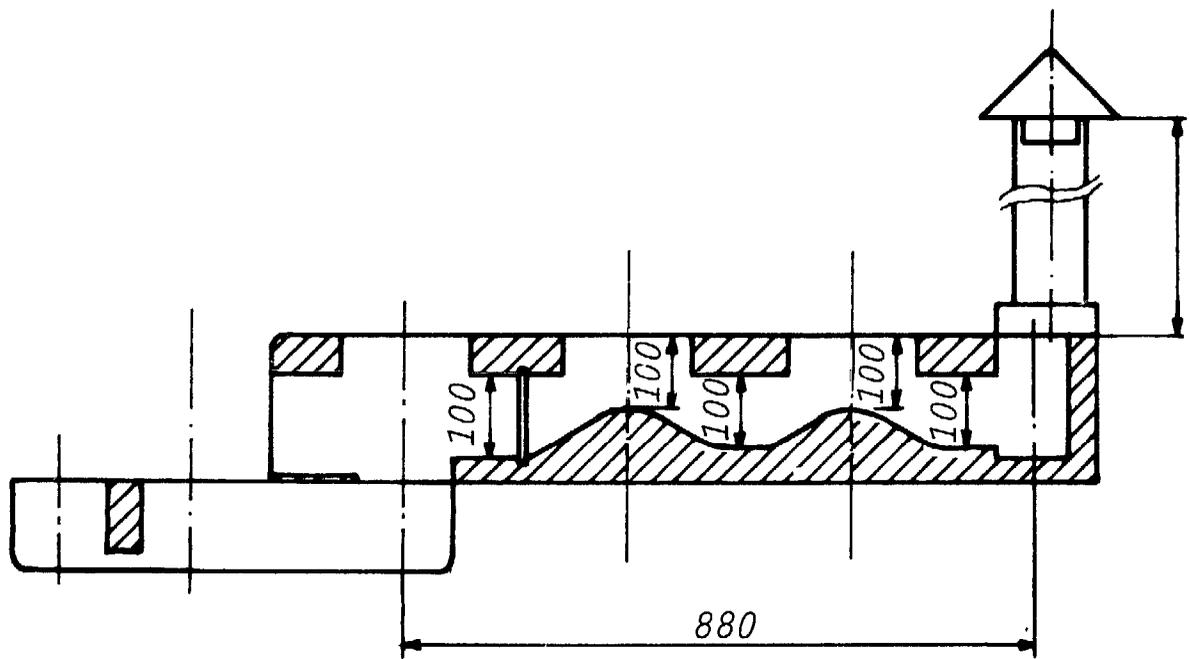
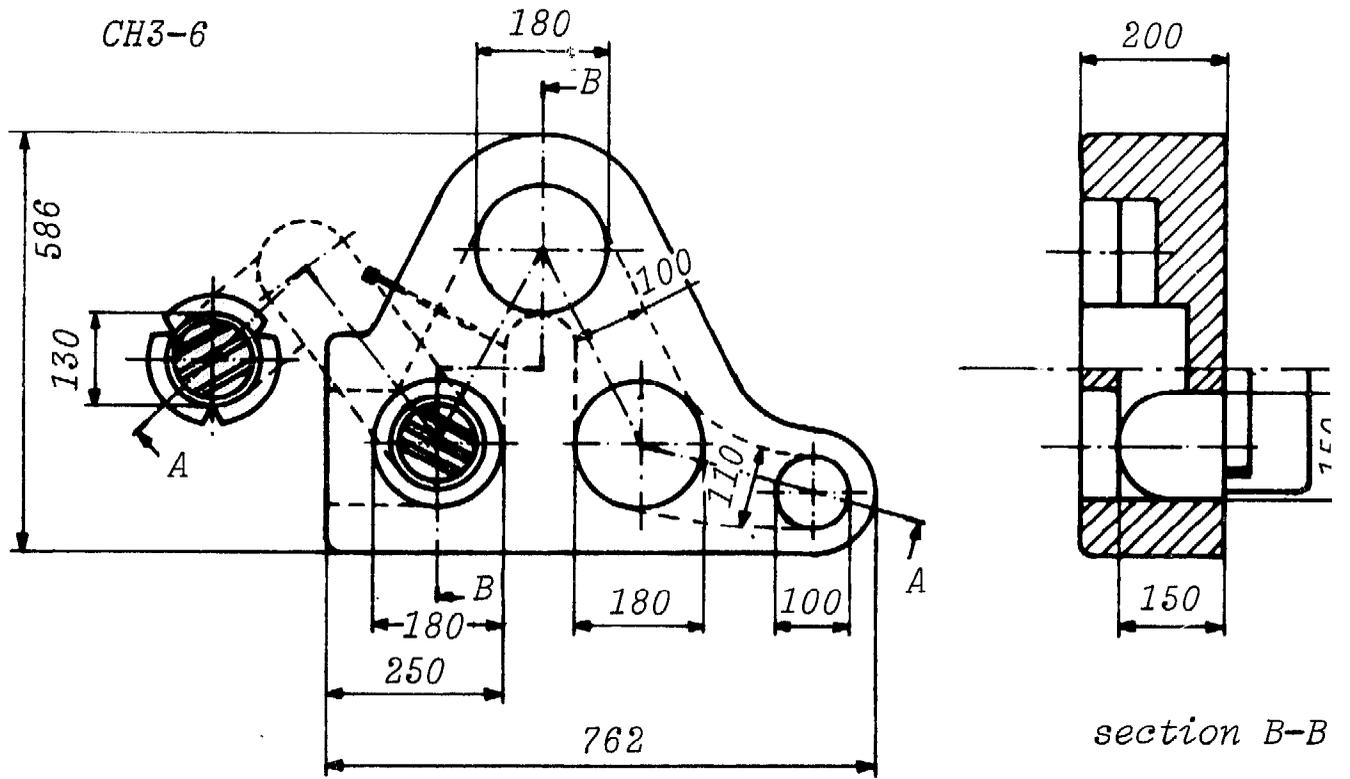
12) *Developed through the Department of Social Welfare and Community Development in Accra, Ghana.*

13) *Food cooking tests by Siwatibau showed good efficiency.*

14) *No field tests known.*

15) *Fuelwood savings of 50% compared to the open fire.*

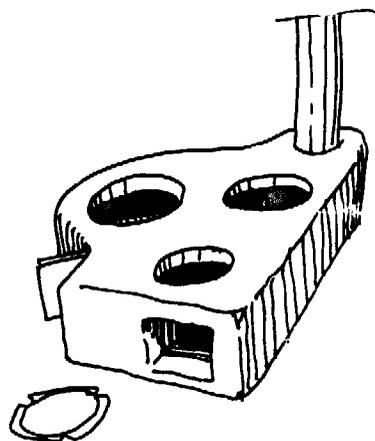
16) *Cambell-Platt 1979, Siwatibau 1978, Anon 1980, b.*



section A-A

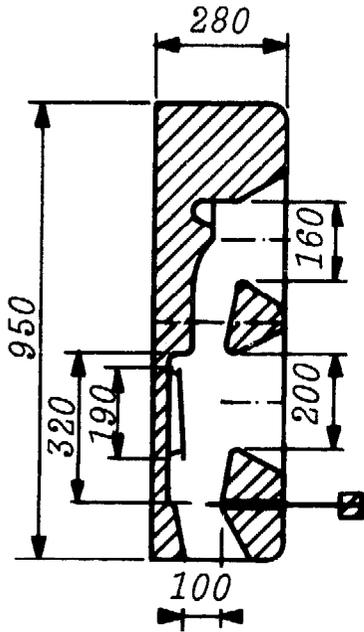


- 1) CH3-6
- 2) Chimney height not specified.
- 3) Mud and metal stove. Accommodates 3 spherical pots of 0,22 m diameter. Has a fireplace for long wood and another for charcoal. Has a chimney, a flue gas damper, a grate in each fireplace. No provisions for secondary air.

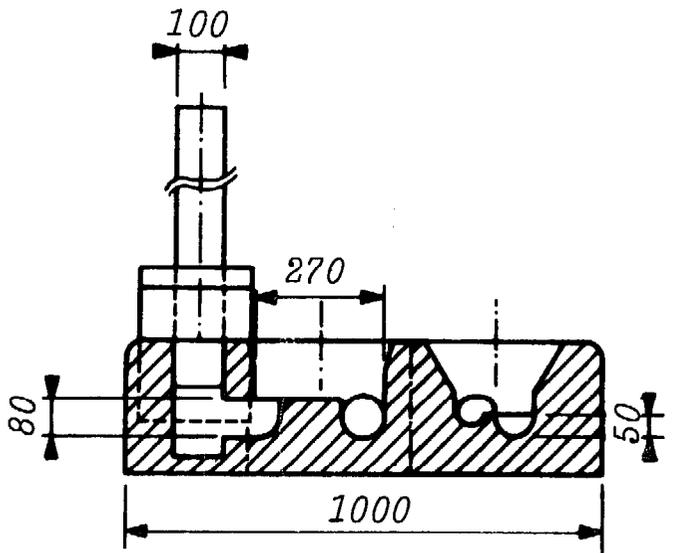
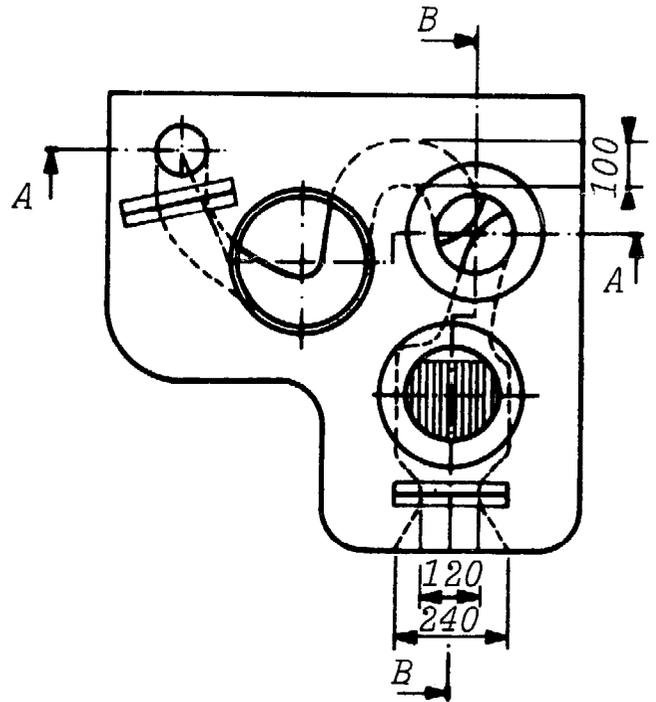


- 4) Controlled by sliding damper between first and second pothole.
- 5) Built of mud. Metal grates. Metal or ceramic chimney. Optional metal collars on potholes.
- 6) 100 kg.
- 7) Wood and charcoal.
- 8) Any length fuel. 0,15 x 0,15 m. Refuels with pans in place.
- 11) Magan chula.
- 12) Developed by the All India Village Industries Association, Maganwadi, Wardha in 1948.
- 13) No laboratory tests known.
- 14) No field tests known.
- 15) 25% to 50% fuel savings compared to the open fire.
- 16) Kallupatti 1955. Krishna Prasad, Nieuwvelt, Verhaart 1979. Anon 1979, c. Anon 1980, b. Anon Undated f.

CH3-8



section B-B



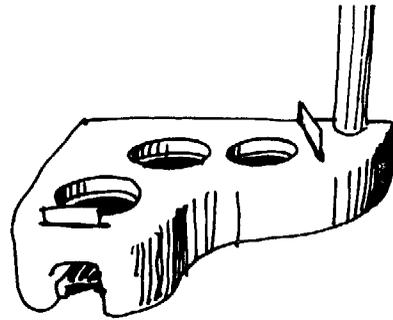
section A-A



1) CH3-8

2) Chimney height not specified.

3) Built of mud and metal. Can take 3 spherical pots of 0,24; 0,19 and 0,27 m diameter. Latter pot mainly for hot water. Has a chimney, air- and flue gas dampers, baffles under last 2 pots, a grate and no secondary air provisions.



4) Control by air- and flue gas dampers. Closing both kills fire.

5) Mud. Dampers of sheet steel. Metal bar grate.

6) 300 kg.

7) Wood.

8) 0,25 m (damper closed). 0,12 x 0,10 m. Refuels with pans in place.

11) New Nepali Chulo.

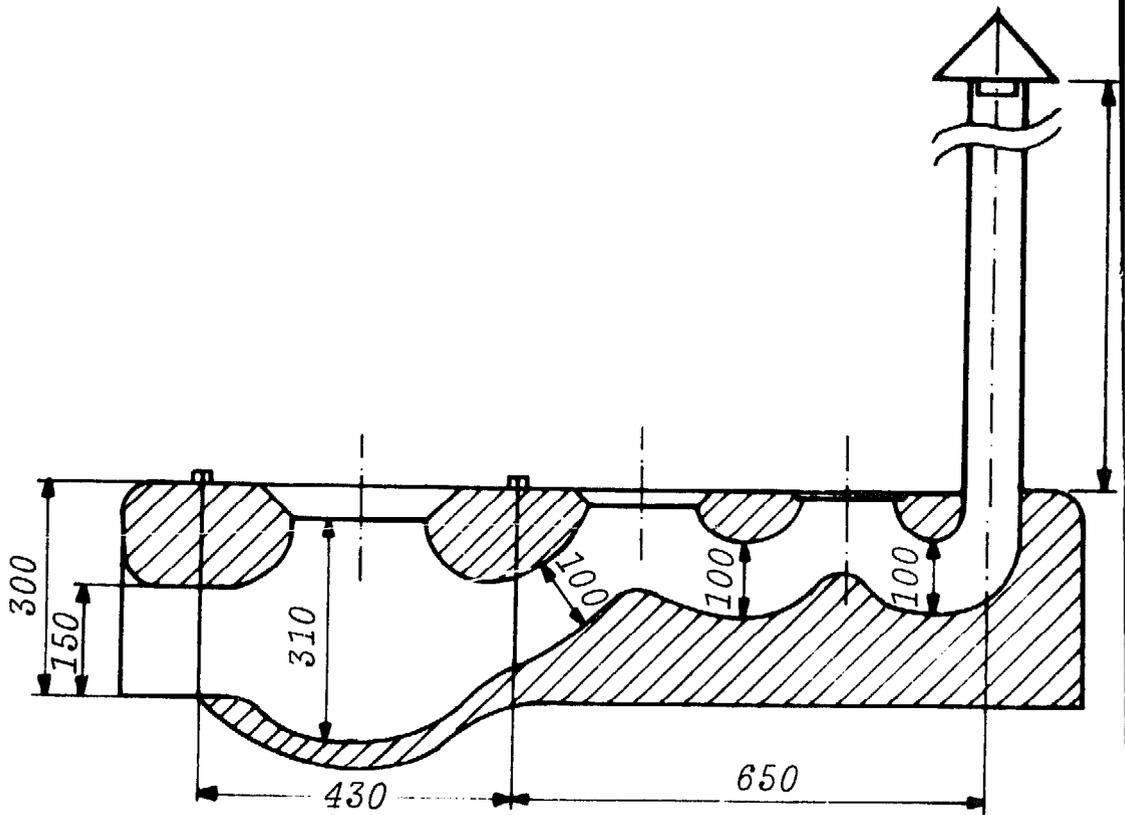
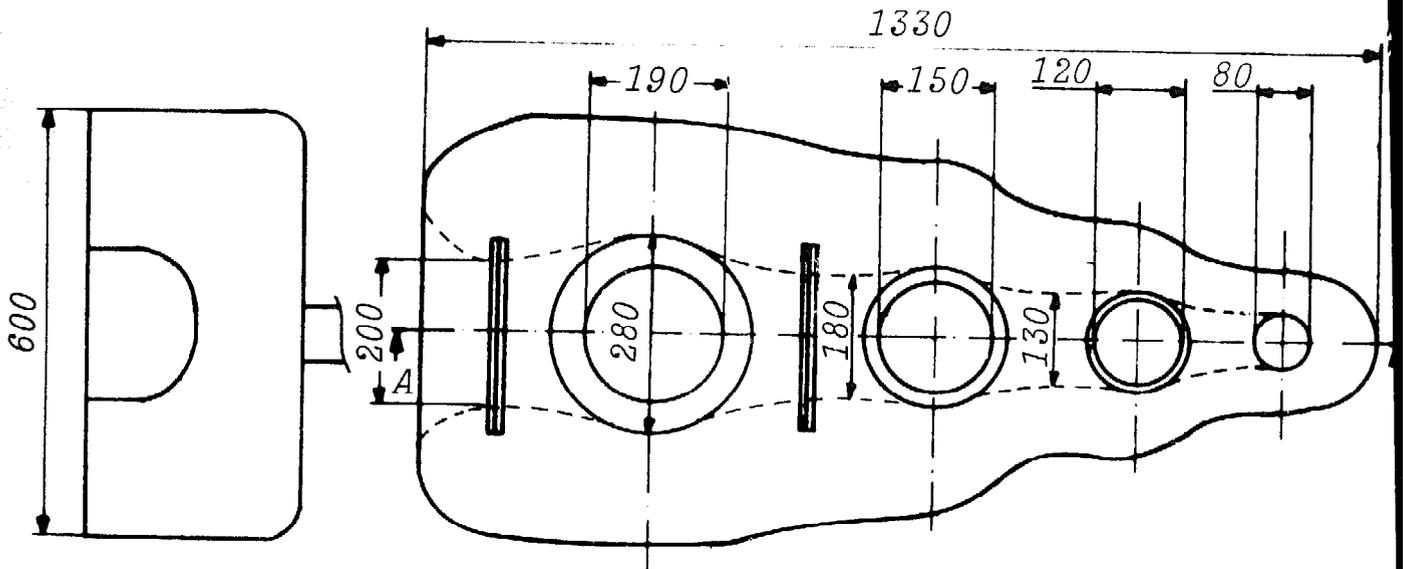
12) Developed at RCASTTU, Nepal.

13) No laboratory tests known.

14) No field tests known.

15) Fuel savings up to 50% compared to the traditional open fire.

16) Anon 1980 b. Acott et al 1980. Anon 1979 a.



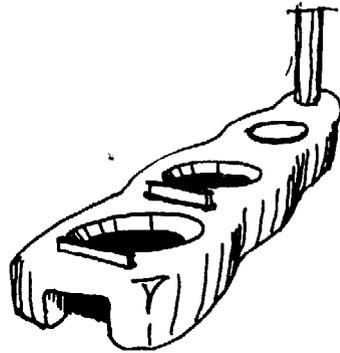
section A-A



1) CH3-11

2) Chimney height not specified.

3) Built of mud, takes 3 spherical pots of 0,25; 0,20 and 0,16 m. Burns short wood. Has a chimney, air- and flue gas damper, no grate, baffles or secondary air provision. Can be used as oven.



4) Control by sliding air damper and damper between first 2 pots. Closing both kills fire.

5) Mud. Dampers and chimney sheet steel.

6) 200 kg.

7) Wood. Rice husks, straw.

8) 0,4 m (damper closed). 0,2 x 0,15 m. Refuels with pans in place.

10) Acts as oven with dampers closed and pothole covered.

11) Lorena Guitar or CETA-Lorena.

12) Developed by CETA, Guatemala and Dian Desa, Indonesia.

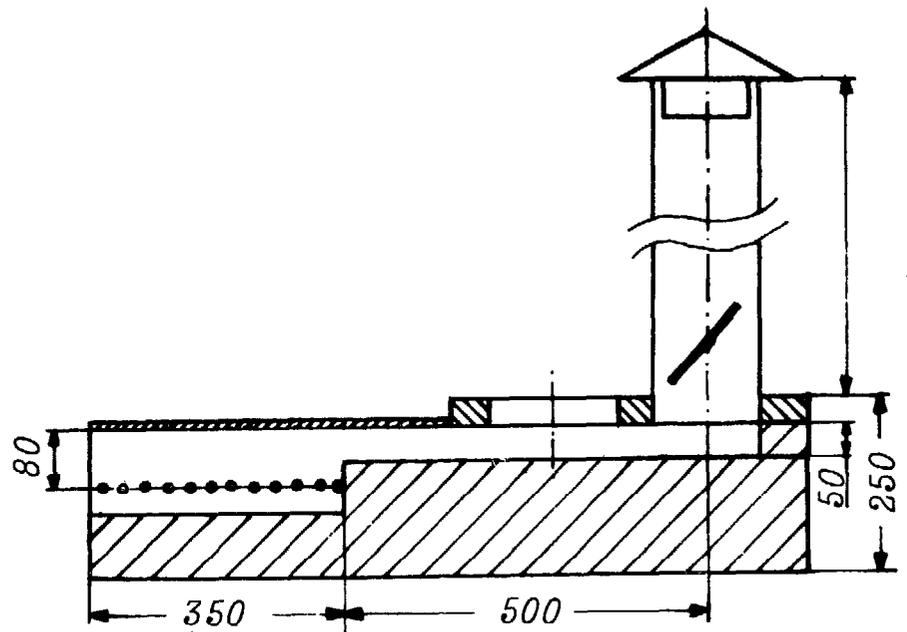
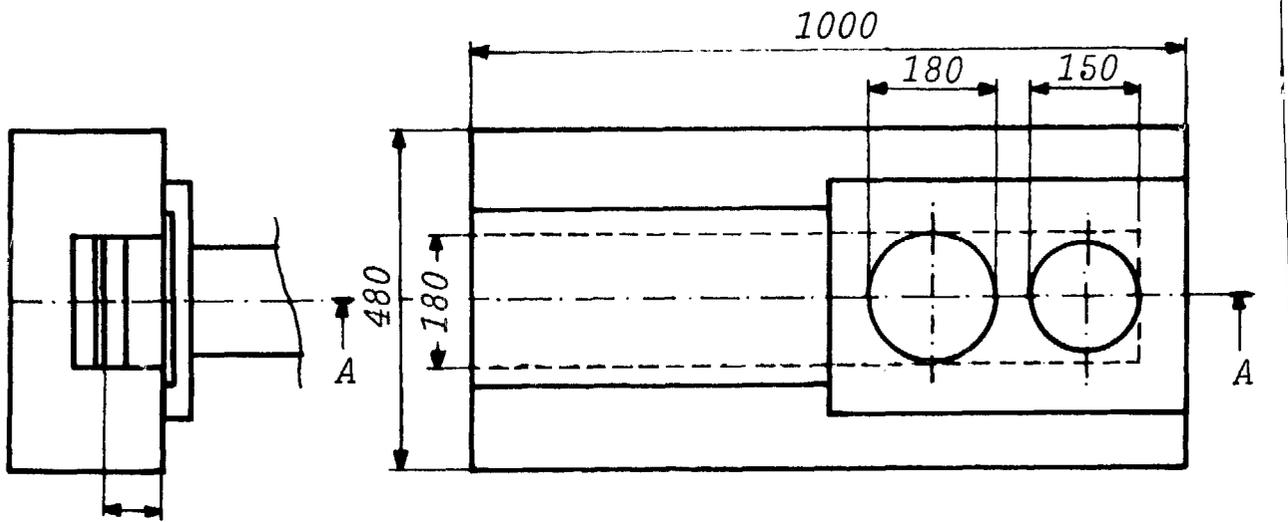
13) Water boiling tests by CETA showed good efficiency.

14) Low to medium for Dian Desa water boiling/food cooking tests.

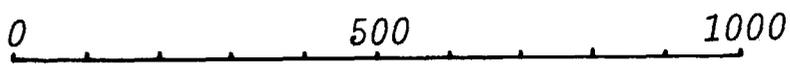
15) Fuel wood savings of 50% compared with the traditional open fire.

16) Joseph, Shanahan, Bialy 1980. Lou Ma 1979.

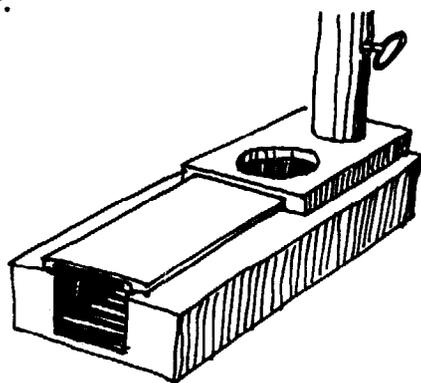
CH3-12



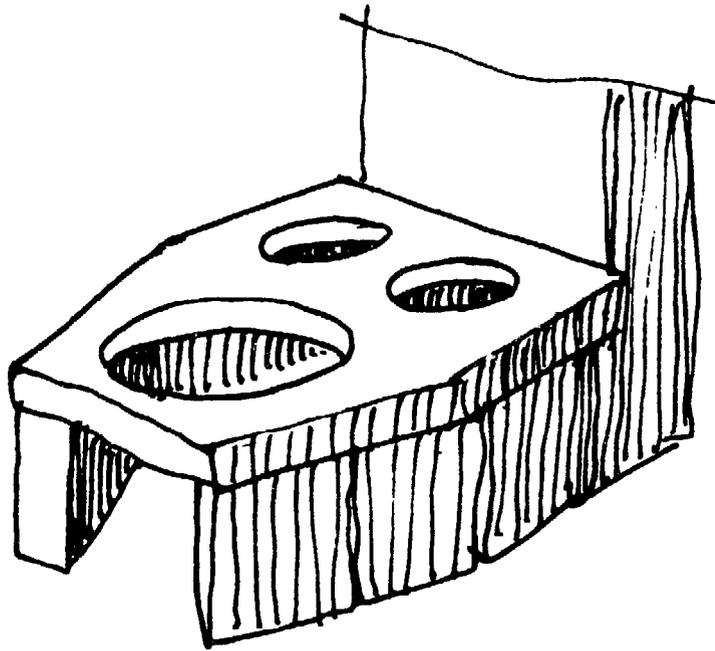
section A-A



- 1) CH3-12
- 2) Chimney height not specified.
- 3) A fixed brick and metal stove which can accommodate 3 pots of which two must have a flat bottom to be placed on a hot plate. The third pot can be spherical with a diameter of 0,18 m. It will burn long wood. It has a chimney, a damper for combustion gases, no baffles, a grate and no provisions for secondary air.



- 4) Fire control by a butterfly-valve in the chimney.
- 5) The stove is built of bricks with a metal plate and a concrete coverplate. It has a metal chimney.
- 6) 100 kg.
- 7) Wood. Agricultural waste.
- 8) Any length. 0,18 x 0,08 m. Refuelling without lifting the pan.
- 11) CETA-stove.
- 12) CETA has done testing and developing on these stoves which are originally traditional models in Guatemala.
- 13) Water boiling tests by CETA showed high efficiency. Food cooking tests showed considerable improvement to the open fire.
- 14) Food cooking test over a period of two weeks showed a considerable reduction in fuelwood use compared to the open fire.
- 16) Joseph, Shanahan, Bialy 1980. Anon undated, a.



1) *CH3-13*

2) *No technical drawings.*

3) *A fixed brick and metal stove which can accommodate 3 pots of spherical shape. 1 big pot and 2 smaller pots. It will burn long wood. It has a chimney, no dampers, no baffles, no grate and no provisions for secondary air.*

5) *The stove is built of bricks and mud but can also be completely built of mud. It is reinforced with steel bars.*

6) *300 kg.*

7) *Wood.*

8) *Any length. No dimensions known. Refuelling without lifting the pan.*

11) *Improved HERL-chula.*

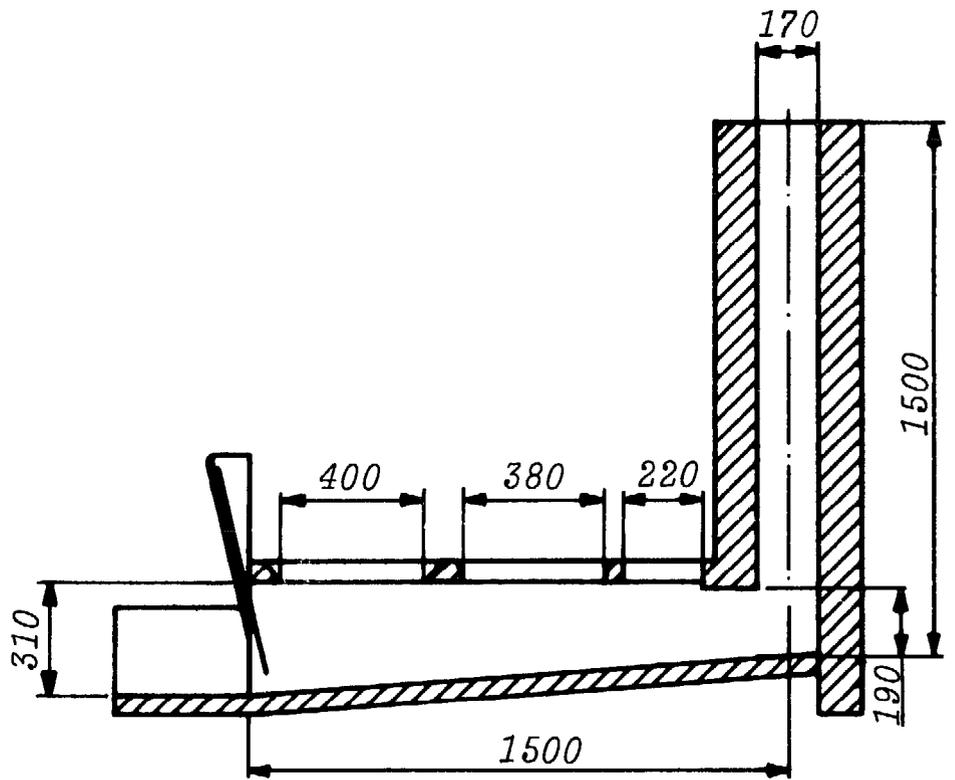
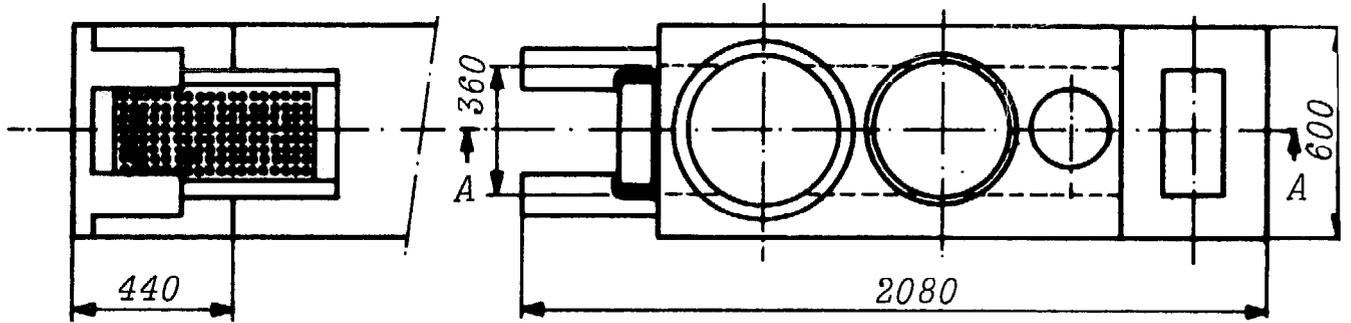
12) *Developed by Penfold and Oot.*

13) *No laboratory tests known.*

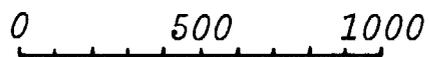
14) *No field tests known.*

16) *Anon 1979 c. Anon 1980 b.*

CH3-14



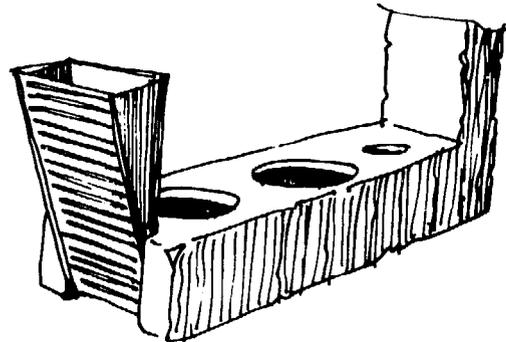
section A-A



1) CH3-14

3) *A fixed brick and metal stove which can accommodate 3 pots of spherical shape. These pots can have diameters of 0,4; 0,38 and 0,22 m. It will burn rice-husks. It has a chimney, no dampers, no baffles, a grate and no provisions for secondary air.*

5) *The stove is built of bricks with a hopper of sheet steel for the rice-husks and a perforated steel plate as grate.*



6) *1000 kg.*

7) *Rice-husks.*

8) *The rice-husks are charged into the hopper from which they gradually fall down on the grate where they are burnt. Refuelling without lifting the pans.*

11) *Gula Jawa stove.*

12) *This stove was developed in Indonesia, East Java, to boil down coconut sap to coconut sugar.*

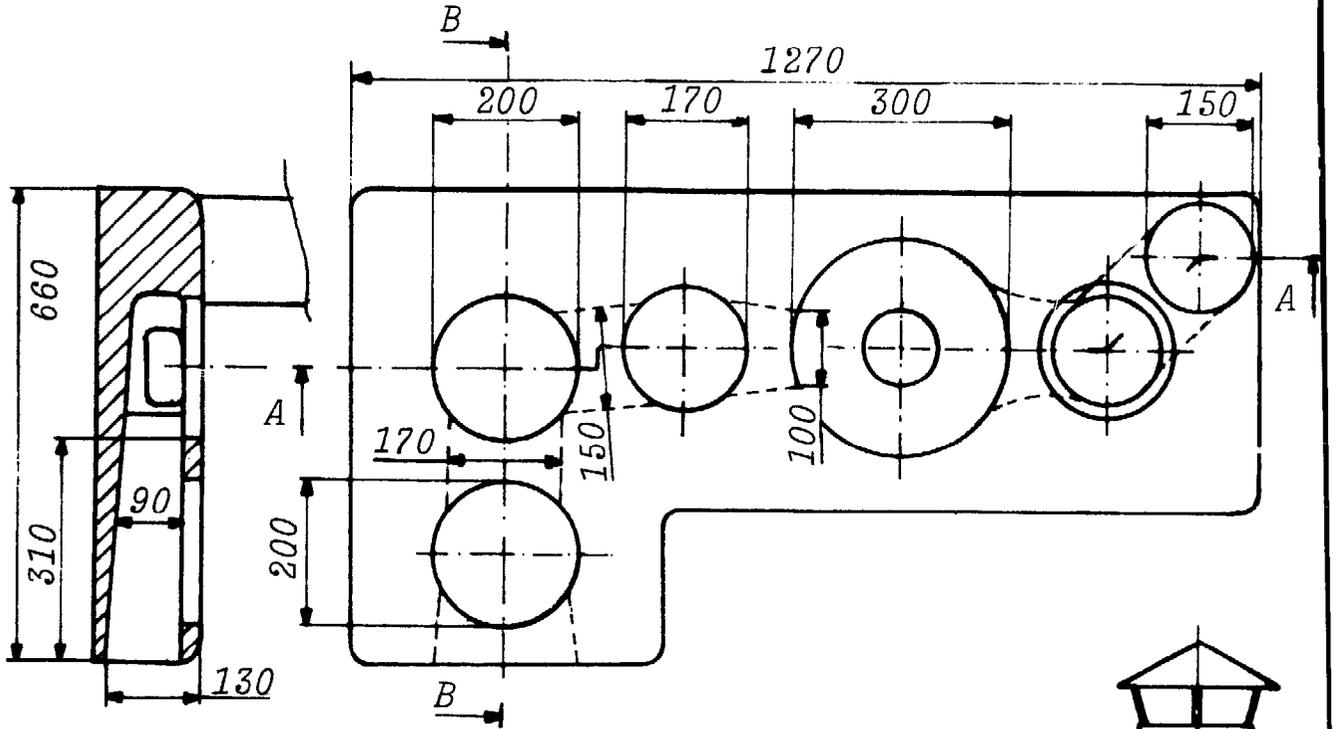
13) *No laboratory tests known.*

14) *No field tests known.*

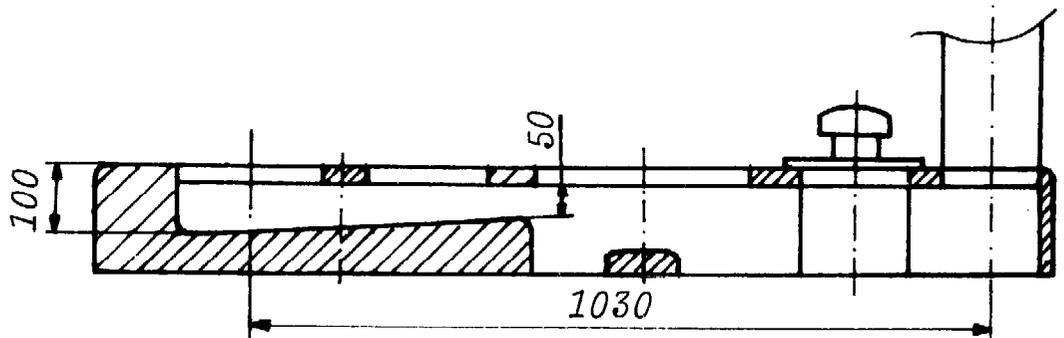
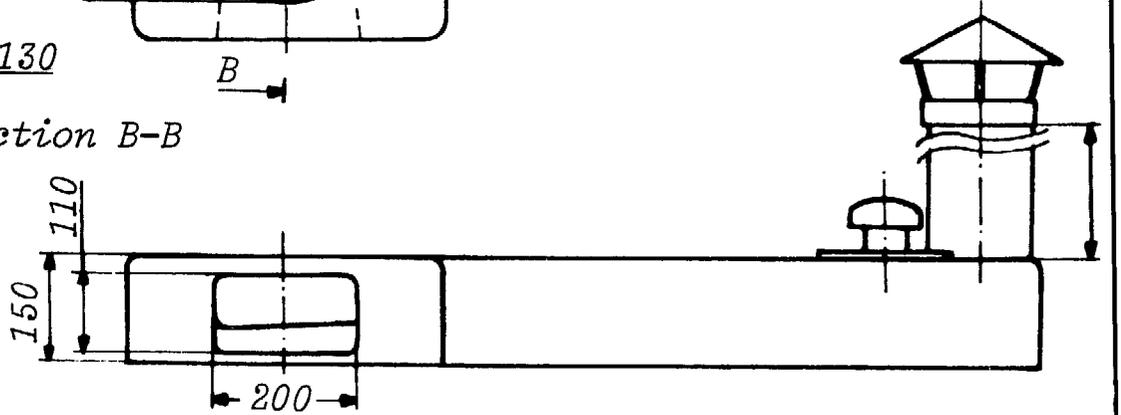
15) *Four hours cooking time on 6 kg of rice-husks.*

16) *Acott et al 1980. Anon 1980 b.*

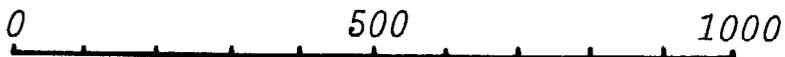
CH4-1



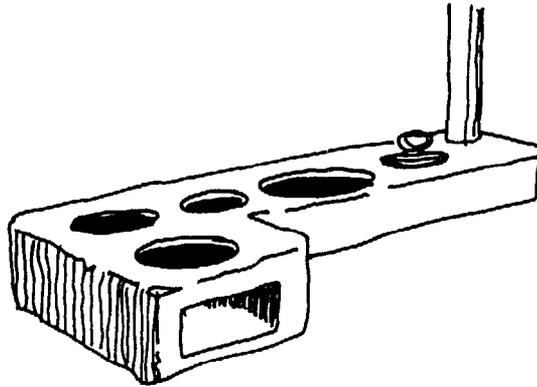
cross section B-B



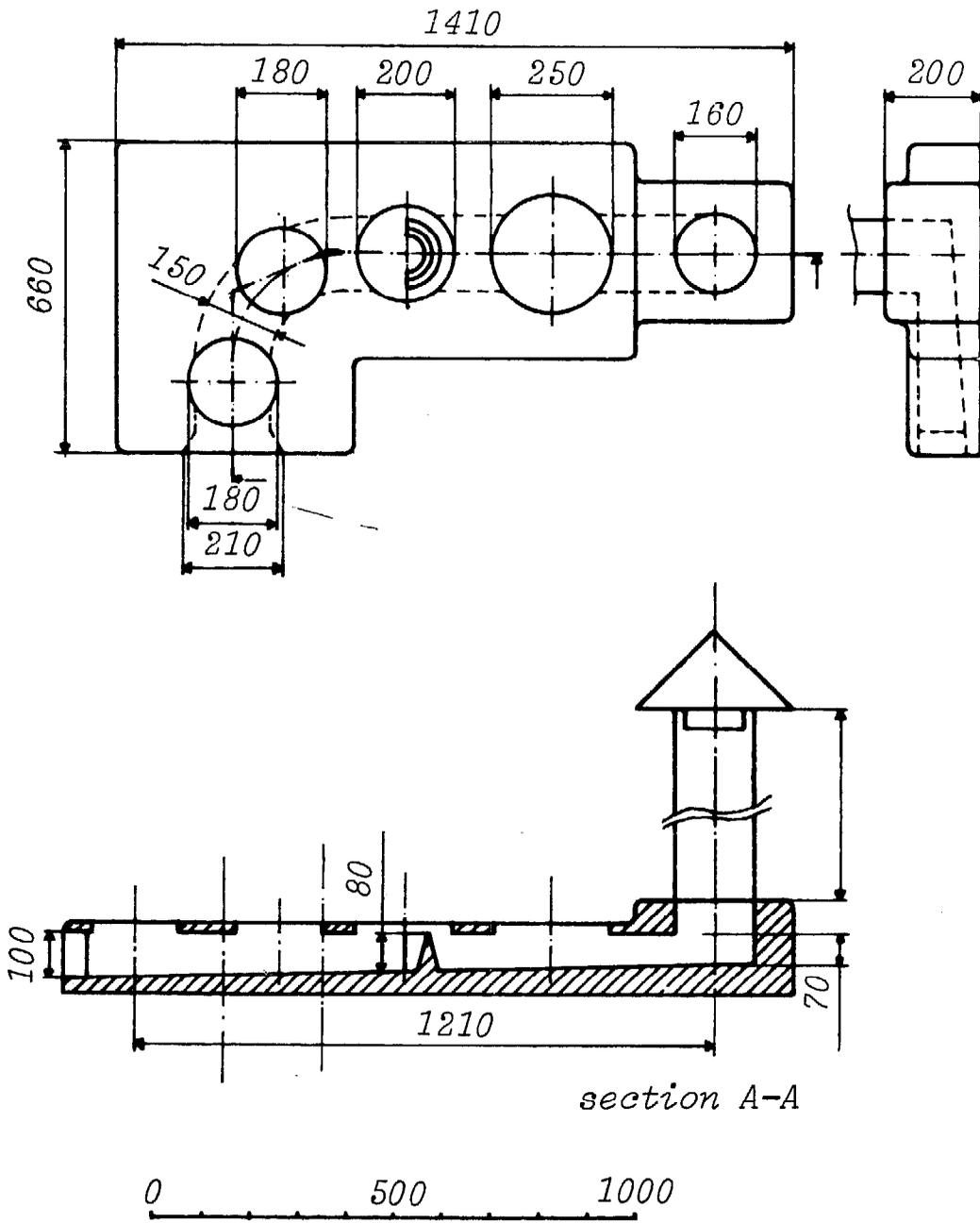
section A-A



- 1) CH4-1
- 2) Chimney height not specified.
- 3) Built of mud. Takes 4 spherical pots, diameters 0,24; 0,24 and 0,21 m. Last hole takes a 0,3 m pot for water heating. Burns long wood. Has a chimney, a flue gas damper, no baffles, no grate, no provisions for secondary air.
- 4) Rotating damper before chimney controls fire.
- 5) Mud. Ceramic chimney and damper. Metal collars for holes optional.
- 6) 150 kg.
- 7) Wood.
- 8) Any length. 0,2 x 0,11 m. Refuels with pans in place.
- 10) Dutt reports 90 C after 1 h for 15 l hot water pot.
- 11) HERL-chula.
- 12) Developed at Hyderabad Engineering and Research Laboratories in 1953. On the same principles other models were developed with fewer pot holes and with grates for coal and charcoal.
- 13) Food cooking tests by Siwatibau showed low efficiency. Water boiling tests by Geller, on a 3-hole model, showed medium efficiency.
- 14) No field tests known.
- 16) Siwatibau 1978. Acott et al 1980. Joseph Undated. Dutt 1978. Geller 1981, a. Krishna Prasad, Nieuwvelt, Verhaart 1979. Raju 1966. Anon 1980, b. Anon 1979, c.



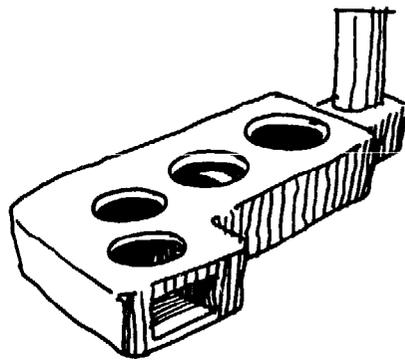
CH4-2



1) CH4-2

2) Chimney height not specified.

3) A fixed mud stove which can accommodate 4 pots of spherical shape. These pots can have diameters of 0,22 and 0,24 m. The last hole is meant for a pot for making hot water. It will burn long wood. It has a chimney, no dampers, a baffle under the third pot, no grate and no provisions for secondary air.



5) The stove is made of mud with a chimney of ceramic or metal pipe.

6) 250 kg.

7) Wood. Combustible waste.

8) Any length. 0,21 x 0,1 m. Refuelling without lifting the pan.

10) The hot water pot contains 8 l. No figures on the achievable temperature.

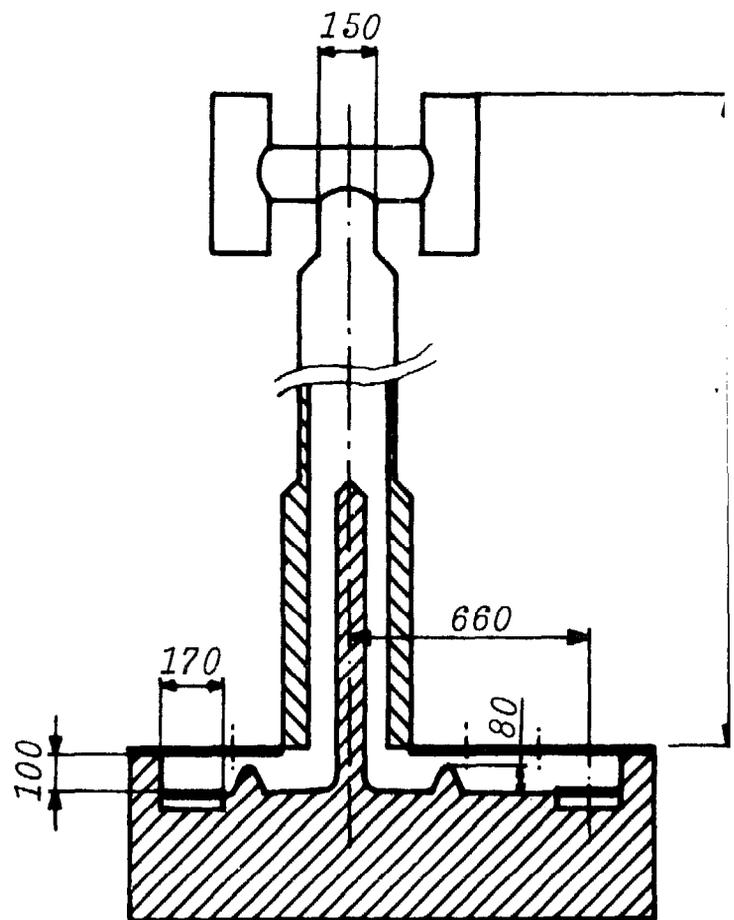
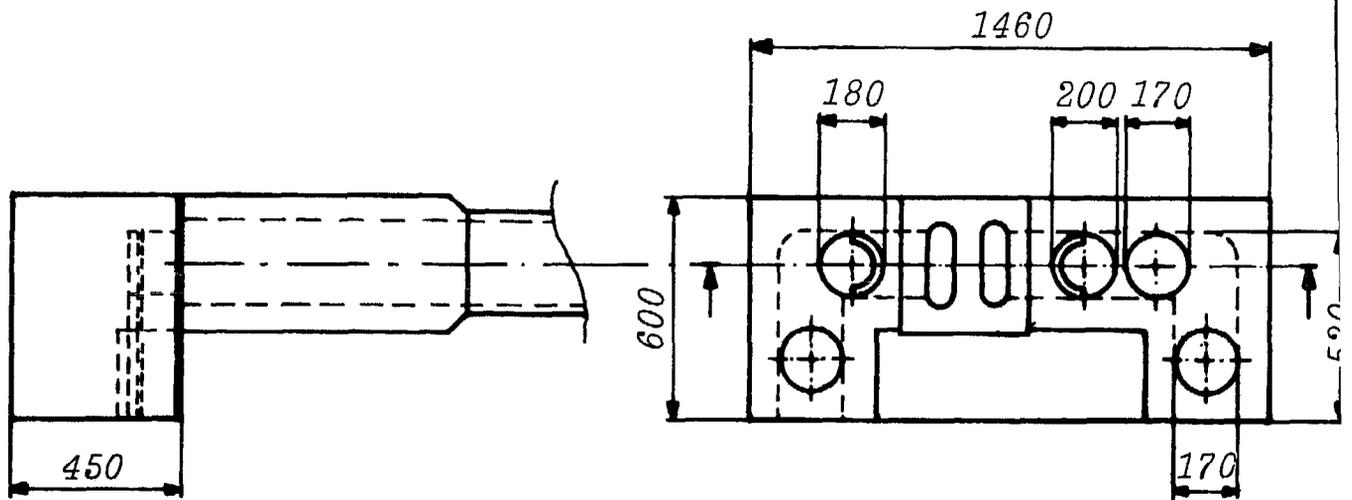
11) Moradabad chula.

13) Water boiling tests by PRAI showed high efficiency.

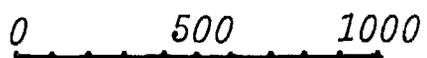
14) No field tests known.

16) Ahuja 1969.

CH5-1



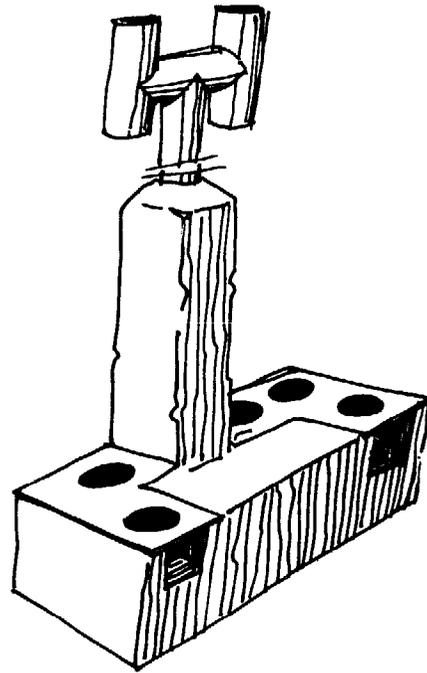
section A-A



1) CH5-1

2) Chimney height not specified.

3) A fixed brick and metal stove which can accommodate 5 pots of spherical shape. These pots can have a diameter of 0,22 m. The stove is really a combination of a three-hole and a two-hole stove, using one chimney. It will burn charcoal. It has a chimney, no dampers, baffles or grates and no provision for secondary air.



5) The stove is built of fire bricks with a metal chimney and grates of metal bars. The top cover plate is made of thick metal sheet.

6) 1200 kg.

7) Charcoal.

8) Charging of the fuel through the first pothole of 0,17 m. For refuelling the pan must be lifted from the stove.

11) C.W.E. Cochin Type Chula.

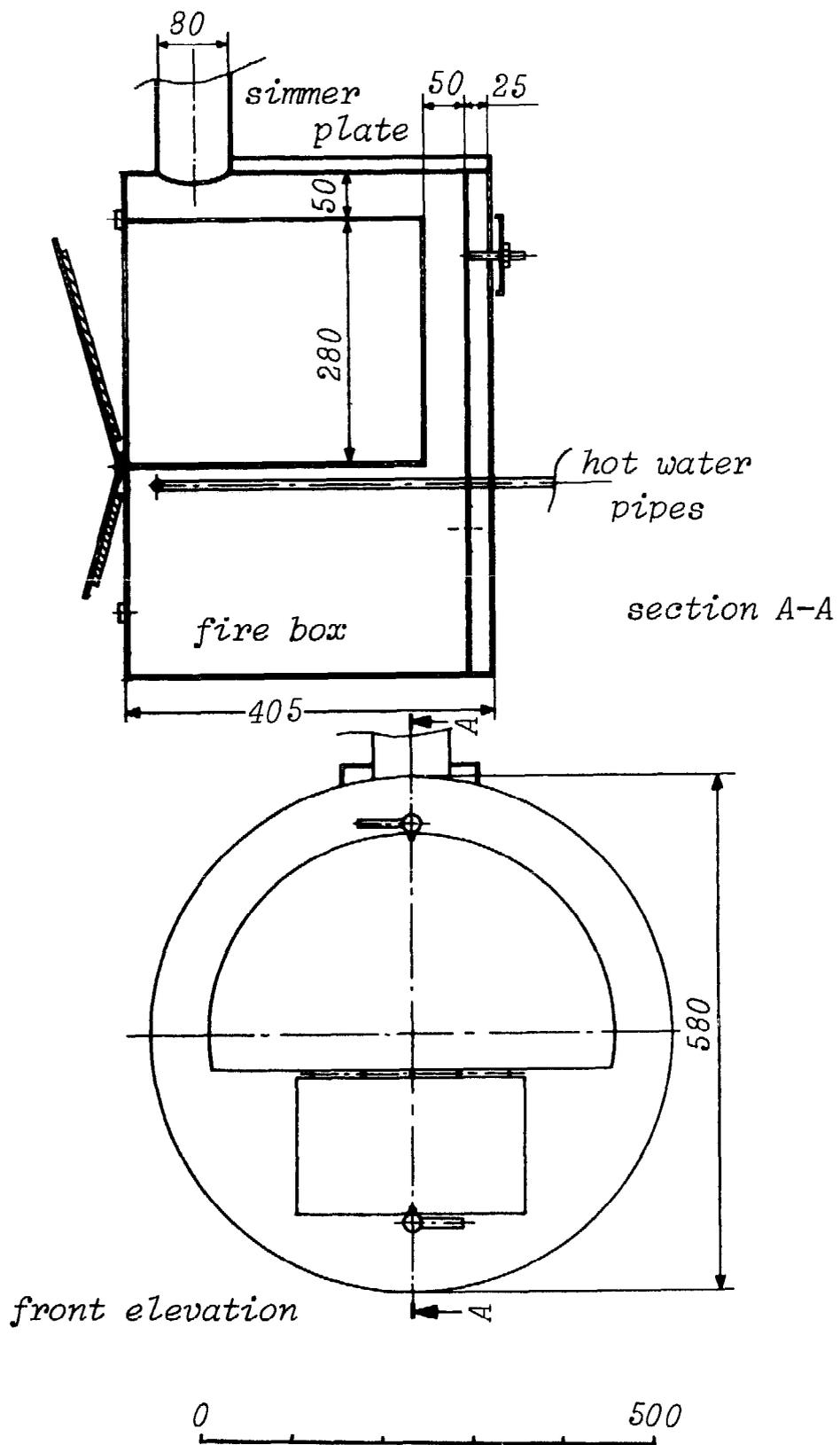
12) This chula originated in India.

13) Water boiling tests at PRAI showed good efficiency.

14) No field tests known.

16) Ahuja 1969.

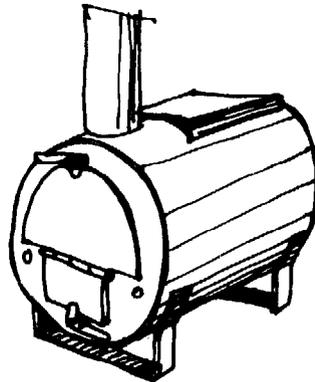
Ovens-1



1) *Ovens-1*

2) *Chimney height not specified.*

3) *A portable metal oven. It will burn long wood. It has a chimney and a damper for combustion air, no grate and no provisions for secondary air. Optional are a heat exchanger of copper pipes for hot water and a simmering plate on top of the oven.*



4) *Control of the fire by a rotating damper for combustion air that can be adjusted accurately.*

5) *The stove is made of an oil drum and sheet metal.*

6) *50 kg.*

7) *Wood.*

8) *0,37 m. 0,2 x 0,15 m.*

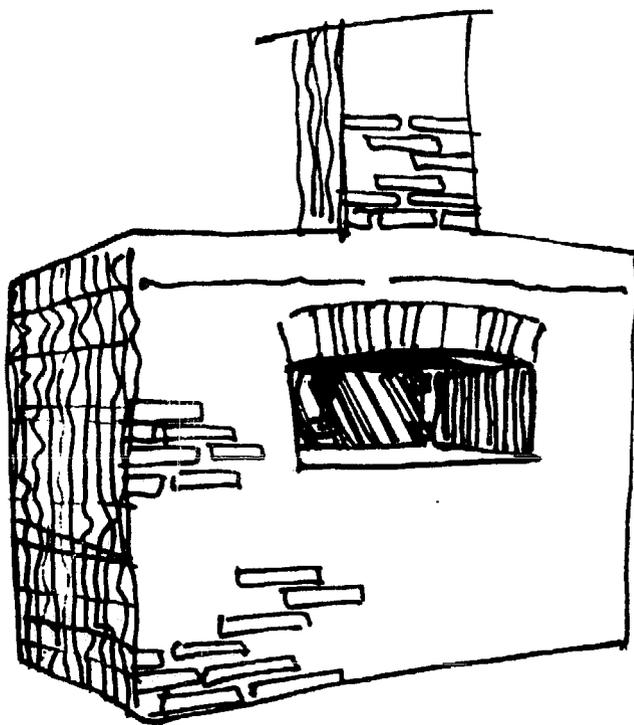
11) *Pat Howdens' oven.*

13) *No laboratory tests known.*

14) *No field tests known.*

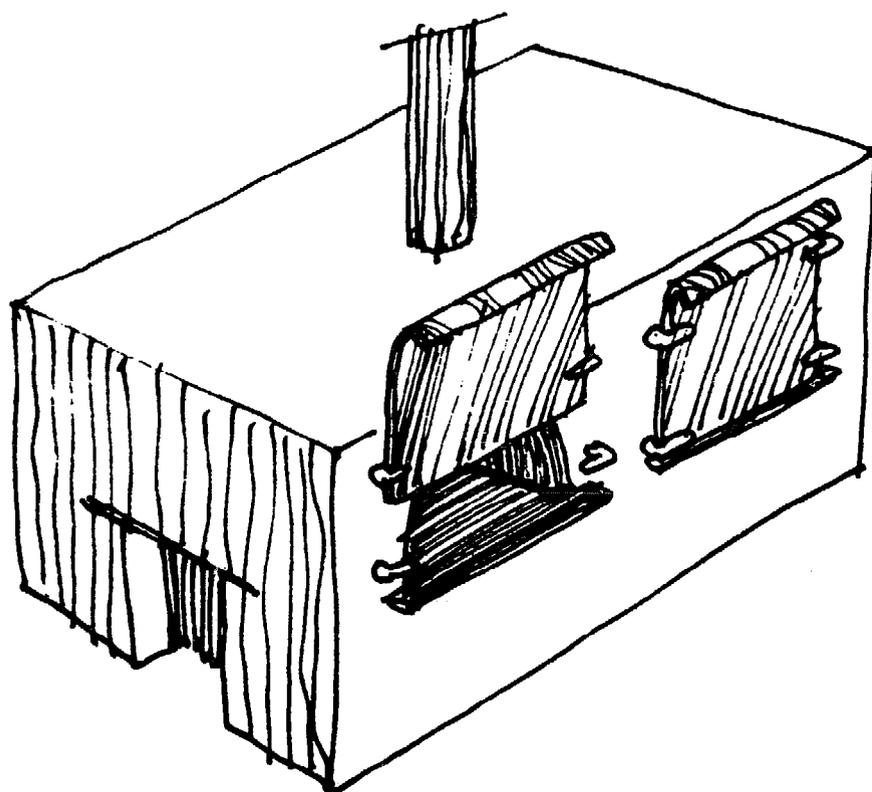
16) *Joseph, undated.*

Ovens-2



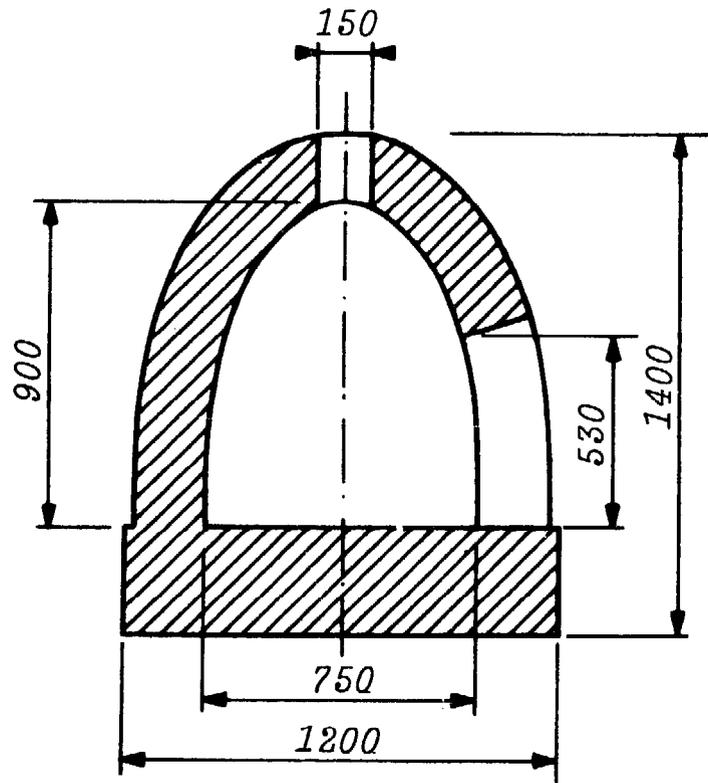
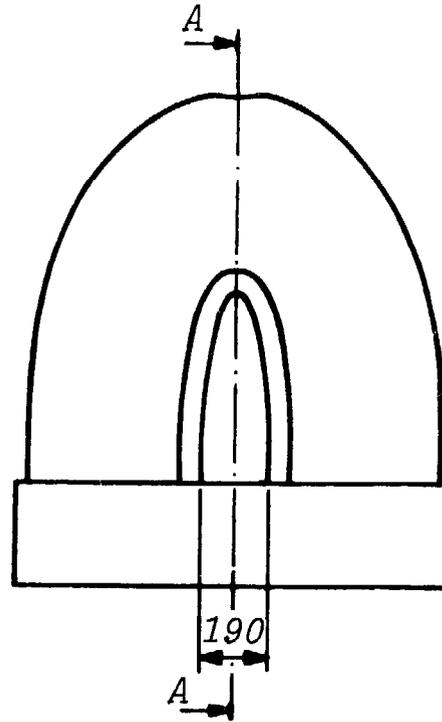
- 1) *Ovens-2*
- 2) *No technical drawings.*
- 3) *A fixed brick and metal oven. It will burn long wood. It has a chimney and a damper for combustion air. It has no grate and no provisions for secondary air.*
- 4) *Fire control by the vertical sliding front door.*
- 5) *The stove is built of bricks with a layer of sand and fire-bricks on the floor of the oven. The chimney is also made of bricks and the door of sheet metal.*
- 6) *10.000 kg.*
- 7) *Wood.*
- 8) *1.6 m. 0,30 x 0,25 m.*
- 11) *Woodburning oven.*
- 12) *Built by Rev. Bertrand Saubolle, Nepal, India.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *VITA Technical Bulletin 11.*

Ovens-3

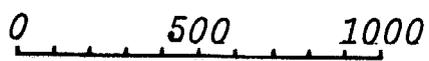


- 1) *Ovens-3*
- 2) *No technical drawings.*
- 3) *A fixed brick and metal oven. It will burn long wood. It has a chimney, no dampers, no grate and no provisions for secondary air.*
- 5) *The oven is built of bricks with two ovens made of half oil drums. The oven rest on two old rail profiles. It has a metal roof plate, a metal chimney and metal doors.*
- 6) *3500 kg.*
- 7) *Wood.*
- 8) *2 m. 0,40 x 0,35 cm.*
- 11) *Oil drum oven.*
- 13) *No laboratory tests known.*
- 14) *No field tests known.*
- 16) *Anon undated, d.*

Ovens-5

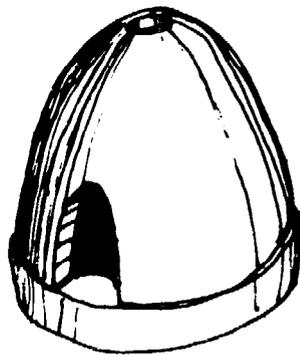


section A-A



1) Ovens-5

3) *A fixed brick oven. It will burn long wood. It has no chimney, no dampers and no grate.*



5) *The stove is completely built of sundried or fired bricks. During the baking the door opening and the smoke hole in the top must be tightly covered with wooden or metal covers.*

6) *1500 kg.*

7) *Wood.*

8) *Any length. 0,19 x 0,53 m.*

11) *Outdoor Oven.*

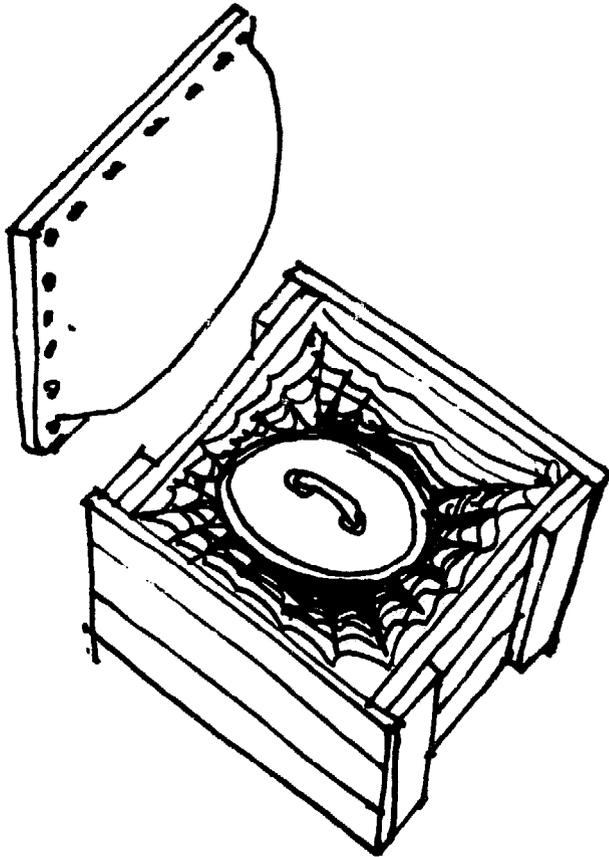
12) *Especially in Ghana this type of oven is widely used.*

13) *No laboratory tests known.*

14) *No field tests known.*

16) *Anon. 1975.*

Others-1



1) *Others-1*

2) *No technical drawings.*

3) *The haybox is a heavily insulated box in which the food in the pan will continue its cooking process after it has been brought to boiling point on a stove. The outside can be made of mud, bricks, wood or metal and the insulation can be hay, straw or any other insulating material. It is very important that the pot with its hot contents is closely surrounded by the insulation.*

11) *Haybox.*

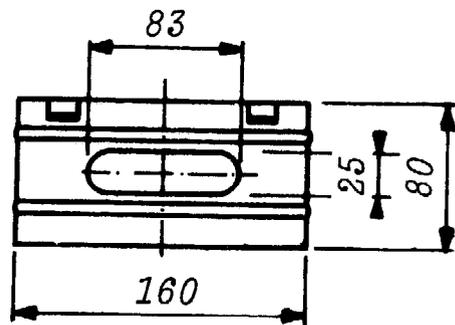
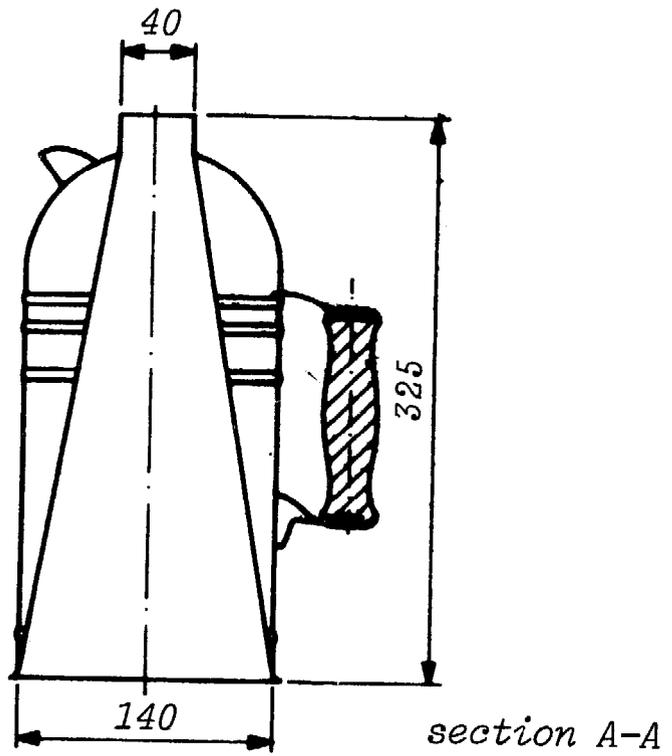
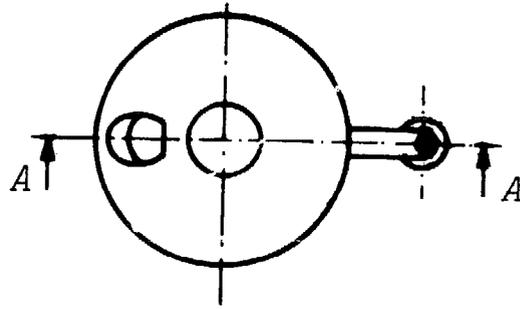
12) *The haybox has been a commonly used cooking device in Europe.*

13) *No laboratory tests known.*

14) *No field tests known.*

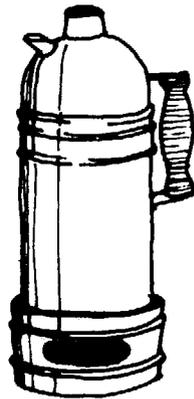
15) *It is firmly believed that the use of the haybox will save many times the amount of fuel that can be saved by more efficient stoves.*

Others-2

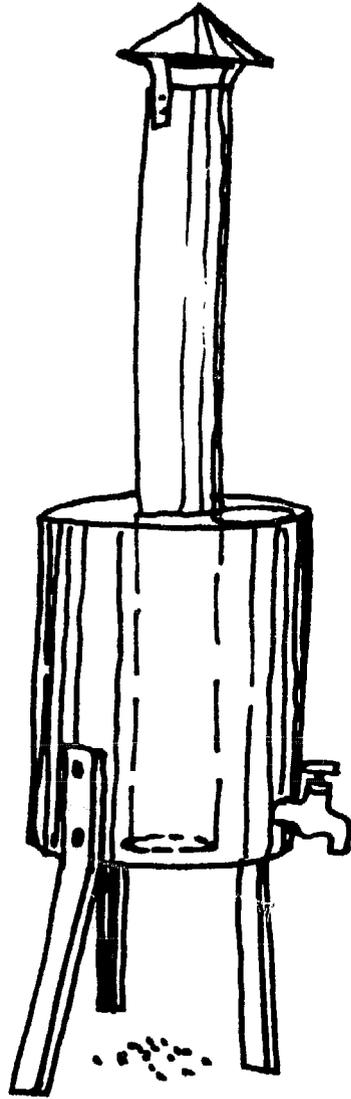


1) *Others-2*

- 2) *A portable metal device to heat and boil water. It will burn thin sticks or short pieces of fuel. It has no external chimney, it is in fact built around a chimney. It has no dampers, no grate and no provisions for secondary air.*



- 5) *The water cooker is made of thin sheet steel or coppersheet.*
- 6) *3 kg.*
- 7) *Wood, straw, twigs and dry leaves.*
- 8) *Any length. The fuel can be fed to the fire either through the hole in the support of 2.5 x 8 cm or through the top hole of 5 cm.*
- 10) *The cooker contains 2 l. of water.*
- 11) *Thermette.*
- 12) *This cooker is industrially made and sold in New-Zealand. The design dates from before World War II. It is used as a camping and picnic device. A second model has a flat top instead of the dome-shaped top.*
- 13) *Waterboiling tests at Eindhoven University of Technology showed very high efficiency.*
- 14) *No field tests known.*



1) Others-3

2) No technical drawings.

3) A portable metal device to heat and cook water. It will burn short fuel. It has a chimney, no dampers, no baffles, a grate and no provisions for secondary air.

5) The stove is made of sheet metal.

6) 50 kg.

7) Wood, charcoal.

8) Fuel must be fed through the top of the chimney. Therefore it must be cut into small pieces.

10) No dimensions known.

11) Hot water stove.

12) A commonly used hot water stove in parts of Africa.

13) No laboratory tests known.

14) No field tests known.

3.5 Numerical code description

General

For brevity the headings under which the stove properties are described are given below. Instead of this heading only the number is given followed by a parenthesis. We distinguish the following headings:

1. Stove classification according to table 3.1.
2. Comment on the drawings. Most of the original drawings have been redrawn to scale for uniformity of presentation. Missing dimensions can be derived from the scale shown on the drawings.
3. A short description gives the principal features of the stove.
4. Control. Dampers for inlet air/combustion gases, provisions for secondary air and extinction of fire are mentioned.
5. Construction materials include alternatives to those specified in table 3.1. and special materials for grates and dampers.
6. An estimate of the mass (weight) of the stove is provided.
7. Basic fuel and capabilities for other fuels.
8. Preparation of fuel. Length of the wood that the stove will accept, the dimensions of the charge opening to indicate the maximum permissible cross-section of the fuel. Refueling procedures.
9. Use. Possibilities for food preparation. Special features for cooking certain foods besides conventional functions.
10. Hot water production facilities, quantity produced.
11. Name under which the stove is known.
12. Origin. Historical facts like the country and region where the stove was developed, date of its original design, number of stoves built, etc.
13. Results of laboratory tests.
14. Results of field tests.
15. Claims without further evidence are mentioned here.
16. References. Bibliographic citations for additional information.

4

Technical stove guide

4.1 Principles of operation of woodstoves

By P. Verhaart

4.1.1 Introduction

A woodstove is used to convert the chemical energy from biomass of vegetable origin into heat and to transfer this to the food to be processed. This takes place via a number of processes, chemical and physical in character.

4.1.2 Fuel

Chemically most fuels of vegetable origin are very similar. The main constituents are cellulose and lignin, the remainder is made up of resin or gum and minerals. The outer parts of plants contain more minerals than the woody parts inside. Soft wood typically contains 0,3...0,5 % minerals (ash) while rice husks after complete

combustion leave behind 25 % of their original dry weight as ashes. Ash is the solid residue that remains behind after complete combustion of a solid fuel. Cellulose and lignin are organic compounds of some complexity but are all built up of three elements, carbon, hydrogen and oxygen. For most kinds of wood the elementary chemical analysis gives very similar results. In a first approximation we can assume dry wood to consist of 50 % of carbon, 43 % of oxygen and 6 % of hydrogen; the balance consists of ash. Also the combustion values vary only mildly for the different kinds of wood, say from 20,1 MJ/kg for resinous wood to 18,2 MJ/kg for other kinds. For other plant parts we may use the same elementary composition and combustion values taking into account the generally higher ash content. The physical shape of fuels can, of course, vary wildly, from large logs of wood to millet stalks, grass or rice husks.

A much used fuel is charcoal. Charcoal is made from wood by heating it. Most of the volatiles are driven off, usually escaping into the atmosphere. Charcoal burns without smoke or smell. It is therefore very suitable for grilling as well as for other heating jobs inside the house such as ironing. The combustion value for charcoal is around 30 MJ/kg, about 1,5 times that of wood but we must remember that in its production about 2/3 to 4/5 of the original mass of the wood has been lost.

4.1.3 Combustion

Combustion presents no problems to engineers as long as it concerns either solid-, liquid- or gaseous fuel. Trouble starts when the originally solid fuel decomposes at a non-constant rate into carbon (in the form of charcoal) and an aerosol consisting of gases and vapours and tiny droplets of a mixture of viscous organic liquids. This is the way wood behaves (see figure 4.1). The volatiles

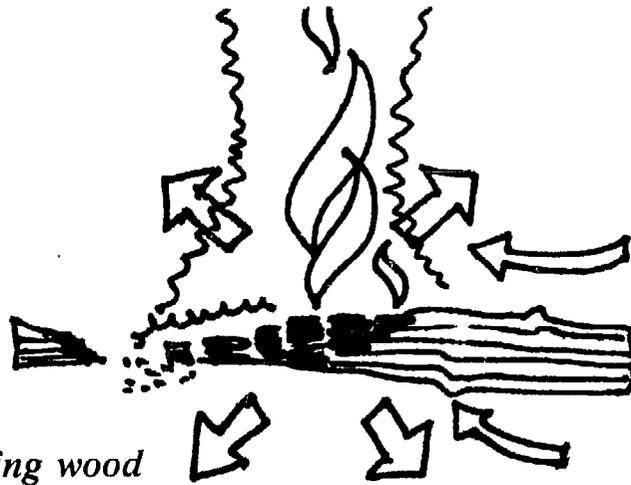


Fig. 4.1 Burning wood

in the wood carry between 2/3 and 3/4 of its heat content. These burn in the region marked core immediately above the fuel bed (see figure 4.2). Air for combustion is entrained from the surroundings by the acceleration of the burning volatiles. In the absence of friction, the velocity of the burning gases can be estimated by

$$v = (g b z)^{1/2} \quad (4.1)$$

where:

v	is the velocity	m.s ⁻¹
b	is the buoyancy parameter	—
g	is the acceleration due to gravity	m.s ⁻²
z	is the height	m

The buoyancy parameter b is roughly equal to:

$$\frac{T - T_e}{T_e}$$

where:

T	is the temperature of the flames	K
T _e	is the ambient temperature	K

Normally b has a value of around 3.

At a height of 10 cm the velocity is about $1,7 \text{ m.s}^{-1}$. Friction makes the velocities somewhat smaller in real systems. The actual process of combustion takes place from the periphery into the centre as one moves up from the fuel bed. The air entering the fire from the surroundings is called secondary air to distinguish it from the primary air that passes through the gaps that naturally occur in a fuel bed. This air is primarily responsible for the burning of fixed carbon (popularly referred to as charcoal) that remains after the expulsion of volatiles from the wood. Some of this air can also be expected to be available for the combustion of volatiles. This will slightly alter the picture presented for their combustion.

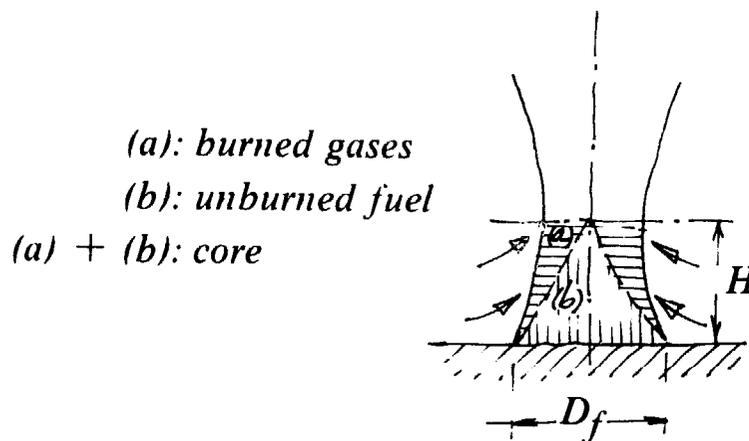


Fig. 4.2 Approximate shape of flame and hot gas region in absence of pan.

The heat output from wood fires is controlled by the rate of burning of the volatiles which in turn is controlled by the rate of their liberation. The latter occurs over a temperature range of $250...500 \text{ }^\circ\text{C}$ and the energy needed for this is met by a feedback mechanism from the fire. As wood is a poor conductor of heat, the time over which these temperature levels are attained over the entire volume of wood is substantial and is essentially a function of the surface to volume ratio of the burning wood. In addition, as the outer layers of the wood char, they form an increasingly effective shield to heat flow since charcoal is a poorer conductor of heat than wood. As the layer of charcoal builds up the charring proceeds more slowly and so does the evolution of volatiles.

For this reason a thick piece of wood will not burn by itself where a thinner piece will. For the same reason a fire of thin sticks will give off larger flames for a shorter time than the same mass of thicker sticks of wood. Figure 4.3 depicts a fire of straw, it gives high flames and the straw is quickly consumed. That a finely divided fuel can have difficulties obtaining sufficient oxygen for combustion is shown by figure 4.4. A heap of sawdust burns very slowly because the air has difficulties reaching the combustion zone. The volatiles that are slowly given off do not have a sufficiently high temperature to burn so they escape in the form of a white to yellowish fog called smoke. Woodsmoke contains a large number of organic chemical compounds that are irritating to the eyes and to the respiratory tract.



Fig. 4.3 A straw fire



Fig. 4.4 A sawdust fire

In general the liberation of volatiles is well matched to the needs of the fire. The energy feedback from the fire to the wood is of the order of 10 % of the heat liberated by the combustion of volatiles (Williams, 1974).

The burning of volatiles results in two zones - zone (a) dominated by the presence of combustion products and nitrogen and zone (b) dominated by unburned volatiles. An examination of figure 4.5. suggests that after a certain height the amount of combustibles available becomes small. Since air entrainment does not decrease

as rapidly, the temperature increases are reduced. Thus one could expect a temperature profile of the type shown in figure 4.5.

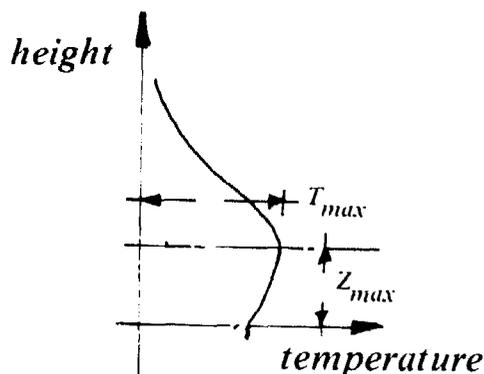


Fig. 4.5 Temperature profile in an open fire

4.1.4 Heat Transfer

In physics and engineering three modes of heat transfer are known i.e. radiation, conduction and convection. In the transfer of heat from a (wood) fire to a cooking vessel all three modes of heat transfer play a role.

Radiation

Heat transfer by radiation takes place mainly from the glowing charcoal. There is also some radiation from flames, especially when they are luminous. The temperatures of the glowing charcoal and the cooking vessel being more or less fixed, the heatflow to the pan from the firebed is dependent on the relative areas and their orientation. The more the pan bottom can 'see' of the firebed, the higher the heat transfer by radiation will be. Radiation also takes place from hot surfaces of the stove to the surroundings. As the heatflow is proportional to the fourth power of the absolute temperature an important portion of the heat generated can be radiated away in badly designed metal cooking stoves or from well designed metal space heating stoves. The radiative heat transfer from a high temperature source to a body at a lower temperature

can be conveniently expressed by the equation.

$$Q_r = F_{12} A_1 (T_1^4 - T_2^4) \quad (4.2)$$

where:

Q_r	is the radiant heat flow	W
	is the Stefan-Boltzmann constant,	
	$5,7 \times 10^{-8}$	$W \cdot m^{-2} \cdot K^{-4}$
F_{12}	is a factor depending on the properties and the relative geometric orientation of surfaces 1 and 2	
T_1	is the absolute temperature of surface 1	K
T_2	is the absolute temperature of surface 2	K
A_1	is the area size of surface 1	m^2

Note that the absolute temperature is obtained by adding 273 to the temperature expressed in degrees Celsius.

Conduction

Conduction is the process primarily responsible for the transport of heat in solids. For example, it is responsible for the heat transfer through the bottom of the pan to its contents. For a flat wall of small thickness and large area the conduction heat flow rate in a direction parallel to the wall thickness can be expressed as

$$Q_{cd} = \frac{\lambda A (T_1 - T_2)}{L} \quad (4.3)$$

where:

Q_{cd}	is the conductive heat flow	W
	is a property of the material called thermal conductivity	$W \cdot m^{-1} \cdot K^{-1}$
A	is the area size perpendicular to the heat flow direction	m^2
T_1	higher wall surface temperature	K

T_2	lower wall surface temperature	K
L	is the thickness of the wall	m

The equation (4.3) becomes very much more complex for other geometries and surface heat transfer conditions. However, it is possible to use equation (4.3) to illustrate certain qualitative features of heat transfer behaviour in stove elements.

In all metal pans the conductivity is very high compared to, for instance, pottery. As the bottoms of metal pans are relatively thin, the temperature difference between outside and inside will be negligible. With clay pots there will be a marked temperature difference between outside and inside surfaces. For that reason alone, the total heat transfer from the combustion gases to the contents of a clay pot will be less than when a metal pan is used.

It is seen from equation (4.3) that the heat transfer is dependent on the conductivity of the wall as well as on its thickness. In metal the heat conductivity is generally high, in view of this and of the fact that metals are usually quite strong and also expensive, it follows that metal constructions will as a rule have a slight wall thickness. All these factors contribute towards a high heat conductivity of metal pans as well as metal stove walls.

The heat conductivity of gases is very low. This is the reason for the low heat conductivity of very porous substances (when dry) such as ashes or sawdust or straw.

Another factor that determines the process of heat conduction is the dynamic behaviour of the system. Generally speaking thin metal walls react much faster to changes in environmental conditions than thick non metallic walls.

Convection

Convective heat transfer is the collective name given to the processes of heat transfer from a flowing gas or liquid. For example: convective heat transfer occurs when hot gases or combustion products flow past the pan bottom. There is a relatively simple formula to calculate convective heat transfer.

$$Q_{cv} = a A (T_g - T_s) \quad (4.4)$$

where:

Q_{cv}	is the convective heat flow	W
a	is the heat transfer coefficient	$Wm^{-2}.K^{-1}$
A	is the area size	m^2
T_g	is the gas temperature	K
T_s	is the surface temperature	K

The major problem in using the formula (4.4) is in assigning a value to a . a is a function of the nature of the flow (laminar or turbulent), the driving force for the flow (forced, buoyancy, etc.), the velocity of the flow, the geometric situation, and the physical properties of the fluid. At the present moment a considerable body of experimental and theoretical information is available for assigning suitable values for a for different situations.

The prospect of using this information for the application we have in mind is examined in greater detail in the next section.

In general it can be stated that a increases with the velocity of flow without ambiguity. All other influences are strongly application specific.

4.1.5 Fluid Flow

The foregoing paragraphs have implicitly brought to attention the importance of fluid flow in the processes of combustion and convective heat transfer. A few aspects of the fluid flow problem as

it is applicable to stoves will be briefly discussed below.

If there were no flow of air to the fire it would soon be starved of oxygen and die. As the density (specific weight) of hot gas is lower than that of the same gas at a lower temperature, it has the tendency to rise. We say that hot air has a positive relative bouyancy with respect to colder air. For this reason the hot gaseous products of combustion will rise and thereby cause air to take its place where it can contribute to the combustion. If we can prevent either the combustion gases from leaving the fire area or the air from entering it, the fire will die for lack of oxygen.

The previous chapter lists a large number of designs that use chimneys. A tall column of hot gases in a chimney weighs less than a column of ambient air, according to the law of communicating vessels this difference in weight results at the base of the chimney in a pressure lower than the ambient pressure. The effect of pressure on fluids is motion in a direction of lower pressure. Hence the chimney at its base draws in combustion gases. The larger the pressure difference between the chimney base and the ambient, the larger is the gas velocity.

A third aspect that is of consequence in this study is friction. For a given pressure difference, the velocity induced will be smaller in the presence of friction. This frictional loss will increase with velocity. As was pointed out in the discussion on convective heat transfer, higher velocities produce higher heat transfer. Thus higher heat transfer has to be bought at the expense of higher frictional loss. In addition losses in a flow system will increase in the presence of bends, abrupt changes in cross sectional area and obstructions.

4.2 Analysis of some stove designs

By K. Krishna Prasad

4.2.1 Introduction

In this section we will apply the general considerations presented in the previous two chapters to a few practical stoves. Engineering design is always an optimization problem involving:

- (a) processes;
- (b) materials and skills of construction;
- (c) operational convenience;
- (d) economic and social considerations.

Presumably this optimization problem has been solved in an intuitive manner for the designs listed in chapter 3 of this monograph. A perusal of the literature describing these designs reveals two general weaknesses. The performance of these stoves is not given and moreover, there is no mention of the rationale behind the choice of dimensions of stoves. The latter is important for adapting the designs to different conditions. In spite of these weaknesses, it is important to study these designs to identify their design parameters and their possible influence on the stove performance. The word performance connotes heat output rates, fuel economy and operation convenience collectively. Due to the almost total absence of quantitative information on the subject, a qualitative picture of the processes will emerge. Such a picture can be expected to assist not only in examining the designs of chapter 3 but also to interpret test data. Three stoves, representing three broad classes, have been chosen for discussion.

- (a) Open fires, representing traditional fires (OL1)
- (b) A mud stove of improved variety (CH2-10)
- (c) A commercially manufactured metal stove (CL2-3)

4.2.2 Open Fires

“...the very real mystique of an open fire as an instrument of relaxation, a focal point for a party, an aid to seduction - just about any use imaginable except heat production.” -Self (1977)

In spite of this rather discouraging opening statement it seems advantageous to understand these traditional fires thoroughly before attempting to construct better stoves.

Overall Features

The overall features of the so-called 3-stone fire used in many traditional societies are presented in a rather abstract manner in figure 4.6. the design parameters for such a system are:

- (a) the fire diameter, D_f
- (b) the fuel bed thickness, B
- (c) the pan diameter, D_p
- (d) the height of the pan from fuel bed top, H .

A purpose of the study would be to gain understanding of the processes that determine the relation among these parameters for good performance. A second purpose is to describe the influence of

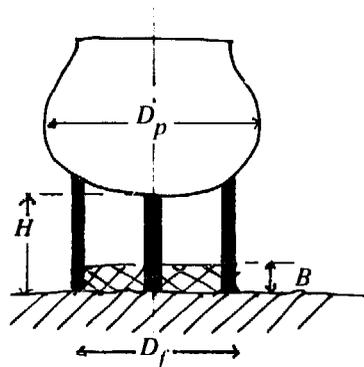


Fig. 4.6 Schematic representation of the 3-stone fire

the surroundings on the system. Certain features of control and convenience will be finally presented.

Combustion

The general discussion presented in section 4.1 requires modifications due to the presence of the pan. The major difference

lies in the temperature profile shown in figure 4.7.- the dashed line is the form in the presence of a pan. However the general arguments of section 4.1 still remain valid and the major effect of the pan is to reduce the heat output of the fire. Two important consequences of the previous discussion need to be mentioned at this stage. The air flow that is entrained above Z_{\max} is too large for the combustion requirements for the volatiles present. This is referred to as the excess air. In most combustion equipment - be it the boiler plant of a large thermal power station, an internal combustion engine or a wood-burning cook stove - the aim of a design is to arrange things so that all fuel gets the requisite air. Since mixing is never complete, a certain amount of excess air is inevitably supplied to ensure the combustion of all fuel. When this excess air becomes too much, temperatures are suppressed. If this temperature falls below the so-called ignition temperatures of the volatiles, they fail to burn.

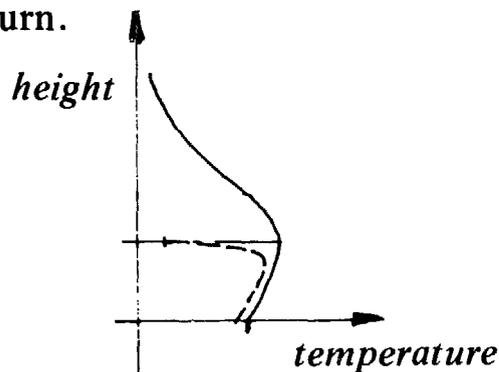


Fig. 4.7 Temperature profile in an open fire with pan

Available evidence (Emmons 1980) suggests that nearly 50 % of the volatiles may go unburnt in an open fire. There are many more details of the process we have not included. Interested readers might wish to consult the literature listed in the bibliography.

For purposes of designing, one needs three quantities from combustion studies:

- (a) the rate of heat output from the fuel bed;
- (b) the maximum temperature in the system; and
- (c) the position at which the maximum temperature occurs.

All these quantities are difficult to calculate in most combustion systems but much more so for wood burning systems. It is easy to see that heat output from the system increases with the area of the fuel bed or D_f and its depth B . From previous experience, it is known that B should not be too large for efficient combustion. D_f really is determined by the pan size or more simply by the quantity of food that is to be cooked. The actual value of the maximum temperature is dependent on the completeness of combustion. In general this is about $1000\text{ }^\circ\text{C}$ for flames of the type we would be interested in. Again only guidelines are available for the position at which the maximum temperature occurs. Roughly speaking the core height H_c is of the order of magnitude of D_f and thus Z_{\max} (see figure 4.7) is about $\frac{1}{2}D_f$. Finally the diameter of the fire is never larger than D_f . Most of these quantities require careful experimentation for their determination.

Heat Transfer

For most of the problems associated with the study of open fires, convection and radiation are the predominant modes of heat transfer. The latter is somewhat easier to handle and we shall consider it first.

Generally speaking, radiation capture by the pan increases

- (a) as D_f/D_p reduces for a given H , i.e. compact fires promote radiant heat transfer, and
- (b) as H is reduced for a given D_f/D_p , i.e. bringing the pan closer to the fuel bed promotes radiant heat transfer.

We present below some quantitative estimates of radiant heat transfer to illustrate the nature of this geometric influence. The radiant heat transfer between the fuel bed and the pan can be represented by equation (4.2). In that equation F_{12} was said to include effects of surface properties and their geometric disposition. We assume that the surfaces are black. This

assumption is reasonable for situations encountered in open fires. The small departures from this assumption in the real situation will make the estimates made below somewhat higher.

The geometry assumed for the results shown below is that of two discs - one representing the top of the fuel bed and the other representing the bottom of the pan. The table below indicates two numbers in each entry - one corresponding to the factor F_{12} and the other corresponding to the power delivered to the pan. The former quantity is independent of the actual values of D_f , D_p and H as long as the ratios D_f/D_p and H/D_f are maintained. But the latter is dependent on the actual sizes used. In addition, it is dependent on the temperatures of the fuel bed and the pan. As can be inferred from figure 4.7, the fuel bed temperature is dependent on its proximity to the pan. It has been assumed that this effect is not significant for cases where H/D_f is equal to or larger than $\frac{1}{2}$ - the only cases considered here. The actual values used for obtaining the results are:

$$D_p = 0,25 \text{ m}; T_1 = \text{fuel bed temperature} = 800 \text{ C} = 1073 \text{ K};$$
$$T_2 = \text{pan temperature} = 100^\circ\text{C} = 373 \text{ K}.$$

The formula used for calculating F_{12} is available in many standard heat transfer text books (see for example Eckert and Drake 1972).

An examination of this table brings out several interesting features. Looking at the numbers in the parentheses horizontally, reduction in the fire diameter by a factor of 2 increases F_{12} by something like a factor of 2. Similar increases are achieved by reducing H/D_f . But the actual heat received by the pan also depends on the area of the fuel bed. For the top row the reduction in heat received by the pan is about 47 % when D_f is halved. Of course the power output by the fuel bed is only $\frac{1}{4}$. At this stage fuel consumption comparisons can not be made, since we have to include convective heat transfer as well.

$\frac{H}{D_f}$	$\frac{D_f}{D_p}$		
	1	0,75	0,50
1	0,627 (0,172)	0,561 (0,273)	0,419 (0,469)
0,75	0,928 (0,254)	0,787 (0,383)	0,550 (0,602)
0,50	1,40 (0,382)	1,13 (0,551)	0,698 (0,764)

Table 4.1 Radiant heat received by pan in kW

Note: The numbers in parentheses are the values of F_{12} .

Convective heat transfer is less straightforward to estimate. Equation (4.4) looks innocent enough. The major problem arises in specifying a as pointed out in section 4.1. The author has considered this question in some detail elsewhere (Krishna Prasad, 1981). The main conclusion of this study was that three different regions over the pan could be identified:

Region 1: pan bottom that is directly above the fire
($20 < a < 40$)

Region 2: pan bottom that is not directly above the fire
($8 < a < 16$)

Region 3: Pan sides ($4 < a < 8$)

The second problem arises in connection with assigning values to T_g . This is dependent on the combustion process. In general the flame temperatures are stated to be about 1000 C (Corlett, 1974). This temperature can be expected to be valid in region 1 mentioned above. For regions 2 and 3 the gas temperatures are much lower. The reduction comes about due to two reasons:

- a) the air entrained by the hot gases reduces the temperature;
and
- b) the extraction of heat by the pan contributes further to the temperature reduction.

The measurements of Bussmann (1981) show that there can be a drop in gas temperature by a factor of 2 along the side of a pan which is 20 cm in height. The actual temperatures prevailing in regions 2 and 3 are a strong function of the fire diameter, i.e. the power output of the fire. Larger fires tend to maintain higher temperatures on the pan sides. Small fires produce much lower temperatures along the pan.

The author's work mentioned earlier considers these questions in detail. Two main conclusions emerge from this work:

- a) the amount of convective heat delivered to the pan can not be very different from that of radiant heat input for the conditions prevailing in a 3-stone fire:
- b) nearly half the total amount of convective heat is delivered through the pan sides.

This second point is one of the strongest features of the open fire; most of the new designs significantly fail in this regard (see the following discussion on mud stoves).

The final question that is to be considered is: to what extent will the dimensioning of the 3-stone fire influence its fuel consumption? Because of uncertainties of convective heat transfer, **it is not possible to provide estimates of fuel consumption in which one could have adequate confidence. The following table has been constructed primarily to illustrate the disastrous consequences caused by not paying adequate attention to the dimensioning of a stove.**

There is one other point to be considered in calculating the fuel consumption. The fuel consumption depends on the task to be performed. The task chosen here is that of bringing 5 kg of water at an initial temperature of 25 C to boil. The following assumptions have been made in arriving at the table:

- 1) the volatiles provide heat for convective heat transfer only;
- 2) the fuel bed provides only radiant heat;
- 3) the radiant heat transfer = convective heat transfer;
- 4) the power output of the total system = 3x radiant output of the fuel bed; and
- 5) calorific value of wood = 18.900 kJ/kg.

$\frac{H}{D_f}$	$\frac{D_f}{D_p}$		
	1	0,75	0,50
1	0,72 (21)	0,46 (23)	0,26 (31)
0,75	0,49 (14)	0,32 (17)	0,20 (24)
0,50	0,32 (9)	0,23 (12)	0,16 (19)

Table 4.2 Fuel consumption in kg for heating 5 kg of water from 25 to 100 C as a function of geometry

Note: The numbers in parentheses denote the time in minutes for fulfilling the task.

The main conclusion to be drawn from the table is that there can be as much as a factor of 4 difference in fuel consumption for the extremes depicted in the table.

There is another aspect to the design of a stove apart from the fuel consumption; it is the time taken to bring a given quantity of water to boil. This is rarely mentioned when presenting new designs (see chapter 3). It is seen from the table that the configuration that yields maximum fuel economy also doubles the time needed to achieve the task (see last row in the table). The time to be spent on a task is a factor dependent solely on the user's preference. **Thus dimensioning of a stove will be effective only when this is ascertained with care.**

We repeat a statement made earlier. **The numbers quoted are not accurate by any standards.** They need to be actually measured for a set of design choices. However, the table is of help in reducing the amount of experimentation required to arrive at optimum dimensioning of a stove. It appears from the table that the fire diameter should be between $\frac{3}{4}$ and $\frac{1}{2}$ of the pan diameter and the pan should be set at a height equal to $\frac{1}{2}$ the fire diameter.

Environmental Effects

There are two effects:

- (i) loss of heat from the pan top; and
- (ii) effect of wind on fire.

If the pan is covered, the first is a relatively minor effect - some calculations suggest it be no more than 2 % of the total heat input to the system (Sielcken and Nieuwvelt, 1980). If it is open, the loss will be much greater during the heating up phase. A major drawback of the open fire is that it is very vulnerable to draught or wind. The effect of wind on an open fire is illustrated in figure 4.8. The consequences are so far-reaching that it is worth describing them in detail.

- (a) The obvious thing to notice from the figure is that it reduces the area over which heat is delivered to the pan (when compared to the situation in figure 4.6.). This implies that A in equation(4.4) gets reduced resulting in a reduction in heat input to the pan. A second implication is a drastic increase in area over which heat is lost to the environment. The relative areas of heat gain and loss depend on the wind velocity relative to the velocity of gases in the fire at the pan height. The figure has been drawn for a case where these two are roughly equal to each other 1 m.s^{08-1} . Note that this is rather a small velocity, 3,6 km/h, smaller than the walking pace of a healthy person. Much higher wind velocities can occur, giving still greater loss of performance.
- (b) In order to sustain the fire under windy conditions, larger fires are built which inevitably lead to lower efficiencies as our earlier discussion suggests.

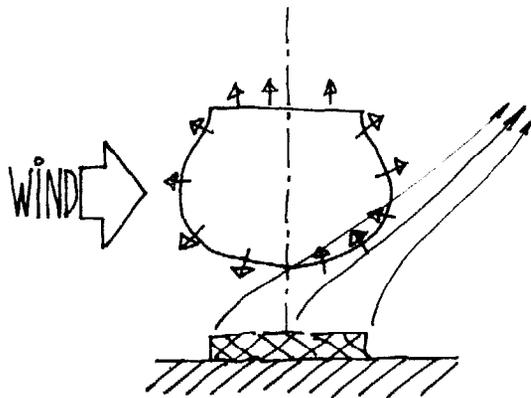


Fig. 4.8 Effect of wind on an open fire

- (c) A strategy to improve performance under such conditions is to reduce H , thus improving area of contact (as can be guessed from figure 4.8.) and increase radiant heat transfer.

However, this can impede proper combustion.

Quantitative estimates of these effects are difficult to provide; the best remedy is to minimise the effect of wind on open fires.

Shielded Fires

The simplest idea is to shield the fire from the wind as shown in figure 4.9. The velocities of the wind downstream of the shield in the region marked as lowest velocity region can be as small as 1/10 of the main wind velocity. Because of the reversed flow region immediately behind the shield, a fire in the region shown in the figure will experience vertically upward velocities. The flame shape (for a rather unsatisfactory shielding) is also shown in the sketch.

$$L \approx \frac{H'}{2}$$

$$H' \approx 3 H''$$

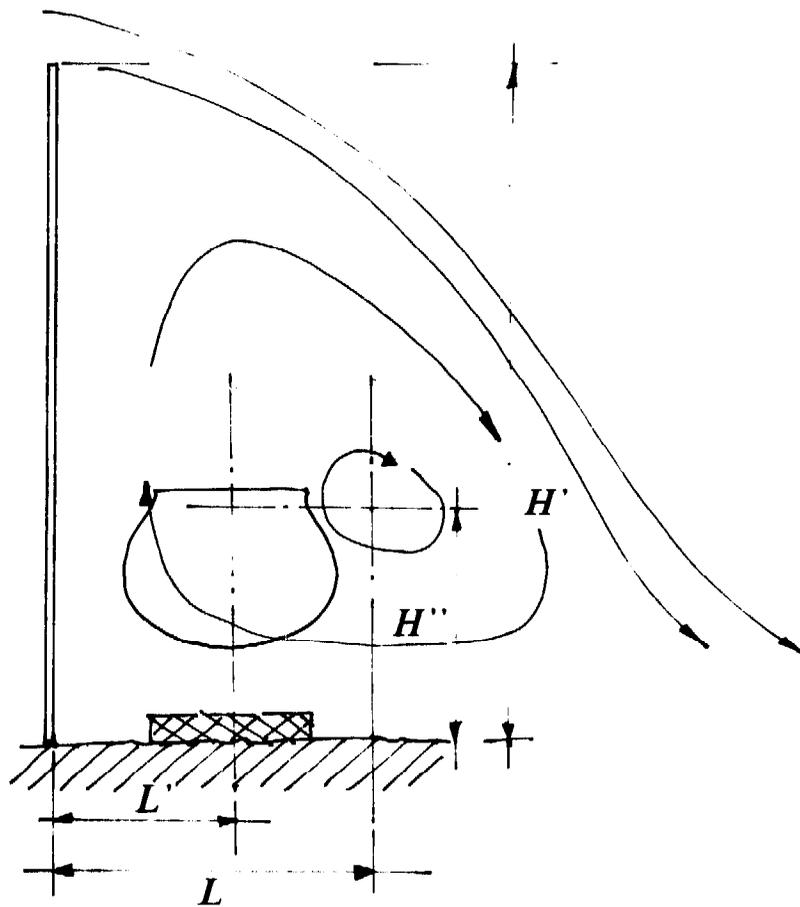


Fig. 4.9 Effect of shield on an open fire

Finally, some reflected radiation and probably some reradiation from the shield can be expected to reach the pan.

Some guidelines for the dimensioning of the different elements in the design are indicated in the figure, of course it is preferable to rely upon on-site experiments for the choice of the dimensions. To avoid problems of support and to take care of changing wind directions, it is advantageous to make the shield in a semi-circular form. For thatched shields, L' should take account of safety considerations.

A second form of shielding is shown in figure 4.10. When properly sized and located it can give significant efficiency increases (De Lepeleire, 1978 and Visser, 1981). The Visser design is the one shown in the figure overleaf. It has a grate (see the discussion below) and a set of secondary air holes for additional air supply to burn the volatiles. Limited laboratory testing shows that it is capable of yielding efficiencies of the order of 50 %. Comparable measurements on open fires yield a maximum efficiency of under 30 % (Visser and Verhaart, 1980). It is interesting to examine the reason for the enormous increase in efficiency provided by a shield even in the absence of wind.

First let us consider the problem of radiant heat transfer. Consider the case $D_f/D_p = 3/4$ and $H/D_f = 1/2$. From table 4.1. we see that only 55 % of the fuel bed radiant power reaches the pan bottom. In an unshielded open fire the rest is lost irretrievably to the environment. In the shielded open fire, the radiant power that is not absorbed by the pan bottom is absorbed by the shield. This results in an increase in the shield temperature. The actual temperature attained by the shield is governed by its material, the amount of heat absorbed by the shield to raise its temperature and the heat lost to the environment by the shield. By virtue of its high temperature the shield reradiates part of the energy it absorbed

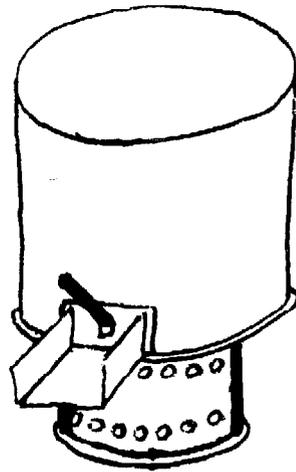


Fig. 4.10 An alternative form of shielding an open fire

back to the pan bottom. In addition the sides of the pan receive some radiant heat from the shield as well. Thus the pan receives much more than 55 % of the fuel bed radiant power, possibly as much as 75 %.

We next turn to the convective heat transfer problem. Firstly if the clearance between the pan and the shield is small, higher gas flow velocities are likely to be produced in the neighbourhood of the pan causing increased values of a in equation (4.4). In addition since air entrainment is suppressed, the gas temperatures tend to be higher. On both these counts, the total convective heat transfer to the pan tends to be much higher than in the case of open fires.

The above argument clearly provides a strong case for adopting shielded fires as a first step in improving fuel economy of open fires.

Grates

A grate used in combination with an open fire will generally improve the performance of an open fire (see figure 4.6.) The main reason appears to be that the primary air enters from under the grate and passes through the fuel bed. Such a distributed air source is likely to start the combustion of volatiles as they pass

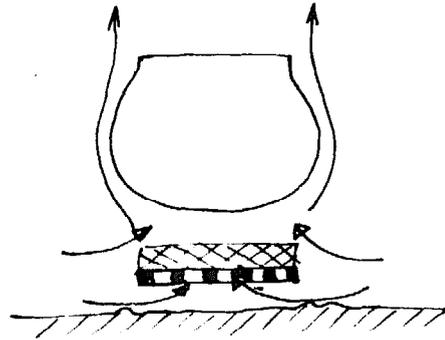


Fig. 4.11 Effect of grate on open fires

through the bed before entering the main combustion space. A secondary effect of a grate is that it helps in defining the combustion space better, thereby promoting the use of compact fires. Thus a grate combined with a suitable shield can produce considerable improvements in fuel economy of an open fire.

Control and Operational Convenience

The control of output in most combustion equipment is controlled by manipulating the fuel supply and simultaneously the air supply. In an open fire a similar control is exercised except that the air supply is controlled in a natural manner, and not by the operator. This can be a limiting factor to obtain low heat output levels.

A serious problem with the open fire is its propensity to smoke. Without any doubt this is an immediate discomfort and can be a long-term health hazard.

4.2.3 An improved Clay Stove

The stove that is going to be discussed in this section belongs to a general class of so-called heavy stoves. The popularity of these stoves among development workers is due to two reasons: the materials that they employ are available almost everywhere and they can presumably be constructed with very little technical skill.

Historically speaking, at least in terms of helping poor people, such stoves were first devised in India at the suggestion of Gandhi (Magan Chula, 1948). The original work was followed up by Raju (1961) in India and independently by Singer (1959) in Indonesia. Incidentally, the latter work, in the opinion of the present author, still remains a classic in stove research. The many designs that are available at the present moment employ essentially the same ideas.

All the stoves of this category exhibit three principal features:

- (a) a closed hearth where combustion of the wood takes place thus protecting the fire from the vagaries of the wind;
- (b) multi-ported design, capable of carrying more than one pan, permitting a certain amount of heat recovery from hot gases that would otherwise have gone to waste; and
- (c) a chimney to provide the draught necessary for bringing in air for combustion and removing smoke from the kitchen environment.

A considerable amount of literature has grown on the subject and along with it, we might add, a substantial amount of publicity among development workers. The emphasis in most of this literature is on the materials and construction of these stoves. They usually have very little to say on the processes in such a stove except the assertion that they use 50 % less fuel than traditional fires. As is evident from the discussion in the previous section, the fuel consumption of an open fire is dependent on so many factors that it seems that a statement like the above is at best misleading.

In this section, we shall examine one such stove to gain a physical appreciation of the problems and prospects of such stoves. In particular, we intend to demonstrate that unless the stove is

designed and manufactured with care, it can show fuel consumptions that are higher than those of an open fire (particularly of the shielded variety).

General Features

The example we have chosen is shown in figure 4.12. (corresponds to CH 2-10 in the data sheets of chapter 3). We shall be considering a number of variations on the original concept to

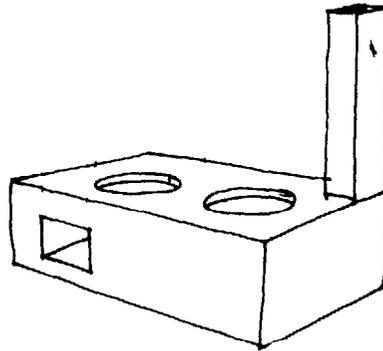


Fig. 4.12 The first concept of the example clay stove

establish possibilities of improving the performance. The figure clearly shows the three elements of such stoves mentioned earlier. We also note the size of the stoves - they are large and weigh upwards of 200 kg. Hence they are not portable and are customarily built in-situ. The third point is the rather small fuel loading door, its base width is smaller than the diameter of the pan hole. Presumably, the logic of this is based on the experience of open fires, where a compact fire leads to higher efficiencies.

The Chimney

The chimney has a profound influence on the behaviour of such stoves. At the first instance we assume a hollow body. The situation is illustrated in figure 4.13. There are three forces governing the gas motion: the buoyancy force, B , of the fire (See discussion on open fires); the chimney draught, D , (dependent on the temperature difference between the gas at the chimney base

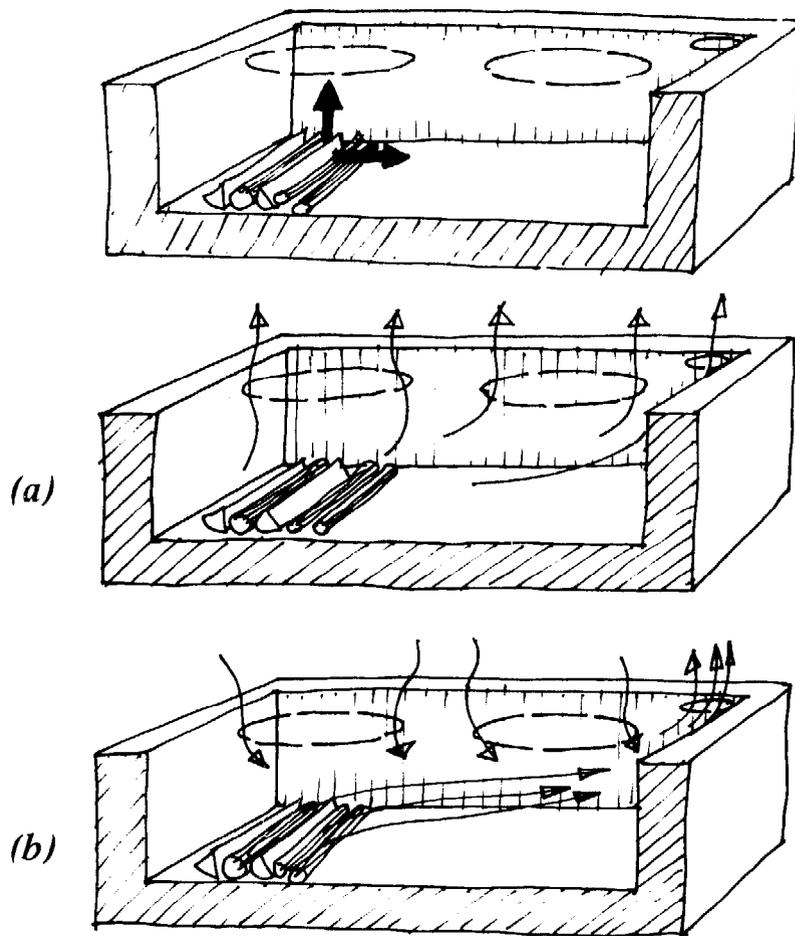


Fig. 4.13 The role of a chimney

and the outside environment, and the chimney height); and F , the frictional force which opposes B and D . In what follows, we shall omit F from our argument assuming that the only influence it will have is to increase the chimney draught requirements.

In principle, all these forces can be manipulated to advantage (or disadvantage!) by the stove designer for obtaining the optimum performance from the stove. B can be altered by changing the rate of burning of the fuel. D can be changed by (i) changing the gas temperature at the chimney base, i.e. by arranging to extract more or less heat from the combustion gases and (ii) changing the height of the chimney. F is manipulated by appropriate designs of passages inside the stove body and the chimney cross sectional area of flow.

We consider two extreme cases in order to gain an appreciation of the role of the chimney.

- (a) When B is very much larger than D : a situation obtained with a very large fire coupled with a very short chimney.
- (b) When B is very much smaller than D : a situation obtained with a small fire and a tall chimney.

In the first case the system behaves very much like an open fire in the absence of wind. Smoke and maybe flames will leak past the first pan. The second pan receives little heat. The design is thus counterproductive. The gas path is shown in figure 4.13(a).

The second case is analogous to an open fire in a windy environment. The combustion gases are now swept away from the first pan and will come into contact with a small portion of the second pan. Thus the first pan will receive only the radiant heat from the fuel bed (which of course can account for at most $\frac{1}{3}$ of the wood's heat content). The second pan will receive a little convective and a very small amount of radiant heat. Next, since the gases deliver a relatively small amount of their heat to the pans, their temperature at the chimney base will be quite high thus making an already poor situation worse. Because of the rather large D , there will be considerable cold air leaks past the pans into the enclosure. This will produce lower temperatures under the second pan thus reducing further its heat input according to equation 4.4. this to a certain extent counteracts the effect of high temperature at the chimney. The gas flow path for this case is shown in figure 4.13(b).

The ideal situation is one where the chimney height is so adjusted to produce $B = D$ just under the first pan. Under such circumstances, the fire will rise up to the first pan where it will

veer to the right under the influence of D . This is known as the balanced draught operation in boiler practice. However, for a small device like a wood-burning stove, it is doubtful whether such a fine tuning of the two forces can be realized. Moreover the system can prove unstable and hunt between two undesirable conditions due to variability of combustion characteristics and uncertainty of fuel quality.

In general it appears preferable to operate with D slightly dominating B . In such a case the first pan will receive less heat input than in a well-shielded open fire operated under optimum conditions. There is some experimental evidence in support of this claim (De Lepeleire 1978, Nievergeld 1980, Visser and Verhaart 1980).

The Baffle

A fruitful approach for improving convective heat transfer is the introduction of a baffle. It is a vital element of any stove that has a chimney and incorporates two or more pans. Even a design with a single pan and a chimney will perform poorly (see Salariya, 1978 for an example). Figure 4.14 shows the form of the baffle originally recommended to be used with the design of figure 4.12. The most important effect the baffle will have is that the burned gases are forced to move up towards pan 1 (irrespective of the relative values of B and D) before turning right in the direction of the chimney.

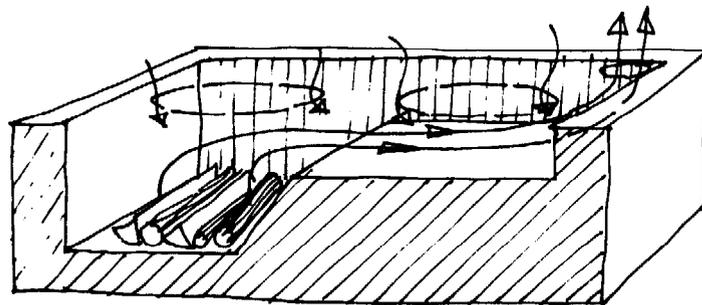


Fig. 4.14 Design of fig. 4.12 with a baffle

The first pan will receive considerable convective heat transfer which was virtually absent in figure 4.13. A second advantage is that the baffle defines the combustion volume better. In particular, the fire is surrounded all around by insulating hot walls except for the fuel loading door and the gap between the baffle and the top of the stove. The 'cold' pan is quite 'far off' (provided height for combustion is adequate). Thus the conditions for complete combustion of the volatiles are much better.

A third aspect of the baffle arises in connection with radiant heat transfer. The increase in radiant heat transfer occurs as explained in the discussion on shielded fires.

Furthermore, the second pan will receive much more convective heat as can be seen by comparing figures 4.13. and 4.14. The weakest link in the closed stove is the convective heat transfer. A baffle is a must to provide adequate area of contact between the pan and the hot gases. In order to determine this the gas motion trajectory needs to be charted. It depends on the forces B and D (already discussed), the shape of the baffle, the location of the chimney vis a vis the fuel bed and in some cases the chimney diameter. To calculate these is an extremely complex task and one has to rely on experiments. No such systematic experiments have been done for geometries that are of interest to stove designs. We thus have to satisfy ourselves with a qualitative picture of the different effects mentioned above.

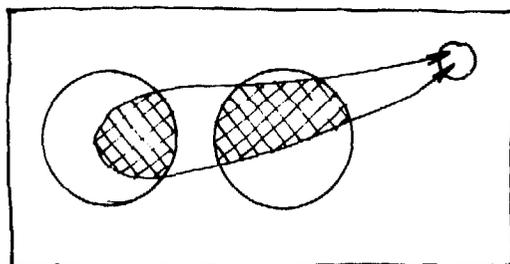


Fig. 4.15 Plan view of stove design of fig. 4.14 showing the gas flow path and contact areas for convective heat transfer.

Figure 4.15. shows the most probable path of the gas motion for the design of figure 4.14. Several interesting features emerge from a study of the figure. The first point is the width of the gas flow path. Under the first pan it is essentially controlled by the width of the fire. For this design it is equal to the length of the wood actually burning in the combustion chamber. Secondly during the entire trajectory the gas is subjected to an accelerating flow field; the chimney diameter is only 70 mm, and it is located on the top right hand corner of the stove. So much so the actual width of the gas motion goes on decreasing as it reaches the chimney. However this reduction is compensated by the increase in a in equation (4.4.) due to increased velocities; to what extent is difficult to estimate at this moment. Thirdly some part on the left hand side of the pan 1 completely misses the hot gas. This missed region is reduced in this design by setting the firing place somewhat to the left of the first pan.

Thus one sees that the design has gained considerably in terms of radiant heat but it has lost enormously in terms of convective heat, when compared with open fires.

Some Design Modifications

A modified design suggested by Micuta (1980) is shown in figures 4.16 and 4.17. It has a grate whose effect has already been

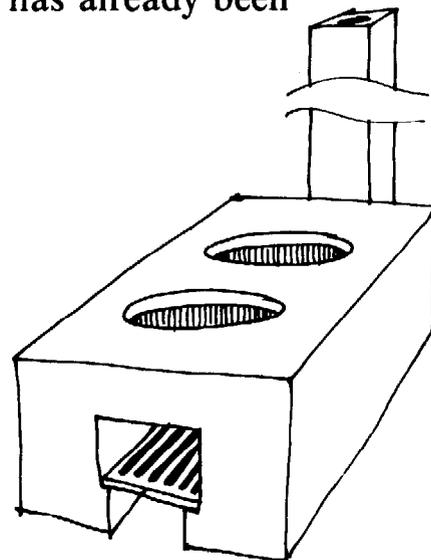


Fig. 4.16 Modification to the design in fig. 4.12

discussed in connection with the open fire. It has an in-line arrangement in which the fuel loading door, the pans and the chimney are all located along a single axis. Figure 4.17. shows that the baffle wall facing the fire is much steeper than the one in figure 4.14. and can be expected to provide much better conditions for combustion as well as radiation. The inlet to the chimney is located at the bottom of the stove rather than at the top as in the previous case. The chimney diameter is larger. Both these factors assist in maintaining larger area of contact between the hot gases and pan 2. The actual contact areas are shown in figure 4.18. As compared to the previous design, the first pan fares worse in this case primarily because the previous design had its fuel loading door centreline offset to the left of the centreline of pan 1.

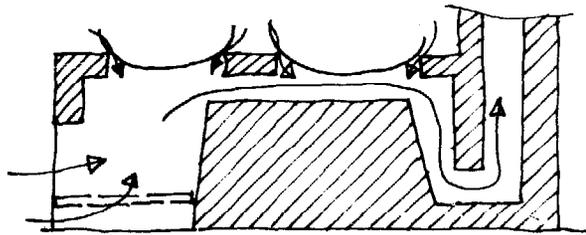


Fig. 4.17 Cross-sectional view of design in 4.16 showing gas and air flow paths

The most significant gain in heat transfer area is observed for pan 2. The chimney height is larger and so is its diameter. The exact effect of this on flow paths is difficult to estimate and requires careful experimentation. On balance one should expect a better performance from this design.

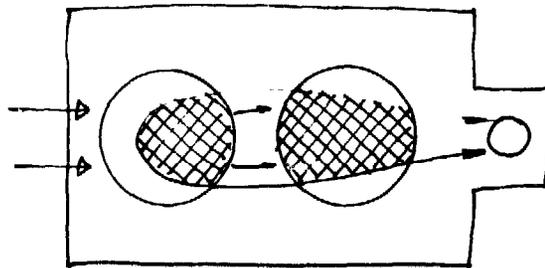


Fig. 4.18 Contact areas for convective heat transfer in design of Fig. 4.17.

One could think of yet another alternative for the baffle (see figure 4.19) with the rest of the design left intact. The heat transfer area for pan 1 is increased (the extent of this increase can only be determined by experiment) with a somewhat smaller increase for pan 2 as well. Probably the best arrangement might be to retain the firing door arrangement of figure 4.12. along with the chimney and baffle configuration of figure 4.19. A word of caution here. Unless the resistances to flow in the two passages of figure 4.19a are matched carefully, there is the danger of the flow completely missing one of the passages.

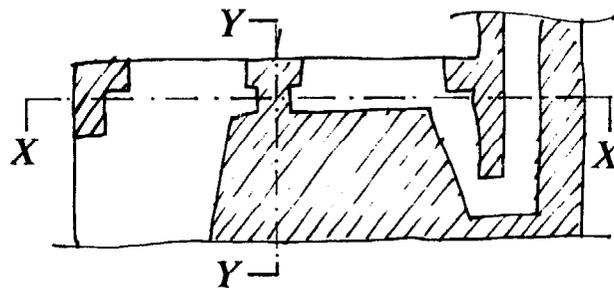


Fig. 4.19 Changing the baffle

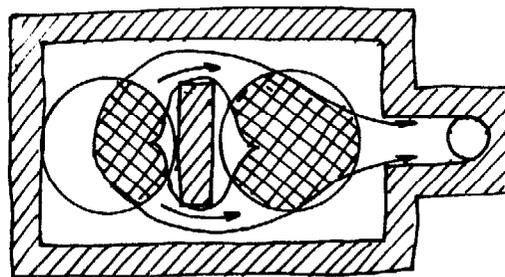


Fig. 4.19 a. Section across XX in 4.19

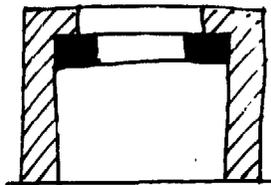


Fig. 4.19 b. Section across YY in fig. 4.19

A remarkable feature emerges from a study of the contact areas in different arrangements for convective heat transfer. Unlike the open fire, it appears advantageous for these designs to maintain

the fire diameter nearly equal to the pan diameter for promoting convective heat transfer to the pans. From our earlier discussion, such a design change will not adversely affect the radiant heat transfer either. For convenience of operation, the above design modification may require wider fuel loading doors, which will mean some loss of radiation. This latter could be reduced by providing an appropriate shutter to the door. Long pieces of wood would then be difficult to use.

Thermal Response

A distinctive feature of these stoves is that they possess a substantial mass. It should be noted that the process considerations detailed above do not require this mass, but structural strength and durability considerations demand it. However this has a profound effect on the performance. The thermal behaviour of such stoves could be considered in three separate time phases:

- (a) initial heating up period, t_h ;
- (b) steady state period, t_s ; and
- (c) cooling period, t_c .

During the period t_h , the stove body uses energy from the combustion to increase its temperature. During the period t_s the stove body temperature distribution does not change with time. During the period t_c it releases the heat it absorbed during the period t_h . The main problem is that different parts of the stove body will have different time constants. Conventional wisdom suggests that such stoves:

- (a) would be inefficient for short intermittent cooking tasks;
- (b) would show rather good performance for long cooking tasks since the inner surfaces of the stove would be at relatively high temperatures and as such will deliver substantial amounts of radiant heat to the pans; and

(c) are capable of keeping things warm.

For making a sound design choice these aspects need to be quantified to some reasonable degree of accuracy. In principle these quantities can be calculated in a rather straightforward manner. In the present case the geometry is very complicated and the computational effort would be quite formidable. Moreover, even if one were to take the trouble, the uncertainty with respect to the boundary conditions can make the outcome suspect. Some effort at modelling the problem and considerable experimentation would be required before one could indulge in design recommendations.

Control

As in an open fire, these stoves can also be made to operate at different levels of power output. But in general the range of power output realizable from closed type stoves is rather limited, as shown by the experiments of Sielcken and Nieuwvelt (1981) and Nievergeld et al (1981) on two very different types of metal stoves. The open fire, however, has the possibility of varying the power output level by varying the fire diameter, D_f . A factor of six variation could simply be accomplished by making D_f vary from D_p to $0.4 D_p$.

Such a procedure is not easily possible for the stoves of the type considered here. However, an alternative method of control is possible.

The alternative method is to introduce a damper somewhere in the flow passage. The customary position is at the bottom of the chimney. By reducing the air supply to the fire, it is possible to achieve low power outputs from the fire. An important requirement for the damper to function properly is that the flow resistances in the different elements of the stove like air inlet, passages in the

stove body, and the chimney should all be approximately equal to one another. If this requirement is not observed, the damper will not serve any useful purpose.

Two major difficulties arise in implementing this in practice. Firstly, in a stove the volume flow through the body and the chimney is considerably larger than at the inlet because of higher temperatures (and consequently lower densities) of the combustion gases than the incoming air. Secondly, the driving force is governed by the temperature at the bottom of the chimney. This temperature is expected to be a strong function of the power output of the fire. As far as the present author is aware, no analysis along the lines indicated above is available at present. The design practice of introducing dampers is based on faith that they will control the power output. But in practice, as the references quoted earlier suggest, this faith is for most part misplaced.

Other Features

There are many other features of the designs considered above that show them in poor light when compared to a carefully operated shielded open fire with a grate. We shall discuss these features below.

- (a) Because there is only one port of entry for combustion air, mixing can be expected to be poor with consequent incomplete combustion. No data have been reported on the required combustion volume under these conditions. Micuta (1980) has incorporated holes in the region around the combustion space in such designs for admission of secondary air. But no data are available to prove or disprove the usefulness of such a concept.
- (b) A large proportion of pan area is exposed to the cold environment and a considerable amount of heat could be lost due to this.
- (c) One could think of sinking the pans inside the stove body to overcome this problem. It should be realized that this is not a novel idea - for at least 50 years South Indian homes have used such an idea for water heating systems. Presumably such practices could exist in many other parts of the world. The problem arises in connection with providing adequate combustion volumes under the first pan. This can make an already bulky stove much bulkier. The additional area of the pan available for heat transfer due to this procedure does not automatically ensure a proportional increase in heat transfer (see for example Nievergeld et al. 1981). There is another problem associated with such designs. They can not accomodate different pan sizes easily without special design features on stoves and/or pans.

(d) An alternative to (c) would be to provide a metal top. The metal can be expected to attain quite high temperatures provided appropriate guiding of the flow is ensured. Such a strategy can have a 3-fold benefit:

(i) the rising convective current from the metal surface would act as a warm shield for the pan sides thus eliminating or at least reducing their heat loss:

(ii) it would assist combustion by preventing the cold pan from coming into contact directly with the fire

(iii) it is of immense help when different pan sizes need to be accommodated.

Of course such a stove can be a serious hazard to small children unless it is placed on an elevated platform.

Needless to say such stoves will cost more. In addition they will require flat bottomed pans.

(e) There is a tendency among stove designers to add more and more pans for greater heat recovery from the combustion gases. There are several designs that use more than three pans. In general it is an unimaginative design practice to use more than two pans. The rationale behind the choice of more pans is presumably the rather high chimney temperatures observed with two-pan configuration. The correct conclusion to draw from this observation is that the gases did not deliver enough of their heat to the two pans. A decidedly cheaper and more intelligent solution is to spend time in designing appropriate baffle systems to increase the heat transfer to the pans. At any rate these designs are supposed to assist in lessening the need for fuelwood of the poor people in the world. The present author finds it difficult to imagine that such people would need to cook four dishes twice a day.

- (f) A related point is the propensity of wood burning systems to produce deposits of tar and creosote in chimnies and passages formed by complicated baffle systems. These can lead to a blockage of flow passages thus considerably impairing the performance of the system. Under unfavourable conditions they can cause fire hazards. The only way to tackle this problem is by regular maintenance.
- (g) The stoves of this type when made out of clay will have a rather short life expectancy, unless sufficient care is exercised in preparing the original mix and in curing the stove after it is built. In addition the pan seats take quite a beating and require special attention during manufacture. Access to the passages for cleaning is not easy and careless cleaning may lead to the stove being damaged.
- (h) Of course life expectancy could be increased by building the stove out of burnt bricks or concrete. The real question in such a case would be: does the stove save enough energy when compared to the shielded open fire to warrant the expense in making bricks? At the present moment this question can not be answered with any degree of confidence and as such this option should not be considered as a viable alternative.
- (i) There is another curious feature about the literature on the subject. Most designers do not specify the power output of the system. In other words one cannot tell with any degree of certainty the time it takes to bring a given quantity of water to boiling point. Note that the open fire is a familiar thing and people out of experience can tell the size of the fire required to achieve a given task. These are new designs and as such people ought to be given this information.

- (j) Finally, while there is a great deal written about socio-cultural aspects, the only concession that is made for these in the design of stoves is to change the diameter of the pan hole. No further comment is needed, on such an attitude to designing stoves.

Summing up the only comments that can be made with certainty on this class of designs is that they:

- (i) can be built at most places with local materials and skills; and
- (ii) they do remove smoke from the kitchen environment.

The rest is largely in the realm of speculation.

4.2.4 A Metal Commercial Stove

To wind up our discussion on stove designs, we briefly consider a metal stove that is commercially manufactured. The design is shown in figure 4.20 and corresponds to CL2-3 in the data sheets of chapter 3.

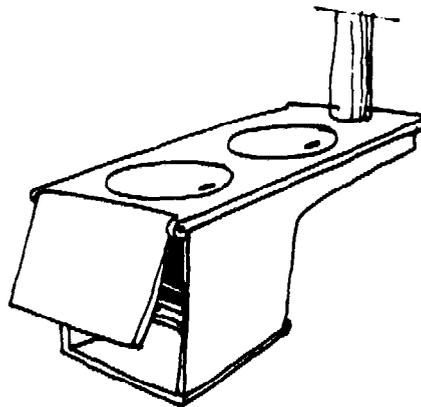


Fig. 4.20 A commercial metal stove

There are no significant differences between this stove and the clay stoves shown in figure 4.12. One can expect the combustion behaviour of such a stove to be similar to that of the stove discussed in the previous section. The fuel loading door is wider than the pan and as such the limitation on contact areas discussed earlier is not so severe. The operator, however, can choose the width of the fire according to the needs of the cooking task.

The major difference between a stove of this type and the stoves of the previous section arises in the thermal behaviour of the stove body. The body attains quite a high temperature rather quickly and steady state is established provided such a steady state is attained in the combustion temperatures. Stated otherwise, the stove body responds to the changes in the firing pattern almost immediately. Thus it is usually assumed that such stoves are efficient for intermittent cooking tasks.

A drawback of such stoves is that the stove loses considerable amounts of heat to the environment by the rather large exposed surfaces. Presumably what the design gains by way of fast response is lost by way of losses to the environment. At least in the mud stoves there is the possibility of a certain heat recovery to keep things warm. The fast response of the stove implies that it cools down equally rapidly.

The second pan in such a design will receive very little heat because the combustion gases cool down considerably before they reach it.

On the basis of the arguments developed in this chapter, there is nothing to commend the use of this stove in preference to the clay stoves of section 4.2.3.

4.2.5 Concluding Remarks

The discussion in this chapter points out that the processes that occur in a wood burning stove are quite complex. While it is possible to give a physical description of the processes rather simply it is not easy to quantify these with any reliability at this moment. Thus, it is fair to state that designing a stove to give a desired performance is not one of those exercises that can be completed on a spare afternoon. The understanding of the processes helps in guessing at a reasonable design.

Whether the promise is realised in practice requires patient testing. If the design of a stove is to be based on a rational approach, such testing needs to be recorded carefully to avoid the painful task of re-inventing the wheel. This is one of the principal reasons why this compendium suggests a systematic testing procedure.

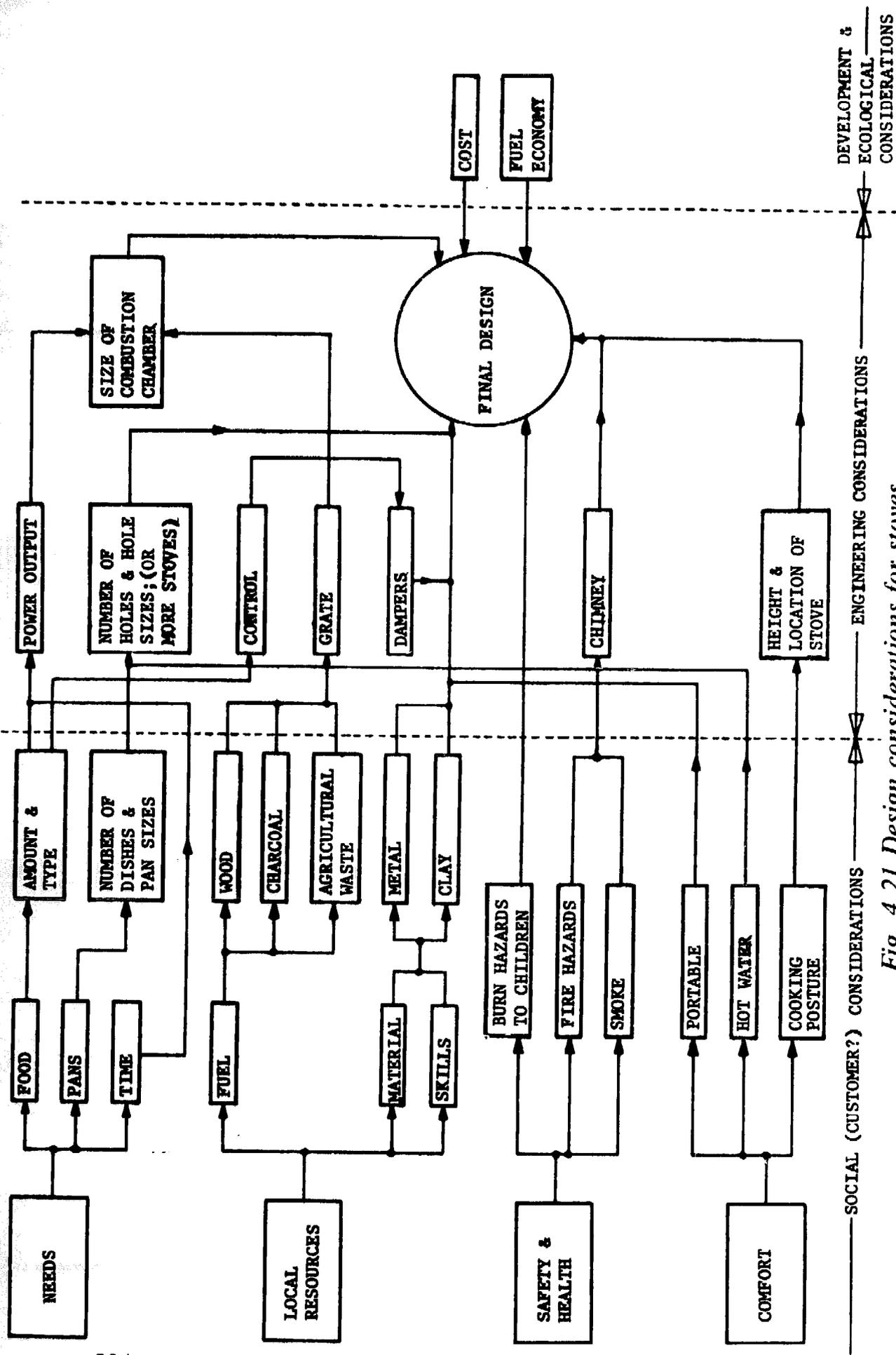


Fig. 4.21 Design considerations for stoves

4.3 On designing stoves

By P. Verhaart

“The object [artifact] renders in material form the pre-existent intention that gave birth to it, and its form is explained by the performance expected of it even before it takes shape”.

—Monod, 1970.

4.3.1 Introduction

Modern engineering design has become a very complex process. The complexity is due to the fact that it is not merely engineering any more. Many non-engineering constraints enter into the picture. These constraints are particularly severe for the category of products this book deals with. The severity is compounded further by the inability of the customers for this class of products to express their wishes in any organized manner. Thus a great deal of care and attention is required before we can arrive at satisfactory designs. An attempt is made in figure 4.21 to present diagrammatically the different types of considerations that come into the picture during the design process for a satisfactory stove.

A few words by way of explanation of the diagram are in order. The diagram is divided into three parts. The central part of the diagram represents the conventional engineering task of designing a stove. It is dictated on the left by social (customer?) considerations and on the right by the development and ecological constraints. Moving from top to bottom one could assign different priorities to the various items. The actual mix of priorities is dependent on the perception of the nature of the problem by the designer. The blocks in the diagram can be thought of as an aid in

formulating different classes of questions. It is not the purpose of this section to delineate all the possible questions that arise from each block. We will satisfy ourselves with one example. Consider the block 'food'. The questions that are relevant are the quantity and the type of food that is to be cooked with the stove and the local cooking habits. This will provide vital information for developing a stove that is tailored to the need.

We shall not elaborate on this point any further. This is not to suggest that these considerations are unimportant, but they are highly location specific. To build a coherent picture of these factors, one requires several case studies with special reference to stoves. These presumably will emerge in the years to come when it might be possible to provide more concrete guidelines than is feasible at the moment. As to the engineering problem of designing stoves, direct data relevant to wood burning stoves are meagre, but one can fall back upon other well established knowledge.

As to this day we do not know of any successful woodstove design that can stand up to a critical examination, we are unable to pass on the relevant data. We will therefore, in this chapter, present all the quantitative information that is available to us and that we consider relevant to the designing of woodstoves.

In many instances we will indicate the need for data while being unable to supply them, for such is the state of the art and the knowledge on the subject.

We will attempt to run through the procedure we would adopt if we were to design a wood burning cooking stove. We will draw from experience where possible, even though it be gained under laboratory conditions or from other systems like gas ranges or large steam boilers. Even so we can only proceed by, at best, making intelligent guesses or risky extrapolations. We hereby hope to

demonstrate the gaps in the knowledge of design parameters. To make a start we begin by presenting figures that are available from standards institutes.

4.3.2 Some Figures From Gas Range Practice

Efficiency

The first value of concern to a designer is the heat load on the pan bottom. This is really the power output of the burner expressed in W.cm^{-2} of the pan bottom area. For gas ranges this is about 7 W.cm^{-2} . The efficiency at this heat load is defined as:

$$\frac{\text{(heat to warm water in pan from } \sim 20^{\circ}\text{C to } \sim 95^{\circ}\text{C)}}{\text{(heat liberated by gas used (upper value))}}$$

The uniform temperature rise of the water must be from about 20°C to about 95°C .

The second question of consequence is the task or a set of tasks that a cooking stove is expected to perform. Since these vary widely in a given community and between different communities, the output of the stove is obviously required to cater for these different tasks. Because of the difficulties involved in standardizing the different type of tasks, it is convenient to work with an agreed system and obtain comparative performance estimates of different designs. The system used is that of heating water over the range of

Pan bottom diameter	Mass of water	Height of water in pan	Relative height of water in pan	Gas range heat output
cm	kg	cm		kW
12	0,5	8,6	0,51	0,79
14	0,845	9,7	0,57	1,08
16	1,31	6,52	0,60	1,40
18	1,93	7,58	0,63	1,78
20	2,71	8,63	0,65	2,19
22	3,68	9,68	0,68	2,65
24	4,86	10,74	0,70	3,15
26	6,29	11,85	0,71	3,71
28	7,93	12,88	0,72	4,30
30	9,85	13,93	0,74	4,93
32	12,1	15,05	0,75	5,61
34	14,6	16,08	0,76	6,34
36	17,5	17,19	0,77	7,11
38	20,6	18,16	0,77	7,91
40	24,3	19,34	0,79	8,77
42	28,2	20,35	0,79	9,68
44	32,7	21,51	0,80	10,61
46	37,5	22,56	0,80	11,61
48	42,7	23,60	0,81	12,62
50	48,3	24,60	0,81	13,73

Table 4.3 Pan sizes and burner power

temperatures mentioned earlier. Taking into account the dimensions of pans commonly used in Western Europe, the heat load of 7 W.cm^{-2} and a reasonable time for heating up, the following table has been arrived at for gas burner powers. (V.E.G. standards, June 1968).

It is seen from table 4.3 that the degree of filling varies from half full for the smallest pan to about four fifths full for the largest sizes. The corresponding heat output of the gas range is mentioned in the last column of the table. Since we have no figures for corresponding tests on woodstoves, the above figures might serve as a guide. One proviso should be mentioned. Since the present day wood burning systems for cooking show much lesser efficiencies, it is necessary to increase the output powers by a factor of around 2 if not more.

It is rarely possible to meet the entire range of power output from a given stove, it is necessary to provide for different capacity stoves. Again borrowing from the gas range practice, the following table gives the recommended range of burner sizes.

Name	Heat output (kW)
Laundry burner	> 4
Large cooking burner	2...4
Standard cooking burner	1,8...2,0
Small cooking burner	1,4...1,8
Simmering burner	0,4...1,4
Dishwarming burner	< 0,4

Table 4.4 Gas burners. (From V.E.G. Standards 1968)

All the above burners with the exception of the dishwarmer must be capable of burning at 15 % of their nominal heat output. Their control valves must have a stop at the position where 15 % of the nominal gas flow is admitted. A simmering burner with an nominal heat output of 0,7 kW or less should have an efficiency of at least 30 %; for a simmering burner with a nominal heat output of

1,4 kW the efficiency must be at least 45 %. A simmering burner of 0,4 kW nominal heat output must be able to keep an aluminium pan of 22 cm diameter and 14,3 cm height, filled with 3,68 kg of water, at 95 C in an environment where the temperature is 20 C. These are some of the essential points that need to be looked at, before starting the design of a stove. As and when data for wood-burning stoves become available the ad-hoc procedure of relying on gas range practice can be phased out.

4.3.3 Combustion Data on Wood

The next question concerns the nature of wood as a fuel. In the following table we find some data relevant to the combustion of wood (the data on European woods are taken from Brame and King 1967, the data on tropical firewoods are taken from Firewood Crops, National Academy of Sciences Washington D.C. 1980)

Name	Density kg.m ⁻³	Ash Content %	Combustion (upper) Value kJ.kg ⁻¹
Ash	736	0,6	18631
Beech	688	0,6	18841
Oak	832	0,4	18254
Fir	480	0,4	20180
Calliandra calothyrsus	650	1,8	19300
Emblica officinalis	750	2	21700
Anogeissus latifolia	900	4	20500
Acacia mearnsii	780	1,5	19500

Table 4.5 Combustion data on wood

Calculating Firewood Consumption

Which wood consumption corresponds to a gross heat output of

1 kW?

To get a heat flow of 1 kW (= 1 kJ/s), we must burn 1/19000 kg/s or about 50 mg (milligram) per second. Per hour this becomes $3600 \times 50 \text{ mg/h} = 180 \text{ g/h}$; so that we can say that: a fire of 1 kW consumes roughly 0,2 kg dry wood per hour.

Combustion Value and Heating Value

For most heating purposes, including cooking, the combustion upper value gives too high a figure. When one of the constituents of a fuel is Hydrogen, complete combustion of that fuel will result in the formation of water vapour. In the determination of the combustion value of a substance the amount of heat is measured that is required to cool the reaction vessel (bomb calorimeter) back to ambient temperature after a carefully weighed amount of the substance has been burnt in it. This means that most of the water vapour will condense and so contribute its heat of condensation. In cooking, except for the very first instant when the cold pan is placed on the fire, no condensation of water vapour takes place. It is therefore not very realistic to use the upper combustion value as a basis for efficiency calculations. For this reason we have the concept of heating value also called lower combustion value besides the upper combustion value. The heating value is the combustion value minus the heat of condensation of the water formed in the combustion process. The average Hydrogen percentage in wood is 6 %. That means that 1 kg of dry wood on the average contains 60 g of chemically bonded Hydrogen. When this is converted into water it forms an amount of water equal to:

$$\frac{2 + 16}{2} 60 \text{ g} = 540 \text{ g} = 0,540 \text{ kg of water}$$

As the heat of evaporation of water is about 2257 kJ/kg, we must subtract about 1220 kJ from the upper combustion value of wood

to get the heating value. (lower combustion value).

Moisture Content of Wood

When we use wood that is not oven dried we need more wood, depending on the moisture content. There are two ways in which the moisture content can be defined.

- a) On a dry wood basis: The moisture content is expressed as the fraction of the mass of dry wood. For example when we have wood with a moisture content on a dry weight basis of 30 % it means that 1,3 kg of this wet wood represents 1 kg of dry wood.

- b) On a wet weight basis: The moisture content is given as the fraction of the weight of the wet wood. For example if we have wood with a moisture content of 30 % on a wet weight basis that means that $100/(100 - 30) = 1,43$ kg of wet wood represents 1 kg of dry wood.

We can see that the moisture content on a wet weight basis gives a more flattering figure.

As to the influence of the moisture on the heating power of wood; the heat of evaporation of the moisture that is present in the wood will have to be supplied by its heat of combustion, thus subtracting from the useful heat.

A further serious consequence of high moisture content in firewood is that on the one hand the heat demand of the moisture may lower the temperature of the volatiles to below their ignition point (the fire smokes and will not burst into flame) while on the other hand the moisture can dilute the volatiles to such an extent that they will not catch fire. In both cases the fire smokes which means that only the heat of combustion of the charcoal remaining after the volatiles have been driven off (about 25 % of its dry mass), will

become available for cooking. In such a case an amount of wet wood corresponding to 1 kg of dry wood, will only supply the amount of heat of:

$$0,25 \times 30 \text{ MJ} = 7,5 \text{ MJ}$$

instead of about 20 MJ for perfectly dry wood.

This is the combustion value of wet wood. To obtain the heating value we have to subtract the heat of evaporation of the water.

This comes to about 22,6 kJ for each percentage point of moisture on a dry weight basis.

Pyrolysis Products of Wood

Pyrolysis means chemical decomposition under the influence of heat.

When wood is heated in absence of air, a mixture of gases and vapours and small droplets of heavier liquids is given off. The main products are listed in table 4.6 below.

Product	Yield per 1000 kg dry wood	
	Rich wood	Lean wood
Charcoal	276 kg	275 kg
Refined turpentine	26,1 l	13,7 l
Pine oil	7,45 l	2,48 l
Resin spirit	13,0 l	7,45 l
Resin oil	87 l	40 l
Creosote oil	28 l	13,0 l
Methanol	3,73 l	6,21 l
Acetic acid	11,25 kg	13,1 kg
Pitch	87,5 kg	39 kg

Table 4.6 Solid and liquid pyrolysis products

In addition, according to the source (Brame and King 1967), 'a considerable amount' of flammable gas is produced with the following composition.

Gas	Formula	Volume %
Carbon dioxide	CO ₂	30
Gaseous hydrocarbons	C _n H _m	8
Carbon monoxide	CO	35
Hydrogen	H ₂	11
Methane	CH ₄	12
Nitrogen	N ₂	4

Table 4.7 Gaseous pyrolysis products

The composition of the products may be important when means are available to set up a wood gas plant. The gases that are produced constitute an excellent fuel for cooking. Besides, a number of the liquid products have considerable trade value while others could be used as liquid fuel. The solid remains of the process, charcoal, is an excellent solid fuel, burning easily and without smoke or smell. Charcoal also is a very good adsorbing agent and can be used for making activated carbon.

4.3.4 Air Requirements and Flue Gas

From the elementary analysis of wood we can get figures for the theoretical air requirements for complete combustion. When we want to find out which part of the air is required for the combustion of the solid part and which for the volatiles, we can get an idea from table 4.6. As it does not appear desirable to do the calculations here it may suffice to sketch the procedure and give

the results. On the average wood contains around 50 % of its dry mass of Carbon, 43 % of Oxygen and 6 % Hydrogen. The end products of complete combustion are assumed to be carbon dioxide and water. The Hydrogen in the wood is assumed to combine with the Oxygen in the wood, this leaves a remainder of Hydrogen for which air is required. One molecule of Carbon needs one molecule of Oxygen and one molecule of Hydrogen needs half a molecule of Oxygen. Air consists of 21 % by volume of Oxygen, the remainder is mainly Nitrogen. The results of such a calculation are as follows:

1 kg of wood needs 1,4 kg or 0,98 m³ of Oxygen at standard temperature and pressure (STP)

1 kg of wood needs 4,6 m³ air at STP.

Note: STP is short for Standard Temperature and Pressure, which means a temperature of 273 K and a pressure of 101,3 kPa.

For our calculations we are probably sufficiently accurate if we assume that the theoretical (stoichiometric) volume of air to completely burn 1 kg of dry wood is 5 m³ at or near sea level (see next paragraph).

Effect of Elevation on Pressure and Density

All results in the following paragraphs are obtained assuming the ambient pressure to be at its standard value. In all practical applications this is sufficiently accurate **except for places at high elevation**. The pressure and the density of the ambient air decrease as the elevation increases as shown in Table 4.8.

Elevation Above sea level m	Air pressure and density relative to same at sea level
0	1,00
500	0,944
1000	0,892
1500	0,842
2000	0,795
2500	0,751
3000	0,709
4000	0,632
5000	0,564

Table 4.8 Effect of elevation on air pressure and density

Excess Air

How much excess air is needed so that we can be assured of complete combustion? From coal fired steam boiler practice we know that excess figures of 1,2 to 1,4 are used (this means 1,2 to 1,4 times the stoichiometric amount). We must note, however that the air supply to a stove is provided by natural draft. In such systems the mixing is not as good as it will be in forced draught steam boilers. Hence excess air requirements can be expected to be higher, say 1,6 to 2.

Primary and Secondary Air

As pointed out in section 4.2, part of the air burns the charcoal and another part of the air burns the volatiles. The easiest way to estimate the relative amounts is to begin with the charcoal. From table 4.6 we conclude that not more than 27 % of the wood becomes charcoal. If this also holds true under the conditions obtaining in a fire, we need primary air only for this 27 % charcoal. For one kilogram of wood we will therefore need 2,7 m³ of primary air and 2,3 m³ of secondary air. When we take an

excess figure of 1,8 the practical figures become:

For 1 kg of dry wood:

4,8 m³ primary air

4,1 m³ secondary air

We should remark that most of the stoves described in chapter 3 do not use separate secondary air, the single current of inflowing air serves both primary and secondary combustion. Considerable experimentation will be necessary before one can obtain definite numbers for the required air flow.

Combustion Volume

Any combustible gas needs a certain volume in which to react with air to form gaseous combustion products and heat. For a fixed flow of gas the volume required becomes smaller as the gas and air are more fully pre mixed and as the walls that enclose the volume are hotter. From preliminary observations on an experimental woodstove that draws in secondary air, -serious experimentation on this stove has not yet begun-, we may venture one figure. In the steel pipe section that forms the combustion chamber and which has an inside diameter of 100 mm, a region of not more than 150 mm high seems to be occupied by the flames. This stove has a heat output of about 1,9 kW and the walls of the combustion chamber have a temperature of between 300 and 400 °C.

For good combustion in a hot chamber with a reasonable supply of secondary air this experimental result suggests:

a combustion volume of 0,6 l/kW

Needless to say, the evidence for this value is at present quite weak.

4.3.5 Grates

From experiments on open fires and on one metal stove we have some figures on grates. Although these figures only apply strictly to the conditions under which the experiments were conducted, we may get some indication as to the order of magnitude. Fires of up to 6,7 kW were built on a grate of 135 mm diameter. This was in a metal stove with a 2 m chimney. Open fires of up to 6.3 kW were built on a 260 mm diameter grate. This may demonstrate the effect of the chimney draught on the combustion intensity on a grate. By extrapolating we tentatively suggest:

With chimney	50 W.cm ⁻²
No chimney	10...15 W.cm ⁻²

4.3.6 Chimney Draught

A chimney should not be considered as merely a means to get rid of the products of bad combustion. In a stove of good design a chimney is a necessary part with the task of providing draught to draw the air into the combustion volume and to overcome the various flow resistances in the stove. In a well designed stove the chimney is an essential part.

The draught, which is an underpressure, created by the chimney is a function of height of the chimney and the temperature of the flue gases that course through it. Table 4.11. gives the static draught per meter chimney height (at sea level) as function of the average temperature of its contents and of the ambient temperature. For operation at elevations over 1500 m multiply the specific chimney

draught by the coefficient from table 4.8.

A chimney should be designed in accordance with the rate of flow of the flue gases, hence on the output of the fire in the stove. In the preceding sections we have given figures for the amount of flue gas produced by the combustion of 1 kg of wood under specified circumstances.

Specific Volume Flow of Air

Let us calculate the volume flow of the combustion gases that we can expect from a 1 kW wood fire. We know from previous calculations that this power is equivalent to a dry wood consumption of 50 mg/s, which is 0,18 kg/h. For this consumption we need combustion air at the rate of:

$$50 \times 10^{-6} \times 9 \text{ m}^3/\text{s} = 0,45 \text{ l/s}$$

Volume Flow of Flue Gas

How much flue gas do we get from that? That is a matter of moisture content of the wood and the temperature of the flue gas (this may be over 900 C near the fire and as low as 150 C in the chimney). Assuming an air excess factor of 1,8 we obtain:

$$V' = \frac{0,58 (3,2634 + 0,4532 \times a) (273 + t)}{99,48 (1 + a) + 1064,2} \text{ l.s}^{-1}.\text{kW}^{-1}$$

where:

V'	is the volume flow	l/s
a	is the moisture content on a dry weight base	—
t	is the fluegas temperature	°C

The results are shown in table 4.9 for different values of t. It turns out that the influence of the moisture content when that is varied from 0...50 % is very slight, no more than a few percentage points. In the table therefore the average values have been entered.

Flue gas temperature C	Flue gas flow litre/s ⁻¹
1000	2,11
900	1,94
800	1,77
700	1,61
600	1,44
500	1,28
400	1,11
300	0,95
200	0,78
150	0,70
100	0,61

Table 4.9 Flue gas flow in l/s for a 1 kW wood fire

In the table the right column tells the story of the flue gas as it passes from one section to an other through the stove and we see that the volume flow of the hottest gas is about 3 times that of the coolest gas in the table.

Dynamic Pressure Loss

The flue gas has to pass through the chimney. The cross-section of the chimney has to be chosen with some care. If it is too small much of the draught will be spent in overcoming flow resistances in the chimney and into the kinetic energy losses of the gas on issuing in the surroundings. If the cross sectional area of the chimney is too large, the hot gases may escape in globs or slugs without contributing to the draught. A good compromise seems to be to let the gases move through the chimney at an average velocity of 0,4 to 1 m/s. The kinetic energy loss Δh per kg gas being equal to:

$$\Delta h = \frac{1}{2} v^2 \text{ J.kg}^{-1}$$

The corresponding pressure loss Δp is given by:

$$\Delta p = \frac{1}{2} \rho v^2 \quad (4.5)$$

In the recommended range we therefore have a loss in draught from kinetic energy losses of:

$$\Delta p = (0,1 \dots 0,5) \rho \text{ Pa}$$

The density of fluegas has been calculated. We give the results in table 4.10.

Fluegas temperature °C	Fluegas density kg.m ⁻³
900	0,2956...0,3050
800	0,3232...0,3335
700	0,3564...0,3677
600	0,3972...0,4098
500	0,4485...0,4629
400	0,5152...0,5306
300	0,6051...0,6244
200	0,7330...0,7564
150	0,8197...0,8458

Table 4.10 Density of fluegas from the complete combustion of wood with the moisture content from 0 ... 50 % and an air excess factor of 1,4 ... 3,0

Specific Chimney Draught

The draught per meter chimney height depends on the density of the flue gas and on the density of the surrounding air. In table 4.11. the specific static chimney draught is given for the fluegas resulting from complete combustion of wood of a moisture content from 0...50 % and an air excess figure of 1,4...3,0.

Ambient temperature °C	Average fluegas temperature in chimney in °C			
	150	200	250	300
20	3,6	4,5	5,2	5,9
25	3,4	4,3	5,0	5,5
30	3,2	4,1	4,8	5,3
35	3,0	3,9	4,6	5,2
40	2,8	3,7	4,4	5,0

Table 4.11 Specific chimney draught in Pa/m as function of ambient and fluegas temperatures.

4.3.7 Flow Friction Factors

Most of the spaces in a stove where flue gases pass through have shapes that can, from a fluid dynamic point of view, be classified in one of the following categories.

- a) Straight channels of constant cross section
- b) Bends
- c) Sudden enlargement of passage
- d) Sudden reduction of passage

The loss in pressure is given via a coefficient f ; this coefficient is multiplied with the density ρ and the square of the velocity v of the flue gas divided by 2:

$$\Delta p = \frac{1}{2} f \rho v^2 \quad (4.6)$$

For straight channels of constant cross-section the friction factor is usually given per unit of length.

Flow Resistance of Stove Elements.

In fluid dynamics two regions of flow are known viz. laminar and turbulent. Laminar flow takes place at relatively low velocities. In engineering practice therefore, turbulent flow is usually encountered.

In domestic wood stoves however, it seems likely that we will encounter gas velocities of such small magnitude that the occurrence of laminar flow seems probable. On the other hand, as the passages are relatively short and the flue gas is the result of combustion in which much wild movement of gas takes place, it is likely that the flow is not stratified as in true laminar flow. Add to this the difficulty of measuring average velocities of this order of magnitude and we have some indication of why we can give so little in the way of hard figures.

If the passages in our stoves were to continue for a sufficient length, say 20 diameters, one could be much more sure about the character of the flow taking place.

We like to be able to take figures from engineering heat transfer practice and apply them to wood stoves. It is the experience from thermal engineering which brings home the importance of knowing the flow regime. For maximum heat transfer under given circumstances it is very important that the flow be turbulent and this can be made clear in a common sense way too.

In laminar flow, as the name suggests, flow takes place in orderly layers parallel to the walls of the conduit. Fluid particles follow paths at fixed distances from the walls. Hot particles far from the walls therefore have no opportunity to give off their heat by contact with the walls. In turbulent flow the fluid particles follow erratic paths with a main component in the stream direction but with random movements perpendicular to it. In turbulent conditions,

therefore, all fluid particles have a better opportunity of exchanging heat with the walls.

A criterion for the flow character is the value of a non-dimensional combination of physical quantities, some of which have to do with the properties of the fluid and others with the average velocity and with the dimensions of the passage. This combination of physical quantities is called Reynolds' number, Re for short, defined as.

$$Re = \frac{\text{density} \times \text{velocity} \times (\text{hydraulic}) \text{ diameter}}{\text{dynamic viscosity}} \quad (4.7)$$

In general it seems to be true to state the following:

If the conditions upstream of the observed passage were turbulent they will become laminar after sufficient length of this passage of constant cross-section has been traversed when the Re number is below 2300.

If the conditions upstream of the passage were laminar the flow will become turbulent after traversing a sufficient length if the Re number is above 2300.

As the passages are generally relatively short it is possible that no really laminar state is achieved. This may be an advantage as the heat transfer will be better than in the laminar state.

Straight Conduits

In straight passages of constant cross section flow resistance is due to friction. In general the magnitude of the pressure drop is directly proportional to the length and to the square of the velocity.

As the velocities we can expect in wood stoves are very low, there is some uncertainty as to the character of the flow we can expect. This determines to a great extent the value of the friction factor we can best employ. As in engineering practise conduits with a circular cross section are by far the most frequently used the values for friction factors were primarily derived for these. Thus an important parameter is the diameter.

For conduits with non-circular cross-section a quantity called the hydraulic diameter is defined as:

$$D_h = \frac{4 \times \text{cross-sectional area}}{\text{perimeter}} \quad (4.8)$$

For a passage with a square cross-section with sides of a cm the hydraulic diameter is:

$$D_h = \frac{4a^2}{4a} = a \text{ cm}$$

For a rectangular passage with sides a and b cm the hydraulic diameter is:

$$D_h = \frac{4ab}{2a + 2b} = \frac{2ab}{a + b} \text{ cm}$$

For straight channels of constant cross-section the pressure loss due to friction Δp is expressed as the product of a friction factor the length, the (hydraulic) diameter and the dynamic pressure:

$$\Delta p = \lambda \frac{L}{D_h} \frac{1}{2} \rho v^2 \quad (4.9)$$

where:

Δp	is the pressure loss	Pa
λ	is the friction factor	—
L	is the length of the passage	m
D_h	is the hydraulic diameter of the passage	m
ρ	is the density of the fluid	kg.m ⁻³
v	is the velocity of the fluid	m.s ⁻¹

The only question now concerns the correct value of the friction factor f . This again depends on the character of the flow, for turbulent flow other values obtain than for laminar flow. This, coupled to the uncertainty of the flow regime in the straight passages under consideration render it very risky to make predictions. The best one can offer at this stage is based on the pressure measurements (Nievergeld and Sulilatu 1981) at the TNO laboratories that were done during actual wood stove tests.

From these measurements a friction factor can be calculated with a value of:

$$\lambda = 2,5$$

In order to be able to calculate the pressure loss due to friction we have to know:

- a) The dimensions of the passage, length, width and height.
- b) The density of the flue gas from its temperature with the aid of table 4.10
- c) The velocity of the flue gas from the volume flow and the dimensions of the passage.

We can expect laminar flow to occur in chimneys. In that case the

friction factor is:

$$\lambda_e = \frac{64}{Re}$$

The viscosity η we assume to be:.

$$\eta = 16 \times 10^{-6} \text{ N.s.m}^{-2}$$

Sudden Contraction.

The important parameter here is the ratio of the two cross-sectional areas A_2/A_1 where:

A_2 is the cross-sectional area of the narrowed passage.

A_1 is the cross-sectional area of the original passage.

From an article by Kämmer (1980) the following relation between the passage cross-sectional area ratio and the pressure loss coefficient can be calculated:

Area ratio $\frac{A_2}{A_1}$	Pressure loss factor f_c
0,2	0,015
0,4	0,048
0,5	0,057
0,6	0,070
0,7	0,060
0,8	0,050
0,9	0,014

Table 4.12 Pressure loss factors for sudden contraction

The pressure loss in this case is calculated by multiplying the dynamic pressure in the original passage with the pressure loss

coefficient:

$$\Delta p_c = \frac{1}{2} f_c \rho v^2 \quad (4.11)$$

Flow Through a Hole

This is a special case of sudden narrowing of the passage where the ratio of cross-sectional areas approaches the value of zero. The fluid velocity upstream of the hole is practically zero.

The formulae for sudden contraction can therefore not be applied. The flow through the hole will then be determined by the difference of static pressure between the upstream and the downstream sites of the hole:

$$p_1 - p_2 = \frac{1}{2} \rho v^2 \quad (4.6)$$

It is often important to know the volume flow V' through the hole:

$$V' = A_2 \left\{ \frac{2 (p_1 - p_2)}{\rho} \right\}^{1/2} \quad (4.12)$$

where:

A_2	is the cross-sectional area of the hole	m^2
p_1	is the static pressure upstream of the hole	Pa
p_2	is the static pressure downstream	Pa
V'	is the volume flow through the hole	m^3s^{-1}
v_2	is the velocity of the fluid issueing from the hole	$m.s^{-1}$
	is the density of the gas	$kg.m^{-3}$

Sudden Expansion.

The pressure loss as a result of sudden enlargement of the passage is due mainly to the loss of dynamic pressure that occurs when the flow from the original passage fills the larger passage. Hence the pressure loss factor is expressed in the cross-sectional areas of the passages.

$$f_e = \left\{ \left(\frac{A_1}{A_2} \right)^2 - 1 \right\}^2 \quad (4.13)$$

The pressure loss is obtained, just as in the preceding paragraph by multiplying the pressure loss factor with the dynamic pressure in the original flow.

Pressure Loss in Bends.

The pressure loss in bends depends on the geometry of the bend as well as on the presence of straight passages downstream of the bend. The pressure loss is expressed in the usual way only now with two pressure loss factors, f is the pressure loss coefficient resulting from the geometry while f_2 is the coefficient which takes into account the presence or otherwise of a straight downstream passage. For a straight downstream passage with a length of 4 hydraulic diameters or less, $f_2 = 1.4$, otherwise $f_2 = 1$. The bend pressure loss coefficient can be read from figure 4.22.

$$\Delta p_b = \frac{1}{2} f_1 f_2 \rho v^2 \quad (4.14)$$

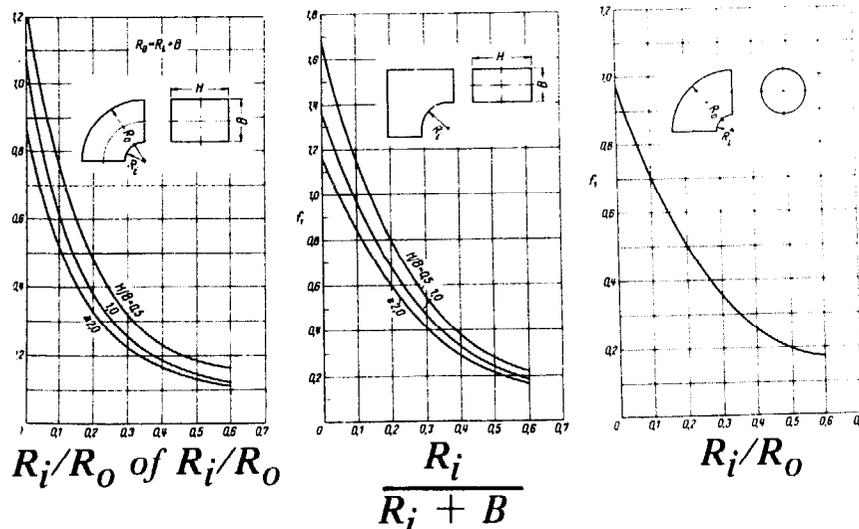
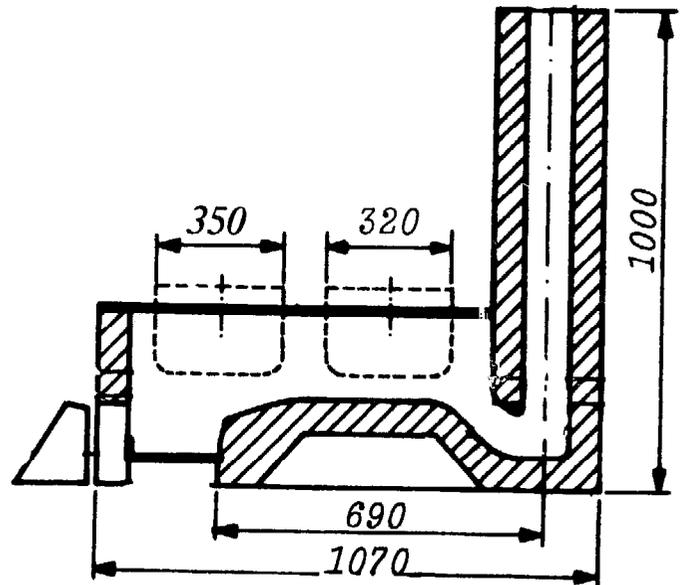
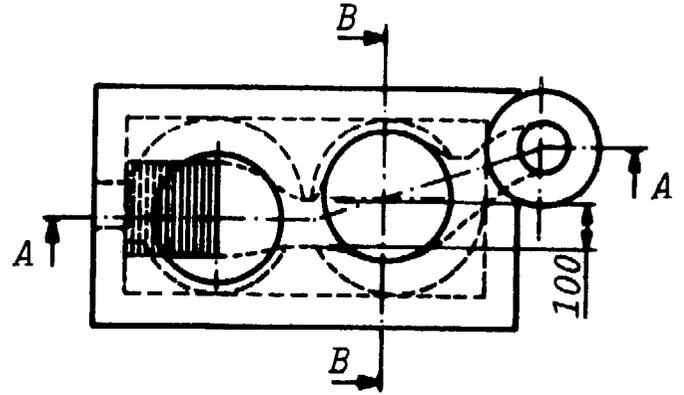
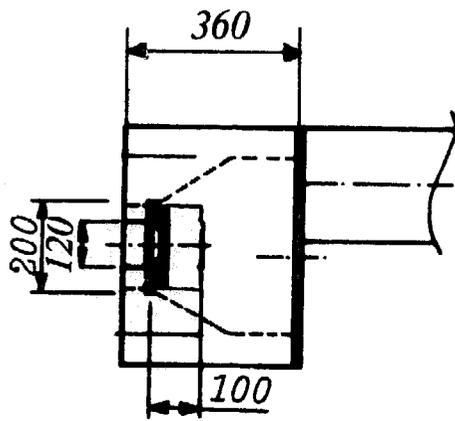


Fig. 4.22 Pressure loss factors for bends (From Kämmer 1980)

4.3.8 Design Exercise

In order to illustrate the use of the material presented in the foregoing chapters we will run through the steps of designing a

CH2-10



section A-A

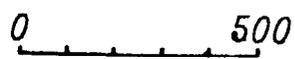


Fig. 4.23 Sketch of Pogbi Stove

woodstove. In this case we restrict ourselves to advising on the possible improvements to an existing stove. As a matter of fact we have actually been requested to give suggestions on this particular stove. It concerns a heavy clay stove with two pan holes, the Pogby Stove (CH2-10).

4.3.8.1 Required Heat Input

From fig. 4 we see that the pan holes are 0,35 m and 0,32 m respectively. If we consider the large pan only and take the required heat input from table 4. (Pan size and burner power) we arrive at a net heat input of:

$$0,5 \times 7 \text{ kW} = 3,5 \text{ kW}$$

We do not take the recommended burner heat output because we cannot expect the same efficiency from the woodstove. If we assume a good efficiency of say 30 % we obtain a required heat output of the fire P of:

$$P = \frac{3,5}{0,30} = 12 \text{ kW}$$

Combustion Volume

We assume the wood to have a cross section of about 30 mm. We also assume the firebed to be only one layer thick. Thus 30 mm of the available space between grate and pan will be taken up by the fuelbed. The remaining space is available as combustion space.

According to the tentative figures the required volume is 0,62 dm³ per kW so that we will need a volume V of:

$$V = 12 \times 0,62 \text{ dm}^3 = 7,44 \text{ dm}^3 = 7740 \text{ cm}^3.$$

Volume Flow of Fluegas

The amount of wood consumed per unit time (from the combustion

data) for a 12 kW fire is:

$$\frac{12}{19.000} = 632 \times 10^{-6} \text{ kg.s}^{-1} \text{ or } 632 \text{ mg/s}$$

Assuming an air excess figure of 1,8 we get an air consumption at 12 kW heat output of:

$$632 \times 10^{-6} \times 5 = 3,158 \times 10^{-3} \text{ m}^3.\text{s}^{-1} \text{ or } 3,16 \text{ l.s}^{-1}$$

This is at atmospheric pressure and ambient temperature (30°C). The volume flow of hot flue gas is much larger depending on its temperature. If we assume its temperature upon leaving the combustion chamber to be 700 °C then the volume flow at that point is:

$$\frac{700 + 273}{303} 3,158 \times 10^{-3} \text{ m}^3.\text{s}^{-1} = 10,14 \times 10^{-3} \text{ m}^3.\text{s}^{-1} \text{ or } 10,14 \text{ l.s}^{-1}$$

Chimney (cross-section and loss)

The easiest way to arrive at a chimney diameter is by trial and error. We choose a diameter and calculate the losses. If they are excessive we choose a larger diameter. We try a diameter $d = 0,1 \text{ m}$. The mean volume flow (at 225 °C) we take from table 4.9.

That is $0,78 \times 10^{-3} \text{ m}^3.\text{s}^{-1}.\text{kW}^{-1}$

For our 12 kW fire we obtain:

$$V' = 12 \times 0,78 \times 10^{-3} = 9,36 \times 10^{-3} \text{ m}^3.\text{s}^{-1}.$$

The resultant velocity v is:

$$v = \frac{V'}{A} = \frac{9,36 \times 10^{-3}}{\frac{1}{4} \pi (0,1)^2} = 1,19 \text{ m.s}^{-1}$$

The Reynolds number then is:

$$\text{Re} = \frac{\rho v D}{\eta} = \frac{0,63 \times 1,19 \times 0,1}{16 \times 10^{-6}} = 4886$$

Which means the flow in this chimney is turbulent. In this case we work with a friction factor:

$$\lambda_t = 0,02.$$

The total pressure loss results from friction as well as from kinetic energy loss. The total loss is then:

$$\begin{aligned} \Delta p &= \frac{1}{2} \left\{ \frac{L}{d} \lambda_t + 1 \right\} \times \rho \times v^2 = \\ &= \frac{1}{2} \left\{ \frac{1}{0,1} \cdot 0,02 + 1 \right\} \times 0,635 \times 1,19^2 = 0,54 \text{ Pa} \end{aligned}$$

which means we have nearly 4 Pa left over for overcoming the friction under the pan.

Note: with a chimney of 70 mm inside diameter the pressure loss would have been about four times what we just calculated.

Pressure Losses after the Second Pan

The flue gas after leaving the passage under the second pan will have to be channeled into the chimney. That involves narrowing of the passage and a change of direction from horizontal to vertical.

a) **The converging passage.**

We assume the passage under the second pan to be of equal width as the pan. This passage has to converge gradually to a square passage with sides equal to the inside diameter of the chimney, we shall assume that to be 100 mm. If carefully made we shall assume no pressure loss in this part.

b) **The bend.**

As we can see from the diagrams of figure 4.23 the loss factor depends to a great extent on the shape of the bend. In our case it seems feasible that we can build a passage with a curved roof and a flat rear side. Then it would look most like the center figure. If we can make the radius of curvature around 50 mm (see figure 4.23) R_i becomes 50 mm. With $H/B = 1$ we get:

$$\frac{R_i}{(R_i + B)} = \frac{50}{(50 + 100)} = 0,33$$

In the figure we find a corresponding bend friction factor:

$$f_1 = 0,4$$

The second friction factor is equal to 1 as the downstream passage stretches out for more than 4 hydraulic diameters. The pressure loss in this bend is calculated with the density corresponding to a temperature of 225 °C (interpolated from table 4.10) of 0,66 kg.m⁻³. According to equation (4.14) the pressure drop in the bend is:

$$\Delta p_b = 0,4 \times 1 \times \frac{1}{2} \times 0,66 \times (1,19)^2 = 0,19 \text{ Pa}$$

Net Available Draught

The net chimney draught available to the stove after subtracting the pressure losses in the chimney and the bend is found by adding the values just calculated and subtracting the sum from the gross chimney draught. Interpolating in table 4.11 for a flue gas temperature of 225 °C we obtain a gross specific draught of 4,5 Pa (at sea level) As our chimney is just 1 m tall, this is also the figure for the gross draught of our chimney. The nett draught p_n then becomes:

$$p_n = 4,5 - 0,54 - 0,19 = 3,77 \text{ Pa}$$

Fuel

Our next steps are very much determined by the shape of the fuel. If long pieces of wood are used and if there are objections to cutting it up into shorter pieces we can not control the airflow into the combustion space, it obviously cannot be closed with sticks of wood protruding from the charging port.

a) Long Fuel.

As sketched above, with long fuel we have no means of controlling the air intake upstream from the fire. This means that the chimney draught must be controlled. We must prevent the flames being drawn away from under the first pan by the chimney draft. It will therefore be necessary to have a chimney damper. However, in order to use the chimney draught constructively we may look into a way to locate most of the flow resistance under the second pan to increase the heat transfer. At the fire space the chimney draught must be just sufficient to draw away the combustion gases. On the one hand the fire must be able to burn freely without the flames being drawn into the flue. On the other hand the draught at the end of the combustion space must be sufficient to prevent flames issuing from the charging door.

b) Short Fuel.

When using short fuel one can have a charging port that can be closed with a door. That opens a possibility to control the air flow to the fire above the fire bed, the so-called secondary air. In this case part of the net chimney draught can be used for drawing air into the fire. The grate can consequently be made smaller and we will have air leakage into the stove from the gaps of both pans. We need dampers for primary and secondary air. The question arises if we need a chimney damper. It seems not, the flow should be sufficiently controlled by the air dampers.

Grate.

As we will see, the grate dimensions for a certain heat output depend very much on whether the stove is chimney aspirated or not. We will do the calculations for both cases.

a) Long Fuel.

We would advise a grate with a separate damper door to be able to control the airflow to the grate. This will to some extent control the output of the fire. As the fire is naturally aspirated, the aeration conditions for the grate are comparable to that for the open fire with a grate. From the limited data available, we tentatively suggest a figure of $120 \text{ kW}\cdot\text{m}^{-2}$. This would result in a grate surface area of $0,1 \text{ m}^2$ or 1000 cm^2 . To fit into a space with a width of 12 cm the depth would become impractically large, 80 cm. The fire would not fit under the first pan and it would be very difficult to manipulate the firebed.

We therefore enlarge the width of the firebed to the limit (pan diameter) of 33 cm. The depth of the grate then becomes 30 cm. The width of the charging door can be left unaltered at 20 cm.

With a surface area of the combustion chamber base (the grate) of 1000 cm^2 , the required gap between the top of the firebed and the pan bottom would become 7,4 cm. Thus the required vertical distance between grate and pan bottom h would become:

$$h = 7,4 + 3 = 10,4 \text{ cm or } 104 \text{ mm}$$

If we are to keep the outside dimensions of the stove as they are then the grate would have to rise about 74 mm from its present position.

b) Short Fuel.

With some of the chimney draught available for drawing in air the grate area can be reduced compared to the situation for long fuel. The figure we can use for grate load now lies between the figure obtained for the open fire with a grate and the figure stated for the chimney aspirated fire. However, that figure was obtained with a 2 m chimney. The difference between the grate loads is 35 W.cm^{-2} , which we might consider to be caused by the 2 m chimney. As our chimney is only 1 m and if we assume other circumstances to be comparable, the 35 W.cm^{-2} is caused by the 2 m chimney. If our 1 m chimney creates half the net draught of the 2 m one, then the extra air drawn through the grate by our chimney would be about the square root of 2 times the amount of the 2 m chimney. In that case however, we have no draught left over for overcoming the flow resistance under the pan. If we now decide to use half the net available draught for aspirating the fire and half for drawing the flue gas through the passage under the second pan, we have a quarter of the draught available that in section 4.3.5 added 35 W.cm^{-2} to the grate load. That means only half the air flow will be drawn through the grate.

So that we may expect a grate load of:

$$12 + 17,5 = 29,5 \text{ W.cm}^{-2}$$

For our 12 kW fire we need a grate area A_g of:

$$A_g = \frac{12 \times 10^3}{29,5} = 406 \text{ cm}^2$$

If we keep to the original width of the combustion space of 12 cm we need a depth of 34 cm.

It will probably be more practical to have a more or less square grate in which case we come to sides of 20 cm.

Grate dimensions: 20 x 20 cm.

The dimensions of the grate are far smaller than the panhole diameter. Therefore the dimensions of the combustion space will remain practically unaltered. The only variables are the position of the grate in the horizontal plane and its height relative to the pan bottom.

It will probably be advantageous to have the grate as near to the front of the stove as possible. In case of high chimney draught the flames may in that case still come in contact with the bottom of the first pan. If we take the area of a horizontal cross-section of the combustion chamber to be equal to the panhole area (of 962 cm²), the height h of the pan bottom above the grate, taking into account a firebed thickness of 3 cm, becomes:

$$h = \frac{7580}{962} + 3 = 10,9 \text{ cm} = 109 \text{ mm}$$

Passage Under Second Pan

a) Long fuel.

Here all net chimney draught can be used for creating a high velocity under the second pan. If we take the passage to be 32 cm wide and 32 cm long the only dimension that remains to be derived is the height b . For this we have to solve equation 4.9. For reasons that will become clear later we do not fill in the pressure loss Δp . The density we obtain from table 4.10. For the temperature we take the average of the temperature with which we assumed the flue gas to leave the fire (700 °C) and the temperature at which it enters the chimney (according to our assumptions 250 °C). This gives a figure of 475 °C and we interpolate the density as:

$$\rho = 0,46 \text{ kg.m}^3$$

With the specific volume flow we can express the velocity v in

the dimensions of the passage:

$$v = \frac{V'}{(0,32 b)}$$

When b is the height of the passage.

For 475 °C the specific flue gas flow (table 4.9) is
1,25 l.s⁻¹.kW⁻¹

Multiplied with the fire power of 12 kW we get a flue gas
flow of 15 l.s⁻¹ or 15 x 10⁻³ m³.s⁻¹.

Substituting all these values into equation 4.9 and after
regrouping we get the following expression:

$$\Delta p = 2,5 \times 0,32 (0,64 + 2b) \times 0,5 \times 0,46 \times 4 \frac{(15 \times 10^{-3})^2}{(0,32 b)^3}$$

The easiest way to obtain an approximate solution is to
calculate Δp for a few values of b . When using a pocket
calculator it does not take long. After a few trials we find:

$$b = 3 \text{ cm: } \Delta p = 8,19 \text{ Pa}$$

$$b = 3,5 \text{ cm: } \Delta p = 5,19 \text{ Pa}$$

$$b = 4 \text{ cm: } \Delta p = 3,55 \text{ Pa}$$

$$b = 4,5 \text{ cm: } \Delta p = 2,53 \text{ Pa}$$

So that we can have a little draught to spare if we make

$$b = 4 \text{ cm}$$

b) Short fuel.

Here we have only half of the pressure available for drawing
the flue gas through the passage under the second pan. The
length and width of the passage are the same as in the
preceeding paragraph. We therefore continue the calculations
for higher values of b .

$$b = 5 \text{ cm: } \Delta p = 1,87 \text{ Pa}$$

$$b = 5,5 \text{ cm: } \Delta p = 1,42 \text{ Pa}$$

$$b = 6 \text{ cm: } \Delta p = 1,11 \text{ Pa}$$

$$b = 7 \text{ cm: } \Delta p = 0,72 \text{ Pa}$$

As we have an available draught of:

$$\frac{1}{2} \times 3,77 = 1,89 \text{ Pa}$$

The height $b = 5 \text{ cm}$ will do nicely.

Provisions for Secondary Air

It might be possible to let air into the combustion chamber above the fuel bed to try to assist the combustion of the volatiles. In that case the best material for the combustion chamber would be fairly thin walled ceramic. Around this combustion chamber there would have to be an air space enclosed by the stove body. A damper would be used to control the secondary air flow.

How much secondary air do we need?

According to the section on primary and secondary air, 1 kg of dry wood needs $4,14 \text{ m}^3$ of secondary air. As our fire consumes $632 \text{ mg}\cdot\text{s}^{-1}$ of dry wood, the secondary air flow becomes:

$$V'_S = 632 \times 10^{-6} \times 4,14 = 2,6 \times 10^{-3} \text{ m}^3\cdot\text{s}^{-1} \text{ or } 2,6 \text{ l}\cdot\text{s}^{-1}$$

a) Long Fuel.

Here we have no chimney draught to pull secondary air into the combustion chamber. We can however make use of the bouyancy of the air around the combustion chamber inside the stove. To that end we must make an intelligent guess at the temperature of that air. If we assume it to take on a temperature of $200 \text{ }^\circ\text{C}$, we must make holes in the upper part of the combustion chamber of such total cross-sectional area

that enough air will be pushed through by its own bouyancy. Where (how high up) can we make the holes? Looking at the drawing of the stove we see that the bottom of the first pan comes to a level of 260 mm above ground. If we take 250 mm to be the highest level at which we can situate these holes we have a column of warm air of 200 mm if we reserve 50 mm for a damper. If we take the temperature of the ambient air to be 30 °C, its density ρ_a will be around:

$$\rho_a = \frac{29}{22,4} \times \frac{273}{(273 + 30)} = 1,17 \text{ kg.m}^{-3}$$

The density of the warm air ρ_{200} will be:

$$\rho_{200} = \frac{29}{22,4} \times \frac{273}{(273 + 200)} = 0,747 \text{ kg.m}^{-3}$$

The difference in weight of the 200 mm tall columns of cool, respectively warm air will create a pressure difference p of:

$$\Delta p = g z (\rho_{30} - \rho_{200}) = 9,81 \times 0,2 \times (1,17 - 0,747) = 0,82 \text{ Pa}$$

The velocity with which the warm air will flow through a hole is found from the expression:

$$v = \left\{ \frac{2 \Delta p}{\rho_{200}} \right\}^{1/2} = \left\{ \frac{2 \times 0,82}{0,747} \right\}^{1/2} = 1,48 \text{ m.s}^{-1}$$

Now we must get a volume flow of 2,6 l.s⁻¹ (at 30 °C) through the holes. At 200 °C this volume flow becomes:

$$V'_s = \frac{273 + 200}{273 + 30} \times 2,6 = 4,06 \text{ l.s}^{-1}$$

To do that at a velocity of 1,48 m/s we must have a total cross-sectional area of the holes of:

$$A_h = \frac{4,06 \times 10^{-3}}{1,48} = 2,743 \times 10^{-3} \text{ m}^2 \text{ or } 27,4 \text{ cm}^2$$

If we should make holes of 11,5 mm diameter, we would have to make about 28 of these holes which seems feasible.

b) Short fuel.

The procedure is exactly as above except that we have a lower pressure in the combustion chamber of 1,9 Pa. The total available pressure difference for pushing the secondary air through the holes is:

$$\Delta p = 1,9 + 0,82 = 2,72 \text{ Pa}$$

Wich will give a velocity v

$$v = \left\{ \frac{2 \times 2,72}{0,747} \right\}^{1/2} = 2,70 \text{ m.s}^{-1}$$

With this velocity the required total cross-sectional area of the holes becomes:

$$A_s = \frac{4,06 \times 10^{-3}}{2,70} = 1,504 \times 10^{-3} \text{ m}^2 \text{ or } 15,04 \text{ cm}^2$$

If we make the same number of holes (28) as in the preceding case that will ensure good mixing of the air and the volatiles which in turn ensures good combustion. The mixing being the result of the higher air velocity. the hole diameter d_h in this case will be:

$$d_h = \left\{ \frac{(4 \times 15,04)}{(3,14 \times 28)} \right\}^{1/2} = 0,83 \text{ cm}$$

So the holes can be made about 8,5 mm.

5

Stove testing

By G. De Lepeleire.

5.1 Why test woodstoves

- to learn about woodstoves and to understand how they work
- to make a choice out of possible alternatives in stove design
- to report results for evaluation.

In this way experience can circulate, at least if misunderstanding is avoided.

5.2 How to test a cooking stove

Stoves are used in many different ways and should be tested accordingly. Now each individual can find out his own way of doing things and spend a lot of time on this. Alternatively one can use 'standard' procedures and concepts as discussed and adopted

by many people. The latter way saves time and effort in stove testing. Moreover if well specified standard procedures are used the reported results can be understood by other people involved in stove design and use. Obviously time and effort will be saved not only when testing woodstoves, but in designing too. In principle the best test procedure seems to be the one that is as close as possible to local operating conditions. However, simplified procedures can speed up testing and make the transfer of experience possible. In practice more than one kind of test shall be used. Anyhow, it is preferable that there be some consensus on concepts and procedures. Some 'standard' would be profitable to everybody.

In recent years woodstoves and woodstove testing have been worked on by different authors, for example Stephen Joseph (1980) and others. Their work was not ignored when the present proposals were drafted. Note that here only field testing by field workers and users are meant. The problem of woodstoves can be looked at from different viewpoints. Scientists often look for highest accuracy and sharp analysis: this is said to be the scientific approach. Policy makers are worrying about ecological and makro-economic disasters and ask the scientists for advice. The end users have other arguments: they are looking for increased comfort and their own micro-economic advantage, for example by wood saving. They are right. It would be fine if these different concerns could be synchronised: there is no fundamental contradiction. A useful concept to quantify the performance of a woodstove should combine different basic qualities.

- 1) It should be clearly defined and understandable not only to scientists but to policy makers and users too.
- 2) It should be easily measured and reported.
- 3) Be reproducible within reasonable limits.

- 4) It should be a simple guide to all the people involved, mainly to the users of woodstoves.

To appreciate performances of an engine or heating equipment engineers are used to talk in terms of efficiency, a dimensionless ratio, for example of a useful output to input. It is mostly applied in sharply defined steady state conditions. However, it has been shown that with woodstoves severe problems arise, not only to find out what is the useful output (this is very close to zero with simmering processes) but also to specify exactly what is the input at a given time. This has to do with the fact that the cooking process has a complicated scenario, often split up in different phases of operation with a transition in between. Moreover things happen in a discontinuous way and heat is stored in and released from the stove body with 'time constants' that can be important as compared to the cooking process duration. Wood charging and burning, heat transfer and the cooking process progression all happen in a way difficult to identify and to predict. The operator cannot and will not arrange a continuously controlled steady state system for the ease of engineers and scientists. It's perhaps disappointing, but true: an engineer, looking for the right spot to check the efficiency of the stove is in a rather uncomfortable situation. It is not astonishing at all that a simple efficiency concept (copied from steady state equipment) expressed as a ratio of useful output to input energy fails. This simplification applied to woodstoves has resulted in a lot of misunderstanding, false beliefs and publicity.

Let's try something else and first formulate the problem. The user has a limited choice: she has to run a kitchen. The kitchen program is often ruled by basic food as dictated by local agricultural potentials, social habits and taste. Very

different cooking processes are involved. For simplicity we can consider the following categories:

- 1) To raise the temperature of water and/or food, and stop. This is the simplest operation. Examples are: boiling water for tea or to warm up food that has been processed earlier.
- 2) **Boiling:** after raising the temperature of food (and water) the temperature must be maintained for a period of time, to achieve some physico-chemical changes in the processed food. The cooking time and fuel consumption drops significantly when the processing temperature is raised. Under atmospheric pressure however the temperature is limited to about 100 °C.
- 3) **Frying:** can be said to be similar to cooking, but oil is used instead of water. Processing temperatures are higher, times in general shorter than with cooking. As food in general contains lots of water, its bulk temperature keeps close to 100 °C.
- 4) Other processes like baking, grilling, etc. Food is heated by radiation and/or conduction in general from a source at relatively high temperature.
- 5) Finally other services may be rendered by a woodfire such as hotwater service, drying, space heating and lighting.

Note that the kitchen program -a scenario of cooking processes- is performed in given conditions (climatic environment, available wood or similar fuels) using specific equipment (cooking pans, woodstoves, ways of cooking). Whereas the engineers' efficiency concepts fail to specify what happens in a kitchen, the concept of **specific wood**

consumption may offer a way out. It can and should be applied at various levels: over longer periods one can compute a specific day consumption, as observed in actual cooking. A closer understanding can result from a systematically organised standard meal test. Finally, water boiling tests allow to speed up testing to identify the influence of single influencing parameters.

5.3 Kitchen performance

(as observed from actual cooking, and expressed in specific day consumption (kg/person.day)). Wood consumption and saving is a year round, complex affair. Direct observation is the right way to be correctly informed on the energetic kitchen performance.

Obviously the larger the family and the longer the time period under consideration, the higher will be the wood consumption.

Therefore it seems adequate to specify the kitchen performance in terms of specific day consumption, it is the ratio of the consumed wood (in kg) to the number of persons in the family multiplied by the number of days involved.

$$\text{Specific day consumption} = \frac{\text{kg wood consumed}}{\text{number of persons} \times \text{number of days}}$$

Note that various circumstances have drastic influence on this specific consumption, such as the social context, the kitchen program, the cooking utensils (size and shape), the woodstove, the way of cooking, the quality of wood or other fuel, the climatic conditions, etc. All this is to be taken into account when a specific day consumption as defined is to be evaluated or reported. For reporting, one might use a presentation as in the appended forms:

- G : general conditions
- E : cooking pots and woodstove equipment
- D : kitchen observation report.

To count the number of persons and the number of days is rather easy: you need no equipment for this.

To measure the wood input, use a suitable balance, for example a spring balance (cfr equipment).

Note that the weight of wood is the only significant indication, not volume or bushels or other local units. Be sure to get all of the inputs in the kitchen area, which therefore should be sharply defined. Look for any kind of fuel used besides wood such as agricultural waste, cow dung etc.

Report commercial fuels too (kerosene, bottle, gas, etc.) in kg. Try to have a long observation period, preferably several weeks. You'll need time to get the right answers to all of the above questions.

5.4 Cooking performance

(as measured in a standard meal test and expressed in specific consumption (kg wood/kg food)). The specific day consumption gives a good overall idea on the energetic kitchen performance. However it does not explain why and how. A closer look can result from a standard meal test. This is actual cooking of an actual, predominant meal. However, beyond the wood consumption, other parameters are observed and reported as well. When the results of various standard meal tests are compared, one can find out what is the influence of one or another parameter, for example the shape and size of cooking pots or firewood. A standard meal test should be organised only after a sufficient period of kitchen observation, in order to know what to do. To report the background, forms similar to G and E can be used. Obviously the information in sheet E will be more specific and precise. Moreover, a standard meal test

report can be given, as in form M , which is very similar to the report sheet on water boiling tests B explained later. The equipment to be used in a standard meal test includes: - a stopwatch - spring balances - possibly calibrated volume measuring devices - possibly a thermometer. Food quantities may be measured by weighing the charged pot. The net food weight is the measured gross weight less the weight of the pot.

5.5 Standard water boiling tests

To really understand what happens, it is often useful to do short and long standard boiling tests. In this case only water is used to simulate food and water mixes. One uses standard water quantities and a standard duration of the cooking process. The fire is managed in the best possible way, using the means as available in normal cooking. A lot of things are observed and reported in detail. As already pointed out, standard boiling tests allow a rapid evaluation of a given stove design as the results can be compared with results from others, operating according to the same procedures. In turn the results obtained in the boiling test can be useful to help people in other places. Standard boiling tests allow a quick investigation of separate stove design (and use) parameters. When doing so, change only one parameter at a time and keep all the others at the same level.

For example:

- if you change the wood size, use the same cooking pots
- if you change a baffle, use the same woodsize, the same cooking pots, etc..

The necessary equipment is the same as for a standard meal test besides a set of thermometers to check the water temperatures.

P.S. Note that for other than boiling processes it seems rather difficult to imagine an easy to do, and still significant, simple test. Frying, baking, grilling etc. should be investigated by standard meal tests.

In general however, it seems reasonable to assume that standard boiling tests may give a first indication for other cooking processes too. Equipment that performs fairly well in boiling is probably good in frying too for processes with comparable duration.

5.6 Testing instruments

- 1) Weighing can be done with any good balance. For field operations a spring balance seems very suitable. It is compact and light, gives direct readings without adjustment and sufficient precision if used within 20...100 % of its full capacity. Occasionally a spring balance should be checked with calibrated weights (1 l. of water is 1 kg of weight). Practically one should use a set of balances with various full scale capacities, for example 1 kg; 5 kg; 15 kg etc. The longer the scale of the instrument, the easier it is to read and the better the precision. It is good practice to fit the balance on a fixed support around eye level and to have a wood basket attached to it. The wood basket should be as light as possible (not more than 10 % of the full capacity of the balance). Don't forget to subtract the basket weight from the reading to get the net weight of wood. Weighing applies not only to wood but to food and water as well. In this case take into account the weight of the cooking pot when reporting the net weight of food (and water).

- 2) Lengths are easily measured. If you do not have a tape measure handy, remember that the ISO-A4 paper measures 297 x 210 mm; perhaps you can use paper with 5 mm

squares. A handspan is about 20 cm. The diameter D of a spheroid cooking pan can be deduced from the circumference L (as measured for example with a cord):

$$D = L/3,14$$

- 3) Volumes can be measured with graduated bottles ad hoc. You can also use commercial bottles from drinks with known content (1/4, 1/3, 1/1 liter...) or perhaps you prefer to use your balance as 1 l. of water is 1 kg.
- 4) Temperature measurements. Glass thermometers are precise but breakable; have some spare thermometers with you. Another way is to use metallic thermometers. These should be calibrated periodically (say at least every 3 months) with a good quality glass thermometer, preferably mercury filled. In any case look for long thermometers. Greater scale lengths give better precision. Remember that cooking of water under normal atmospheric pressure occurs at 100 °C. Check your thermometer each time you have boiling water. On the other hand, the body temperature is lower and rather variable.
- 5) Measurement of the relative humidity (R.H) of the air in field conditions is easiest with a hair hygrometer or a similar instrument. Recalibrate it frequently. To do so, wrap it in a wet cloth, leave it for five minutes, and adjust to 100 %. R.H. is important for the moisture of so called air dry wood. An other way might be to have a calibrated stick of thin wood, with known oven-dry weight. (as measured after drying in a ventilated oven at 120 °C for two hours). For a fast response, the wood stick should be thin (max. 3 mm). When exposed to humid air, the wood stick absorbs moisture, its weight increases to M_x . An estimate of the moisture content

of air dry firewood can be based on:

$$\left(\frac{M_x}{M_o} - 1\right).$$

Or, if possible, obtain a piece of wood, weigh it immediately and keep it until it can be taken to a laboratory to be dried in an oven. After drying weigh it again (on the same scales, if possible). The difference in weight is the weight of moisture driven out.

5.7 Concluding remarks

For useful results and correct understanding, testing should be done with care and continuous attention for details. Therefore testing is a demanding job. However, testing according to standard procedures is recommended for several reasons.

- a) It will facilitate easy understanding by others.
- b) It will permit comparing the results from different places.
- c) It will help in identifying useful design features.

A test should be repeated several times in order to be able to assess the accuracy of the results.

Kitchen observation report

Form O

- (1) Number of persons
 (2) Typical kitchen program (one day)

Food		Cooking process				Comments (b)
Type	kg	Type	Start time	Duration (minutes) high low		
Other woodfire uses (specify)						

Observed fuel inputs in kitchen area (c)

Date (d)	kg	wood				char-coal kg	other kg	solid type	oil kg	gas kg	temp. °C	
		(e)	(f)	(g)	(h)						night	day
SUM left												
Cons.												

(4) Total solid fuel consumed (wood + other solid + charcoal x 1.5) = kg.

Number of persons

Number of days

specific day consumption = $\frac{\text{.....}}{\text{.....}} = \text{.....} \frac{\text{kg}}{\text{pers. day}}$

- (a) For ex.: short boiling, simmering, grilling, baking.....
- (b) For ex.: stirring is needed.....
- (c) Sharply define the kitchen area; weigh any input. At start, weigh any fuel within kitchen area; at end: weigh any fuel left.
- (d) Start and stop observation at same hour to get a full number of days.
- (e) Report H for hardwood, S for softwood.
- (f) Report 3 for green or wet wood; 2 for airdry, strong wood; 1 for dead insect eaten wood.
- (g) Give diameter as 2 cm; 2...5 cm, 5...10 cm.
- (h) Report G for gathered wood; B for bought wood.

Cooking pots

	N 1	N 2	N 3	N 4	N 5
Shape (1)
Material (2)
Weight (kg)
Capacity (l)
Diameter (cm)
Height (cm)
Lid (cm)
Free Height (cm) (3)
Used for:

Sketch on backside of this sheet.

-
- (1) Flat bottom (F), curved bottom (C)
 - (2) For example, ceramic, iron or steel, aluminium
 - (3) Free height under the pot bottom in normal use on the stove.

Traditional open fire or

-
- 1) Stove class: (*)
(open/shielded/closed) (light weight, heavy weight) stove with (one, two, three) potholes.
 - 2) Drawings and sketches on back of this sheet (**)
 - 3) Short description
 - 4) Particulars
 - a) (no) chimney (diameter cm, height cm, material))
 - b) (no) grate (size x % free area, material))
 - c) (no) dampers (upstream/downstream of fire) (sliding, rotating)
 - 5) a. Commercial materials:
metal kg, ceramic kg, cement kg.
other (specify) kg, gross weight kg.
 - b. Skills and tools for construction
common user's level, artisan's level (specify)
 - 6) Accepted fuels:
 - wood in (any) length up to cm
 - other fuels (specify)
 - fuel charging procedure
 - 7) Uses beyond common cooking
 - 8) Origin of the stove

(*) Circle appropriate statement.

(**) Inside dimensions are very important. Be sure to include the dimensions (in cm) of: pot hole diameters/fire box net dimensions/fuel charging port/gas flue cross-section under the pan bottom/chimney diameter and height/Stove body top cover thickness and material etc.

Country

City or village

Urban/rural/mixed environment

Climate data:

Annual rain: mm water.

Mean temperature (dry season: °C) (wet season: °C)

Wind (low, medium, high): (dry season:) (wet season:)

Family (community living around one common kitchen)

number of:	m e n	w o m e n	c h i l d r e n	
	.....	.....	.....	who cannot read or write
	.....	.....	.....	who can read
	.....	.....	.....	who can write

Total number of persons

Professions:

independent farmers

independent artisans

other independent professions

employees (private sector)

employees (public sector)

Relative economic situation: poor/middle class/rich.

Estimated fuel consumptions (in % of total energy consumption)

wood (%), (charcoal (%), (other solids (%), (oil (%), (gas (%).

If wood is bought: cost ratio wood/food % (now)
..... % (5 years ago).

If wood is gathered: distance km (now) (5 years ago)
time spent pers. day/week (now)
..... pers. day/week (5 years ago)

Comments on woodfire and alternatives (2)

(comfort, risks, cost, expectations,)

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

Comments on "Improved" woodstoves:

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

(1) To be enclosed with the forms O, M and B

(2) Ask men and women separately.

Standard meal test report

Form M

Menu for persons

1. Test conditions.

Date Location (1) Operator (2)

Ambient temperature °C

Available fuels:

- wood (hard/soft (type 1, 2 3) (air dry, moist, wet) (round split) (3)
 - number of pieces total weight kg (4)
 - thickness (diameter) 2 cm 5 cm 10 cm
 - length 20 cm 50 cm (5)
- other fuels: (6), total weight kg

Cooking pots and stove used in present test as in sheet E

Instruments used in this test:

spring balances, kg cap. scale length cm
 (glass/metallic) thermometers, scale from to °C, length cm.

2. Test details

Time	Fuel (7)	Air (8)	Smoke (9)	Pot N 1 kg	Pot N 2 kg	Pot N 3 kg (10)
	kg .....					..... (11)

3. Test results

	Pot N 1	Pot N 2	Pot N 3
food and water input:	..... kg	..... kg	..... kg
processed food (12):	..... kg	..... kg	..... kg
evaporation (12):	..... kg	..... kg	..... kg
Total processed food:			..... kg

Total available wood was:	(A) (13)	..... kg
wood left (not charged) is	(B)	..... kg
charged wood is	(C)	..... kg
recovered wood is	(D)	..... kg
recovered charcoal	(E)	..... kg
equivalent wood recovery	(F) = (D) + 1.5 (E) =	..... kg
consumed wood (kg)	(G) (C) - (F)	..... kg

Specific consumption $X_u = \frac{\text{consumed wood}}{\text{total processed food}} =$ kg

Legend Form M

- (1) City or village, country
- (2) Name
- (3) Circle correct statement: type 1 = dead, insect eaten wood; type 2 = dry strong wood; type 3 = green wood.
- (4) Use a suitable balance. Cfr testing equipment.
- (5) Cross where applicable. If possible, use homogeneous fuel quality and size in boiling tests.
- (6) Specify for example cow dung, rice husks, millet stalks...
- (7) First clean the fire box. Some ash may be left but no charcoal. If long wood is used: note number of pieces and total weight of wood put on fire at start. Afterwards note time:
 - when wood is pushed into the fire;
 - when wood is pulled back;
 - when wood is removed from fire and extinguished.If short wood is used: note first wood charge and following charges in kg; when fire is extinguished. Similarly for other short fuel. Note time intervals for these events.
- (8) If an air damper is used: report + when damper is opened, - when damper is closed.
- (9) Report no smoke (NS); light smoke (LS); smoke (S); dense smoke (DS).
Attention: The smoke referred to above is smoke issueing from any part of the stove, not from the chimney. If possible report gas temperature in chimney.
- (10) Report all the inputs (food + water) in each seperate pot. (in kg)
- (11) Report the cook's actions, with corresponding time for example: on hole N 1: stirring, lid on; off stove at 11.32; on hole N 3 at 12.10 etc...
- (12) As weighed after processing. Evaporation is (input - processed food).
- (13) Any of the reported wood quantities (A), (B), (C), (D), (E) is weighed before, during, or after the test. Other data are computed. For wood and charcoal recovery extinguish fire, for instance with dry sand. Seperate charcoal from wood by beating the wood on a hard stone for example. Weigh remaining wood and all of the charcoal separately.

Standard water boiling test report

Form B

1. Test conditions.

Date Location (1) Operator (2)

Ambient temperature °C

Available fuels:

- wood (hard/soft (type 1, 2 3) (air dry, moist, wet) (round split) (3)
 - number of pieces total weight kg (4)
 - thickness (diameter) 2 cm 5 cm 10 cm
 - length 20 cm 50 cm (5)
- other fuels: (6). total weight kg

Cooking pots and stove used in present test as in enclosed sheet E.

Instruments used in this test:

spring balances, kg cap. scale length cm
 (glass/metallic) thermometers, scale from to °C, length cm.

2. Test details

Time	Fuel (7)	Air (8)	Smoke (9)	Pot N 1 kg	Pot N 2 kg	Pot N 3 kg (10)
	kg .....					..... (11)

3. Test results

Pot N 1

water charge was: 1 = kg. (12)
 water left after test: (W) 1 = kg
 evaporation loss is difference = kg (12)

Total available wood was: (A) (13) kg
 wood left (not charged) is (B) kg
 charged wood is (C) kg
 recovered wood is (D) kg
 recovered charcoal (E) kg
 equivalent wood recovery (F) = (D) + 1.5 (E) = kg
 consumed wood is (G) = (C) - (F) kg

Standard specific wood consumption:

$$(14) \text{ (short/long test) } X1 = \frac{\text{consumed wood (kg)}}{\text{water in pot N 1 (l or kg) after boiling}} =$$

$$\frac{(C) - (F)}{(W)} = \dots \frac{\text{kg}}{\text{kg}}$$

Legend Form B

- (1) City or village, country
- (2) Name
- (3) Circle correct statement: type 1 = dead, insect eaten wood; type 2 = dry strong wood; type 3 = green wood.
- (4) Use a suitable balance. Cfr. testing equipment.
- (5) Plot (X) in suitable case. If possible, use homogeneous fuel quality and size in boiling tests.
- (6) Specify for example cow dung, rice husks, millet stalks...
- (7) First clean the fire box. Some ash may be left but no charcoal. If long wood is used: note number of pieces and total weight of wood put on fire at start. Afterwards note times:
 - when wood is pushed into the fire;
 - when wood is pulled back;
 - when wood is removed from fire and extinguished.If short wood is used; note first wood charge and following charges in kg; time these events, also: - when fire is extinguished. Similarly for other short fuel.
- (8) If an air damper is used: report + when damper is opened and - when damper is closed.
- (9) Report no smoke (NS); light smoke (LS); smoke (S); dense smoke (DS).
Attention: The smoke referred to above is smoke coming from any part of the stove, not from the chimney.
If possible report gas temperature in chimney.
- (10) Standard is : 50% full cap. in pot N 1, full cap. in other pots.(*)
- (11) Use a lid with a hole for the thermometer. Use a long thermometer which rests on the pot bottom. Mark 'boil' when boiling point is reached and precise time instant. Extinguish fire for short water boiling test. Go on for one hour simmering for long boiling test. Report water temperatures every five minutes. When simmering, keep temperature over 95 C.
- (12) The water quantity at start and after the test is measured separately for each of the spots on the stove. It can be done by volume or by weight (1 l. = 1 kg).
- (13) Any of the reported wood quantities (A), (B), (C), (D), (E), is weighed before, during or after the test. Other data are computed. For wood and charcoal recovery: extinguish fire for example with dry sand. Separate charcoal from wood by beating the wood on a hard stone for example. Weigh remaining wood and all of the charcoal separately.
- (14) Circle the appropriate specification short or long. (*)
Pot N 1 on hole N 1; Pot N 2 on hole N 2; etc.

6

Glossary

By P. Verhaart

In this chapter an effort is made to explain to non technically trained readers a little about measuring units and their use as well as some terms they may not be familiar with.

6.1 Units

In accordance with international practice as well as for our own convenience, we have exclusively used units of measurement belonging to the so called International System (abridged S.I.) of units in this compendium.

6.1.1 Basic Units

The basic units for as far as this compendium is concerned are:

The unit of length, the meter, abridged m.

The unit of mass, the kilogram, abridged kg.

The unit of temperature, the Kelvin, abridged K.

The unit of time, the second, abridged s.

All other units consist of combinations of the basic units defined above. Some of these combined units are so frequently used that they have been given names of their own. These names belong to persons who have in their time done much to advance the sciences.

6.1.2 Combined Units.

The most important of these are:

- 1) The unit of surface area, the square meter, symbol m^2
- 2) The unit of volume, the cubic meter, symbol m^3
- 3) The unit of velocity, the meter per second, symbol $m.s^{-1}$.
- 4) The unit of volume rate of flow, the cubic meter per second, symbol $m^3.s^{-1}$.
- 5) The unit of acceleration, the meter per square second, symbol $m.s^{-2}$.
- 6) The unit of specific mass or density, the kilogram per cubic meter, symbol $kg.m^{-3}$.
- 7) The unit of specific volume is the reciprocal of 5), the cubic meter per kilogram, symbol $m^3.kg^{-1}$.
- 8) The unit of force is called Newton, abridged N. The Newton

is the unit of mass times the unit of acceleration, the Newton is 1 kilogrammeter per second squared or
 $1 \text{ N} = 1 \text{ kg.m.s}^{-2}$.

- 9) The unit of energy or work is the Joule, abridged J, the Joule is the unit of length times the unit of force thus
1 Joule = 1 Newton meter or
 $1 \text{ J} = 1 \text{ kg.m}^2.\text{s}^{-2}$.
- 10) The unit of power is the Watt, abridged W, the Watt is the unit of energy per unit of time thus 1 Watt is 1 Joule per second or
 $1 \text{ W} = 1 \text{ J.s}^{-1} = 1 \text{ kg.m}^2.\text{s}^{-3}$.
- 11) The unit of pressure is the Pascal, abridged Pa, the Pascal is the unit of force per unit of surface area thus the Pascal is the Newton per square meter or
 $1 \text{ Pa} = 1 \text{ N.m}^{-2} = 1 \text{ kg.s}^{-2}.\text{m}^{-1}$.
- 12) The unit of calorific- or combustion value is the Joule per kilogram, J.kg^{-1} .
- 13) The unit of specific heat is the Joule per kilogram Kelvin, $\text{J.kg}^{-1}.\text{K}^{-1}$.
- 14) The unit of mass flow is the kilogram per second kg.s^{-1} .
- 15) The unit of heat flux is the Watt per square meter W.m^{-2} .

6.1.3 Multiples and Fractions.

As it is not always convenient to write very large or very small numbers it has become standard practice to use prefixes before the

units to denote multiples or fractions. Recommended multiples and fractions are those factors which can be expressed as positive or negative powers of 10 which are whole multiples of 3. Fractions and multiples in frequent use are tabulated in table 6.1.

Prefix	Abridgment	Factor
nano	n	10^{-9}
micro	μ	10^{-6}
mili	m	10^{-3}
kilo	k	10^3
Mega	M	10^6
Giga	G	10^9

Table 6.1 Notation of multiples and fractions.

Other fractions and multiples.

In practice some other fractions and multiples are used.

In chapter 3 we often see the centimeter used as the unit of length. Centi is the prefix for one hundredth. One centimeter (cm) is therefore equal 10 millimeter (mm).

6.2 Conversions

As the International System of Units has not yet been in existence long enough for every individual to forget all other units it seems useful to give conversion factors for the most important non-SI units still persisting

6.2.1 Traditional Units.

In table 6.2 a number of the most important non-SI units has been gathered together with the conversion factors in the hope that it can be of some use to those that are not yet familiar with SI units.

The arrangement of the table is as follows:

Going from left to right we see the name of the traditional unit,

next we see the conversion factor followed by the SI unit. To convert the traditional unit to the corresponding SI unit we multiply the traditional unit with the conversion factor.

To convert the SI unit to the corresponding traditional unit the SI unit is divided by the conversion factor.

The only quantities that do not become converted by multiplication only are the temperature scales. As both traditional scales have an arbitrarily chosen zero point (from a physical point of view), the conversion is not complete without an addition or subtraction.

Table 6.2 Conversion factors

Quantity	Non SI unit	Conversion factor	SI unit
Length	foot	$3,048 \times 10^{-1}$	m
	inch	$2,54 \times 10^{-2}$	m
	mile	$1,609 \times 10^3$	m
	yard	$9,144 \times 10^{-1}$	m
Mass	ton (long)	$1,016 \times 10^3$	kg
	ton (metric)	$1,000 \times 10^3$	kg
	ton (short)	$9,072 \times 10^2$	kg
	ounce (avdp)	$2,835 \times 10^{-2}$	kg
	pound (advp)	$4,536 \times 10^{-1}$	kg
Time	clay	$8,640 \times 10^4$	s
	hour	$3,600 \times 10^3$	s
	minute	$6,000 \times 10$	s
Surface area	acre	$4,047 \times 10^3$	m ²
	sq. foot	$9,29 \times 10^{-2}$	m ²
	sq. inch	$6,452 \times 10^{-4}$	m ²
	sq. mile	$2,59 \times 10^6$	m ²
	sq. yard	$8,361 \times 10^{-1}$	m ²

Quantity	Non SI unit	Conversion factor	SI unit
Volume	barrel (oil)	$1,589 \times 10^{-1}$	m^3
	bushel (Brit.)	$3,637 \times 10^{-2}$	m^3
	bushel (U.S.)	$3,524 \times 10^{-2}$	m^3
	cord	3,625	m^3
	cu. foot	$2,832 \times 10^{-2}$	m^3
	cu. inch	$1,639 \times 10^{-6}$	m^3
	cu. yard	$7,646 \times 10^{-1}$	m^3
	fluid ounce (Brit.)	$2,841 \times 10^{-5}$	m^3
	fluid ounce (U.S.)	$2,957 \times 10^{-5}$	m^3
	gallon (Brit.)	4,546 x	m^3
	gallon (U.S.)	3,785 x	m^3
	pint (Brit.)	$5,682 \times 10^{-4}$	m^3
pint (U.S.)	$4,731 \times 10^{-4}$	m^3	
Velocity	knot	$5,144 \times 10^{-1}$	m/s
	ft/min	5,08 x	m/s
	km/h	$2,778 \times 10^{-1}$	m/s
	mile/h	$4,47 \times 10^{-1}$	m/s
Volume flow	barrel/day	$1,840 \times 10^{-6}$	m^3/s
	cu. ft/min	$4,719 \times 10^{-4}$	m^3/s
	gallon/min (Brit.)	$7,577 \times 10^{-5}$	m^3/s
	gallon/min (U.S.)	$6,309 \times 10^{-5}$	m^3/s
	m^3/h	$2,778 \times 10^{-4}$	m^3/s
Specific mass	lb/cu. ft.	$1,602 \times 10^1$	kg/m^3
	lb(cu. in.	$2,768 \times 10^4$	kg/m^3
	lb/gal. (Brit.)	$9,991 \times 10^1$	kg/m^3
Specific volume	cu. ft./lb.	$6,243 \times 10^1$	m^3/kg

Quantity	Non SI unit	Conversion factor	SI unit
Force	kg(f)	9,81	N
	lb. (f)	4,44	N
Energy	B.t.u.	$1,054 \times 10^3$	J
	calorie	4,186	J
	ft. lb	1,356	J
	kcal	$4,186 \times 10^3$	J
	HP. hour (Brit.)	$2,686 \times 10^6$	J
	HP. hour (Metr.)	$2,646 \times 10^6$	J
	kg(f).m	9,81	J
kWh	$3,600 \times 10^6$	J	
Power	Btu/h	$2,929 \times 10^{-1}$	W
	ft. lb/h	$3,766 \times 10^{-4}$	W
	fl. lb/s	1,356	W
	HP. (Brit.)	$7,46 \times 10^2$	W
	HP. (Metr.)	$7,35 \times 10^2$	W
	kcal/h	1,163	W
Pressure	Atmosphere	$1,013 \times 10^5$	Pa
	bar	$1,000 \times 10^5$	Pa
	cm. Hg	$1,33 \times 10^3$	Pa
	in Hg	$3,386 \times 10^3$	Pa
	lb (f)/sq. in	$6,895 \times 10^3$	Pa
Heating value	Btu/lb.	2,324 x	J/kg
	cal/g	4,186 x	J/kg
Specific heat	Btu/lb. F	$4,186 \times 10$	J/(kg.K)
	kcal/kg C	$4,186 \times 10$	J/(kg.K)

Quantity	Non SI unit	Conversion factor	SI unit
Mass flow	kg/h	$2,778 \times 10^{-4}$	kg/s
	kg/min	1,667 x	kg/s
	lb/h	$1,260 \times 10^{-4}$	kg/s
	lb/min	$7,56 \times 10$	kg/s
Heat flux	Btu (m.sq.ft)	3,153	W/m ²
	kcal/(m ² .h)	1,163	W/m ²
Heat conductivity	Btu./(ft.h.F)	1,729	W/(m.K.)
	Btu. in/(sq.ft.h.F)	1,441 x	W/(m.K.)
	kcal/(m.h.)	1,163	W/(m.K.)

6.2.2 Temperature Scale Conversion

The SI scale of temperature is the Kelvin scale. The Celcius scale is converted into the Kelvin scale by adding 273,15 to it, thus:

$$K = ^\circ C + 273,15$$

It is easy to see that temperature difference has an equal value whether expressed in C or K.

To convert the Fahrenheit scale into the Kelvin scale the F value is multiplied by 5/9 and 255,37 added to the product thus:

$$K = \frac{5}{9}F = + 255,37$$

To convert degrees Fahrenheit to Celcius, the Fahrenheit temperature is decreased by 32 and the result multiplied with 5/9 thus:

$$C = \frac{5}{9}(F - 32)$$

6.2.3 Example

Remember that all SI units are without a prefix the **except the unit of mass, the kg**. A mass expressed in gram is converted into kg before doing any calculations.

Problem: What is the theoretical mean rate of heat output (power) of a fire in which 300 g of dry wood per hour is burned? The heat of combustion (heating value) of this particular wood is 19 MJ/kg.

Solution.

The rate of wood consumption is

$$\frac{300}{1000} \text{ kg per } 3600 \text{ s is } \frac{300}{1000 \times 3600} \text{ kg}\cdot\text{s}^{-1}$$

This represents a heat output rate of:

$$\frac{300}{1000 \times 3600} \times 19 \times 10^6 \doteq 1583 \text{ J/s} = 1583 \text{ W}$$

The heat output rate is evidently 1,583 kW.

6.3 Technical terms

In the following some technical terms, used in this compendium, with which we think that readers who are not used to technical texts might have some difficulties, are explained. We do so only hesitantly as, while compiling the list of words we were very

conscious of balancing on the borderline of, on the one hand giving an incomplete list of words and, on the other hand talking down to the reader. Needless to say, we wish to do neither.

6.3.1 Technical Glossary

Ambient	Lying round, surrounding, encompassing. With respect to a stove, ambient temperature means the temperature in its neighbourhood (say the kitchen).
Analogous	Having analogy, similar in attributes, circumstances, relations or uses. Flow of heat from a high temperature body to a body at a lower temperature is analogous to a flow of water from an overhead tank into the kitchen.
Baffle	A suitable placed obstruction in a stove body to achieve desired flow paths and flow velocities.
Buoyancy	The force experienced by a lighter body placed in a heavier environment. The rising of a smoke column in the atmosphere or an air bubble in water provide examples of buoyancy forces in action.
Combustion	The action or process of burning. It is the process by which the chemical energy stored in the fuel is converted into heat.
Conduction	The transmission of heat etc. from particle to particle of a substance. The simplest example of this process is that of a long metal rod with one of its ends placed in a fire. The other end will feel hot to the touch after a short time. We say then that heat from the hot end has been transferred to the cold end

	through the metal rod by conduction.
Convection	The transportation of heat etc. by the movement of a heated substance. Water in a vessel placed on a fire gets heated due to hot water rising from the bottom and cold water descending. The process is called natural convection. When a pump is used for creating fluid motion the heat transfer under such conditions is called forced convection.
Density	The mass of a substance per unit volume.
Diffusion	The spontaneous molecular interpenetration of two fluids without chemical combination. The simplest manifestation of this process is the colouring of a glass of water by a drop of ink.
Dilatation	The action or process of expanding, enlarging or widening.
Efficiency	The ratio of effect obtained divided by the effort spent.
Entrainment	The action of dragging away with or after a moving fluid. The smoke issueing from a chimney into the atmosphere looses its identity after a certain distance by dragging with it or entraining air from the surroundings.
Optimization	To set for the best possible performance. The optimization process is particularly valuable when one has to contend with conflicting requirements.
Perimeter	The length of the boundary enclosing the area.
Phenomenon	A thing that appears or is perceived or observed, applied chiefly to a fact or occurrence, the cause of which is in question.
Qualitative	Relating to the nature, kind or character. The degree of excellence etc. possessed by a thing. For example "The heat transfer coefficient (in

Quantitative	<p>equation 4.4) increases as the velocity of the fluid increases” is a qualitative statement. Relating to quantity or its measurement, ascertaining or expressing extent, size or magnitude.</p> <p>The previous statement in quantitative terms will read as: “With doubling the velocity, the heat transfer coefficient increases by 41 %.”</p>
Radiation	<p>The action of sending out rays of light or heat. The most common manifestation of radiation heat transfer is the experience of feeling hot when one approaches a fire.</p>
Thermal decomposition	<p>The action of chemical changes taking place under influence of heat.</p> <p>When wood is heated it experiences thermal decomposition resulting in the liberation of volatiles (see below).</p>
Volatiles	<p>Substances that will form and escape in the form of gas, vapour and mist under influence of heat.</p>

7

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