Forest Products Research Division
Royal Forest Department
Ministry of Agriculture and Cooperatives

IMPROVED BIOMASS COOKING STOVE FOR HOUSEHOLD USE

Submitted to the
National Energy Administration
Ministry of Science, Technology and Energy

Under the
Renewable Nonconventional Energy Project
Royal Thai Government
U.S. Agency for International Development

"Household development in any society can only be achieved when the most important part of the kitchen, the cookstove, has also been improved."

ACKNOWLEDGEMENTS

I wish to express my appreciation to USAID/Thailand, to the National Energy Administration and Department of Technical and Economic Cooperation for their support and for providing a timely opportunity to prove the wood energy conservation case in rural application. The Royal Forest Department responded eagerly to the request for project personnel and facilities needed for implementation.

I am obliged to Mr. Suthi Harnsongkram, the Director of Forest Products Research, who had kindly helped in the execution of the project plan in his capacity as the Department's Director General.

Acknowledgements are due Miss Pojanee Jongjitirat of KMIT for the preparation of the main part of this final report and for helping with the stove's promotional training; Mr. Banyat Srisom for the final improved stove's technical drawings, development of production technique and quality control for improved designs, and helping with the stove's promotional training; Mr. Piroj Uttarapong of Kasetsart University for assisting in test data compilation, stove cataloguing, and promotional training.

Mr. Arkom Vejsupasook, the component assistant, Mr. Songdham Jaikwang, and Miss Malee Rungsrisawadth, project officers, were indispensable for the day-to-day project operation, by conducting the experiment and collection of data, commissioning the improved stove's production, and organizing of promotional training programs.

Personally, I wish to extend my special thanks to Mr. Sompongse Chantavorapap, the project manager, and Mr. Mintara Silawatshananai, the USAID project officer, for their unfailing assistance whenever problems arose.

I am also grateful to my research colleaques whose names are all listed in the Annex for their invaluable contribution to the success of this project.

Finally, credit is given to secretarial and the editorial staff of the Office of Project Support who patiently strived for a quality final report.

Aroon Chomcharn
Component Leader
Stove Improvement Component
Royal Forest Department

CONTENTS

Page

EXECUTIVE SUMMARY 11
List of Tables 17
List of Figures 21
Terms and Abbreviations 25

CHAPTER 1 INTRODUCTION

A. The Project 31
B. Historical Background 32
C. Statement of the Problem 34
D. Objectives of the Study 36
E. Potential Benefits for Rural Development 37
F. Scope of Work 37

CHAPTER 2 REVIEW OF LITERATURE

A. Stove Construction and Design 43
B. Standard Methods of Testing Stove Performance 48
C. Factors Affecting Stove Performance 51
D. Conclusion 53

CHAPTER 3 PLAN AND DESIGN OF THE PROJECT

A. Laboratory and Facility Set Up 57
B. Collection of Existing Local Stoves 57
C. Investigation of Existing Stove Performance 58
D. Analysis of Stove Physical Factors 58
E. Development of Improved Prototype 58
F. Testing of Prototype and Remodification 58
G. Production of Developed Stoves 59
H. Field Promotion of Developed Stoves 59

CHAPTER 4 EXPERIMENTAL TECHNIQUES AND PROCEDURES

A. Fuel Type and Preparation 63
B. Tests of Existing Thai Cooking Stoves 64

CONTENTS (continued)

Page

C. Test for the Effect of Internal Variable on the Charcoal Bucket Stove 66

D. Test for the Effect of External Variables on the Charcoal Bucket Stove 68

E. Test for the Effect of Variables on the Non-chimneyed Wood Stove 70

F. Test for the Effect of External Variables on the Non-chimneyed Wood Stove 71

G. Test for the Effect of Internal Variables on Chimneyed Wood Stove 72

H. Test for the Effect of Internal Variables on Chimneyed Rice Husk Stove 73

I. Test for the Effect of Internal Variables on Non-chimneyed Rice Husk Stove 73

J. Development of Improved Stove Prototype 75

CHAPTER 5 ANALYSIS OF RESULTS AND DISCUSSION

A. Physical Structure of Commercial Stoves 79

B. Terminology 85

C. Performance of Commercial Stoves Tested 85

D. The Effect of Internal and External Variables 99

CHAPTER 6 THEORETICAL ANALYSIS OF CHARCOAL STOVE

A. Mathematical Model of the Bucket Stoves 135

B. Evaluation of Parameters 143

C. Model Application 144

D. Discussion and Evaluation 162

CHAPTER 7 STOVE MODELS DEVELOPED

A. Improved Stove's Terminology 167

B. Improved Charcoal Stove Model "RFD-1" 173

C. Improved Non-chimneyed Wood Stove Model "RFD-2" 175

D. Improved Chimney Wood Stove 180

E. Improved Non-chimneyed Rice Husk Stove 186

F. Improved Chimneyed Rice Husk Stove Model "RFD-3" 187

CONTENTS (continued)

Page

CHAPTER 8 IMPROVED STOVE DESIGNS AND PRODUCTION

A. Technical Drawings of Improved Stove 197

B. Construction Instructions 197

C. A Mass Production Scheme to Make Charcoal and Wood Stoves Using the Hydraulic Press 209

CHAPTER 9 IMPROVED STOVE PROMOTION

A. Overall Target of Stove Promotion 213

B. Creation of Public Awareness 215

C. Introduction/Training on Efficient Stoves 216

D. Introduction and Distribution of Sample Stove to Household Users 229

E. Organization of Stove Manufacturers to Produce Improved Design Stoves 229

CHAPTER 10 CONCLUSIONS 237

CHAPTER 11 RECOMMENDATIONS 241

ANNEXES

I. Commercial Charcoal Bucket Stove Investigated 245

II. Commercial and User Built Wood Stove Without Chimney Investigated 285

III. Commercial Wood Stove With Chimney Investigated 303

IV. Commercial Rice Husk Stove With Chimney Investigated 309

V. List of Staff and Personnel for Stove Improvement Component 317

REFERENCES 321

EXECUTIVE SUMMARY

Energy for household cooking in Thailand depends largely on biomass mainly in the form of wood and charcoal. The annual consumption of both fuels in terms of solid wood is approximately 40 million cubic meters, with an estimated value of well over 7.5 billion baht. If this quantity of wood fuel were to be provided by commercial fuels such as kerosene, LPG and LNG, the national spending on such imports would be at least three times higher. Furthermore, many problems would exist both with effectively distributing these forms of energy to rural areas, as well as with its prohibitive cost.

Statistics on wood consumption of the country reveal that the use of wood for fuel is approximately 75-80% of all uses (with such purposes as construction and industrial applications comprising the remainder). This consumption ratio indicates that the country's dependence on wood fuel is likely to persist for a long time to come.

The present scarcity of fuelwood has already appeared in many areas of the country. This will occur more frequently as the natural forest diminishes and the population increases. In order to correct this problem, in addition to planting more fast-growing species of trees, conservation through the improvement of inefficient cooking stoves is necessary. As a consequence the Cooking Stove Improvement for Household Use Project was launched.

The objectives of the project were:

a) to investigate the performance of existing stoves currently used in Thailand,
b) to make necessary improvements on each type of stove (charcoal, wood, and agriresidue) for better fuel efficiency and ease of operation,
c) to establish improved stove production techniques suitable for small-scale rural industries,
d) to disseminate information, technology and/or improved hardware to stove users, manufacturers, and the general public, and
e) to increase the number of trained personnel and institutional research facilities for future campaigns investigating efficient biomass cooking stoves.

This project component was operated by the Forest Products Research Division of the Royal Forestry Department. The operation phase was started in March 1982 and ended in September 1984. Activities undertaken included collection and selection of commercial stoves, stove development to yield better design, prototype testing, improved stove production and fabrication, and promotion of the improved final models.

Accomplishments can be summarized as follows:

1) The performance of household cooking stoves in Thailand (both commercial and user-built models) was investigated.
2) Based on the heat utilization efficiency (HU) rating under the same test standard, it was found that the average HU's for LPG, pressurized kerosene, charcoal bucket, nonchimneyed wood, chimneyed wood, nonchimneyed rice husk, and chimneyed rice husk stoves were 46, 48, 27, 20, 12, 16, and 5% respectively.
3) The improvements on the five generic types of biomass stoves mentioned above have resulted in HU increases of 26% for charcoal, 35% for nonchimneyed wood, 58% for chimneyed wood, 20% for nonchimneyed rice husk, and 100% for chimneyed rice husk stoves as compared with the average existing models.
4) In addition to the HU increase (indicating the net increase in work output per unit fuel input), certain stove features were also improved -- particularly the stove rim design to accommodate various sizes of pots and pans, fire-resistant characteristics of pottery liners for charcoal and wood stoves, and increases of their service lives.
5) A better clay raw material for pottery liner stoves was identified and a production technique suitable for rural industries developed. A trial production by village stove makers employing this technique was successful. 2000 charcoal and 1200 wood stoves of acceptable quality were obtained with good production precision.
6) The component conducted nine improved stove training courses for concerned rural government officials and rural stove users. The reception for the improved models (particularly charcoal and nonchimneyed wood stoves) was very encouraging. The reception for rice husk stoves was also enthusiastic, but was restricted to a few rural areas only.
7) During the trial promotion, approximately 1500 charcoal, 800 nonchimneyed wood, 150 nonchimneyed rice husk, and 50 chimneyed rice husk stoves were distributed to trainees, to interested government and private organizations, and to individual users upon request.
8) As a result of the project implementation, a modest stove laboratory, adequately equipped with basic facilities for future work, was established at RFD.

CONCLUSIONS

As a result of the implementation of the Improved Biomass Cooking Stove Component, many activities and achievements took place. Accomplishments can be described as follows:

1. As a part of institution strengthening, the component has succeeded in establishing a cooking stove testing laboratory at the Forest Products Research Division, Royal Forest Department. Through project funding, the laboratory was equipped with invaluable, basic test instruments and facilities--including a microcomputer system for future applications.

2. Long-term training of project personnel to increase their future capabilities was minimum because time was short (30 months) and they were needed on site to carry out project tasks. Therefore, all technical personnel were indispensable for project implementation. They could not be spared for long term training.

3. The component has produced five generic types of improved cooking stoves: namely, the charcoal bucket stove, wood stoves with and without chimneys, and rice husk stoves with and without chimneys. The absolute heat utilization for charcoal and both types of wood stoves increased up to 7% over that of the average commercial models. Further, an increase of 5 and 3% was achieved with rice husk stoves with and without chimneys respectively. In terms of comparative efficiency increases, the charcoal stove reached a 26% increase over the average commercial models, while for wood stoves with and without chimneys they were 58 and 35% respectively. The increase for the rice husk stove with chimney was 100%, or double the efficiency of the average commercial models. The rice husk stove without chimney had the least increase, 15 - 16%.

4. The investigation conducted on existing commercial stoves revealed that fuel efficient cooking stoves for charcoal, wood, or rice husk are rare. The laboratory tests have led to the identification of the stoves' critical physical parameters. They consist of stove weight; exhausted gap/area; combustion chamber capacity; rim design for proper fit of variously-sized pots and pans; grate-to-pot distance; grate parameters such as hole area, hole size and distribution, and thickness; height of chimney, and flue gas baffle (for chimneyed stoves). Other strong factors also influencing stove performance are external variables--fuel load or fuel feeding rate, amount of water to be boiled, and the wind factor. The information obtained was later used for redesigning the improved stove models.

5. Good quality clay material suitable for stove manufacturing has been identified and a production technique has also been developed for small-scale and home industries. Local stove manufacturers in one district of Roi-et Province were trained without any difficulty in this technique of stove production. Improved stoves, particularly charcoal and nonchimney wood models, are heat refractory and can withstand thermal shock much better than present

commercial ones. In addition, the application of the internal mold has greatly improved the precision necessary to control the critical internal dimensions. This method was found to be superior to the traditional one using an external mold which hardly controlled the internal dimensions.

6. The production cost of the improved models as described in (2) above presently is approximately 2.5 times more than the cost of the poorer quality commercial models. However, when compared with top quality charcoal bucket stoves sold in the market, the improved models' cost is 25 - 30% lower. Therefore, in long-term commercial production, the improved models will be competitive when production increases and more improved stoves reach the market.

7. So far, nine improved stove promotion and training programs have been carried out among villagers at various places around the country. The reception for the charcoal bucket and the non-chimney wood stoves was very good, while the good reception of the rice husk chimneyed stove was limited to a few localities where only rice husk is available. The chimneyed wood and non-chimneyed rice husk stove are of less interest to rural users than the charcoal bucket and the non-chimneyed wood and the rice husk chimneyed stove. It is believed that with good follow-up and promotional effort, some of the improved developed models will withstand harsh use and serve users well in rural kitchens. However, these long-term results are yet to be seen.

8. Because of time constraints, the project had a limited time to approach manufacturers on a large scale. However, among a few large manufacturers in the Central area, the response to the idea of mass production of the developed models was not enthusiastic. This lack of enthusiasm is perhaps a result of stove manufacturers being accustomed to the production of their rough products and being reluctant to manufacture stoves with which they have little or no experience. Moreover, they probably want to see the market for high quality, efficient stoves develop first before committing their resources to their production. Therefore, more time and more education are needed for them to change their attitude and adapt their production techniques.

RECOMMENDATIONS

On the basis of the overall work of this project, some recommendations are presented below:

1. Because stove development and promotion involve the social customs and habits of millions of people in Thailand and around the world, it is highly recommended that stove research and development be carried on to further improve present designs and find more alternatives for users.

2. Stove development should emphasize each generic type of stove; namely, charcoal, wood with and without chimney, and agriresidue stoves with and without chimney so that users have choices.

3. Stove research and development must not only emphasize the good conversion efficiency, but it must also facilitate ease of use and other cooking functions, without causing undue change in people's cooking habits.

4. Stove promotion is a most difficult activity. It will take a great deal of time and resources. Therefore, continuous effort must be made for at least five years with reasonable financial and human resource support in order to see a real impact among 6 million rural users.

5. In Thailand there are quite a few researchers and interest groups working on stove development and promotion. Unfortunately, all lack guidelines and coordination. For national stove programs to be directed toward this common goal, leading government agencies are needed to provide close coordination.

6. During the course of stove development, many contacts were made with experienced stove manufacturers. It was found that, regardless of their long experience, their basic understanding of good stove configuration, design and its performance was very much lacking. This problem was also manifested in the presence of a large majority of poor quality and less efficient commercial stoves in the market. Therefore, it is strongly recommended that concerned government agencies take an initiative toward arranging formal training programs for the promotion of the essential, scientific knowledge required among stove manufacturers. Incentives or approaches such as offering a certificate and/or reward to manufacturers of efficient stoves would be a highly motivating factor.

7. The lack of understanding among users on the criteria for selection and use of efficient cooking stoves was also evident. Therefore, the concerned government agency should establish a long-range,adequately funded educational campaign program for efficient stoves--particularly through primary and secondary school systems.

8. The cost of improved design stove production is still high. If simple hydraulic molding can be developed and employed at the village level, production costs can be greatly reduced. Under these conditions stove dimensions will be more precise and the production rate will be increased significantly.

9. Selection of clay raw material and improvement of the clay mixture and firing to attain a product with fire resistant characteristics (particularly, the charcoal stove body) are essential to a stove's long service life. The weight of the stove also needs further reduction (to achieve peak performance with even lower charcoal loads).

10. The improved non-chimneyed wood stove is quite efficient for the present developed model. It can conveniently be used to replace three-rock stoves. However, the same problems exist in its mass production techniques as exist for the charcoal stove.

11. Smoke in the kitchen is a problem inherent in non-chimneyed wood stoves including the three-stone and open fire. Research should be carried out in Thailand to determine whether smoke from undeveloped and even developed stoves (which noticeably gives less smoke over the undeveloped ones), has any significant effect on long-term health of users.

12. Up to the present time, the one hole chimneyed wood stove has attained an efficiency up to only 18-19%. In addition, there are problems fitting pots and pans to this stove. Therefore, it is recommended that development on this type of stove be continued in order to improve both heat utilization efficiency and compatability with various pots and pans. Moreover, the stove material (as in the case of the non-chimneyed wood stoves and the charcoal stove) should also be investigated.

13. Even though, at present, the chimneyed rice husk stove is still not popularly used in Thailand, the chance for this stove to become popular in certain regions is high. This is because it can use granulated fuels other than rice husk (such as sawdust, peanut shell, seed waste, household biomass scraps, etc). There are several further improvements that need consideration. These include the improvement of the stove's configuration to fit various pots and pans and reduction of its weight so that sometimes it can be moved around the house (yard) when needed. For two people to carry the stove, the weight should not exceed 50 kg.

14. The experience gained from the stove promotional campaigns among rural users, even in its short duration, strongly indicated that there is a good chance of success in replacing relatively inefficient stoves among 6 million rural Thai families with efficient stoves. It is, therefore, recommended that the government support a nationwide efficient stove promotional campaign for users and manufacturers as soon as possible.

15. Since better biomass cooking stoves, in part, mean better living for millions of rural families around the world, the idea of continuous development to attain even better performance than the present developed models should be the challenging subject among applied research scientists and concerned institutions.

LIST OF TABLES

Table	Title	Page
4.1	Characteristics of Biomass fuel use in the experiment	64
5.1	Physical dimensions of tested charcoal stoves	80
5.2	Physical dimensions of tested wood stoves without chimneys	82
5.3	Physical dimensions of tested wood stoves with chimneys	84
5.4	Physical dimensions of rice husk stoves without chimney	86
5.5	Physical dimensions of rice husk stoves with chimney	87
5.6	Average testing results of commercial charcoal stoves	88
5.7	Average testing results of wood stoves without chimney	96
5.8	Average testing results of wood stoves with chimney	97
5.9	Average testing results of rice husk stoves with chimney	98
5.10	Average testing results of rice husk stoves without chimney	100
5.11	Test result of the effect of stove gap/exhausted area on HU and time to boil	103
5.12	Test results of the effect of grate hole area on HU and time to boil	104
5.13	Test result of the effect of grate-to-pot distance on HU and time to boil	107
5.14	Test result of the effect of combustion chamber size on HU and time to boil	108
5.15	Test result of the effect of air inlet door on HU and time to boil	110
5.16	Test result of the effect of grate thickness on stove performance	113
5.17	Test result of the effect of insulation on HU and time to boil	113
5.18	Test result of the effect of stove weight on the HU and time to boil	115
5.19	Test result of the effect of initial weight of charcoal on stove HU and time to boil	116

LIST OF TABLES (continued)

Table	Title	Page
5.20	Test result of the effect of initial weight of water on HU and time to boil	117
5.21	Test result of the effect of pot size on HU and time to boil	119
5.22	Test result of the effect of charcoal size on HU and time to boil	120
5.23	Test result of the effect of wind on HU and time to boil	121
5.24	Test result of the effect of air relative humidity on HU and time to boil	122
5.25	Test result of the effect of stove gap on HU and time to boil of the wood stove	123
5.26	Test result of the effect of grate on HU and time to boil of wood stove	124
5.27	Test result of the effect of grate hole area on wood stove performance	126
5.28	Test result of the effect of grate-to-pot distance on stove performance	127
5.29	Test result of the effect of wind on wood stove performance	128
5.30	Test result of the effect of firewood feeding rate on the stove performance	130
6.1	Group of stoves that have similar behavior and show good correlation in regression analysis	150
7.1	Physical characteristics of RFD-1 charcoal stove relating to external variables	174
7.2	Average test results of RFD-1 charcoal stove under different use conditions	174
7.3	Test results of improved nonchimneyed wood stove model RFD-2 with bucket	179
7.4	Performance of the prototype improved chimneyed wood stove	185
7.5	Test results of improved chimneyed rice husk stove model RFD-3	191
8.1	Compositions and fired resistant property of some local clay materials used for stove and pottery productions	199

LIST OF TABLES (continued)

Table	Title	*Page*
9.1	Comparison test for efficiency between developed and commercial stoves in Mahasarakarm	217
9.2	Comparison test for efficiency between developed and commercial stoves in Saraburi	219
9.3	Comparison test for efficiency between developed and commercial stoves in Sakolnakorn	221
9.4	Comparison test for efficiency between developed and commercial stoves in Pitsanulok	225
9.5	Comparison test for efficiency between developed and commercial stoves in Saraburi	226
9.6	Comparison test for efficiency between developed and commercial stoves in Chachoengsoa	227
9.7	Comparison test for efficiency between developed and commercial stoves in Mahasarakarm	228
9.8	Comparison test for efficiency between developed and commercial stoves in Saraburi	230
9.9	Comparison test for efficiency between developed and commercial stoves in Nan	231

LIST OF FIGURES

Figure	Title	*Page*
5.0	Time-temperature characteristic curves of charcoal bucket stoves	90
5.1	Performance rating based on heat utilization efficiency (HU) of commercial charcoal bucket stoves	91
5.2	Performance rating based on time to boil of commercial charcoal bucket stoves	92
5.3	Performance rating based on heat utilization efficiency (HU) of nonchimneyed and chimneyed wood stoves	94
5.4	Performance rating based on time to boil of nonchimneyed and chimneyed wood stoves	95
5.5	Performance rating based on heat utilization efficiency (HU) of nonchimneyed and chimneyed rice husk stoves	101
5.6	Performance rating based on time to boil of nonchimneyed and chimneyed rice husk stoves	102
5.7	The effect of exhausted gap on the stove efficiency and time to boil	105
5.8	The effect of the grate hole area on the stove efficiency and time to boil	106
5.9	The effect of grate-to-pot distance on the stove efficiency and time to boil	109
5.10	The effect of combustion chamber volume on the stove efficiency and time to boil of three different stoves tested	111
5.11	The effect of air inlet door on the stove efficiency and time to boil	112
5.12	The effect of grate thickness on the stove efficiency and time to boil	114
5.13	The effect of the initial weight of charcoal on the stove efficiency and time to boil	118
5.14	The effect of exhausted gap on efficiency of various wood stoves	125
5.15	The effect of grate-to-pot distance on the heat utilization efficiency (HU) of wood stoves	129
6.1	Structure of the ideal Biomass cooking stove	137

LIST OF FIGURES (continued)

Figure	Title	Page
6.2	Geometry of the ideal stove	145
6.3	Relationship between the area of the opening for inlet air and the grate hole area	147
6.4	Relationship between exhaust area and gap height	148
6.5	Relationship between variable X, defined in equation (49), and time to boil	151
6.6	Model prediction of the effect of grate-to-pot distance on the stove efficiency, stove mass and time to boil	153
6.7	Model prediction of the effect of wall thickness on the stove efficiency, stove mass and time to boil	154
6.8	Model prediction of the effect of inside diameter of stove at the bottom on the stove efficiency, stove mass and time to boil	156
6.9	Model prediction of the effect of inside diameter of stove at the pot stand on the stove efficiency, stove mass and time to boil	157
6.10	Model prediction of the effect of gap height on the stove efficiency, stove mass and time to boil	158
6.11	Model prediction of the effect of grate diameter on the stove efficiency, stove mass and time to boil	160
6.12	Model prediction of the effect of grate hole area on the stove efficiency, stove mass and time to boil	161
7.1	Drawing of improved charcoal bucket stove showing various parts of the construction and terminology	168
7.2	Drawing of improved nonchimneyed wood stove showing parts of the construction and terminology	169
7.3	Drawing of developed chimneyed wood stove prototype showing the construction and terminology	170
7.4	Drawing of improved nonchimneyed rice husk stove showing the construction and terminology	171
7.5	Drawing of improved chimneyed rice husk stove showing the construction and terminology	172
7.6	Improved charcoal stove model "RFD-1"	177

LIST OF FIGURES (continued)

Figure	Title	*Page*
7.7	Improved charcoal stove model "RFD-1"	178
7.8	Improved nonchimneyed wood stove model "RFD-2"	181
7.9	Improved nonchimneyed wood stove model "RFD-2"	182
7.10	Prototype of developed chimneyed wood stove showing different parts of construction	183
7.11	Nonchimneyed rice husk stove, the "Improved Meechai" model	189
7.12	Improved rice husk stove with chimney, the "RFD-3" model	193
8.1	Technical Drawing of the Improved Charcoal Stove	201
8.2	Technical Drawing of the Improved Wood Stove	202
8.3	Technical Drawing of the Improved Rice Husk Nonchimneyed Stove .	203
8.4	Technical Drawing of the Improved Rice Husk Stove with Chimney	204
8.5	Preparation of biscuits and firing to be used later for clay mixture	205
8.6	Production of charcoal stove on the potter's wheel using the internal mold	205
8.7	Disassembling of the internal mold from a newly made charcoal stove	206
8.8	Improved charcoal and wood stove after finished firing and ready for further fabrication	206
8.9	Grate hole design for charcoal stoves	208
8.10	100-ton hydraulic automatic press machine for charcoal and wood stove	210
9.1	Introduction of developed stoves to participants	233
9.2	Stove contest for efficiency comparison between commercial stoves and developed models	233
9.3	Trainee participation in installing stove's parts	234
9.4	Distribution of developed stoves to all participants	234

TERMS AND ABBREVIATIONS

A	total surface area, sq cm
A_e	gap area, sq cm
A_g	grate hole area, sq cm
A_i	area of opening for the inlet air, sq cm
c_{pw}	heat capacity of water, J/gm C
D	wall thickness, cm
D_b	outside diameter of the stove at the bottom, cm
D_g	outside diameter of the stove at the grate position, cm
D_t	outside diameter of the stove at the pot stand, cm
d_b	inside diameter of the stove at the bottom, cm
d_g	inside diameter of the stove at the grate position, cm
d_t	inside diameter of the stove at the pot stand, cm
E_c	heating value of charcoal, 26340 J/gm
E_f	heating value of fuel, J/gm
E_k	heating value of wood kindling, 17890 J/gm
F_{12}	view factor from surface 1 to surface 2
G	gap height, cm
Gr	Grashof number
ΔH	heat of combustion, J/gm
H	grate-to-pot distance, cm
H_{ba}	distance between the base and the apex of the outside cone, cm
H_{gb}	distance between the grate and the base of the outside truncated cone, cm

H_{tg}	distance between the grate and the pot stand of the outside cone, cm
HU	heat utilization efficiency, %
h	heat transfer coefficient, W/sw cm C
h_{ba}	distance between the base and the apex of the inside cone, cm
h_{fg}	latent heat of vaporization, J/gm
h_{gb}	distance between the grate and the base of the inside truncated cone, cm
h_{tg}	distance between the grate and the pot stand of the inside cone, cm
k	thermal conductivity, J/cm s°C
L	heat of vaporization of water at 100°C, 2256 J/gm
m_c	mass of charcoal, gm
m_s	stove weight, kg
$\dot{m}_v$	rate of evaporated water, gm/s
m_{wo}	initial weight of water, gm
$\dot{Q}_{abs}$	rate of heat absorption, J/s
$\dot{Q}_h$	rate of heat supplied to water, J/s
$\dot{Q}_1$	rate of heat loss, J/s
Q_{sens}	sensible heat of water, J
$\dot{Q}_w$	rate of heat absorbed by water, J/s
q_{cond}	heat flux by conduction, J/s sq cm
q_{rad}	heat flux by radiation, J/s sq cm
S	specific heat of water, 4.18 J/gm
	surface area of pot, sq cm
T	temperature, °C
T_{amb}	ambient room temperature, °C
T_{boil}	boiling water temperature, °C
T_w	water temperature, °C

T_1	temperature of water at start of test, °C
T_2	temperature of water at boiling point, °C
TTB	time to boil, min
t	time, min
v_{conv}	velocity of buoyant gas, cm/s
W	weight of water in pot at start of test, gm
W_c	weight of charcoal remaining at end of each test, gm
W_e	weight of water evaporated at end of each test, gm
W_f	weight of fuel used, gm
W_k	weight of kindling, gm
ρ	density, g/cu cm
σ	Stefan-Boltzmann constant
η	efficiency of stove, %

Chapter 1

Introduction

INTRODUCTION

This publication presents the major findings on the testing and development of biomass cooking stoves in Thailand--stoves that use wood, charcoal and agricultural residues. The Stove Improvement Project has four major parts responsible for different project functions;

1. Stove Testing: Selection of available commercial stoves to be tested;

2. Stove Development: Measurement and analysis of stove performance to yield designs of new models;

3. Stove Construction and Fabrication: Production of engineering drawings of the newly developed designs as well as construction and fabrication of the stoves; and

4. Stove Promotion: Carrying out field promotion for the newly developed, highly efficient stoves.

A. THE PROJECT

Stove Improvement is one component of 14 separate components involved in the Renewable Nonconventional Energy Project #493-0304. Projects carried out include:

Industrial Biogas
Biomass Gasification
Charcoal Improvement
Energy Master Plan Support
Micro-Hydro Project
National Energy Information Center
Pyrolysis of Rice Husks
Regional Energy Centers
Solar Thermal Processes
Solar/Wind Assessment
Stove Improvement
Village Survey
Village Woodlots
Water Lifting Technology

This Project is jointly funded by the United States Agency for International Development (USAID) and the Royal Thai Government through the National Energy Administration (NEA) and Royal Forest Department. The Stove Improvement program is operated by the Forest Products Research Division of the Royal Forest Department.

B. HISTORICAL BACKGROUND

This section briefly discusses the evolution of cooking stoves in the world (and Thai cooking stoves in particular) in terms of popular types of hardware and cultural and social habits associated with various models.

Evolution of Cooking Stoves in the World

Evidence of the use of biomass fuel, particularly wood, has been found within the caves of Peking man as early as 400,000 years ago (Bronowski,1973). At that time, biomass was presumably used as fuel for weather conditioning (warmth). Its application to cooking developed later. While styles and methods of cooking have developed into a variety of artistic and elaborate forms, the biomass cooking stoves which are the hardware supporting this activity (as holders for cooking utensils and as fuel combustion chambers) have changed very little in structure and performance from their ancient predecessors.

When compared with modern stoves such as oil, gas, and electric, the biomass cooking stoves are far less efficient. The efficiency of kerosene or LPG fuelled stoves can be as high as 45-48%, while that of a wood stove averages only 15-20%. Even though the gap in efficiency is partially explained by the lower calorific value of the wood fuel, the main problem still rests heavily on the hardware design of the stove itself.

The development of stoves can be seen as occurring over two periods of time. The first period began with the birth of the three stone stove and continued until the discovery and application of electricity. The second period has lasted from that time until the present. While the latter period amounts to only about 100 years, the first period lasted many thousands of years.

The slow development of biomass cooking stoves in the early period can be explained by the abundant supply of wood and the consequent lack of any demand for higher efficiency stoves. Most of the effort toward improved stove design in the second period of time has been in the area of the electric, gas, and oil stoves popular in western countries. The application of scientific principles and knowledge to the design of better biomass cooking stoves has been neglected. However, as the world population has increased tremendously in the last 100 years, particularly in poor and less developed countries that are dependent on biomass cooking stoves, the demand for wood fuel has risen sharply. The increase in demand coupled with the rapid loss of forest land to agriculture has made the procurement of wood for cooking both difficult and expensive. With the current situation, the time has come for humankind to start applying modern engineering principles to the design of biomass cooking stoves in order to improve this long neglected but widely and daily used appliance.

History of Thai Cooking Stoves

In Thailand, as in many developing countries, a large majority of people cook meals with biomass fuels. The largest proportio.. of biomass fuel consumption consists mainly of wood (59.8%) and charcoal (29.9%) (Pounoum, Wongopalert, and Arnold 1982). Other types of biomass used as cooking fuel make a considerably smaller contribution. These include rice husk (8.0%), rice straw (1.7%), and coconut shell (0.6%). The wood and charcoal consumption in terms of solid wood are reported to be 40 million cubic meters annually. The quantity of solid fuel used for cooking is certainly going to increase in the near future because of the increase in population. Substitution with other fuels will be limited. This increasing trend of fuelwood consumption cannot be ignored because it results in a greater demand on the fuelwood supply. In fact, a fuelwood scarcity has already occurred in many areas of the country.

Cooking in Thailand relies heavily on wood because of its ideal nature as a fuel. However, most of the biomass stoves used by Thai families are still inefficient. If the efficiency of the stove could be improved by only 5-10% (in fact 50% improvement can be achieved over the average commercial models), the quantity of wood and charcoal consumed by 6 million rural families in Thailand can be greatly reduced.

A survey of popular types of biomass cooking stoves is very essential because it can be used as a guideline for stove improving strategies. Many new designs of highly efficient stoves have failed to gain popular acceptance because the new models require changes in family cooking habits and social traditions. In addition, the operation of newly introduced designs is often more difficult. Hence, some important factors influencing the acceptance of highly efficient stoves by rural families are considered in the following discussion of hardware and cultural and social habits.

Popular types of hardware

A survey of cooking hardware used by Thai rural families (Pounoum, Wongopalert, and Arnold 1982) reported that the most popular type was a bucket stove which accounted for 71% of rural families. Eighteen percent of rural families use the three-stone stove and 11% use other types of stoves that use fuel such as rice husk, sawdust, biogas, etc. The bucket stoves commercially sold in the markets are primarily designed for charcoal. However, some bucket stoves are designed for dual purposes where either charcoal or wood can be used for fuel. Unfortunately, these dual features have significantly compromised the stove efficiency (to be discussed later in this report). Prices vary from 20 baht to 300 baht depending on design, workmanship and bucket materials. For example, a stainless steel bucket stove may cost 150 baht a piece: it is the most expensive stove.

The bucket stove is believed to have originated in China as it is known by Chinese name, "Ang-lo", which means "red color" (the color of low temperature fired clay). The period in which the bucket stove was brought to Thailand is not known. It possibly could have been brought here as long as 1,000 years ago during the earliest trade between Thailand and China during the Sukhothai Period. Or, on the other hand, the bucket stove may have come with Chinese migration during the Chinese civil war because the word "Ang-Lo" is from the dialect of one Chinese ethnic group that migrated to Thailand in large numbers during that time. If this is true, then the time of its appearance in Thailand would be only about 100 years ago.

The three-stone is really an ancient cooking stove used throughout the world that may have originated hundreds of thousands of years ago. It still exists today, and in Thailand is used only with wood. For other biomass, such as rice husk, sawdust, and peanut shells, the other stove is used, particularly in central areas where fuelwood is scarce. Rice husk stoves normally include chimneys because burning husks requires an induced draught to facilitate continuous combustion. Recently, non-chimney rice husk stoves have been found being used by some Kampuchean refugee families at Kao-I-Dang, Refugee Camp in eastern Thailand. Both types of rice husk stoves, chimney and non-chimney, have not been widely used in Thailand so far.

Cutltural and social habits

The size of a Thai family averages 6 persons. To cook food for this number of people usually takes about 45 minutes to 1 hour. Most of the cooking is of rice (boiling or steaming), with an average cooking time of about 15-30 minutes. Meat and vegetable dishes are usually cooked rapidly thereafter and, hence, the cooking time is less than 10 minutes/dish. This kind of cooking always requires high heat intensity, and therefore, a one-hole stove is preferred over multiple ones. Furthermore, in Thai culture, members of the family do not gather around the fireplace after the meal, drinking tea or coffee. Hence, the second pot hole (used for warming a hot drink) is not needed. Neither hot water for bathing nor room heating is required.

For these characteristics and cooking practices of Thai families, the bucket stove is considered the most suitable and, therefore, has become the most popular type of cooking stove throughout the country. It is believed that at least 4 million bucket stoves are being employed in Thailand at present.

C. STATEMENT OF THE PROBLEM

The problems associated with biomass cooking stoves are discussed in the following section.

Use of Inefficient Cooking Stoves

Rough efficiency tests have been performed on commercial charcoal, wood as well as three-stone stoves at the user end (Pounoum, Wongopalert, and Arnold 1982). It was found that most biomass stoves are inefficient. For example, the average efficiency of wood burning stoves is 13.6%, and charcoal bucket stoves 21.6%. The low efficiency performance of cooking stoves is due mainly to poor design. For instance, the bucket stoves available on the market usually have an overly large exhaust gap through which a large quantity of sensible heat escapes. The stove rim is also poorly designed and can accommodate only a few pots and pans. Some wood stoves do not have grates and hence air for combustion is distributed poorly, resulting in poor combustion of the fuel.

Lack of Knowledge and Awareness in Selecting Good Stoves

Almost all people who use biomass cooking stoves daily seem to be unconcerned about the stove performance. This may be due to the lack of awareness and knowledge of how a good stove could perform and the inability to recognize higher efficiency stoves. The selection of the appropriate type of stove for specific biomass fuel is also very important. For example, if charcoal is used in a bucket stove designed for wood, the efficiency of that stove will be reduced at least by 5-10%.

Lack of Interest and Knowledge Among Manufacturers in the Production of Good Stoves

Even though there exist some large bucket stove manufacturers in Thailand, the majority of biomass cooking stoves are generally produced within family industries where members of the family do the work. Stove manufacturing knowledge (or poor knowledge) and skill has usually been passed down through new members over time. However, after conversing with many manufacturers, it was found that most of them still lack the interest and knowledge to recognize the essential features of good stoves. The idea of competing for cheaper products among stove manufacturers without concern for quality is quite prominent. This has brought about poor efficiency and durability of stoves on the market.

Lack of Knowledge of Stove Maintenance

Commercial stoves are made of a low temperature fired clay material. Their durability when exposed to very high temperatures, such as the hot glowing charcoal bed in the combustion chamber, is such that it will last only about 3-6 months at the most without an outside restraining device. If this fired clay stove is bucketted and properly filled with insulating materials and lined around the inside wall with an inexpensive refractory mixture, the service life of the stove can be prolonged to approximately 1 year. Good care of stoves such as the repairing or the replacing of the grate, refractory lining, and rim sealing can greatly help to extend the stoves life expectancy. Unfortunately, most household tenders also lack this knowledge. In addition, it has been found that quite often the stove is overloaded with charcoal above the combustion chamber and hence, the cooking pot that rests on the charcoal bed will directly assert its own weight on to the grate. This will damage the grate and cause stove degradation. Hot liquid splashing on to the stove rim and inside the combustion chamber due to severe boiling also affects the stove's life expectancy because it will cause the stove's rim and body to crack.

Lack of Understanding of Fuel Preparation

Wet fuel burns less effectively than dry fuel because part of the heat of combustion is consumed to evaporate the water. Fresh wood generally contains about 50% moisture; therefore, wood should be ideally dried down to a moisture content of approximately 15%-12% before use. This can be done easily by placing it under the grate during cooking, or by letting it air dry for several days after splitting. It was found that many household cooks do not practice fuelwood preparation and drying. Another factor that contributes to the inefficient consumption of fuel is the lack of understanding of fuel use. For example, some household cooks insert a large piece of log into the stove. This kind of practice not only prolongs cooking time but also requires more firewood. In addition, the heavy wood piece can damage the stove structure easily. Smaller sized wood burns more effectively than fuel of a larger size, since a smaller size has a larger surface area of combustion with air. Therefore, large pieces of wood should be split or chopped into smaller ones for more efficient use of fuel.

High Cost, Limited Production and Distribution of Good Stoves

Since the main energy sources for cooking in Thailand are wood and charcoal, the degradation of natural forest has become evident in many areas of the country. The rate of deforestation has increased tremendously during the last decade. For example, the forest areas of the country have been reduced from 273,628 sq.km. in 1961 to 156,600 sq.km. in 1982 (Forestry Statistics 1982). Even though the depletion of the forest is not only caused by the consumption of fuelwood for cooking but also by slash and burn agriculture, road construction, etc., 40 million cu.m./yr of wood fuel is used for cooking alone. This will contribute significantly to the wood scarcity problem in the near future.

Fortunately, commercial, fast-growing tree plantations that produce fuel (such as the mangrove, Eucalyptus, and Casuarina) can somewhat reduce the depletion of wood. However, if the commercial wood plantations are not expanded on a large scale, or are developed without the attempt to reduce heavy woodfuel consumption by initiation of efficient stoves, or by encouraging the people to grow more wood for their own use, Thailand's natural forests can become exhaused within a very short time.

D. OBJECTIVES OF THE STUDY

The following are the five major objectives of the study:

1. To established a model stove testing and evaluation center to accommodate the national need for present and future research and development of biomass cooking stoves.

2. To conduct a systematic investigation on present performance of existing stoves being used in Thailand.

3. To make necessary improvements in terms of heat conversion efficiency, ease of operation and durability for three generic types of stove; namely, charcoal, wood, and rice husk/agriresidue.

4. To develop an improved stove production technique suitable for present small scale and medium scale rural industries.

5. To disseminate information, improved hardware and/or technology generated by this study to stove users, manufacturers, and the general public.

E. POTENTIAL BENEFITS FOR RURAL DEVELOPMENT

The potential benefits expected to be gained by the people who live in rural areas of Thailand are:

1. Decrease in national overall fuelwood consumption, and hence, an indirect decrease in the rate of deforestation.

2. Helping stimulate the establishment of indigenous renewable sources of energy in community, village and private woodlots through the popular employment of efficient biomass cooking stoves.

3. Retarding the rate of increase of imported petroleum derived cooking fuels.

4. Reduction of cooking time as well as ease of cooking through the use of highly efficient stoves and also a plausible reduction in kitchen air pollutants due to more complete combustion of the fuel.

5. Individual savings on stove costs and woodfuel costs due to longer service life and better efficiency.

6. The improvement of material and technology for constructing the developed stoves combined with the better understanding of stove operation, care, and maintenance will altogether help the economy of stove producers and users in the long run.

F. SCOPE OF WORK

The stove improvement component project was designed to investigate types of biomass fuels and types of cooking stoves. Charcoal, wood, and rice husk are the prominent biomass fuels used in Thailand and, hence, were to be selected for this study. The popular types of cooking stoves among users and those which are strictly used for household cooking were to be chosen for stove development. A detailed scope of work which includes laboratory set up, stove testing, analyses of stove performance, designs of developed models, construction and fabrication, and stove promotion follows. These lists present the steps that were to be taken for all aspects of the project.

Laboratory Set Up

1. Selection of the site and laboratory construction at the Royal Forest Department.

2. Acquisition of test instruments and facilities.

3. Acquisition of technical consultants and researchers.

Stove Testing Program

1. Collect from the field various models of stoves used in different parts of Thailand.

2. Select fuels to be used in tests and determine standard fuel preparation methods.

3. Select appropriate cooking and water boiling experiments and techniques.

4. Test the cooking stoves according to the selected testing experiment.

Analyses of Stove Performance Yield Design of Improved Model

1. For each model tested, determine the design parameters to be modified.

2. Measure the performance of stove models and the effects of changes in design parameters; performance measures include fuel consumption, rate of heat generation, cooking and boiling times, and efficiency determination.

3. Select stove designs which have good performance characteristics.

4. Design the prototype of developed models.

Stove Construction and Fabrication

1. Discuss with village craftsmen the methods of fabrication, the materials available for fabrication and the cost of constructing the units.

2. Select and improve clay materials for stove production.

3. Improve technique of stove production.

4. Trial production of developed stoves in actual small scale rural stove manufacturing factories.

5. Prepare stove guideline for fabrication, use, and maintenance.

6. Prepare technical drawings of developed stoves.

Stove Promotion

1. Introduce developed stoves through government agencies and villagers via training courses, and information/brochure distribution.

2. Organize stove manufacturers to produce improved design stoves.

3. Distribute stove samples to household users in rural areas via Regional Energy Center of NEA.

Chapter 2

Review of Literature

REVIEW OF LITERATURE

Biomass cooking stoves have been used by human beings for a long time but the knowledge of how various stove designs perform under different conditions is still vague. Most of the work done in the past was directed at trying to improve stove configuration; a few studies attempted to develop methods of testing stove performance. In this Chapter, a review of stove construction and design, methods of testing stove performance, and factors affecting stove performance will be presented.

A. STOVE CONSTRUCTION AND DESIGN

Various stove configurations are seen in Thailand and overseas. The variation comes about as a consequence of cooking habits and simplicity. In some countries people prefer to sit while cooking, while in others standing is preferred. To suit such cooking habits, stoves are constructed differently. In this section, construction and design of open fire Thai stoves, and overseas stoves are reviewed.

Open Fire Stoves

The open fire stove is a primitive stove which is still widely used in the developing world. The fire is encircled by more stones, bricks,cement, or lumps of other incombustible material. The open fire stove,sometimes called the three-stone stove (or fire), has no cost; no special materials or tools are needed to construct it and it can be located anywhere. Moreover, the heat output from the fire can be controlled by adding or withdrawing fuel.

Many different arrangements are found. Many countries use metal trivets; the trivet consists of a horizontal metal ring to which three legs are attached. In Senagal, 55% of the rural population uses trivets (Modon et al., 1982).

Thai Stoves

A variety of stoves can be found in Thailand, both user built and commercially manufactured. Charcoal bucket stoves, which can be found almost everywhere in Thailand, have been studied by Thai investigators (Osuwan and Boonyakiat, 1982). The structure of this stove will be described in a later chapter. The book by Dunn, et al.(1982) and De Lepeleria, et al.(1981) also has detailed descriptions. Since the Thai charcoal bucket stove was investigated in this study, it is appropriate to review the literature and the various investigations already conducted.

Thai Charcoal Bucket Stove

Although there are various kinds of bucket stoves in Thailand, they have a common structure. The stove is normally made of fired clay in the shape of an inverse truncated cone, (or cylinder) which is placed in a metal (generally zinc) bucket-liked container; hence, the name "bucket stove." Charcoal is the main fuel for this kind of stove.

In 1982, Meta Systems, Inc. Thai Group, sponsored by USAID, investigated the performance of Thai charcoal bucket stoves made by different local manufacturers (Pounoum, et al., 1982). The group utilized boiling water tests and cooking tests (described later in this chapter) in their study. Using the water boiling tests, they found that the ratio between the water and the fuel affected stove performance more than the size of stove and cooking vessel. Time to boil ranged from 11 to 51 minutes. Pounoum et al. (1982) also considered the effect of starter fuels on stove efficiency, since starter fuels vary among villagers. Using the "cooking test," they compared the quantities of fuel, food and water used in cooking rice. The average amount of released heat from the fuel consumed was found to be 3.2 kilocalories per gram of food cooked. Further, stove efficiency obtained from "the water boiling test" demonstrated that the average value used by food in cooking was 650 calories per gram of food.

Osuwan and Boonyakiat (1982) applied water boiling tests to examine the performance of Thai charcoal bucket stoves. They found that stove performance was affected by stove size, air inlet area, gap height, grate hole area, aluminium pot size, quantity of water used in the test, and quantity and mass of charcoal. Their results showed that stove performance improves if stove diameter is increased, or the air inlet area is decreased, or the gap height is reduced. The efficiency of stove performance varied from 20.86 to 33.95%.

Meechai rice husk stove (Meechai, undated)

The Meechai stove is composed of four structural metal pieces: a cone, a stove body, stands, and an ash receiver. The cone, the stove body and the ash receiver are made from scrap metal or galvanized sheet; the stands are steel rods. The stove body is put into the cone, which itself is set on the stands; rice husks fill the space between the stove body and the cone. At the apex of the cone, an ash removal service is positioned to let the ash fall out of the stove.

Sooksunt economy stove (Sooksunt, 1981)

The Sooksunt stove can be made of bricks, cement, or a mixture of clay and rice husk. It has a chimney. There are three types. Type 1 can be used with any kind of fuel except rice husk and sawdust. Type 2 can be used with any fuel. Type 3 is designed for the Hill Tribes in Thailand and cannot use rice husk or sawdust as fuel. Detailed designs can be found in the article by Sooksunt (1981).

The rice cooking test was performed to test cooking time. For a family of 5 people, the Sooksunt stove can steam rice in 30 minutes. The time used as reported was not much different from that required by gas stoves.

The stove is recommended for a medium income family (Intrapanich, 1981) because it can use any waste materials as fuels.

Suwat stove (Suwat, undated)

The Suwat stove has two pot holes; each pot hole is made from steel and insulated with sand, ash, clay, and cement. The first pot hole is above the combustion chamber; the second is located between the first and a steel chimney. An efficiency of approximately 23% has been obtained from the stove when sawdust is used as fuel, and 17% when rubber wood wastes are used.

Nai La stove

The Nai La stove is made from a cylindrical paint can, 6-7 inches in diameter and 12 inches high. At the lower part of the can, 2" x 2" air inlet hole is cut away to be used as the ignition port. Since the stove is made from a can, it is sometimes called a "canned stove" (Bumroong, 1981).

Fuels used are normally sawdust and rice husk. The packing of fuel is achieved by placing a long bamboo stick or a pipe at the axis of the can. After the can is filled with fuel and compressed in the bucket, the stick is pulled out, leaving a hole for combustion along the tunnel from the outway ignition port.

It has been found that stove efficiencies are 14-16%, and 12% when sawdust and rice husk are used as fuel, respectively.

Noi Palipu (1981) has improved this stove in both construction materials and size to gain more durability and reliability for daily practical use.

This stove has been recommended for the family with low income since the material for construction is inexpensive and easy to find (Intrapanich, 1981).

Economy fixed stove

The Economy fixed stove is made of cement and brick, or clay. There are two pot seats aligned with a chimney. The stove base is tilted such that the distance between the base and the chimney is lower than that between the base and the pot seat. Fuel can be wood or rice husk.

Overseas Stoves

Stoves found in developing countries are summarized below.

Traditional stoves

The traditional Bangladesh Chula consists of a short, slightly downward-sloping tunnel dug into the ground, with a pothole cut in the roof at the end. The fire is lit beneath the pot and is kept alight by feeding it with fuel pushed in from the open end of the tunnel. In some cases, the size of the firing chamber is increased, and two potholes are provided. The depth of the firing chamber in these Chula stoves is approximately 40-55 cm. (Omar, undated).

Tungku Muntilan (Joseph et al, 1980) report that a traditional stove constructed in Magelang, Central Java, Indonesia, is constructed from clay and has approximate dimensions of 65 cm x 33 cm x 22 cm. It weighs approximately 20 kgs. There are two pot seats, the second acting as a chimney. The stove is sun dried, not fired. It hardens after use in the kitchen.

Portable stoves

In Kenya and other East African countries, a metal stove called a Jiko (Foley and Moss, 1983) is made from scrap metals in the form of a cylinder approximately 25 cm in diameter and 15 cm high. It has a perforated metal grage mid-height. Pot supports are fixed to the top edge and project inward a few centimeters. Fueling is done by feeding small pieces of charcoal around and under the pot, or by lifting the pot. Ashes are removed through a small side door at the base of the stove. This door can be used as a means of controlling the flow of air to the grate.

In India, a stove made of light sheet steel is equipped with a carrying handle, like that on the bucket. In some areas, the stove is lined with mud and cement. This insulates the stove, and cuts down on the radiant heat loss from the sides (Gupta and Usha, 1980).

A cylindrical stove with an outside wall of steel and an inner lining of cement is also used in Indonesia. The grate consists of iron bars fixed into the lining (de Lepeleire et al, 1981).

The Rural Energy Laboratory of the Central Power Research Institute, Bangalore (India), has developed a stove, called a Priyagni (Cookstove Bulletin, 1984). The stove is cylindrically shaped with metal stands to keep it steady and help in moving it. A cylindral combustion chamber closed both at the top and the bottom has slotted plates of a particular pattern. A grate is fitted inside the chamber slightly above the bottom slotted plate. The dimensions of the slotted plate and the chamber have been proportioned to achieve improved combustion. An aluminium sheet lining is also provided in the chamber to reflect heat and to reduce wall radiation loss. The stove has been produced in 3 different sizes--small, medium and large.

The Keren stove, a stove widely used in Central Java for boiling water and frying, is made of fired clay. It consists of a spherical firebox over which a pot is placed. There are 7 holes (1.5 cm in diameter) spaced evenly around the sides at the base of the firebox. The diameter of the firebox is 24 cm and the height is 16 cm. The entrance of the firebox is 18 cm wide and 7 cm high. The stove weighs 3 kgs (Joseph et al, 1980).

The single pot ceramic Chula is found in many Asian countries. It is called Keren in Indonesia, Kamado cooker in Japan. This stove is usually cylindrical, approximately 15 cm in diameter and 10 cm in height, weighs about 5 kg and is easily portable. Fuel is added through a hole in the side at ground level. Wood, straw, dung, and other materials are burned as fuel.

When charcoal is used as fuel, a grate is required (Foley and Moss, 1983).

Tunga Sae, used in urban areas of Indonesia, is made from clay by a potter using either a pottery wheel and/or coiling techniques. It consists of a firebox, a connecting flue and a second pot seat. The connecting flue slopes up from the firebox and has a cross-section of 8 cm x 8 cm. The firebox has a height of 21 cm and a diameter of 24 cm. The second pot seat has a height of 25 cm and a diameter of 20 cm. The stove weighs 8 kgs. Wood or wastes can be burned in this stove. When the first pot boils, it can be interchanged with the second pot to achieve faster cooking time and lower wood consumption. The first pot, now on the back hole, will simmer while the pot on the front is brought to boil (Joseph et al, 1980).

A stove especially made for burning rice husk is used in Bali. It simply consists of an open-top oil drum with a hole in the side at ground level. Before loading it with rice husk, a thick stick is laid horizontally across the bottom of the drum from the center outward through the hole in the side. Another stick is held vertically at the center. The rice husk is then packed tightly around the two sticks. When a fire is required, the sticks are removed, leaving passage for air through the opening in the side, across the base, and up through the center of the fuel bed. The fire is kindled at the bottom, and provides approximately two hours burning (Cook Stoves Handbook, 1982).

Recently, a company in the U.S.A. designed and constructed a portable stove, called the Z Stove (private communication). The stove is made of a pop-riveted, galvanized sheet steel box 7 x 7 inches square, 10 inches tall and 4 pounds in weight. The stove features a cylindrical firebox inside, with a galvanized screen fire grate at its bottom, an aperture for inserting bits of fuel, a small drawer beneath the grate for insertion of kindling, a draft/damper control, an X-type cooking vessel support and a wire bale handle. The stove can burn any solid fuel from wood to animal dung. The manufacturer claims that the stove is highly efficient. However, ITDG testing, showed that the Zip was 25.4 to 29.7% efficient (from Testing of the Zip Stoves, Stove Project Technical Notes No. 3).

Fixed stoves

Fixed stoves are usually constructed from mud, mud and clay bricks, or mud and sand. Collectively, these are often referred to as mud stoves. When constructed, these stoves are sometimes coated with a thin paste of cowdung to prevent them from cracking.

In a simple fixed stove design, fire surrounds three sides with an opening for fuel at the front. It is built to take a single pot. The pot is sometimes seated on three or more small raised mounds around the pot hole. These permit the hot gases and smoke from the fire to escape upwards around the sides of the pot. In other cases the pot sits tightly into the pot-hole. In some rural areas of India, the opening for the fuel is bridged across to provide a complete surrounding for the bottom of the pot (Cook Stove Handbook, 1982).

Many types of mud stoves have two or more potholes. Magan Choolah stoves in India are made from mud, dung or straw cuttings and cowdung. This stove has three potholes situated at the three corners of a triangle and interconnected by ducts. The hot gases pass from the first pot seat to the second, and then to the third. One damper is positioned in the connecting duct between the first and second pot seat to control the rate of combustion. A chimney is incorporated as a smoke outlet (Tata, 1979). Similar mud stoves are found in the urban areas of Indonesia (de Lapeleire et al, 1981).

A smokeless HERL Choolah stove was designed at the Hyderabad Engineering Research Laboratories in Hyderabad, India (Tata, 1979). It is made from bricks and mud or only mud. There are 4 pot seats situated on a L-S shaped duct, the first three are for cooking, the fourth is for heating water. One damper is positioned inside the connecting duct between the fourth pot seat and the chimney to control the rate of combustion. Only the first pot seat receives the maximum heat. When one or two pot seats are in use, the others are kept closed.

In some mud stoves with two or more potholes, these potholes are positioned more or less symmetrically over the firing chamber and each pot obtains roughly the same amount of heat. One of these stoves is an improved HERL Choolah, which has three pot seats (Tata, 1979). A variety of forms (varying only in detail) are used in different parts of Indonesia (de Lapeleire et al, 1981; Singer, 1961).

The Lorena mud stove which was developed at the Ahagui Experimental Station, Guatemala has five openings for cooking and a chimney for smoke outlet (Tata, 1979; Kaufman, 1983). The first pot is heated directly by fuel; the others are heated by the hot gases which pass through a long system of ducts connecting one pot seat to others. There are three dampers: the first is in the duct that connects the mouth of the stove to the first pot seat; the second is between the second and the third pot seats; and the third is between the fourth and the fifth pot seats.

B. STANDARD METHODS OF TESTING STOVE PERFORMANCE

Although human being have been using biomass cooking stoves for a long time, standard methods of comparing stove performance evolved only recently. Joseph and Shanahan (1980) realized the necessity of standardizing testing methods; they found that improper stacking of wood could produce as much as a 100% in difference performance figures.

A few methods of testing have been proposed (Joseph and Shanahan, 1980; Joseph, 1979). For a stove test to be useful, Joseph (1979) recommends that the test should be simple, reproducible, adaptable to any fuel stove, and reflect local cooking practices. It is found that neglecting the last recommendation can cause a poor stove performance when used with different practices (Joseph and Shanahan, 1980).

In addition, Joseph (1979) suggests that the tests should be able to determine the amount of energy used to cook a meal or boil water, and the amount of biomass fuel consumed. The reason for these two determinations is that the first will give the heat utilization or cooking efficiency, and the second the combustion efficiency.

The performance of a stove is usually expressed in terms of heat utilization. This term is defined as "the ratio of heat absorbed by the water to heat liberated from the burning biomass" (Joseph and Shanahan, 1980). There are two kinds of heat utilization: one does not include the heat required in evaporating, the other includes the heat required in evaporating.

Another term that is sometimes used in comparing stove performance is "burning rate". Burning rate is defined as the amount of wood (biomass) burnt (in the experiment) divided by the duration (of the experiment) (Joseph and Shanahan, 1980). The burning rates are found to vary with size of wood.

Two types of tests are commonly carried out on stoves: one is the "boiling water" test, and the other is the "cooking food". Other tests such as combustion tests are also sometimes used (Joseph, 1979).

Boiling water tests

There are 4 tests being used as standard methods:

1. A fixed quantity of water is evaporated, with fuel and time as variables.

2. Quantities of fuel and water are fixed, with time as a variable.

3. A fixed quantity of fuel is burnt, with the quantity of water evaporated and time as variables.

4. The quantity of water evaporated within 30 minutes is determined, with fuel as a variable.

Water boiling tests have been used by the Department of Applied Physics and Mechanical Engineering at Eindhoven University of Technology in the Netherlands, to study the performance of the Family Cooker and the De Lepeleire/Van Daele stove.

Ponnoum et al.(1982) have used the boiling water tests in studying the performance of charcoal bucket stoves and wood stoves in Thailand. They found difficulty in identifying the time at which boiling started.

Joseph et al.(1980) have developed another method of testing. They set the boiling time and vary the time for evaporation. For example, a pot of water takes a certain time, say "t" minutes, to boil. The water is then allowed to evaporate for 10, 20, 30, and 60 minutes. At the end of the experiment, the following measurements are recorded:

- Weights of wood used and remaining and
- The amount of water evaporated at each evaporating time. These measurements are then used to calculate heat utilization.

Cooking food tests

Simulated cooking tests measure the amount of fuel used and the time taken to cook a variety of standard meals under controlled conditions. The principle objective of the cooking test is then to determine the influence of the stove design on the amount of fuel used and time taken to cook a meal (Joseph and Shanahan, 1980).

Cooking rice tests have been used by Pennoum et al. (1982) in investigating the performance of charcoal bucket stoves and wood stoves in Thailand. They measured the quantities of fuel, food, and water used. All the tests were performed with metal cooking vessels. Regular rice was placed in a pot and covered with water. The quantity of rice and the ratio of water-to-rice was determined based on household practices. The water and rice were brought to a boil. After a short period of time the excess water was poured off and the rice dried either over the fire or away from the fire. The rice cooking took from 25 to 40 minutes.

One important point that must be stressed to investigators using this kind of test is that the tests should involve cooking local dishes and that it is necessary to prepare the food in the same way for each test, using the same type of food. To obtain such information, a survey of the villagers' cooking habits must be performed. This approach has been carried out carefully by Pennoum et al. (1982) in their investigation of stove performance in Thailand. Designers also need to devise their own grading systems in collaboration with local women, to ascertain what the women regard as "cooked" food--for all the types of cooking (frying, baking, stewing, etc.). It is also important to get different village women to use the stove to cook these same meals and see if there is a change in the time taken and fuel wood used (Joseph, 1979).

Steaming and open steaming are the two processes frequently used in cooking (Joseph, 1979). Steaming involves bringing water to boil and letting it evaporate. The steam then passes through the food. Some of the steam escapes and some condenses on the food and on the lid. If there is no food in the pot, the amount of heat required to totally evaporate the water is less than if there is food. Consequently, steaming of food cannot be simulated using only boiling water. In the case of open steaming, a small amount of food is placed in a relatively large pot of water, which is evaporated slowly. Most of the energy involved in the cooking process is used in the boiling and evaporating of water. Thus boiling water can simulate the process of slow open steaming. The simulation can also be applied to stewing.

Combustion test

In combustion tests (Joseph, 1979), gas analysis and measurement of the stack temperature were obtained. These data gave a measure of how much heat was being lost due to process combustion. According to this test, fuel is burning efficiently if:

- The percentage of CO is less than 0.5%;
- The average amount of oxygen in the flue gas is less than 11%; and
- The average carbon dioxide content in the flue gas is approximately 6-8%.

Measurement of the chimney temperature, in the combustion test, indicates how much heat is being transferred to the pots. A high stack temperature means that the pots cannot absorb the amount of heat being liberated. As the temperature of gases decreases, the amount of air being drawn into the combustion chamber also decreases.

C. FACTORS AFFECTING STOVE PERFORMANCE

Problems that occur in the stove are classified and discussed below.

Convective heat loss

Convection is the mechanism by which gas moves up due to a difference in temperature. In stoves, convection can occur through the exhaust gap. When gas with a high temperature leaves the stove, it carries thermal energy with it. This energy is considered a loss.

Wind promotes this mode of heat loss. An example is the open fire. Efficiency of an open fire drops in the windy condition since the fire is not protected. Efficiency can be improved by constructing a shield to protect the fire from the wind. It is found that the efficiency of an open fire stove increases to approximately 17 percent when the fire is moved into the kitchen (Vita News, 1984).

In bucket stoves, it is found that stove efficiency can be increased by reducing the size of the exhaust area (Somchai and Kanchana, 1983). The improvement is due to the reduction of convective heat loss through the gap.

In stoves with many pot seats such as the Smokeless HERL Choolah, convection can be reduced by closing the seats that are not used (Tata, 1979). When all the seats are used, the convective loss is low since hot gases have to pass all the pot holes; hence, a higher proportion of the heat contained in them is usefully absorbed.

Conductive heat loss

Conductive heat loss occurs when the stove is not well insulated. Such loss is seen in the metal stove. To reduce this loss, the stove has to be insulated. However, thick insulation can also reduce stove performance during one or two hours of cooking, since massive walls absorb more heat than bare walls lose to the outside (Vita News, 1984).

Radiative heat loss

Since heat is transferred to the pot mainly by radiation, any loss due to radiation can affect stove efficiency. It is believed that radiative heat loss can occur through the exhaust gap (Somchai and Kanchana, 1983). Reducing the gap will decrease the radiative heat loss, and hence, improve stove performance. In the case that the pot does not fit the pot seat, radiative heat loss is high.

Size of fuel

One of the problems affecting the comparison of stove performance (even when stoves and test conditions are standardized) is the size of the fuel used. It is found that the efficiency of the bucket stove increases when the size of the charcoal decreases (Somchai and Kanchana, 1983).

Types of biomass

There are many kinds of biomass fuel that can be used in stoves. They include wood, charcoal, and agricultural wastes such as rice husk. These fuels, when combusted, supply heat unequally. Chomcharn et al (1981) used the water boiling test to study the efficiency of a bucket stove fuelled by different types of charcoals, different firewood species, sawdust, rice husk, and lignite briquets. They found that the efficiency of the bucket stove varied with the fuel type used and ranged from 18.5 to 33.1%.

Air supply

Since the energy obtained in the stove is the energy from combustion, the degree of combustion strongly limits stove performance. There is no doubt that wood, which has a high heat of combustion, will poorly render heat under the conditions of insufficient supply or undersupply of air. On the other hand, if air is oversupplied, a certain amount of heat will be used in raising the temperature of excess air. This air then leaves the stove together with the exhaust gas. In this latter case, stove performance also decreases.

Internal variables

The initial project study that appeared in the interim report (Sherman and Bunyat, 1983) revealed that the internal variables of the charcoal stove(such as stove weight, grate hole area, exhaust area, air inlet area, and slope of the inner wall) strongly affect stove performance.

Stove material

As a stove can be made from either clay, cement, or metal, its efficiency varies. Openshaw (undated) compared metal and clay cooking stoves. He found that 40% of charcoal used could be saved by the household if the household used a clay stove instead of metal stove. In addition, the material chosen more or less reflects the long term service ability.

D. CONCLUSION

In the above review of the literature, it is apparent that there are many problems associated with biomass household cooking stove research, development and use. Therefore, before researchers embark on a stove development program they must first accommodate the multi-faceted complex of problems of cooking stoves. Precognition of and distinctions between should be made regarding the following:

- Stove types and kinds: chimneyed or non-chimneyed, single pot or multiple pot holes, appropriate size to suit the need for individual or family in the working area.

- Social nature or tradition of cooking: size of the family, normal duration of cooking time, low heat vs intense heat requirement, cuisine, extra services required from the stove besides cooking, etc.

- Special requirements for stove users: speediness in cooking, ease of operation, reliability and consistency of stove performance, and the accommodation of various sizes and shapes of pots, pans, and woks.

- Materials and techniques for construction: inexpensive, locally available material vs expensive exotic material, simple construction vs complicated construction, and the stove's durability.

- Fuel types and physical characteristics: charcoal, wood or agri-residues, fuel's forms in lump, long stick, chip, granule, dust, briquette and etc., fuel's moisture content, density, specific heat of combustion, soundness of the fuel, i.e. fresh or biodegradable.

- Methods for testings and performance evaluations of cooking stoves: water boiling vs simulated food cooking tests, duration of tests, assignments of dependent and independent measuring criteria such as time, fuel load, water evaporated, etc.

Chapter 3

Plan and Design of the Project

PLAN AND DESIGN OF THE PROJECT

The project design aimed at:

- Establishing a laboratory and facility to perform project tasks as well as for long-term stove improvement research and development;
- Collecting existing local stoves for testing and evaluation;
- Investigating existing stove performance;
- Analyzing the physical factors of stoves that inhibit performance;
- Developing an improved prototype;
- Testing the prototype and its remodification;
- Producing developed stoves; and
- Promoting developed stoves in the field.

A. LABORATORY AND FACILITY SET UP

The project required an experimenting room for testing stove performance. An area of approximately 80 sq.m. was located behind the Forest Research Institute at the Royal Forest Department in Bangkok. The room consisted of space for storing the stoves, two large cement top counters for handling hot stoves during the testing, a sink with tap water for cleaning purposes, and an exhaust hood with ventilation fans for outletting the combustion smoke. All tests were conducted in this natural environment.

The instruments applied to accompany the tests included: 3 weighing scales of different ranges from 500 gm, 7 kg, and 20 kg. 3 cromel/alumel thermo-couple and digital thermometers with a range of 0-800 °C for temperature measurement; bulk thermometer with a range of 0-100 °C; hygrometer for humidity measurement; electric oven for fuel drying; a series of aluminum cooking pots with sizes ranging from 16 cm to 32 cm; measuring tapes and calipers for dimensional measurements; and workshop tools.

B. COLLECTION OF EXISTING LOCAL STOVES

As previously mentioned, the three generic types of biomass cooking stoves (which consist of the charcoal stove, wood stove, and rice husk stove) were the main concern of the project for further development. The task of this phase was to collect as many of the various kinds (with various features) of these three types of stoves. Since biomass cooking stoves were widely distributed throughout the country, a stove collecting team was sent out to various locations to collect the stove samples and bring them back to the laboratory for testing.

C. INVESTIGATION OF EXISTING STOVE PERFORMANCE

Efficiencies of all collected stoves were evaluated using the same standard testing conditions which is described in the next chapter. All calculations based on data received from the stove testing were done on an IBM main frame computer at Kasetsart University. The results were analyzed closely for relevant relationships between the efficiency and the physical structure of the stoves. This information was critical for stove development.

D. ANALYSES OF STOVE PHYSICAL FACTORS

The stoves physical factors (such as section for air inlet, area for exhaust gas outlet, combustion chamber, grate, stove body, etc.) were analyzed. If one of these factors was changed so was the geometry of the stove. Such an effect was classified as an internal variable. There was another group of variables that had no effect on the geometry of the stove when their values changed (wind velocity, humidity, air temperature, pot size, etc.). This group made up the external variables. The effects of both the internal and external variables on the performance of stoves were studied. The understanding of their effects on the stove performance would be crucial in designing stoves with high efficiency.

E. DEVELOPMENT OF IMPROVED PROTOTYPE

When the order of most important variables that affected the efficiency of the stove was determined from the test analysis, design of high efficiency stoves corresponding to the prominent variables was then accomplished. Technical drawings of the stove prototype were made.

After achieving the design of the stove prototype, the next step involved the selection of suitable quality stove materials, and, finally, construction of the stove prototype. Stove assembly closely followed the guidelines of the technical drawing.

F. TESTING OF PROTOTYPE AND REMODIFICATION

The finished stove sample was then subjected to the same efficiency tests. The results were compared with the existing stoves. This step might be carried out several times to assure that the developed stoves had reliable performance and high efficiency.

G. PRODUCTION OF DEVELOPED STOVES

Several manufacturers were selected for the production of the developed stoves. Guidelines and information were provided to the manufacturers to ensure consistency of the products made in large quantities.

H. FIELD PROMOTION OF DEVELOPED STOVES

The developed stoves were introduced to the public via mass media, schools, rural development organizations--both private and governmental. Relevant information for stove promotion was distributed in the form of pamphlets, manuals, brochures. Short term instruction on how to make, to select, and to properly operate various types of cookstoves that conserve wood and other biomass resources were also provided. Training of villagers, village leaders and rural development officers on the fabrication and selection of good stoves was also undertaken.

Chapter 4

Experimental Techniques and Procedures

EXPERIMENTAL TECHNIQUES AND PROCEDURES

This chapter will discuss the experimental techniques and procedures involved in selecting and preparing fuels (firewood, charcoal, and rice husk), testing local existing cooking stoves, standard testing conditions, definition of heat utilization efficiency, and testing for the effects of the internal and external variables of charcoal and wood stoves.

A. FUEL TYPE AND PREPARATION

Besides having appropriate kinds of fuels for the three generic types of cooking stoves (namely, firewood, charcoal, and rice husk) preparation of the fuels was necessary to ready them for testing. Using fuels with varying characteristics can lead to inaccurate stove performance measurements. The following sections discuss the method of preparing the fuel by type of fuel.

Firewood

Firewood selected for the experiment was approximately 4 year old plantation grown *Casuarina junghuniana*. The diameter was between 2.5 - 7.5 cm. Each piece was then split laterally into 2 - 4 smaller pieces and sun-dried for several days.

Charcoal

In urban areas, charcoal is the most popular fuel for cooking. It burns without smoke or smell and is thus suitable for indoor use. The charcoal used in the experiment was produced from plantation grown *Rhizophora apiculata*, a premium mangrove species for charcoal making. The selected species was approximately 10 - 12 years old and of a diameter of about 2.5 - 5 cm. The process of firing the wood into charcoal occurred in standard commercial brick beehive kilns.

Rice husk

In the central area of Thailand, rice husk is often used for cooking. It is usually used in a rice husk stove. The cost of this fuel is very low.

The rice husk used in the laboratory was obtained fresh from a commercial rice mill near Bangkok. It was dried later under laboratory conditions.

The important characteristics of firewood, charcoal, and rice husk used in the experiment are summarized in Table 4.1.

Fuels used in all of the experiments were acquired in large quantity and stored inside the test building under the same conditions.

Table 4.1 Characteristics of Biomass Fuel Used in the Experiment

Fuel	Density (gm/cm)	Moisture content (%)	Heating value (MJ/kg)	(Kcal/kg)
Charcoal	0.78	3.5 - 5.0	26.34	6,300
Wood	0.75 - 0.85 (ave. 0.79)	10.0 - 13.0	17.89	4,280
Rice husk	0.11	10.0 - 13.0	13.79	3,300

B. TESTS OF EXISTING THAI COOKING STOVES

Approximately 36 different types of charcoal bucket stoves, 39 wood stoves, and 5 rice husk stoves were brought back to the laboratory for performance evaluation. The physical dimensions of every stove were measured and recorded. These physical values were very important variables, and were used later in the analyses. All tests were performed by the Royal Forest Department staff. During each test run, combustion characteristics and stove behavior were observed closely. The numerical, measured values of required information on water, ambient temperature, humidity, fuel weight, water weight, etc. were recorded on a data sheet. Efficiency for each test run was then evaluated, and the calculations were performed by an IBM mainframe computer at Kasetsart University.

In order to study the performance and efficiency of various types of stoves, standard testing conditions need be followed. The procedure used in these experiments is summarized in the following section.

Standard Testing Conditions

All the tests were conducted under the following standard conditions:

- Pot diameter: 24 cm (pot no. 24). (This pot size is commonly found in rural kitchens);
- Wood kindling weight: 50 gm for wood stove, 30 gm for charcoal and rice husk stoves;
- Fuel weight: for charcoal, use 400 gm, for wood and rice husk, feed in at normal rate as needed;
- water weight: 3,700 gm.

The pot is weighed and filled with 3,700 gm of water. The initial temperature of the water is controlled at 28 ± 1°C, 50 gm of kindling is placed into the combustion chamber and ignited. About 30 seconds of lighting time should be sufficient to ensure that the kindling is ignited. The charcoal is then loaded onto the burning kindling. The pot is covered with a lid and is placed on the stove and the time is immediately recorded. The temperature of the water in the pot is measured every few minutes until the water starts to boil. Time required to bring the water from its initial state to the state of boiling is noted; the noted time is called "time to boil". Time to boil is one of the important variables which determine the characteristic performance of a cooking stove.

When the water starts to boil, the lid is removed and boiling is continued for 30 minutes. After 30 minutes, any water remaining in the pot is reweighed as is any remaining fuel. The amount of water evaporated and the weight of the charcoal consumed in the test are then calculated. For wood and rice husk stoves, the test procedures are carried out in the same manner.

Stove efficiency is calculated from the data gathered in the procedure discussed above. The term "efficiency" will be used interchangeably with "heat utilization efficiency" in order to conform with the use of this word in other publications.

Heat Utilization Efficiency (HU)

The heat utilization efficiency (HU) is the percentage of actual energy transferred from potential energy stored in the fuel to the water in the pot. The equation for determining the HU value is adapted from Joseph (Joseph, 1979).

$$HU, \% = \frac{[S_w \times W_m (T_f - T_i) + (L \times W_e)}{[(E_{fm} \times W_f) + (E_{km} \times W_k)] - (E_{co} \times W_c)} \times 100$$

Where,
S_w = Specific heat of water, 4.18 J/gm

W_m = Weight of water in pot at start of test, 3,700 gm

T_f = Temperature of water at boiling point, 100° C

T_i = Temperature of water at start of test, °C

L = Latent heat of water at 100° C, 2,256 J/gm

W_e = Weight of water evaporated at end of each test, gm

E_{fm} = Heat value of fuel, J/gm

W_f = Weight of fuel used, gm

E_{km} = Heat value of wood kindling, J/gm

W_k = Weight of kindling, gm

E_{co} = Heat value of charcoal, J/gm

W_c = Weight of charcoal remaining at end of each test, gm

C. TEST FOR THE EFFECT OF INTERNAL VARIABLE ON THE CHARCOAL BUCKET STOVE

Most Thai bucket stoves have the following important physical features:

- Stove gap/exhaust area;
- Grate hole area;
- Grate-to-pot distance;
- Combustion chamber size;
- Air inlet door; and
- Grate thickness.

The variation of one of the above characteristics is expected to have an impact on stove performance. These variables, moreover, are properties of the stove itself. Hence, they can be called the internal variables.

To study the effect of one of the internal variables, it is necessary that the others are kept unchanged, or constant. The variable that is tested is varied in the range of its physical limit. Additional tests on a few more stoves may be required to confirm the effect of that variable on stove performance. This experimental technique was used in all project experiments.

Stove Preparation for the Internal Variables Study

Stove gap/exhaust area

The stoves used in this study were stove nos. 1/5 and 1/31; their respective gap areas were 98.4 and 98.6 cm. For these two stoves, the time to boil and the charcoal consumption were experimentally determined; the HU values were subsequently calculated. The gap areas of each stove was then reduced three times by adjusting the pot rest. The gap area tested on stove no. 1/5 was 86.1, 65.6, and 20.5 cm. The gap areas tested on stove no. 1/31 were 86.0, 65.6 and 40.2. The stoves were retested for time to boil and charcoal consumption.

Although the exhaust area did not appear in the equation for finding the HU value, it can indirectly affect stove performance. The exhaust area regulates the flow rate of the exhaust gas from the combustion chamber. As a consequence, the loss of heat, due to natural convection of gas through the gap, varies accordingly. For this reason, the exhaust area of the gap had to be considered as one factor that influenced stove performance. In this study, the gap area was reduced by adding clay to its width; this means that after the addition of clay, the length of the exhaust area is virtually unchanged. The variation of exhaust area, then, can be represented by the change in gap height.

Total grate hole area

Stove no. 1/5 was used in this experiment. The diameter of the grate was 15 cm, and the total grate area was 176.5 cm. The total grate hole area was 80.0 cm.

To study the effect of grate hole area on stove performance, the grate hole area had to be varied by reducing the number of holes. The hole reduction was carried out by plugging the chosen holes with a rice husk ash and clay mixture. However, it should be kept in mind that the holes chosen to be filled up were distributed properly so that the inlet air, after reducing the grate hole area, was still distributed uniformly.

Two tests using gap height as a parameter were performed to study the effect of the grate hole area on stove performance; both tests used stove no.1/5. The grate hole areas, with the above procedure, were set at 80.0, 52.8 and 26.4 cm. The gap height of the stove was changed, using the method described in the above section on stove gap/exhaust area. It was 0.5 cm in the first test and 2.5 cm in the second.

Grate-to-pot distance

Grate-to-pot distance is defined as the distance measured from the surface of the grate to the pot bottom. This internal variable has a direct effect on stove performance; if the distance is small, the pot is near the flame and stove performance is good--as would be expected. On the contrary, a large distance would render a poor stove performance. However, too small a distance will restrict charcoal loading and charcoal capacity.

Stove no. 1/4 was used in this experiment. The grate-to-pot distance was varied from 7.5 cm to 9.3 cm and then to 11.0 cm. A distance of less than 7.5 is not recommended since the combustion chamber becomes too small to hold enough charcoal to cook a meal. Time to boil, the amount of water evaporated and the amount of charcoal consumed were all recorded.

Combustion chamber size

The test for the effect of combustion chamber size on stove performance used three charcoal bucket stoves: stove nos. 1/28, 1/A3, and 1/D1. The respective volumes of the combustion chamber were 4,216, 2,460, and 2.946 cm. After the first series of tests was completed, the volume of each stove's combustion chamber was reduced by increasing the lining thickness to 3,414 cm (for stove no. 1/28), 1,787 cm (for stove no. 1/A3), and 1,510 cm (for stove no. 1/D1). All stoves were then subjected to the same test.

Air inlet door

Stove no. 1/5 was used to study the effect of the air inlet door area on its performance. The stove had a gap height of 1 cm and an air inlet door area of 66 cm. The area was later reduced to 49.5, 33.0, and 16.5 cm, which corresponded to 75, 50 and 25% of the initial area. The stove (as each door area was reduced) was tested for performance.

Grate thickness

Stove nos. 1/E3 and 1/E4 were tested for grate thickness. The grate thickness for both stoves was initially 2.0 cm and was later changed to 3.6 cm. At these two grate thicknesses, the test for the efficiency was performed.

D. TEST FOR THE EFFECT OF EXTERNAL VARIABLES OF THE CHARCOAL BUCKET STOVE

In the previous section, the internal variables--the properties of the stove--were discussed. There is another group of variables that can affect the performance of the stove, but they are not the properties of the stove itself. The variables in this group are called the external variables. Examples of them are:

- Initial weight of charcoal;
- Initial weight of water;
- Pot size;
- Charcoal size;
- Wind effect; and
- Humidity effect.

To study the effects of the external variables (pot size, charcoal size, wind and humidity) a laboratory test was conducted, using the same testing procedure described in this chapter in the section on Standard Testing Conditions. For the initial weight of charcoal and the initial weight of water, the other two external variables, one of them is varied at a time.

Stove Preparation for the External Variable Study

The external variable experiments tested the initial weight of charcoal, the initial weight of water, the pot size, the charcoal size, the wind effect, and the humidity effect. Procedures are discussed below.

Initial weight of charcoal

Stove no. 1/5 was used in this experiment. The first test for stove performance was performed with the initial weight of charcoal at 300 kg and the initial weight of water at 2,300 kg.

The experiments were then repeated, keeping the same initial weight of water, but changing the initial weight of the charcoal to 350 and 450 gm.

The above procedure was repeated with the initial weights of water set at 3,000 and 3,700 gm. The results obtained from the experiments were used in calculating the HU values of the stove.

Initial weight of water

The experimental technique for this study was described in the last section. The data is analyzed to obtain effect of initial weight of water on stove performance.

Pot size

Stove nos. 1/4 and 1/E3 were used in this experiment. Three different pots with diameters of 24, 28, and 32 cm were used. The test was carried out under standard conditions.

Charcoal size

In order to study the effect of charcoal size on stove efficiency, a long piece of charcoal (an approximately uniform cross section) was cut into pieces. These were then used in the experiment. The term "size", in fact, refers to the length of the charcoal. In this test, two different lengths of charcoal were used: 2.54, and 10.16 cm. Stove nos. 1/5, 1/12, 1/14 and 1/20 were used in the test.

Wind effect

Stove nos. 1/2, 1/5, 1/17, and 1/20 were used to test the effect of wind. Wind was induced by an electric fan; the speed was measured by an anemometer. The tests were first performed without turning on the fan; this represents the condition without wind effect--the reference condition. Later, the tests were repeated with the fan on. The wind speed for stove nos. 1/2, 1/5, 1/17 as measured was 80 m/min, and for stove no. 1/20 was 86.7 m/min.

Humidity

Stove no. 1/5 was used in the experiment. The humidity of the experimenting room was measured by a psychrometer (wet and dry bulb thermometers). In order to test the stove under an environment of varying humidity the test was performed at various times of day and in different seasons. The percentages of humidity recorded on six experimental days were 68, 74, 76, 78, 80, and 92.

E. TEST FOR THE EFFECT OF VARIABLES ON THE NON-CHIMNEYED WOOD STOVE

Similar to the charcoal bucket stove, the internal variables being studied include:

- Stove gap/exhaust area;
- Grate hole area;
- Grate-to-pot distance;
- Air inlet door; and
- Ratio of exhaust area to grate hole area.

The variation of one of the above characteristics is expected to affect the performance of the wood stove in a manner similar to that of the charcoal stove.

Stove Preparation for the Internal Variables Study

Stove gap/exhaust area

Twenty-two wood stoves, having different gap areas and being made by different manufacturers, were tested for the effect of the gap on stove performance. The gap heights ranged from 1 to 3.0 cm. Each stove was tested at least three times. Time to boil was recorded, and the HU values were calculated from the difference between the amounts of wood initially put into and left in the stove.

Total grate hole area

To investigate the impact of the grate hole area on stove performance, wood stoves from various sources were used. The stoves were divided into 3 groups according to the number and the size of the grate holes. Group A had 37 grate holes with a diameter of 2.5 cm; in group B, the hole was 1.5 cm in diameter, and the total number of holes was 90; group C had 61 holes, each of which was 1.23 cm in diameter. Every stove in the test had the same grate-to-pot distance of 12 cm.

Grate-to-pot distance

More than twenty wood stoves were used to study the effect of grate-to-pot distance on stove performance. The distance ranged from 9 to 17.5 cm. The stoves were again obtained from different manufacturers. Each stove was tested at least three times.

Air inlet door

The impact of the air inlet door on stove performance was studied with the wood stoves having door open at first and closed later. Each stove was tested at least three times. Time to boil and HU value were then calculated.

F. TEST FOR THE EFFECT OF EXTERNAL VARIABLES OF THE NON-CHIMNEYED WOOD STOVES

Only the effect of wind velocity and fuel feeding rate were studied.

Stove Preparation for the External Variables Study

Wind effect

The effect of wind on stove performance was studied. Three stoves were used in this investigation; each was run at least three times under two conditions--with and without wind. Wind was induced by an electric fan. The wood stoves came from different manufacturers. Time to boil was noted and the HU values were calculated.

Fuel feeding rate

In this test, the wood was fed into the stove at different rates. The rate was measured along with the weight of wood, since wood was put into the stove at regular intervals Three rates were studied, labelled low, medium and high. The tests were performed using two wood stoves, one with a grate height of 12 cm and the other with a grate height of 15 cm. The weights of wood for the low, medium and high rates were 0.84 kg, 1.00 kg, and 1.21 kg, respectively, for the first stove. The weights of wood for the second stove were 1.31, 1.53, 1.75 kg, which reflect the low, medium, and high rates of fuel feeding, respectively.

G. TEST FOR THE EFFECT OF INTERNAL VARIABLES ON CHIMNEYED WOOD STOVE

Stove performance tests were conducted on three wood stoves with a chimney. They were used to test the effect of chimney materials, metal ring around the pot hole and the baffle. No external variables were investigated.

Stove Preparation for the Internal Variable Study

Metal ring around pot hole

Performance of wood stove no. 2/11 was measured for the effect of the metal ring around the pothole. The stove initially had a metal ring. After it had been tested, the ring was then removed. The stove was then retested. All the necessary data for comparing efficiency were recorded.

Chimney material

To study the effect of chimney material on stove performance, stove no. 2/12 was used. The stove was first tested as initially constructed. Later, the chimney material was changed to iron, and the stove was then retested. The material was changed again to cement and another test was performed. Data were recorded under each condition.

Baffle

Stove no. 2/12 (the same stove used to investigate the effect of chimney material) has no baffle between the firing chamber and the chimney; therefore, it was used to study the effect of a baffle on stove performance. Two kinds of baffles were examined: one made of fire clay and the other made of iron. The iron baffle was tested first. The standard test was then applied to estimate stove efficiency. The iron baffle was then replaced by a fire clay baffle and the test was repeated.

H. TEST FOR THE EFFECT OF INTERNAL VARIABLES ON CHIMNEYED RICE HUSK STOVE

Four internal variables were investigated for their effects on the performance of the chimneyed rice husk stove. They were the fuel gas outlet area, base-to-pot distance, firing chamber, and chimney height.

Stove Preparation for the Internal Variable Study

Fuel gas outlet area

A chimneyed wood stove was used to study the effect of the fuel gas outlet area on stove performance. The initial outlet area of the stove was 95.0 sq cm. This area was reduced by adding clay to the outlet in the second and the third runs; the areas were 47.0 and 38.0 sq cm, respectively. In each case, time to boil and amount of fuel used were recorded.

Base-to-pot distance

To study the effect of base-to-pot distance on the performance of the chimneyed wood stove, stoves with different distances were used. In the test, the distances were varied from 18.0 to 36.0 cm. Each stove was tested at least 3 times. Data on time to boil and amount of fuel used were collected.

Firing chamber

The effect of the firing chamber on stove performance was studied by varying the size of the chamber. This was done by adding clay to the chamber to reduce its volume. The initial size of the firing chamber was 16,600 cu cm; it was then reduced 3 times. The volume became 16,400, 12,600, and 12,400 cu cm, respectively. Data were collected for time to boil and amount of fuel used.

Chimney height

The chimney height is another parameter that affects the performance of the stove, since height causes change in the rate of exhaust outflow. To study this effect, the chimney of a stove was decreased from 230 to 200 cm. Time to boil and amount of fuel used before and after reducing chimney height were recorded.

I. TEST FOR THE EFFECT OF INTERNAL VARIABLES ON NON-CHIMNEYED RICE HUSK STOVE

Since there are many kinds of non-chimneyed rice husk stoves, testing all the stoves marketed would have been tedious. Only one stove design was chosen as the representative of non-chimneyed rice husk stoves. This stove was designed by Mr. Meechai.

The Meechai stove consists of 2 parts -- the outer cone and the inner cylinder. For the outer cone, the following parameters were studied: height, upper diameter, lower diameter, slope angle of cone, and number of air inlet holes. For the inner cylinder, the effects of height, exhaust area, and fuel flow area were investigated. The dimensions of the reference Meechai stove are as follows:

Outer cone

Height	37.0 cm.
Upper diameter	46.0 cm.
Lower diameter	8.0 cm.
Slope angle of cone	63.0 deg.
Number of air inlet holes	329

Inner cylinder

Diameter	16.0 cm.
Exhaust area	184.0 sq cm.
Fuel flow area	163 sq cm.

Stove Preparation for the Internal Variable Study

Height of the outer cone

Four Meechai stoves were used to study the effect of the height of the outer cone on stove performance. The heights were 30.5, 33, 37.0, and 47.0 cm. Time to boil and amount of fuel used were recorded.

Upper diameter of the outer cone

To investigate the impact of the upper diameter of the outer cone on Meechai stove performance, three stoves were used. The diameters of the stoves were 46.0, 43.0, and 41.0 cm.

Lower diameter of outer cone

Three stoves were used to study the effect of the lower diameter of the outer cone on stove efficiency. These stoves had diameters of 8.0, 9.0, 10.9 cm, respectively. The water boiling test was used to compare stove efficiency. Time to boil and amount of fuel used were noted.

Number of air inlet holes

The Meechai stove is similar to other types of stoves in that air inlet holes control the supply of fresh air to combustion. Indeed, the number of air inlet holes has some impact on stove performance. The investigation used stoves with the following numbers of holes: 331 and 274. Each stove was tested at least 4 times.

Height of inner cylinder

The inner cylinder contains the firing chamber. As a consequence, the height of the cylinder was expected to affect stove performance. Only three stoves were used in the study. Each was tested at least 5 times. The heights of these three stoves were 16.0, 19.0, 20.0 cm.

Exhaust area

To investigate the effect of the exhaust area, four stoves were subjected to the test. The exhaust areas were 184, 165, 129, 123 sq cm, respectively.

Fuel flow area

Rice husk in Meechai stove has two roles--it is used as fuel, and it insulates the stove. The insulating rice husk, which is situated in the space between the inner cylinder and the outer cone, sooner or later becomes fuel for combustion. Thus, the fuel flow area should control the fuel supply to the stove. To verify this hypothesis, four stoves with the fuel flow areas of 163 and 184 sq cm were tested. Each stove was run at least two times. Data on time to boil and amount of fuel consumed were recorded.

J. DEVELOPMENT OF IMPROVED STOVE PROTOTYPE

Using the techniques outlined in the previous sections, the effects of both internal and external variables on stove performance were studied. The results were then used to design a high performance stove. To achieve this end, all the internal variables had to be analysed carefully. The analysis indicated which factors contributed significantly to stove performance.

Five prototypes of different stoves were developed; they were prototypes of a charcoal stove, a wood stove with and without chimney, and a rice husk stove with and without a chimney. These prototypes were then tested to ensure high performance prior to commissioning persons to produce the stove in quantity for trial promotion.

Chapter 5

Analysis of Results and Discussion

ANALYSIS OF RESULTS AND DISCUSSION

This chapter analyzes the measured values of the physical structure of commercial stoves. Performance and characteristics of tested commercial stoves are evaluated and discussed. An intensive analysis of the internal and external variables affecting commercial charcoal and non-chimneyed wood stoves performance is presented in the chapter.

A. PHYSICAL STRUCTURE OF COMMERCIAL STOVES

Of the five types of biomass cooking stoves already mentioned, the commercial charcoal bucket stove and the wood bucket stove without chimney are the most popular in Bangkok and urban areas. Their structure consists of an inverted truncated cone made of fired clay placed inside the metal sheet bucket. The prominent component parts of both charcoal and wood bucket stoves that may influence the stove's behavior are: pothole diameter, size of fuel firing chamber, grate diameter, grate hole area, grate thickness, grate-to-pot distance, exhausted gap, stove wall thickness, and air inlet area. Most bucket stoves are insulated with a mixture of rice husk ash and clay. Since the fuel feeding method of a wood stove differs from that of a charcoal stove, the wood stove includes a small removable feeding port above the air inlet door. In practice, this bucket wood stove is often used for charcoal fuel also.

While the structures of the bucket stove for charcoal and wood use in urban areas are similar, the physical appearance of the wood stove in rural areas may vary from place to place. Some wood stoves are shaped like a dome, some like a horseshoe, an enclosed horse shoe, a pit in the ground and three stones; almost none have any insulation or grates.

The measured physical dimensions of charcoal and non-chimneyed wood stoves are shown in Table 5.1 and Table 5.2. Since their shapes are so diverse, the appearance of each individual stove is fully displayed by the photographs in Annex I and II at the end of this report.

For wood stoves with chimneys, there are three distinct models, namely Saeng Pen, Samrong, and Banpong. Their physical configurations can be seen in Annex III. The main structural components of this stove are much the same as those of the wood stove without chimney, except for a fuel gas outlet port with connected chimney located at the opposite side of the fuel feeding port. The dimensions of the fuel gas outlet area and the chimney as well as other important structures are listed in Table 5.3.

For the rice husk stove without chimney, the only practical type found is used by the Kampuchean refugees in Khao-I-Dang camp and is called the "Meechai Stove". (See the photograph in Chapter 7). This kind of rice husk stove was constructed from a rough drawing at the RFD workshop and was tested for performance. Its main features consist of an outside fuel receptacle cone and an inner combustion cylinder. Between these two parts

Table 5.1 Physical dimensions of tested charcoal stoves

Code no.	Name/source	Stove wt (cm)	Pot hole diameter (cm)	Firing chamber (cm^3)	Grate dia (cm)	Grate hole dia (cm)	Grate no.of hole	Grate hole area (cm^2)	Grate thickness (cm)	Grate to pot (cm)	Exhaust gap (cm)	Exhaust area (cm^2)	Ave.wall thickness (cm)	Air inlet area (cm^2)
1/2	Rangsit	12.2	19.0	2426	17.5	1.3	85	112.0	4.0	12.0	2.0	96.0	5.8	70.0
1/3	Rangsit	8.7*	19.0	2426	17.7	1.3	85	112.0	3.5	12.0	1.8	97.0	4.1	70.0
1/4	Rangsit	12.8	19.0	2426	17.5	1.3	85	112.0	4.0	12.2	1.5	76.0	5.9	70.0
1/5	Rangsit(stainless case)	9.3	16.0	1575	15.0	1.3	61	80.0	3.5	12.0	1.0	41.0	5.7	66.0
1/6	Rangsit	8.6	20.0	2065	15.5	1.2	61	69.0	3.5	12.0	1.0	41.0	5.8	66.0
1/7	Ayudthaya	6.4	21.0	1931	19.0	2.1	19	66.0	3.5	12.0	1.0	41.0	5.8	66.0
1/8	Unknown	8.1	18.0	1831	17.5	1.8	19	48.0	1.8	6.5	2.0	68.0	3.8	60.0
1/9	Chachoengsao	8.1	18.0	1832	15.7	1.8	19	48.0	2.0	9.0	1.5	70.0	5.4	55.0
1/10	Unknown	6.6	21.0	2475	18.5	2.4	19	86.0	1.8	8.0	1.0	90.0	3.4	66.0
1/11	Unknown	4.3*	20.0	2176	18.0	1.6	27	54.0	1.6	10.0	2.0	80.0	2.2	58.0
1/12	Boopprarm	7.2	21.0	2856	19.5	1.5	37	55.0	1.6	10.0	2.0	80.0	2.2	58.0
1/13	Samyakohichai	10.7	22.0	2390	18.5	1.9	27	96.0	1.8	10.0	1.6	74.0	6.2	48.0
1/14	Boopprarm	19.0	20.0	3464	19.0	1.5	37	65.0	2.0	11.0	2.5	113.0	6.1	60.0
1/15	Banglane	10.0	20.0	2865	19.0	1.5	36	65.0	1.2	9.0	2.0	108.0	6.0	76.0
1/16	Ayudthaya	6.7	21.0	2518	14.5	2.0	19	59.0	2.0	7.5	1.0	45.0	3.4	66.0
1/17	Cholburi	5.9	17.0	2013	15.0	1.6	27	54.0	1.5	10.4	1.2	50.0	4.7	50.0

Table 5.1 (continued)

Code no.	Name/source	Stove wt (cm)	Pot hole diameter (cm)	Firing chamber (cm^3)	Grate dia (cm)	Grate hole dia (cm)	Grate no.of hole	Grate hole area (cm^2)	Grate thickness (cm)	Grate to pot (cm)	Exhaust gap (cm)	Exhaust area (cm^2)	Ave.Wall thickness (cm)	Air inlet area (cm^2)
1/18	Cholburi	7.2	21.0	3202	18.5	1.8	27	68.0	1.9	11.0	2.0	96.0	3.9	70.0
1/19	Samrong	10.5	18.0	3042	15.5	1.8	37	94.0	1.8	11.0	2.5	101.0	6.3	70.0
1/20	Cholburi	10.2	23.0	2516	20.0	1.8	37	94.0	1.9	7.0	2.0	102.0	5.3	70.0
1/21	Darnkwian	11.1	22.5	2414	20.0	1.8	27	68.0	1.8	9.0	3.0	107.0	4.5	80.0
1/22	Banpong	9.5*	20.0	3155	18.5	1.5	48	85.0	2.5	11.0	0.8	38	3.4	80.0
1/23	Rangsit	7.2*	16.0	1575	15.0	1.3	61	80.0	3.8	12.0	1.0	41.0	4.2	66.0
1/24	Cholburi	13.8*	22.0	3815	10.5	1.9	27	77.0	2.2	11.0	2.2	112	6.1	108.0
1/25	Rangsit	13.2	19.0	2426	27.0	1.3	85	112.0	4.0	9.0	2.0	96.0	6.2	70.0
1/25	Darnkwian	6.6*	23.0	2700	20.0	1.8	30	75.0	1.6	9.5	1.5	90.0	2.8	86.0
1/28	Sa-Sua	12.2	23.0	4216	20.0	1.6	37	74.0	2.2	10.0	2.3	131.0	4.5	124.0
1/29	Sa-Sua	13.3	19.0	3414	17.0	1.6	37	74.0	2.0	11.5	2.0	85.0	4.8	124.0
1/30	Nakornchaisri	18.0	20.0	2992	19.0	1.5	73	131	3.5	12.0	2.0	102	3.7	127.0
1/31	Nakornchaisri	11.8	17.0	2250	16.5	1.4	61	94.0	3.0	12.0	0.5	20.0	6.2	88.0
1/32	Nakornchaisri	8.2*	20.0	2992	19.0	1.5	73	131	3.5	12.0	2.0	102.0	3.7	127.0
1/33	Nakornchaisri	6.7*	17.0	2550	17.0	1.4	61	94.0	3.0	12.0	0.5	20.0	3.8	88.0
1/34	Bangsue	10.0	20.0	2829	18.0	1.8	27	68.0	1.5	9.0	1.8	103.0	6.3	105.0
1/35	Bangsue	8.0	17.0	2176	16.0	1.6	27	54.0	1.6	11.0	1.7	82.0	5.6	81.0
1/36	Bangsue	6.5	15.0	1568	13.5	1.7	19	44.0	1.6	9.5	1.9	56.0	6.2	75.0
1/37	Booppararm	6.5	15.0	1130	13.0	1.3	19	25.0	1.5	9.0	0.7	60.0	4.6	38.0
1/38	Unknown	10.0	19.0	2000	16.0	1.0	89	70.0	1.8	10.0	1.9	122.0	4.2	56.0

* Naked stove without insulation and bucket.

Table 5.2 Physical dimensions of tested wood stoves without chimney

Code no.	Name/source	Stove wt (cm)	Stove ht (cm)	Pot hole diameter (cm)	Firing chamber (cm^3)	Grate dia (cm)	Grate hole dia (cm)	Grate no.of hole	Grate hole area (cm^2)	Grate/base to pot (cm)	Exhaust gap (cm)	Exhaust area (cm^2)	Wall thickness (cm)	Primary air port (cm^2)	Feeding port (cm^2)
1/2	Rangsit	12.2	27.0	19.0	2426	17.5	1.3	35	112.0	12.0	2.0	36.0	6.0	70.0	54.0
1/8	Unknown	8.1	18.5	18.0	1832	17.5	1.8	19	48.0	9.0	1.5	70.0	5.4	75.0	55.0
1/9	Chachoengsao	8.7	23.0	23.0	3232	20.5	1.8	37	94.0	6.5	3.0	60.0	4.8	90.0	57.8
1/12	Booppararm	7.2	23.5	21.0	2855	19.5	1.5	37	65.0	9.0	2.0	80.0	4.6	118.0	60.0
1/13	Samyakphichai	10.9	18.0	22.0	2390	18.5	1.9	27	76.0	10.0	1.5	74.0	6.2	48.0	44.0
1/19	Samronge	18.0	16.5	18.0	3040	15.5	1.8	37	94.0	11.0	2.5	101.0	6.3	70.0	56.3
1/20	Cholburi	10.2	24.0	23.0	2516	20.0	1.8	37	94.0	7.0	2.0	102.0	5.3	70.0	15.7
1/21	Darnkwian	11.4	30.0	22.5	2414	20.0	1.8	27	68.0	9.0	3.0	107.0	4.5	34.5	80.0
1/24	Cholburi	13.8	27.0	22.0	3815	20.5	1.9	27	77.0	11.0	2.2	112.0	6.1	108.0	224.0
1/25	Rangsit	12.2	30.0	19.0	2426	27.0	1.3	85	112.0	9.0	2.0	96.0	6.0	78.0	81.3
2/1	Roi-et (original)	5.9	21.0	22.0	7600		no grate			20.8	1.3	25.3	2.0	-	296.4
2/2	Thick dome, clay	11.8	14.8	23.0	5800	——		"	——	14.8	2.1	162.0	7.0	-	181.5
2/3	Thick horse shoe, clay	18.2	15.3	25.0	6870	——		"	——	15.3	1.4	89.3	8.0	-	225.0
2/4	Morn Pakred, modified	2.5	12.0	27.0	7440	24.5	1.5	91	160.9	12.0	2.5	90.7	1.7	20.0	243.0
2/5	Morn Pakred, small	2.5	12.0	18.0	3600	——	no grate		——	14.0	5.0	210.0	2.0	-	280.0

Table 5.2 (continued)

Code no.	Name/source	Stove wt (cm)	Stove ht (cm)	Pot hole diameter (cm)	Firing chamber (cm^3)	Grate dia (cm)	Grate hole dia (cm)	Grate no. of hole	Grate hole area (cm^2)	Grate/base to pot (cm)	Exhaust gap (cm)	Exhaust area (cm^2)	Wall thickness (cm)	Primary air port (cm^2)	Feeding port (cm^2)
2/6	Tripod	0.9	14.0	20.0	4080		no grate			14.0	-	-	-	-	82.0
2/7	Horn Pakred, large	3.3	14.0	27.0	7440	———	"		———	14.0	5.4	222.6	2.0	-	332.0
2/8	Modified Roi-et, clay	6.6	15.0	22.0	4560	———	"		———	14.8	1.0	55.5	3.8	-	204.3
2/9	Horse shoe, clay	8.1	13.4	25.0	6380	———	"		———	11.5	2.5	197.1	5.5	-	208.0
2/10	Thin horse shoe, clay	7.4	14.0	22.0	4560	———	"		———	12.0	3.6	77.6	3.8	-	325.0
2/13	Dome, clay	9.3	15.0	24.0	5400	24.5	1.5	91.0	160.9	14.5	1.3	62.4	4.0	60.0	175.0
2/16	Pot shaped, clay	10.3	18.5	22.0	7030	———	no grate		———	18.0	1.8	86.4	5.0	-	157.5
2/22	Dome with cap, clay	11.3	18.7	22.0	6840	24.5	1.5	91.0	160.9	17.2	1.5	73.1	3.3	76.0	202.0
2/23	Modified Roi-et, clay	14.0	19.0	24.5	4950	24.5	1.5	91.0	160.9	12.2	1.8	86.6	3.5	115.0	114.0
2/24	Cylinder, steel	3.7	17.0	17.0	2040	23.4	1.2	89.0	99.5	13.0	0.5	32.2	1.8	42.0	94.5

Note stove 1/2 - 1/25 are of the bucket type and 2/1 - 2/24 are the non-bucket

Table 5.3 Physical dimensions of tested wood stoves with chimney

Code no.	Name/source	Stove wt (kg)	Stove ht (cm)	Pot hole diameter (cm)	Firing chamber (cm^3)	Grate dia (cm)	Grate hole (cm)	Grate no. of hole	Grate hole area (cm^2)	Grate to pot (cm)	Flue gas outlet (cm^2)	Ave. wall thickness (cm)	Primary air port (cm^2)	Feeding port (cm^2)	Chimney ht (cm)
2/11	Saeng Pen	24.8	33.5	19.0	5190	22.0	2.0	23	72.3	17.0	75.0	4.8	34.0	209.3	71.0
2/12	Samrong	24.3	32.5	20.0	4400	20.5	0.5	37.0	65.4	17.0	22.6	4.2	185.7	[illegible]	80.0
2/15	Barpong	69.5	28.0	29.0	5890	24.5	2.0	30.0	44.3	12.0	23.8	7.0	216.0	243.0	230.0

there is a gap through which the rice husk flows. The slope of the outside cone plays an important role in facilitating the rice husk's slide to the combustion zone. The combustion air is drawn in through the punched holes evenly distributed on the lower part of the outer cone wall. A list of the physical dimensions of rice husk stoves without chimneys is shown in Table 5.4.

For rice husk stoves with chimneys, five recognizable makes are found, namely Ngo Gew Ha of Lamlooka, Thai Charoen of Rangsit, Takeseng of Banglane, Sayun of Samrong, and Sooksunt of Dhonburi. The rice husk stoves are made of either cement or fired clay. They are quite heavy, a factor decreasing their popularity. The prominent features of this type of stove include a pothole, firing chamber, grate, air inlet port, fuel gas outlet port, chimney, ash removed port, and stove high mass body. The physical dimensions of the five stoves described above are measured and presented in Table 5.5. Photographs of these stoves are shown in Annex IV.

B. TERMINOLOGY

For clarity, the terminology used for describing the features of each type of stove is presented in Fig. 7.1 to 7.5 in Chapter 7.

C. PERFORMANCE OF COMMERCIAL STOVES TESTED

The performance of the charcoal stove, wood stove with and without chimneys and rice husk stoves with and without chimneys is discussed as follows:

Charcoal Stove

The results of 34 commercial stove performance tests shown in Table 5.6 indicate that their efficiencies vary from 23% - 32%. The time to bring water from the initial controlled temperature to the boiling point varies from approximately 17 minutes - 32 minutes. The rate of fuel consumption or burning rate varies from about 6 gm/min to nearly 8 gm/min. Fig. 5.1 and Fig. 5.2 show the plotted values between the individual stove and its efficiency and the stove and its time to boil.

The stoves with high efficiency (such as stove no. 31, 17, 36, 5 and 33) have shown a prominent effect on the rate of bringing water temperature to boiling. That is, the time to boil of a group of high efficiency or good stoves is shorter than a group of low effieicney or poor stoves.

Time-temperature characteristic curves of poor and good charcoal stoves are shown in Fig. 5.0.

Table 5.4 Physical dimensions of rice husk stoves without chimney

Code no.	Outer cone			Air inlet		Insulation	Inner cylinder			Fuel flow gap area (cm²)
	Upper diameter (cm.)	Lower diameter (cm.)	height (cm.)	No.	ø, cm.		Diameter (cm.)	Height (cm.)	Exhausted area (cm²)	
A	46.0	8.0	37.0	329	0.6	no	21.0	16.0	184.0	163.0
B	46.0	8.0	37.0	329	0.6	yes	21.0	16.0	165.0	163.0
C	43.0	9.0	30.5	331	0.6	yes	21.0	16.0	165.0	163.0
D	43.0	9.0	30.5	331	0.6	yes	21.0	20.0	129.0	184.0
E	43.0	9.0	30.5	331	0.6	yes	21.0	16.0	184.0	163.0
F	43.0	9.0	30.5	274	0.9	yes	21.0	19.0	123.0	163.0
G	41.0	10	33.0	274	0.9	yes	21.0	19.0	123.0	163.0
H	41.0	10	33.0	274	0.9	no	21.0	16.0	165.0	163.0
I	41.0	10	33.0	274	0.9	no	21.0	20.0	129.0	184.0

Table 5.5 Physical dimensions of rice husk stoves with chimney

Code no. *	Name/source	Stove wt (kg)	Stove ht (cm)	Pot hole diameter (cm)	Firing chamber (cm^3)	Grate slope (°)	Air inlet area (cm^2)	Flue gas outlet area (cm^2)	Chimney ht (cm)	Base to pot distance (cm)
3/2	Ngo Gew He	85.0	38.0	32.0	19,000	45	490.0	78.0	240.0	29.0
3/3	Thai Charoen	96.0	39.0	21.0	17,100	47	420.0	78.0	240.0	29.0
3/4	Thai Charoen	96.0	39.0	33.0	16,600	44	442.0	95.0	240.0	26.0
3/4A1	Thai Charoen	96.7	39.0	33.0	16,400	44	442.0	47.0	240.0	26.0
3/4A3	Thai Charoen	96.7	39.0	33.0	16,400	44	442.0	95.0	240.0	26.0
3/4B1	Thai Charoen	96.0	39.0	33.0	12,600	44	442.0	95.0	240.0	26.0
3/4B2	Thai Charoen	96.0	39.0	33.0	12,400	44	442.0	38.0	240.0	26.0
3/5	Banglane	95.5	59.0	30.0	19,100	40	703.0	113.0	230.0	36.0
3/5A	Banglane	95.5	59.0	30.0	19,100	40	703.0	113.0	200.0	36.0
3/5A1	Banglane	95.5	59.0	30.0	19,100	40	703.0	46.0	230.0	36.0
3/5A2	Banglane	95.5	59.0	30.0	19,100	40	703	116.0	230.0	36.0
3/6	Sayun	65.0	28.0	27.0	5,200	41	362.5	28.0	240.0	23.0
3/8	Sooksunt	62.0	22.5	28.0	10,600	47	270.0	71.0	160.0	19.0
3/8C2	Sooksunt	62.0	22.5	28.0	10,600	30	210.0	71.0	160.0	18.0

* Stove numbers which followed by letter codes such as A, A1, B2, and C2 indicate that modifications have been made to the original models to observe the performance responses.

Table 5.6

Average testing results of commercial charcoal stoves

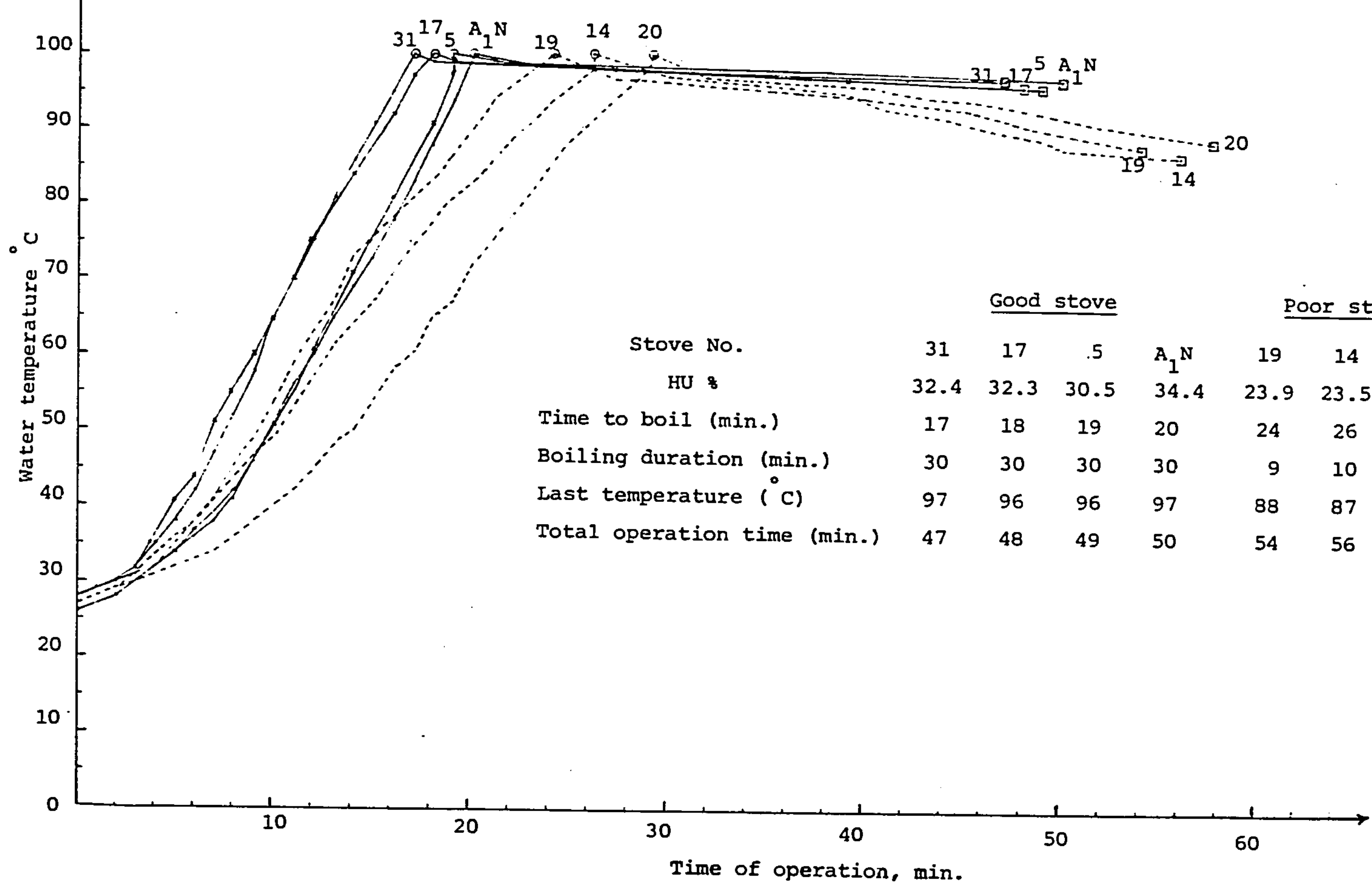
Stove no.	No. of test	Fuel used (gm)	Burning rate (gm/min)	Time to boil (min)	Heat conversion efficiency(%)
1/2	6	337.0	6.57	21.7	24.96
1/3	6	332.0	6.17	22.3	25.70
1/4	6	340.0	7.01	18.8	28.19
1/5	18	330.0	6.47	21.1	30.53
1/6	3	316.0	5.45	18.0	28.53
1/7	6	316.0	5.45	28.0	25.61
1/8	3	323.0	5.65	27.3	24.07
1/9	3	313.0	5.94	23.0	28.42
1/10	3	295.0(min)	4.81(min)	31.7	26.54
1/11	3	312.0	5.96	22.3	26.41
1/12	7	316.0	6.01	22.6	29.02
1/13	11	325.0	6.05	23.9	26.12
1/14	6	327.0	5.73	27.2	23.53(min)
1/15	9	323.0	5.92	24.6	27.21
1/16	6	301.0	5.29	27.2	27.45
1/17	6	320.0	6.42	20.0	32.30
1/18	7	325.0	6.17	23.6	26.85
1/19	8	344.0	6.45	23.8	23.89
1/20	6	315.0	5.10	32.0(max)	24.94
1/21	3	313.0	5.47	27.3	24.73
1/22	3	317.0	5.96	23.3	28.11
1/23	6	322.0	6.27	21.5	29.17
1/24	6	327.0	6.23	22.7	25.60
1/26	3	325.0	6.07	23.7	24.36
1/28	9	342.0	6.82	20.1	25.60
1/29	4	343.0	6.86	20.0	25.85

Table 5.6

(continued)

Stove no.	No. of test	Fuel used (gm)	Burning rate (gm/min)	Time to boil (min)	Heat conversion efficiency (%)
1/30	7	364.0 (max)	7.77 (max)	16.9	24.25
1/31	6	334.0	7.17	16.7 (min)	32.43 (max)
1/32	8	360.0	7.57	17.6	24.61
1/33	3	340.0	7.04	18.3	30.51
1/34	5	336.0	6.58	21.2	26.07
1/35	6	340.0	6.83	19.8	27.35
1/36	5	322.0	6.34	20.8	30.67
1/37	3	322.0	5.75	26.0	28.07
	Average	327.0	6.21	22.8	27.00

Figure 5.0 Time-Temperature characteristic curves of charcoal bucket stoves



	Good stove				Poor stove		
Stove No.	31	17	5	A_1N	19	14	20
HU %	32.4	32.3	30.5	34.4	23.9	23.5	24.9
Time to boil (min.)	17	18	19	20	24	26	29
Boiling duration (min.)	30	30	30	30	9	10	11
Last temperature (°C)	97	96	96	97	88	87	89
Total operation time (min.)	47	48	49	50	54	56	59

Figure 5.1 Performance rating based on heat utilization efficiency (HU) of commercial charcoal bucket stoves.

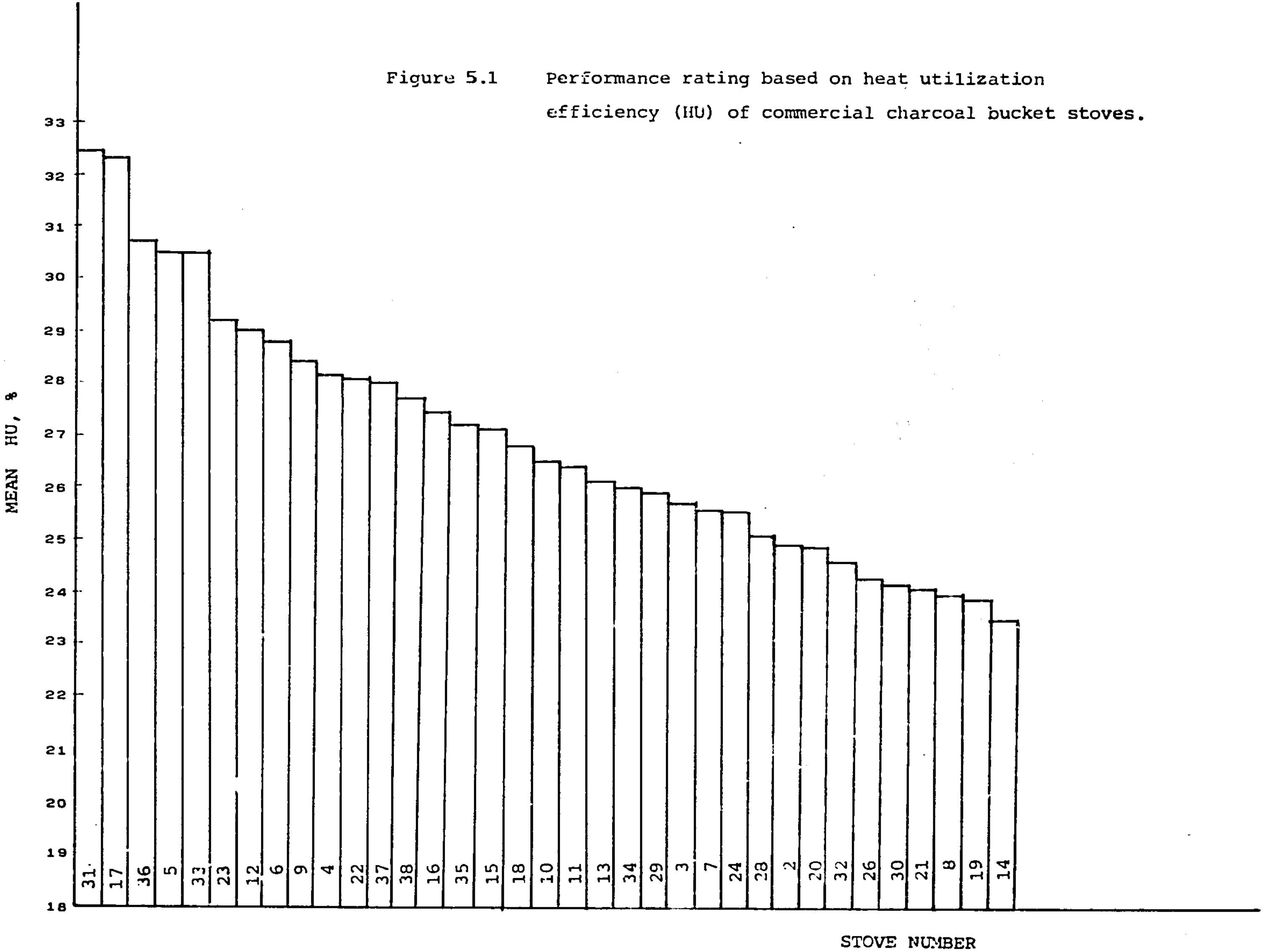
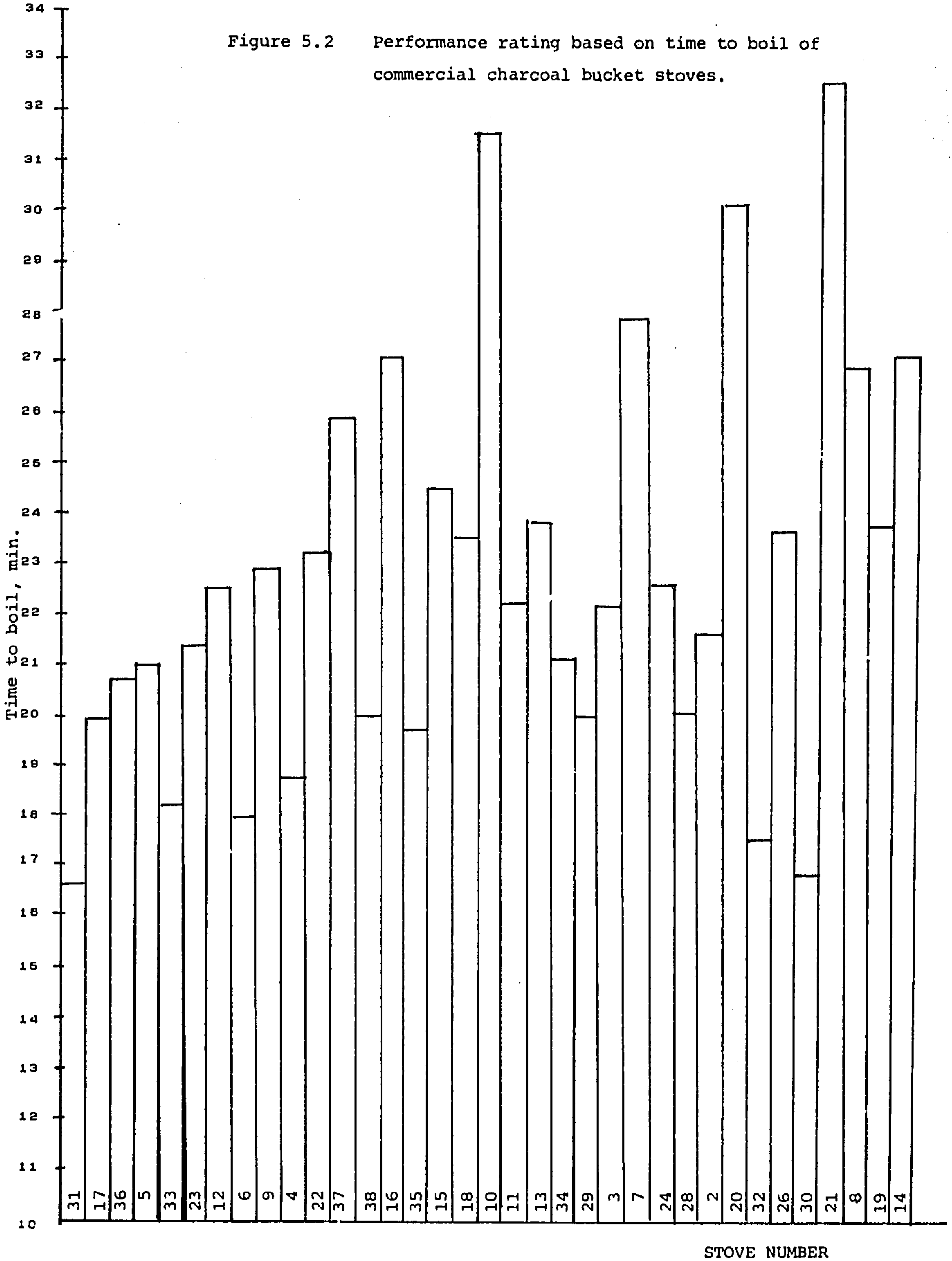


Figure 5.2 Performance rating based on time to boil of commercial charcoal bucket stoves.



Wood Stove without Chimney

25 wood stoves were subjected to the performance tests. The results show that the efficiency of non-bucket wood stoves, i.e., stove No. 2/1 to 2/24, varies from 14% - 23%. For bucket-type wood stove, (stove No. 1/2 to 1/25), the efficiency varies from 18 - 25%. (See Fig. 5.3 - 5.4 and Table 5.7). The time to boil for both types of stoves ranges from 17 - 19 min. and fuel burning rates range from 22 - 35 gm/min. The wood stoves with buckets have much the same level of effective performance as these non-bucket counterparts (that is around 21%).

Wood Stove with Chimney

Table 5.8 and Fig. 5.3 and 5.4 show that the efficiency of stove No. 2/11, 2/12 and 2/15 is 13.88, 16.30 and 11.0, respectively. The time to boil is in the range of 17 - 19 minutes.

These chimneyed stoves perform at a considerably low level when compared to the wood stove without chimney. Hence, the wood stove with chimney can be regarded as an inefficient type of cooking stove. The low HU and long time to boil of commercial chimneyed wood stoves as compared with the nonchimneyed are mainly caused by two factors;

a) Too much heat (and flame) loss has occurred through the flue gas exit hole which is located just the opposite of the fire feeding port and no flame restriction or baffle exists.

b) The stoves are poorly designed in such a way that only a small portion of the pot bottom comes into contact with the flame, thus causing poor heat transfer.

Rice Husk Stove with Chimney

From Table 5.9, the performance of the six original models tested were as follows. The heat utilization efficiency ranged from 4.2 to 7.1% and averaged 5.6%. Time to boil was between 18.5 - 28.2 minutes and averaged 23.4 minutes. The burning rate ranged from 58.5 - 160.7 gm/min and averaged 99.8. The overall rice husk consumption per test was on the average 5.2 kg.

After the original designs were modified according to the specifications in Table 5.5, their performance improved considerably. The average HU increased to 8.3%. Time to boil varied greatly (15.7 - 30 min), but on the average remained like the unmodified model. The big reduction was in the fuel used and the average burning rate which were 4.0 kg and 79 gm/min respectively. This is equivalent to approximately a 25% fuel saving. The very low efficiency value of the original models is due mainly to a great amount of heat loss through the flue gas exit. For example, for stoves 3/4 and 3/4A1, the efficiency of the former is increased by 100% (from 5.15 to 10.30%) upon reducing the area of the flue gas outlet by one half (from

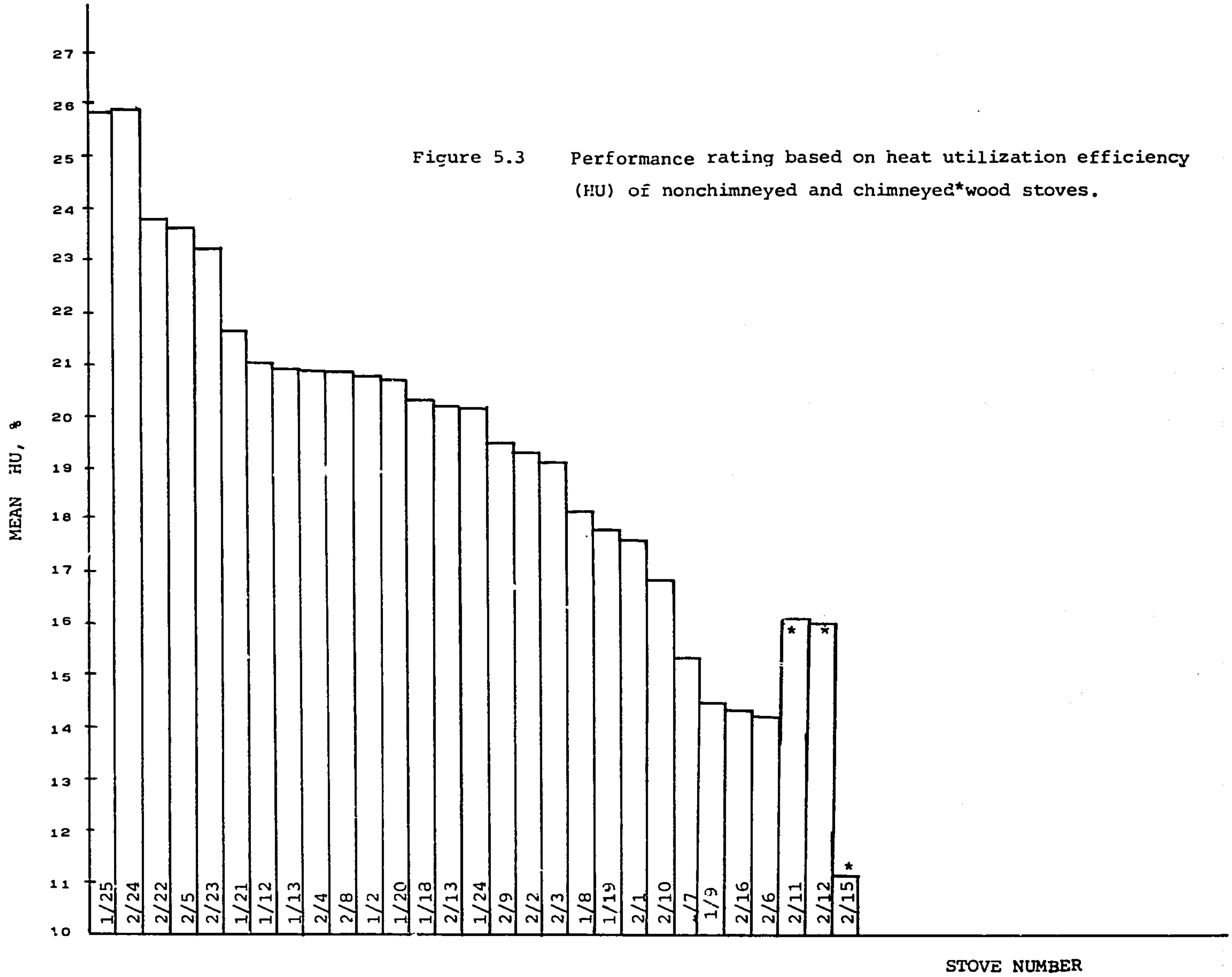


Figure 5.3 Performance rating based on heat utilization efficiency (HU) of nonchimneyed and chimneyed*wood stoves.

Figure 5.4 Performance rating based on time to boil of nonchimneyed and chimneyed*wood stoves.

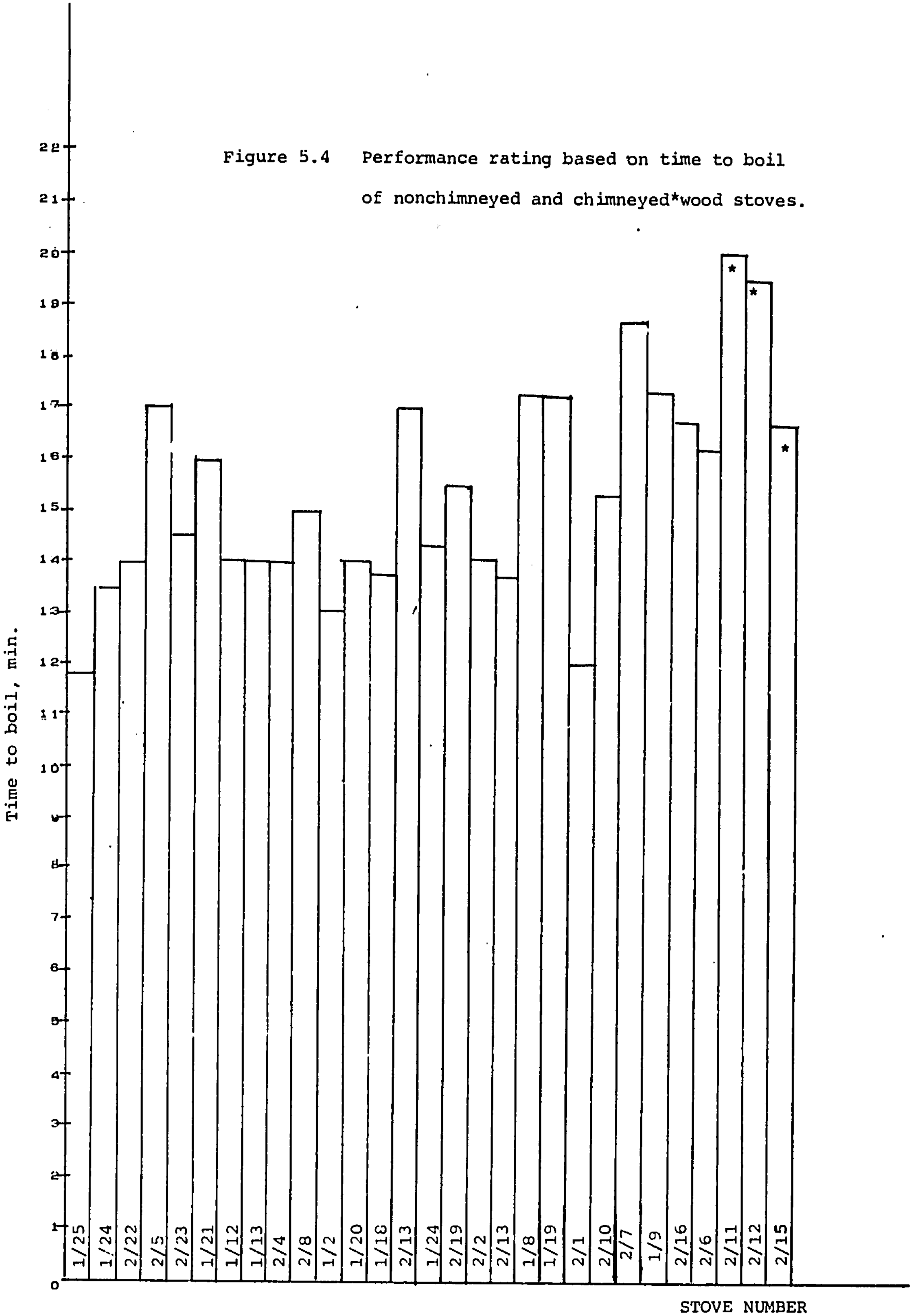


Table 5.7

Average testing results of wood stoves without chimney

Stove no.	No. of test	Fuel used (gm)	Burning rate (gm/min)	Time to boil (min)	Heat conversion efficiency(%)
2/1	6	1483	35.36(max)	12.0	17.59
2/2	3	1308	31.08	14.0	19.25
2/3	4	1251	28.60	13.7	19.08
2/4	3	1134	25.80	14.0	20.96
2/5	4	1078	23.07	17.0	23.57
2/6	4	1394	30.23	16.2	14.20(min)
2/7	3	1372	28.13	18.7(max)	15.39
2/8	4	1236	27.46	15.0	20.92
2/9	4	1266	27.84	15.5	19.48
2/10	3	1303	28.74	15.3	16.77
2/13	3	1192	25.29	17.0	20.20
2/16	3	1468	31.50	16.7	14.37
2/22	6	1258	29.31	13.0	23.80
2/23	6	1143	25.82	14.5	23.20
2/24	5	1034	22.57(min)	16.0	23.47
1/2	3	1337	31.09	13.0	20.80
1/8	3	1253	26.48	17.3	18.30
1/9	3	1625	34.24	17.3	14.48
1/12	3	1265	28.77	14.0	21.01
1/13	3	1202	27.34	14.0	20.99
1/19	3	1330	30.00	14.3	17.75
1/20	3	1415	32.19	14.0	20.60
1/21	3	1367	29.75	16.0	21.63
1/24	8	1059	24.40	13.5	25.90
1/25	10	1054	25.28	11.8(min)	25.90(max)
Average		1273	28.41	14.3	19.8

Table 5.8

Average testing results of wood stoves with chimney

Stove no.	No. of test	Fuel used (gm)	Burning rate (gm/min)	Time to boil (min)	Heat conversion efficiency(%)
2/11	3	1316	27.0	18.7	16.32
2/12	3	1247	26.2	17.70	16.30
2/15	3	2186	46.5	16.7	11.0
	Average	1583	33.2	17.7	14.54

Table 5.9

Average testing results of rice husk stoves with chimney

Stove no.*	No. of test	Fuel used (gm)	Burning rate (gm/min)	Time to boil (min)	Heat conversion efficiency (%)
3/2	5	5863	117.30	20.0	5.48
3/3	4	5147	93.30	25.2	4.95
3/4	4	5303	103.59	21.3	5.15
3/5	4	7789	160.70 (max)	18.5	4.24 (min)
3/6	3	3736	65.56	27.0	7.13
3/8	5	3394	58.49	28.2 (max)	6.57
Original model ave.		5205	99.82	23.4	5.59
3/4 A1	3	4472	84.45	23.0	10.30
3/4 A3	3	3513	68.07	21.7	7.48
3/4 B1	3	3877	70.57	25.0	7.23
3/4 B2	3	2531	42.23	30.0	9.16
3/5 A	4	6686	139.10	18.0	5.15
3/5 A1	3	4280	93.74	15.7 (min)	7.05
3/5 A2	3	4436	88.12	20.3	11.14 (max)*
3/8 C2	3	2498	48.46 (min)	21.7	9.23
Modified models ave.		4037	79.34	21.9	8.34

* The test condition deviates from normal, using pot 30 cm. diameter.

95 to 47 cm²). The same result was also obtained from stove Number 3/5 and 3/5A1 where the efficiency was increased by 66% with the reduction of the original flue gas exit by approximately 60%. The chimney height also has an impact on the stove efficiency since too high a chimney causes high suction of hot gas; too low a chimney hinders the outflow of the gas and creates a difficulty in initial ignition. In both cases poor heat utilization efficiency will result. Stove No. 3/5 and 3/5A illustrate this effect.

These trial modifications were later used as the bases for redesigning the improved model.

Block diagrams in Fig. 5.5 and 5.6 show the HU and time to boil of the rice husk stove plotted against the stove number.

Rice Husk Stove without Chimney

Test results from Table 5.10 have indicated that the stove made according to the original drawing (that is, stove code A but with better steel material for construction) had the HU of 17% and time to boil of approximately 14 minutes. Various trials of modifications of physical structures shown in Table 5.4 (stove code B to I) took place such as the insulation of outer cone, changing of cone slope, changing size and number of air inlet holes, the inner cylinder height and exhausted gas outlet, and rice husk flow gap between the outer cone and inner cylinder. These parameters have, more or less, some influence on the stove performance. The reduction of exhausted area seems to increase the stove efficiency, as indicated by stoves B and D in Table 5.4. Stoves B and C illustrate the effect of the height of the outer cone: the HU increases from 15.34 to 18.58% when the height decreases from 37.0 to 30.5 cm. However, the best combination was obtained from stove G where the HU and TTB are 20.3% and 11.4 minutes respectively. This stove was used as a basis for the improved model.

The foregoing sections summarize the stove testing results. A thorough analysis of the results of stove testing needs a knowledge of heat and mass transfers. To illustrate such a method of analysis, the results of testing the charcoal bucket stove and the wood stove without chimney will be discussed in detail in the following section.

D. THE EFFECT OF INTERNAL AND EXTERNAL VARIABLES

This section studies the effect of various factors on stove performance. The factors are divided into 2 main groups according to their characteristics: first, properties that are fixed for a stove such as the stove gap and inlet air area; secondly, properties that can be changed such as wind, humidity, and charcoal weight. The first group is called internal variables, and the second the external variables.

Table 5.10

Average testing results of rice husk stove without chimney

Stove no.	No. of test	Fuel used (gm)	Burning rate (gm/min)	Time to boil (min)	Heat conversion efficiency (%)
A*	6	1929	44.04	13.8	16.97
B	2	2002	47.12	12.5	15.34
C	4	1628	38.73	12.0	18.58
D	5	1804	42.75	12.2	18.32
E	3	1848	42.69	13.3	16.00
F	5	1736	41.24	12.2	19.52
G	5	1887	45.57	11.4	20.29
H	5	1704	40.36	12.2	17.68
I	5	1755	42.39	11.4	18.87
	Average	1810	42.77	12.3	21.70

* The model A is an original design.

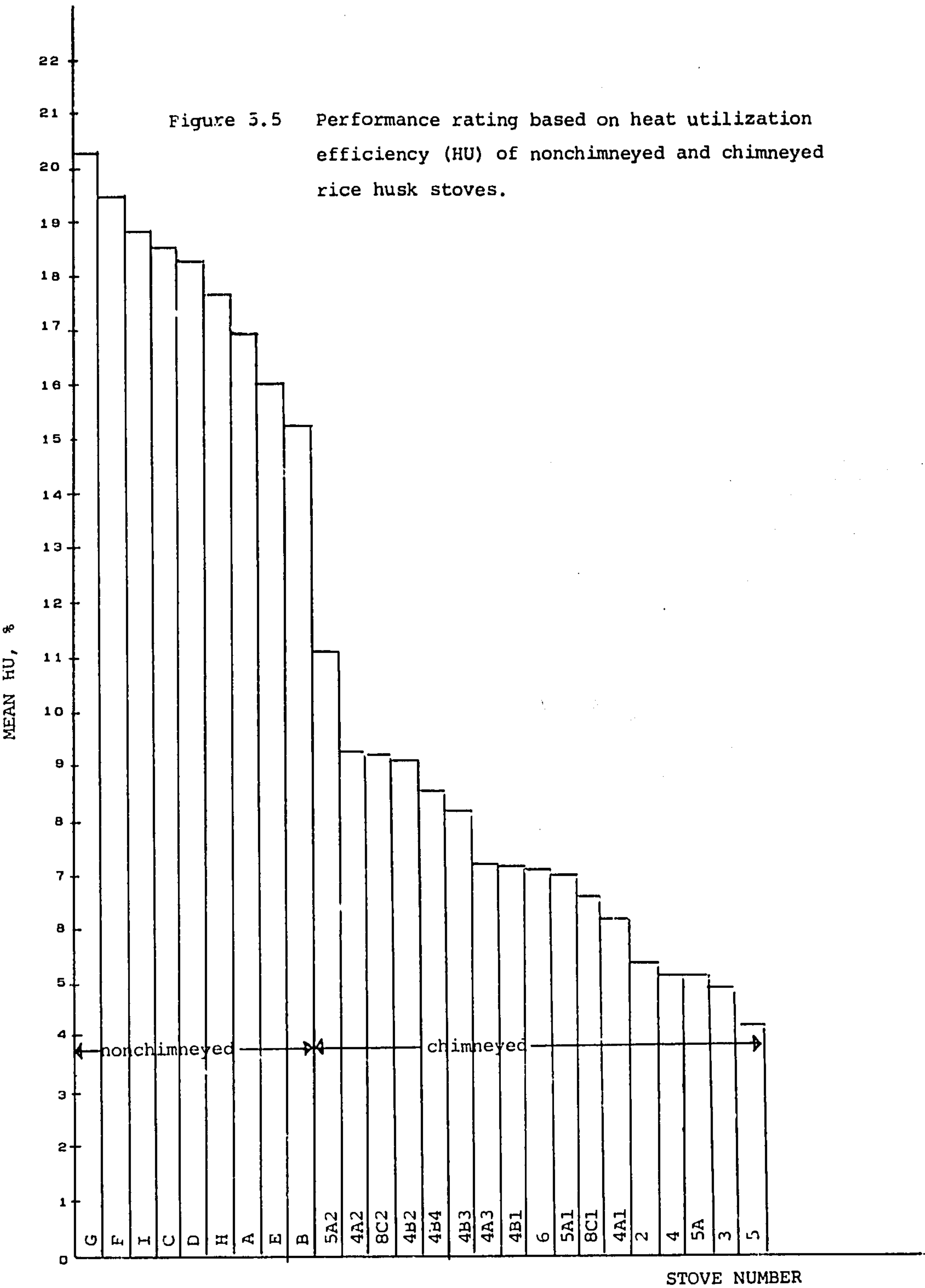
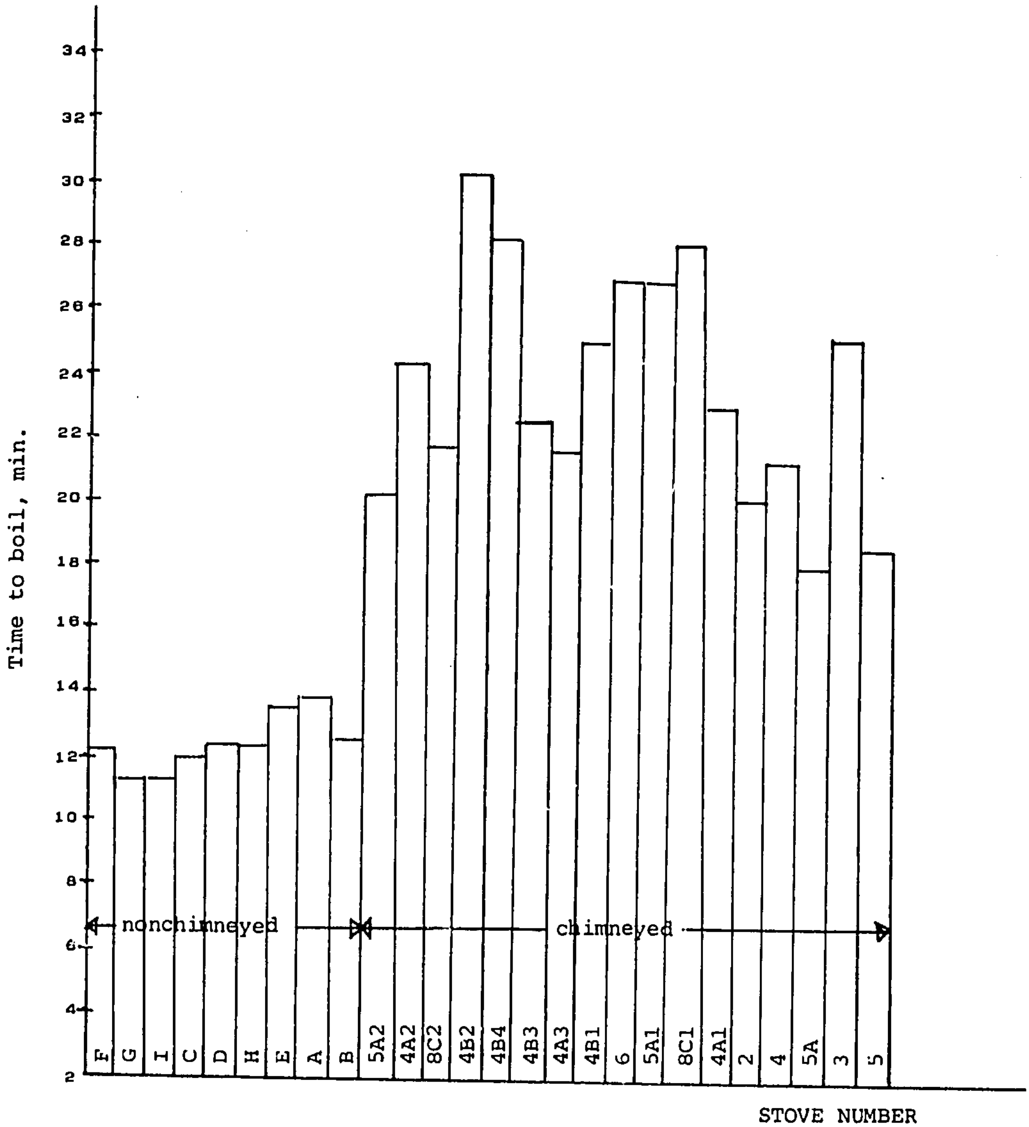


Figure 5.5 Performance rating based on heat utilization efficiency (HU) of nonchimneyed and chimneyed rice husk stoves.

Figure 5.6 Performance rating based on time to boil of nonchimneyed and chimneyed rice husk stoves.



Internal Variables

The internal variables are the characteristics that come with the stove. They include all the geometrical structure of the stove: stove exhaust gap, grate-hole area, grate-to-pot distance, combustion chamber size, air inlet door, and grate thickness. The results of changing such variables will be discussed. For all terms used in the following section please refer to the illustration in Fig 7.1 in Chapter 7.

Exhausted gap/exhausted area

Test condition:	Charcoal	=	400 gm.
	water	=	3,700 gm.
	pot diameter	=	24 gm.

Table 5.11 Test results of the effect of stove gap/exhausted area on HU and time to boil.

Stove No.	No. of tests	Gap area (sq cm)	Gap height (cm)	Time to boil (min)	Unburned charcoal (gm)	HU (%)
1/5	3	20.5	0.5	19.0	92	34.5
	4	65.6	1.6	18.0	70	29.7
	3	86.1	2.1	18.7	62	28.0
	4	98.4	2.4	18.0	54	27.2
1/31	3	40.2	1.1	16.0	60	32.8
	3	65.6	1.6	16.3	60	29.3
	3	86.0	2.2	16.0	52	28.3
	3	98.6	2.6	18.0	48	26.6

Results and Discussion

From Table 5.11, as the exhausted gap increases from 0.5 cm to 2.4 cm for stove No. 1/5, and from 1.1 cm to 2.6 cm for stove No. 1/31, the HU value decreases from 34.5 to 27.2% and 32.8 to 26.6%, respectively. With stove No. 1/5, when the exhausted gap is increased by a factor of 4.8, the stove efficiency is decreased by the ratio of 21% of the original value. Similarly, an increase of the gap by a factor of 2.3 in stove No. 1/31 decreased the stove efficiency by the ratio of 19%. Hence, both stoves show an identical trend.

The efficiency of the stoves is inversely proportional to the exhausted gap or the exhausted area. The larger the exhaust area, the greater a combustion heat energy that is allowed to escape through it. The optimum gap determined from this experiment is 0.5 cm. From Fig. 5.7, if both lines are extrapolated, the efficiency of the stoves should be even higher, or approaching infinity as the gap area approaches zero. However, with the real physical structure of the stove, the exhausted gap of under 0.5 cm is considered the minimum limit for combustion air to flow through, without disturbing the optimum combustion rate, particularly when operating the stove from cold conditions.

Grate hole area

Test condition:			
	charcoal	=	400 gm.
	water	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.12 Test results of the effect of grate hole area on HU and time to boil.

Stove No.	No. of tests	Gap height (cm) %	Grate hole (cm^2)	area (%)*	Time to boil (min)	Unburned charcoal (gm)	HU (%)
1/5	3	0.5	80.0	45.3	19	92	34.5
	3		52.8	29.9	21	98	34.1
	5		26.4	14.9	26	109	32.3
1/5	4	2.5	80.0	45.3	18	54	27.3
	3		52.8	29.9	20	67	27.1
	3		26.4	14.9	24	87	27.0

* -% of total grate area

Results and Discussion

From Table 5.12, and Fig. 5.8 the efficiency of the stove increases with the increase in grate hole area. With a smaller gap of 0.5 cm, the effect is, however, more prominent than with the larger gap of 2.5 cm. This should be expected since the gap has proven to be a strong factor controlling the stove efficiency as previously discussed.

Grate hole area has a strong influence on time to boil and the amount of unburned charcoal. At 0.5 cm gap, time to boil increases from 19 to 26 minutes and the amount of unburned charcoal increases from 92 to 109 gm as its grate hole area decreases from 80 to 26.4 sq cm. Similarly, at 2.5 cm gap, the decrease in the grate hole area by the same amount causes time to boil and the amount of unburned charcoal to increase from 18 to 24 minutes and 54 to 87 gm, respectively.

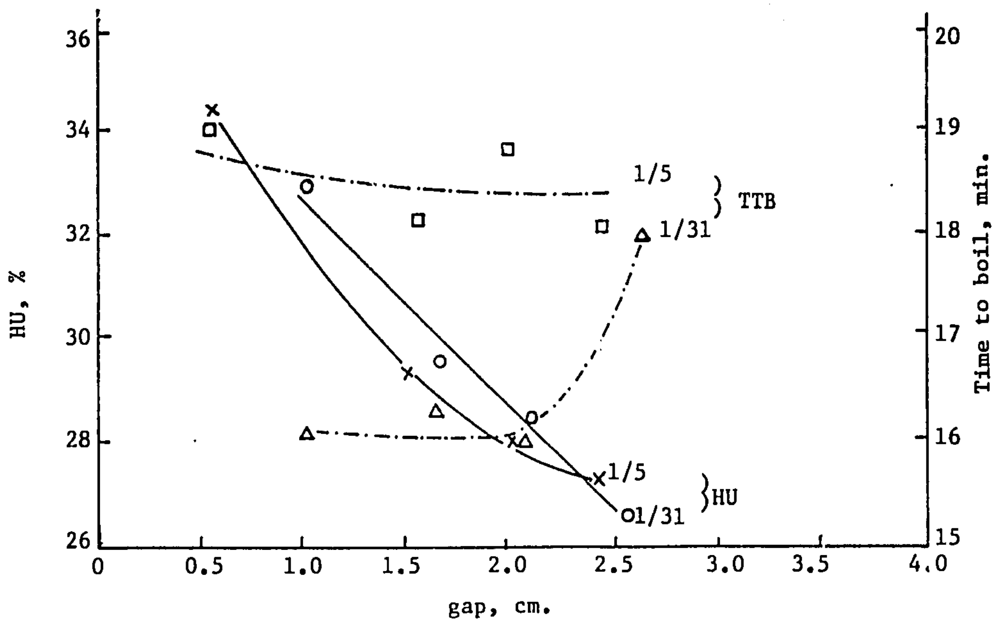


Fig. 5.7 The effect of exhausted gap on the stove efficiency and time to boil.

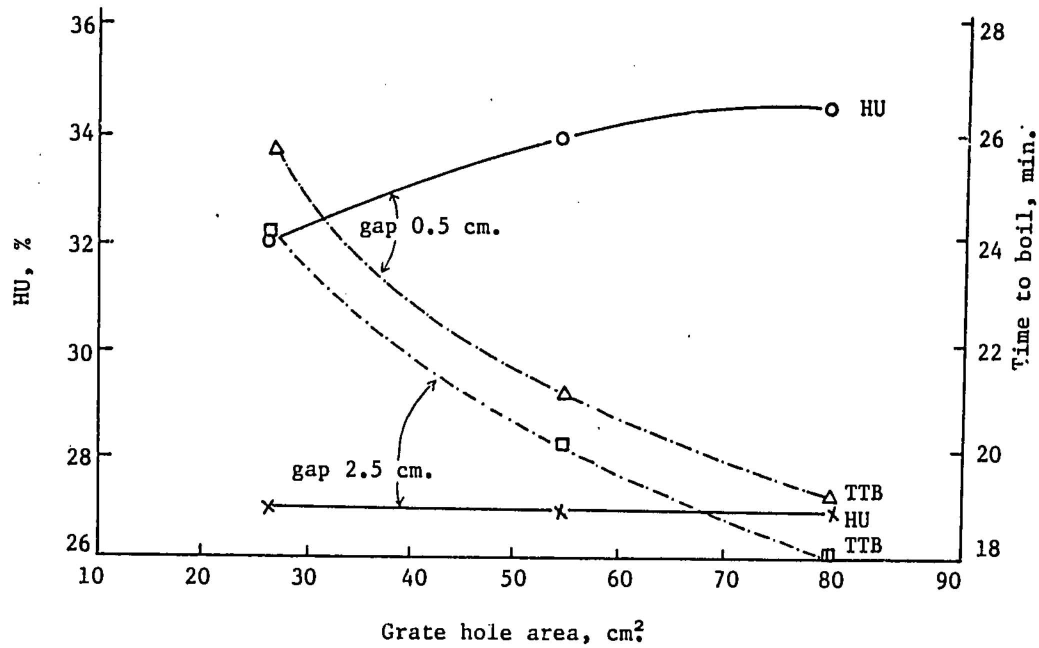


Fig. 5.8 The effect of the grate hole area on the stove efficiency and time to boil.

Grate-to-pot distance

Test condition:	charcoal	=	400 gm.
	water	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.13 Test result of the effect of grate-to-pot distance on HU and time to boil.

Stove No.	No. of test	Grate-to-pot distance (cm)	Time to boil (min)	HU (%)
1/4	6	11.0	18.8	28.2
	5	9.3	15.4	31.1
	6	7.5	19.0	28.2

Results and Discussion

The curve as shown in Fig. 5.9 indicates that the optimum value of grate-to-pot distance is 9.3 cm. At this point the stove yields 31% efficiency.

The grate distance is one of the important factors that distinctly influence the stove performance. A parabolic curve means that either too short or too long a grate-to-pot distance will lower the stove efficiency. With the shallow grate, the hot charcoal bed is closer to the gap and more heat will be lost through it by radiation. In addition, the shallow grate will decrease the firing chamber capacity, causing a packing up of charcoal up to the pot bottom. Consequently, the draft from the bottom is limited and poor combustion results. On the other hand, if the grate is too far from the pot, the stove efficiency will fall again. This can be explained in terms of radiative heat flux from surface 1 to surface 2 which is inversely proportional to the distance. Hence, when the grate-to-pot distance is past the optimum value the efficiency begins to fall. From this experiment with the medium stove size (23.5 cm pot hole diameter) and 400 gm of charcoal load, the optimum value of grate-to-pot distance is about 9 cm.

Combustion chamber size

Test condition:	charcoal	=	400 gm.
	water	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.14 Test result of the effect of combustion chamber size on HU and time to boil.

Stove No.	No. of test	Combustion chamber volume (cu cm)	Time to boil (min)	HU (%)
1/28	9	4,216	20.1	25.6
	4	3,414	20.0	25.9
1/A3	4	2,460	15.7	30.8
	3	1,787	18.0	33.1
1/D1	4	2,946	19.7	26.9
	4	1,510	18.0	30.6

Results and Discussion

It can be seen from Table 5.14 and Fig. 5.10 that the decrease in combustion chamber increases the HU value of the stove. For example, the HU value of stove No. 1/A3 increases from 30.8 to 33.1% when the combustion chamber decreases from 2,460 to 1,787 cu cm; the HU value of stove No. 1/D1 also increases from 26.9 to 30.6% corresponding to the decrease in the chamber from 2,946 to 1,510 cu cm. Not much increase in the HU value of stove No. 1/28 is observed as the result of the reduction of the chamber because the percentage of reduction from original design is smallest. Besides, this stove has many features in addition to the chamber size that are poorly designed (see Annex I).

The volume of the combustion chamber is reduced by adding a clay-rice husk ash mixture to the inside wall of the stove. By doing so, the wall thickness increases; consequently, the insulation may improve slightly. But more importantly, the diameter of the combustion chamber decreases due to the enlargement of the stove wall. With the same amount of charcoal being loaded, the distance between the glowing charcoal and the pot bottom gets nearer as compared with the stove without reducing the combustion chamber. As a consequence, more radiative heat can reach the water as the distance becomes smaller.

For stove No. 1/28, the reduction of the chamber does not show a significant effect on the performance. This is due to the fact that although its volume is reduced from 4,216 to 3,414 cu cm, the chamber size is still quite large to contain 400 gm of charcoal. The distance between the glowing charcoal and the pot bottom would therefore vary slightly when the same amount of charcoal is loaded. The improvement of the radiative heat transfer is, hence, insufficient to clearly reflect its effect on the stove performance. However, a slight increase of the HU value can be noticed from the experiment.

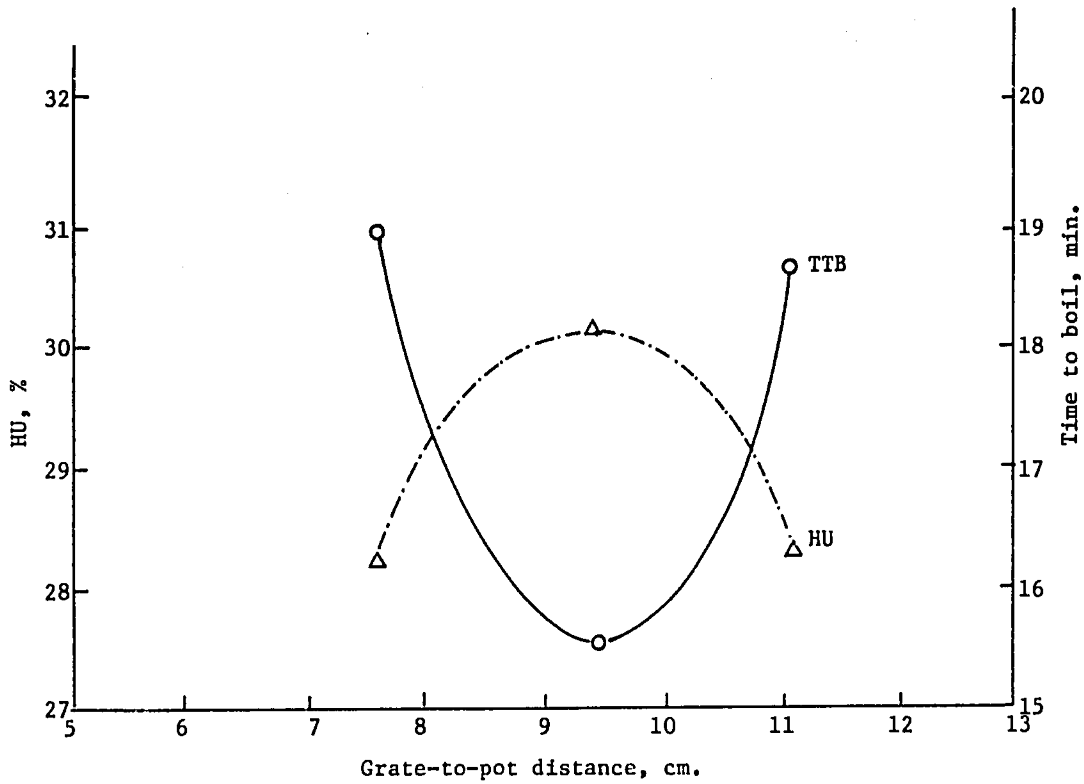


Fig. 5.9 The effect of grate-to-pot distance on the stove efficiency and time to boil

Air inlet door

Test condition: charcoal = 400 gm.
water = 3,700 gm.
pot diameter = 24 cm.

Table 5.15 Test result of the effect of air inlet door on HU and time to boil.

Stove No.	No. of tests	Exhausted gap (cm)	Air (%)	Inlet opening (sq cm)	Time to boil (min)	HU (%)
1/5	18	1	100	66.0	21.0	30.5
	8		75	49.5	24.9	29.6
	7		50	33.0	22.1	29.8
	7		25	16.5	22.6	30.9

Results and Discussion

The effect of air inlet door area is small. The air inlet varies from 100% opening down to 25%, the HU value only differs by 1.3%. See Fig. 5.11.

Since the amount of air flow through the stove combustion chamber is governed by the temperature gradient between the air inlet door and the exhausted gap, if the inlet opening gets smaller, by the equation of continuity, i.e., $Q_{air} = A_1V_1 - A_2V_2 = $ constant, the velocity of the inlet air will be increased. Hence, the combustion rate will not be affected by the supply of oxygen in the air. This is why the HU value of Fig. 5.11 is constant. The time to boil, however, shows the tendency of increasing as the air inlet area is decreased.

Grate thickness

Test condition: charcoal = 400 gm.
water = 3,700 gm.
pot diameter = 24 cm.

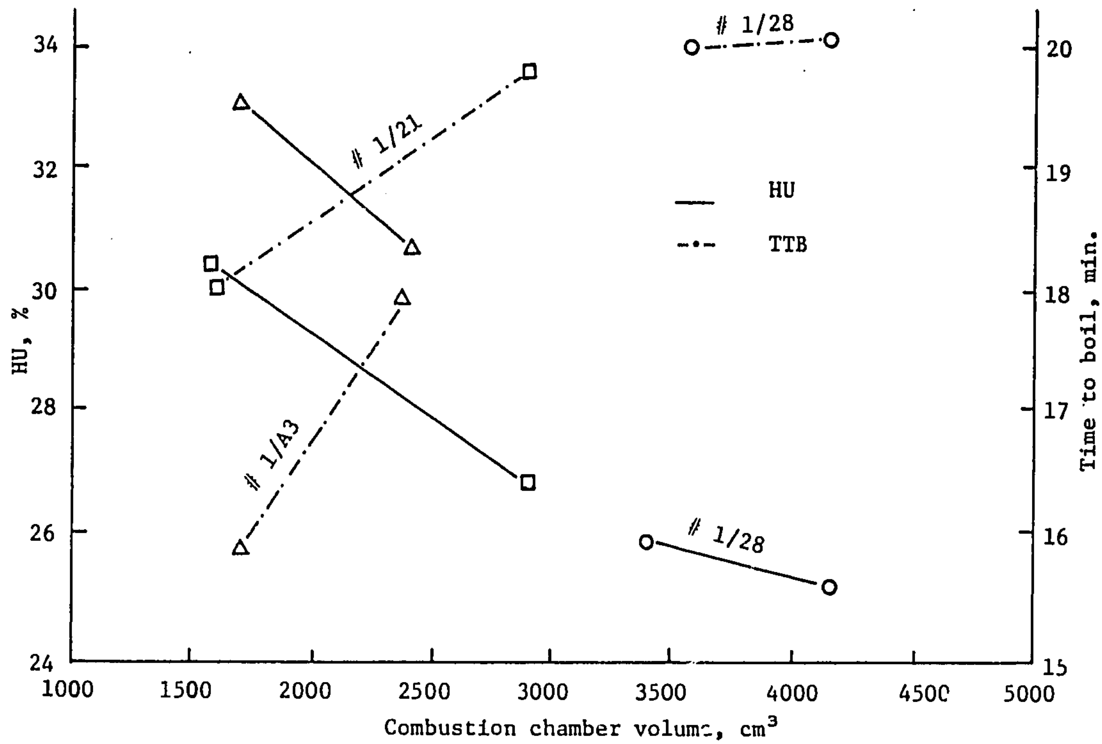


Fig. 5.10 The effect of combustion chamber volume on the stove efficiency and time to boil of three different stoves tested.

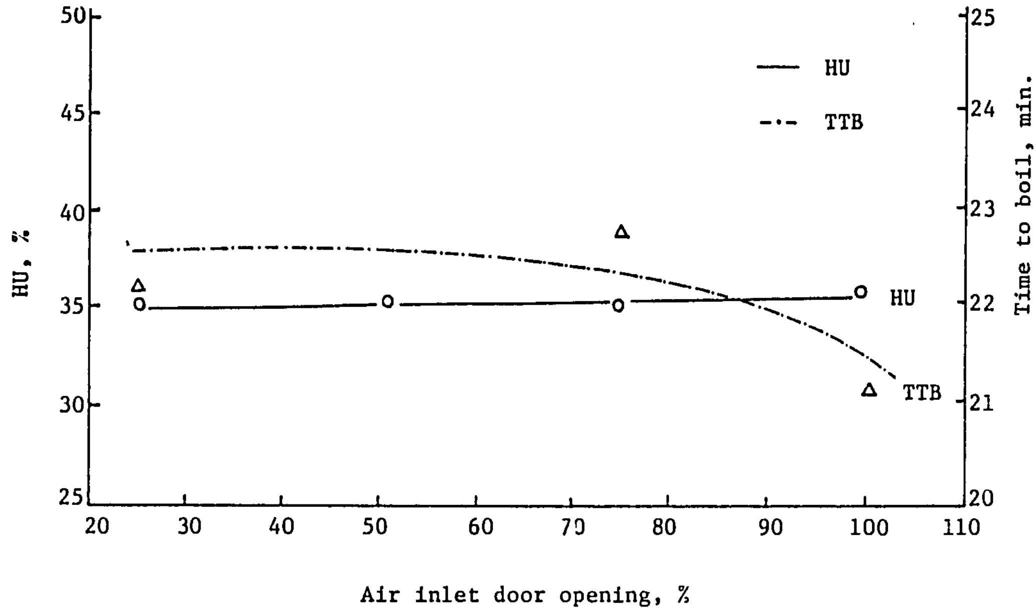


Fig. 5.11 The effect of air inlet door on the stove efficiency and time to boil.

Table 5.16 Test result of the effect of grate thickness on stove performance

Stove No.	No. of test	Grate thickness (cm)	Time to boil (min)	HU (%)
1/E3	5	2.0	16.6	31.3
	5	3.6	16.0	34.1
1/E4	5	2.0	19.4	30.1
	5	3.6	16.8	33.6

Results and Discussion

Only two values of grate thickness, as restricted by the stove firing chamber and grate-to-pot distance parameters, were chosen for the experiment: 2 cm and 3.6 cm. The tests for efficiency were performed on stove No. 1/E3 and 1/E4. The test results from Table 5.16 and Fig. 5.12 showed that the thicker grate gives a higher efficiency. The HU values for the first stove are 31.3 and 34.1% for the grate of 2.0 and 3.6 cm thick, and 30.1 and 33.6% for the second stove, respectively.

With the thicker grate, the heat lost by conduction is smaller because the grate is made of clay and rice husk ash which is a considerably good insulator. Therefore, the thicker grate seems to be the best (as long as the thickness increase has not significantly altered other physical parameters). Time to boil seems to slightly increase as the result of this change. However, more experiments should be performed to determine the optimum value of grate thickness based on different size of stoves.

Stove insulation

Test condition:	charcoal	=	400 gm.
	water	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.17 Test result of the effect of insulation on HU and time to boil.

Pair No.	Stove No.	Insulation	Time to boil (min)	HU (%)
1	1/3	no	22.3	25.7
	1/4	yes	18.8	28.2
2	1/23	no	21.5	29.2
	1/5	yes	21.1	30.5
3	1/33	no	18.3	30.5
	1/31	yes	16.7	32.4

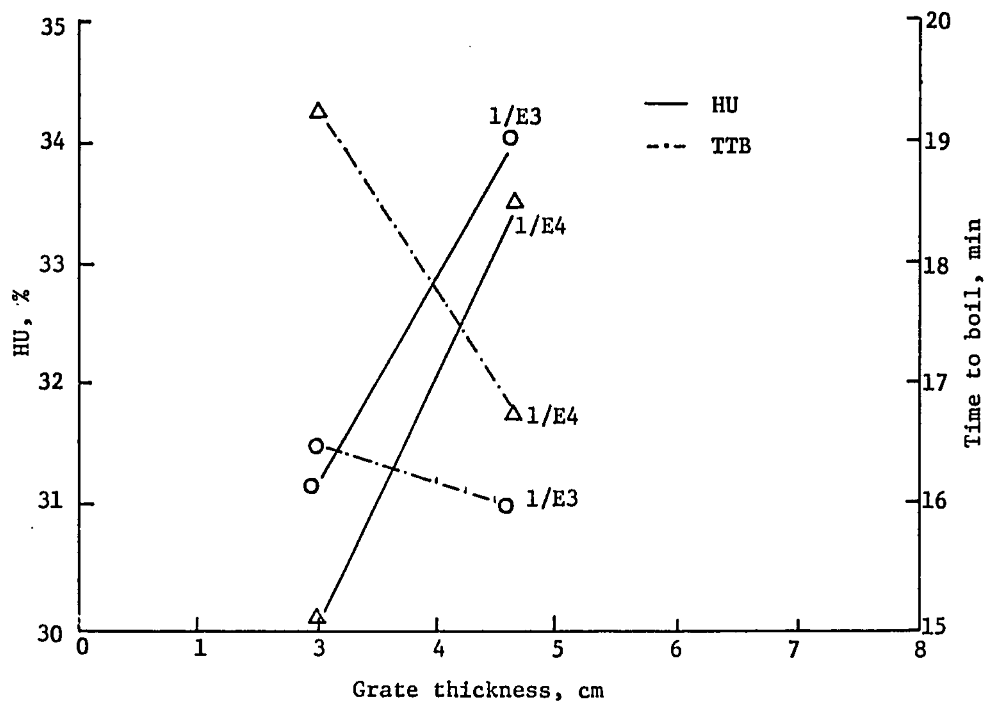


Fig. 5.12 The effect of grate thickness on the stove efficiency and time to boil

Results and Discussion

The bucket stove as the name implies has a bucket to contain the pottery body inside; between the bucket and the body is found insulation normally made from rice husk ash-clay light weight material. The function of the insulation and the bucket are threefold: that is, to minimize heat loss from the inside wall; to provide the constraint against thermal expansion without causing stove cracking or the stove integrity in long term service; and to facilitate transportability of users both from the market and during use. To study the effect of insulation, a matched pair of identical stoves were tested (one with, the other without insulation and bucket); the results are as shown in Table 5.17. From Table 5.17 it is quite apparent that the non-insulated stove performs more poorly than the insulated counterparts. The pair of larger size stoves (No. 1/3 and 1/4) showed a stronger effect than the smaller size pair in both HU% and time to boil. This may be due to the fact that a larger size stove has greater surface area for heat loss than the smaller one.

Stove's weight

Test condition:	charcoal	=	400 gm.
	water	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.18 Test result of the effect of stove weight on the HU and time to boil.

Pair No.	Stove No.	Stove weight (kg)	Time to boil (min)	HU (%)
1	1/2	12.2	21.7	25.0
	1/5	9.3	21.1	30.5
2	1/30	18.0	16.9	24.3
	1/31	11.8	16.7	32.4
3	1/32	8.2	17.6	24.6
	1/33	6.7	18.3	30.5
4	1/35	8.0	19.8	27.2
	1/36	6.5	20.8	30.7

Results and Discussion

Heat absorption by the stove largely depends on its weight. This is particularly true for the household cooking stove where it is normally started from cold conditions and used for a short duration (within one hour) with limited charcoal load. Almost all of the stoves tested regardless of this variation in physical parameters show that the charcoal stove efficiency varies more or less inversely with its weight. The stove sample pairs in Table 5.18 come from the same make and design.

From Table 5.18, it is quite clear that the stove weight has a strong effect on the stove heat utilization efficiency but almost no effect on the time to boil. It must be pointed out, however, that the chamber size of each stove in the pair studied was not the same. It was larger for the heavier stove. Therefore, combustion chamber size must also be combined with the stove weight. It is not possible to single out the weight factor alone.

The Effect of External Variables

The external variables are the environmental factors. These include the initial weight of charcoal and water, pot size, charcoal size, wind, and air relative humidity.

Initial weight of charcoal

Test condition: pot diameter = 24 cm.
exhausted gap = 1 cm.
water weight = 2,300, 3,000, 3,700 gm.

Table 5.19 Test result of the effect of initial weight of charcoal on stove HU and time to boil.

Stove No.	No. of test	Water weight (gm)	Charcoal weight (gm)	Time to boil (min)	HU (%)
1/5	5	2,300	300	17.0	26.3
	4		350	14.0	27.6
	4		450	13.0	30.8
1/5	4	3,000	300	16.5	30.1
	4		350	16.5	30.8
	4		450	16.8	32.2
1/5	4	3,700	300	24.0	30.7
	4		350	21.0	30.5
	4		450	19.0	32.0

Results and Discussion

In this experiment, the weight of charcoal varied from 300 to 350 and 450 gm, and the weight of water controlled at 3 levels: 2,300, 3,000, and 3,700 gm. Test results from Table 5.19 and Fig. 5.13 showed that at all water weight levels, the efficiency of the stove increases with the increase in charcoal load. The trend is weaker, however, as the amount of water is increased to the highest level (3,700 gm). Time to boil is also reduced as the charcoal load is increased.

These behaviors should be expected because when the amount of charcoal increases, the distance between the top charcoal layer and the pot bottom decreases as previously discussed. Furthermore, the increase in charcoal load has contributed to more energy input but with a lower percentage of heat loss due to the absorption by the the stove's mass.

Initial weight of water

Test condition: pot diameter = 24 cm.
charcoal weight = 300, 350, 450 gm.
exhausted gap = 1 cm.

Table 5.20 Test result of the effect of initial weight of water on HU and time to boil.

Stove No.	No. of tests	Charcoal weight (gm)	Water weight (gm)	Time to boil (min)	HU (%)
1/5	4	300	2,300	17.0	26.3
	4		3,000	16.5	30.1
	4		3,700	24.0	3[illegible].7
1/5	4	350	2,300	14.0	27.6
	4		3,000	16.5	30.8
	4		3,700	21.0	30.5
1/5	4	450	2,300	13.0	30.8
	4		3,000	16.8	32.2
	4		3,700	19.0	32.0

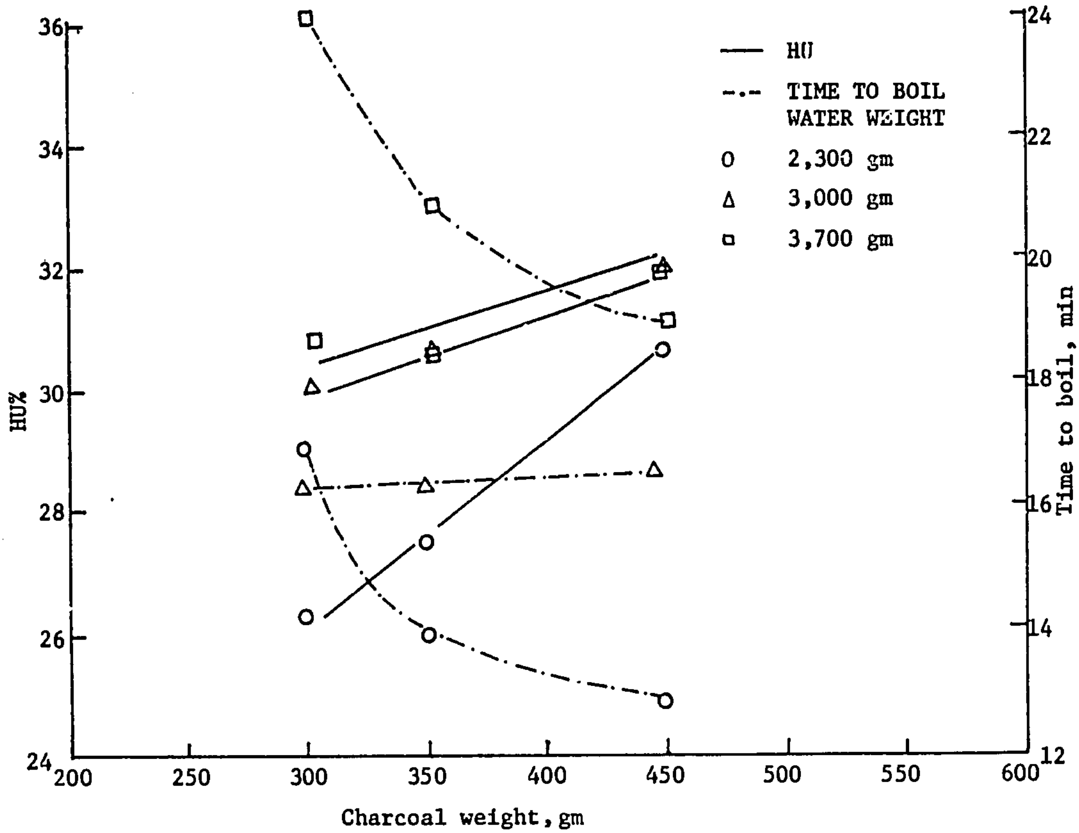


Fig. 5.13 The effect of the initial weight of charcoal on the stove efficiency and time to boil

Results and Discussion

The effect of initial water weight variation on the HU and time to boil was tested at three charcoal load levels. Test results from Table 5.20 shows that, in most cases, the efficiency increases slightly with the increase of initial water weight. The effect is considerably noticeable only when the water weight is increased from 2,300 gm to 3,000 gm, but after that point the efficiency seems to reach the peak regardless of charcoal load. The increased in time to boil is evident as the amount of water is increased.

Theoretically, the amount of heat required to increase the temperature up to its boiling point is proportional to the amount of water. Therefore, it is no surprise that time to boil increases from 17.0 to 24.0 minutes in the 300 gm charcoal load, from 14.3 to 21.0 minutes in the 350 gm charcoal, and from 13.0 to 19.0 minutes in the 450 gm charcoal load as the weight of water increases from 2,300 to 3,700 kg. As for the HU, since the geometrical structure of the stove has not changed, heat produced by combustion of charcoal occurs at the same rate. Therefore, the rate of heat transfer to the water is not varied by the amount of water. Consequently, the accumulation of energy by the water is unchanged. Even after the temperature of water reaches the boiling point, heat accepted by the water within half an hour of prolonged boiling is not different for all cases. The efficiency of the stove, therefore, is not greatly effected by the change of the initial weight of water particularly when the charcoal load satisfies the combustion chamber capacity as in the case of 350 and 450 gm.

Pot size

Test condition: charcoal weight = 400 gm.
water weight = 3,700 gm.

Table 5.21 Test result of the effect of pot size on HU and time to boil.

Stove No.	No. of tests	Pot size (cm)	Time to boil (min)	HU (%)
1/4	6	24	18.8	28.2
	5	28	16.4	28.5
	5	32	16.4	28.1
1/E3	5	24	16.5	34.1
	3	28	15.0	34.1
	3	32	16.0	34.8

Results and Discussion

The size of the cooking containers does not affect the efficiency of the stove. As shown in Table 5.21, the HU values are nearly constant when the size of the pot varies without changing the amount of water. This is due to the fact that in changing the pot size, the geometrical structure has not changed significantly: the distance between the top glowing charcoal layer to the pot bottom will change only slightly; i.e., a larger pot sits higher on the stove's pot rests but at the same time a larger pot has more heat absorbing surface at the bottom and side wall. However, one might expect more heat loss in the larger pot than in the smaller one, owing to a larger surface exposed to the surroundings but this may be offset by the greater water evaporating surface for the larger pot size. The effect of pot size on time to boil seems to be insignificant within the size range tested.

Charcoal size

Test condition:	charcoal weight	=	400 gm.
	water weight	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.22 Test result of the effect of charcoal size on HU and time to boil.

Stove No.	No. of tests	Charcoal size (cm)	Time to boil (min)	HU (%)
1/5	3	2.54	18.3	31.5
	3	10.16	18.3	31.6
1/12	3	2.54	17.7	27.5
	3	10.16	22.3	28.0
1/14	3	2.54	17.0	24.4
	3	10.16	23.7	23.8
1/20	3	2.54	19.0	24.5
	3	10.16	23.7	25.5

Results and Discussion

Table 5.22 indicates that the size of the charcoal has an insignificant effect on the stove efficiency. Time to boil increases as the size of the charcoal increases: 17.7 to 22.3 minutes in stove No. 1/12, 17.0 to 23.7 minutes in stove No. 1/14, and 19.0 to 23.7 minutes in stove No. 1/20. For stove No. 1/5, the time to boil does not change. This observation can be perhaps explained by the fact that the design of this stove, particularly the grate, is superior to others and therfore can compensate for charcoal size while the average design can not.

The increase in time to boil could be attributed to the decrease in burning surface of the larger size pieces charcoal. During the heating up time, heat is released from the combustion faster when the charcoal size is small, and vice versa. Therefore, the water needs a shorter time to boil with the small-size charcoal. However, a larger amount of charcoal is used up during the heating-up process. When the experiment is in the boiling period, the rate of heat released from the small-size charcoal diminishes because a large portion of the charcoal was used previously. The overall effect is that the efficiency is not significantly different between the two charcoal sizes investigated.

Wind

Test condition: charcoal weight = 400 gm.
water weight = 3,700 gm.
pot diameter = 24 cm.

Table 5.23 Test result of the effect of wind on HU and time to boil

Stove	No.	No. of tests	Wind spped m/min	Time to boil min	Time to boil rel. change %	HU %	HU rel. change %
1/5	41	8	0	21.1		30.5	
	1	3	80	18.0	-14.7	22.6	-26
1/12	80	7	0	22.6		18.4	
	2	3	80	23.3	+ 5.7	18.4	-36
1/17	50	6	0	20.0		32.3	
	1.2	3	80	26	+30.0	21.9	-32
1/14	113	6	0	27.2		23.5	
	2.5	3	80	not boil	+ ∞	15.6	-34
1/20	102	6	0	30.3		24.9	
	2	3	80	not boil	+ ∞	16.6	-33

Results and Discussion

The effect of wind was simulated by the use of an electric fan approximately 16 inches in diameter placed at the distance of about 2 m from the stove air inlet port. The wind speed was measured by a vane type anemometer located right in front of the air inlet port. The result from

Table 5.23 shows that the stove efficiency drops drastically when subjected to the wind of 80 m/min (or 4.8 km/hr). The drop in HU relative to original value (without the wind) ranges from 26 - 36%. Time to boil, except for stove number 1/5, increased as little as 6% of original value to 30% and even to infinity in the case of stove number 1/14 and 1/20 where the water cannot be brought to the boil. It is interesting to note that stove number 1/5 has less time to boil when subjected to wind and the least change in HU. The behavior of this stove can be simply explained by the better control of heat loss since its exhausted gap/area (1 cm/41 cm^2) is very narrow (Table 5.1). For those stoves with wider gaps and exhausted areas such as number 1/14 and 1/20 (where the exhausted gaps/areas are 2.5 cm/113 cm^2, and 2.0 cm/102 cm^2, respectively), the HU drops and time to boil increases considerably.

Air relative humidity

Test condition:	charcoal weight	=	400 gm.
	water weight	=	3,700 gm.
	pot diameter	=	24 cm.

Table 5.24 Test result of the effect of air relative humidity on HU and time to boil.

Stove No.	No. of tests	Humidity (%)	Time to boil (min)	HU (%)
1/5	1	68	23.0	29.0
	2	74	20.5	31.6
	1	76	21.0	31.6
	1	78	22.0	31.3
	1	80	19.0	30.6
	3	92	22.7	29.2

Results and Discussion

The effect of air relative humidity on the HU and time to boil was investigated using the test results that were previously recorded over a long period of time in which changes in humidity had actually occurred. The test results in Table 5.24 indicate that the HU and time to boil do not vary with the humidity.

Air relative humidity presumably should influence the rate of water evaporation from the pot during boiling. For example, at low relative humidity the evaporation rate should be higher and vice versa. However, this has proved not to be the case. The plausible explanation is that at a very high vapor pressure of the boiling water, resulting from an intense heat generated by the glowing charcoal under the pot, more than enough energy potential is created to evaporate the water from the pot.

The change in air relative humidity, therefore, can have essentially no additional effect on the evaporation rate.

E. WOOD STOVE WITHOUT CHIMNEY

In investigating the performance of the wood stove without chimney, the variables are also classified in a similar way as in the charcoal stove. They are divided into two groups--internal and external variables.

Internal Variables

In this section, the effect of internal variables are studied. These internal variables are stove gap, grate vs nongrate, grate hole area, and grate-to-pot distance.

Stove gap/exhausted area

Table 5.25 Test result of the effect of stove gap on HU and time to boil of the wood stove.

Stove No.	No. of tests	Gap exhausted (cm)	Time to boil (min)	HU (%)
2/25R	5	1	12.6	28.92
2/88	4	1	11.2	27.62
2/1B	5	1.5	12.4	27.34
2/13E	5	1.3	12.0	27.04
2/24R	8	0.63	13.5	25.93
2/5B	3	1.5	12.7	25.71
2/22B	8	1.5	14.0	24.43
2/4B	3	2.7	11.0	23.47
2/23	6	1.8	14.5	23.20
2/9B	8	2.0	12.0	22.76
2/21N	3	3.0	16.0	21.63
2/12S	3	2.0	14.0	21.01
2/13S	3	1.6	14.0	20.99
2/2S	3	2.0	13.0	20.80
2/20S	3	2.0	14.7	20.69
2/18S	3	2.0	13.7	20.28
2/24S	3	1.5	14.3	20.19
2/8S	3	1.5	17.3	18.13
2/19S	3	2.5	14.3	17.75
2/9S	3	3.0	17.3	14.48

Results and Discussion

As indicated with the charcoal stove, the gap has an effect on the stove efficiency. In the case of the wood stove, even when the mechanism of heat transfer is different, this effect is also observed. Fig. 5.14 is the plot of the HU values of wood stoves from various manufacturers against the gap heights. The scattering of points in the figure is due to variations of stove geometry of different makes. Nevertheless, the trend can be deduced easily; as the gap height decreases, the stove efficiency increases.

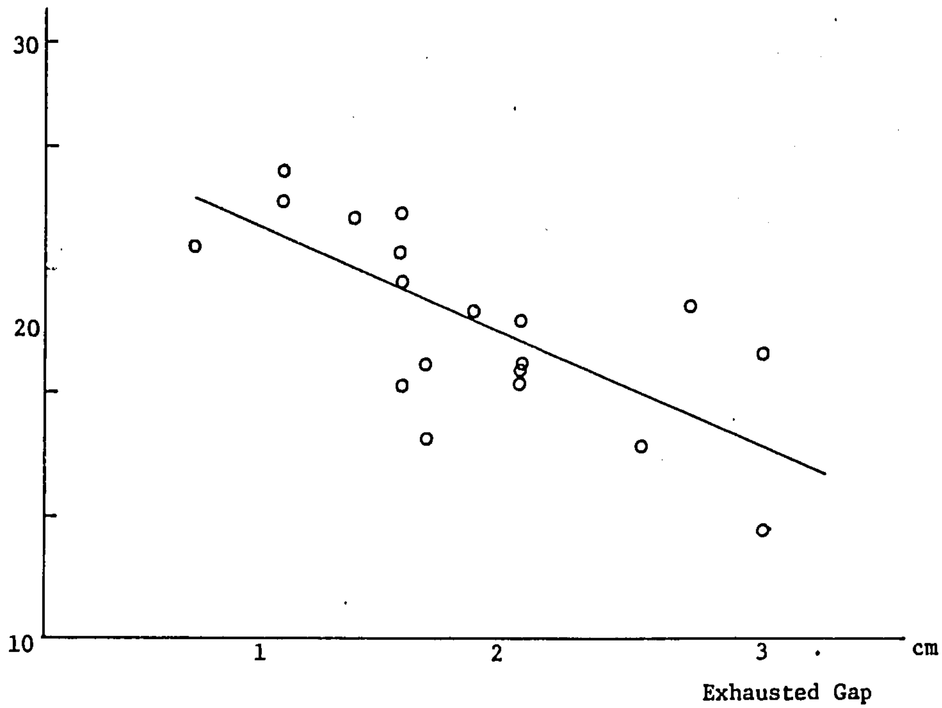
The increase of stove efficiency with the decrease of gap can be explained in the same line as that of the charcoal stove. When the gap is large, heat is easily lost through the gap by the flame and exhaust gas convections. With the smaller gap the flame from burning firewood has a better contact with the pot side wall before exit to the atmosphere.

Grate vs nongrate design

Table 5.26 Test result of the effect of grate on HU and time to boil of wood stove.

Stove No.	No. of tests	Base or grate-to-pot distance, cm	Firewood used, gm	Time to boil min	HU %	Remarks
2/5	4	14.0	1,078	17	23.6	stove
2/6	4	14.0	1,394	16.2	14.6	group
2/7	3	14.0	1,372	18.7	15.4	without
2/9	4	11.5	1,266	15.5	19.5	grate
2/10	3	12.0	1,303	15.3	16.8	
	Average	13.1	1,283	16.5	17.9	
2/4	3	12.0	1,134	14	21.0	stove
2/13	3	14.5	1,192	17	20.2	group
2/22	6	12.2	1,258	13	23.8	with
2/23	6	12.2	1,143	14.5	23.2	grate
2/24	5	13.0	1,034	16	23.5	
	Average	12.8	1,152	14.9	22.3	

Fig. 5.14 The effect of exhausted gap on efficiency of various wood stoves.



Results and Discussion

Comparing the two designs of wood stove (with and without grate), the test results in Table 5.26 indicate that with comparable base or grate-to-pot distance the stove group with grate has a much better heat utilization efficiency on the average.' The absolute efficiency difference is 4.4%. The times to boil are 16.5 and 14.4 minutes for the group without and with grates respectively. This difference, however, is considered to be insignificant for practical use. The stove with grate consumes approximately 10% less fuel on the average than the group without grate.

The reason for the better performance of the stove with grate is that the primary air induced from underneath the grate contributes to a more complete combustion of fuel than those stoves without grates where the air can enter the combustion chamber through the firewood feeding port only. The poorer combustion of nongrate stoves can be easily observed by the end of the test since more unburned charcoal remains.

Grate hole area

Table 5.27 Test result of the effect of grate hole area on wood stove performance.

Stove No.	No. of test	Grate hole number	Grate hole diameter (cm)	Grate hole area (sq cm)	Time to boil min	Time to boil average	HU %	HU average
2/8B	4	90	1.5	159.0	11.2		27.68	
2/23	6	90	1.5	159.0	14.5		23.20	
2/1B	5	90	1.5	159.0	12.4		27.34	
2/13E	5	90	1.5	159.0	12.0		27.04	
2/22B	8	90	1.5	159.0	14.0		24.43	
2/1GI	7	90	1.5	159.0	12.4		25.97	
2/24R	8	90	1.5	159.0	13.5		25.93	
2/25B	4	90	1.5	159.0	11.7	17.7	25.27	25.5
2/8E	9	37	2.5	181.6	16.7		25.57	
2/20A	10	37	2.5	181.6	15.9		23.56	
2/13B	8	37	2.5	181.6	12.0	14.9	22.76	24.0
2/8GI	4	61	1.23	72.5	12.0		26.36	
2/1A	6	61	1.23	72.5	13.8	12.9	25.12	25.7

Results and Discussion

The effect of grate hole area on the stove efficiency was studied by selecting stoves of different grate designs. Three sets of hole diameter and a varying number of holes were investigated; they are: A, 2.5 cm diameter and 37 holes; B, 1.5 cm diameter and 90 holes; and C, 1.23 cm diameter and 61 holes. The respective grate hole areas of A, B, and C are 181.6, 159.0, and 72.5 sq cm. The efficiencies of A, B, and C are shown in Table 5.27. Only a slight increase in the stove efficiency with the decrease in the total grate hole area was observed: the efficiency of A was 24.0%, B 25.5%, and C 25.74%.

The above phenomenon can be explained in terms of radiative heat loss. Through the grate holes, radiative heat can easily pass to the ash chamber. Consequently, a grate with a smaller total hole area improves the performance of the stove. In addition, the secondary air is always available through the firewood feeding port; therefore, the reduction of primary air inlet area by almost 2/3 does not cause the stove performance to change significantly.

Grate-to-pot distance

Table 5.28 Test result of the effect of grate-to-pot distance on stove performance.

Stove No.	No. of tests	Grate distance (cm)	Time to boil min	Time to boil average	HU (%)	HU average
2/A1	3	9	15.0		23.04	
2/A1A	4	9	14.5		24.48	
2/A1A1	3	9	15.0		25.70	
2/A2A	4	9	14.25		26.00	
2/A2	3	9	14.67	14.7	24.32	24.7
2/C1	5	10	14.6		25.10	
2/C1A	4	10	14.75		27.12	
2/D2A	4	10	15.25		25.20	
2/D2	3	10	14.66		25.34	
2/E2	3	10	16.0		25.00	
2/F1	6	10	15.33		26.05	
2/1G	3	10	15.66	15.2	25.65	25.6
2/A2	5	11	15.6		27.53	
2/A3A	4	11	18.0		26.82	
2/A4A	3	11	18.0		28.0	
2/A4	5	11	18.0	17.4	28.25	27.7
2/C2	5	12	15.2		23.78	
2/C2A	4	12	14.5		25.87	
2/D1	3	12	13.67		25.00	
2/D1A	4	12	13.75		26.82	
2/F2	6	12	14.5		26.35	
2/F2A	3	12	14.33	14.3	26.80	25.8
2/30B	6	13	21		19.11	
2/30A	3	15	18.33		19.75	
2/30	3	16	28.67		15.67	

Results and Discussion

The effect of the grate-to-pot distance on the stove performance is shown in Table 5.27 and Fig. 5.15. As the distance increases from 9 cm to about 11.0 cm, the average efficiency increases from 24.7 to 27.7%. However, as the distance increases further, the stove efficiency drops. This behavior is also observed with the charcoal stove.

At the small grate-to-pot distance, it is likely that the glowing wood is too near to the gap, causing high convective heat loss through the gap. Moreover, with too small a distance, firewood pieces would tend to jam up the combustion chamber causing limited flame to come into contact with the pot bottom and insufficient temperature of the chamber itself to initiate off-gas combustion with the incoming secondary air. When the distance increases, this loss reduces; the performance, hence, improves. However, at great distances the radiative heat which is intercepted by the pot drops more quickly than the decrease in heat loss through the gap, resulting in the poor performance of the stove.

External Variables

Only two external variables are studied: wind effect, and fuel feed rate.

Wind effect

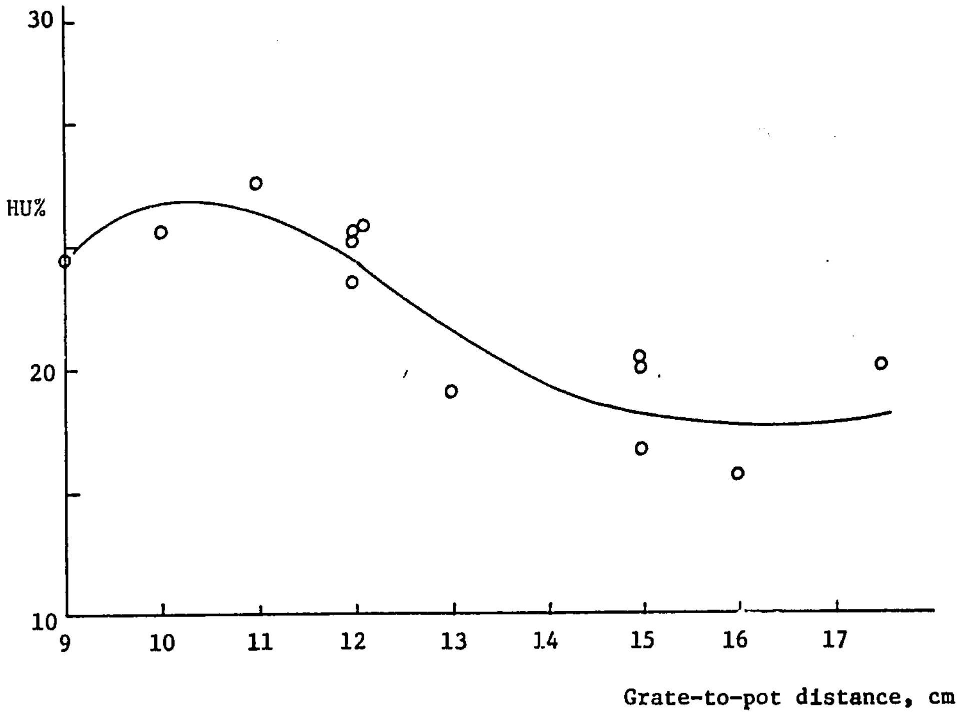
Table 5.29 Test result of the effect of wind on wood stove performance.

Stove No.	No. of tests	Wind velocity (km/hr)	Time to boil (min)	HU (%)
2/2S	3	normal	13.0	17.65
2/2B	3	6.3	13.7	16.21
2/21N	3	normal	16.0	21.63
2/21W	3	6.0	14.7	17.03
2/25C	8	normal	11.9	21.64
2/25D	3	5.0	14.0	14.58

Results and Discussion

From Table 5.28, wind is found to have a strong effect on the efficiency of the wood stove. In one experiment, the HU values dropped from 21.63% to 17.03%, when the wind is induced through the use of an electric fan. In another experiment, the HU values decreased from 21.64 to 14.58%. All of

Fig. 5.15 The effect of grate-to-pot distance on the heat utilization efficiency (HU) of wood stoves



the experiments, including those with the charcoal bucket stove, indicate a similar effect when the stove is subjected to wind. The amount of drop in efficiency, however, depends on the design characteristics, particularly the exhausted gap and fuel feeding port size.

The decline in performance is due to the increase of heat loss by flue gas and flame convection through the gap, and the oversupply of air to the combustion. If more air is supplied than required by the combusted wood, the heat-up of excess air will decrease the temperature of the combustion chamber. Therefore, the warm excess air, which contains a large amount of thermal energy, will be lost with the flue gas.

Fuel feed rate

Table 5.30 Test result of the effect of firewood feeding rate on the stove performance.

Stove No.	No. of tests	Average feeding rate gm/min	Time to boil min	HU %	Remarks
2/8E	3	21.5	13.8	24.8	grate-to-pot distance = 12 cm for both tests
	3	25.7	11.3	22.5	
	3	27.9	15.0	18.5	
2/13A	3	31.6	11.4	23.5	
	3	38.8	9.7	21.9	
	2	42.0	9.4	20.9	

Results and Discussion

Unlike the charcoal stove where the fuel is loaded in the combustion chamber at one time at the begining of ignition, the wood stove needs to be fed with firewood gradually and at a proper distance to obtain the best combustion flame directed toward the pot bottom. The firewood feeding rate as shown in Table 5.29 indicates that this factor is quite sensitive to the efficiency of the stove. A higher feed rate causes the drop in HU for both stoves evaluated. The time to boil shows a decreasing trend as the feed rate is increased (with one exception, for stove number 2/8E, where at the fastest rate of 27.9 gm/min the time to boil increases). This may be due to the clogged up combustion chamber and firing since this stove has a small firewood feeding port and combustion chamber.

The drop in HU with a faster firewood feeding rate can be recognized by two important phenomena; first, the rate of heat absoption by the pot is not directly proportional to the rate of heat released by the fuel, particularly when the flame is forced through the exhausted gap with poor contact with the pot side; secondly, the clogging-up effect of the combustion chamber when too much or too fast firewood is fed in causes the incomplete combustion of hot gas.

Chapter 6

Theoretical Analysis of Charcoal Stove

THEORETICAL ANALYSIS OF THE CHARCOAL STOVE

A. MATHEMATICAL MODEL OF THE BUCKET STOVES

As seen in the preceding sections, the effects of only a few factors on stove efficiency were studied experimentally. These factors include the distance from grate to pot H, the grate hole area A_g, the gap height G, the wall thickness D, and the stove weight m_s. Consequently to be of any use, any mathematical model of the stoves has to relate the efficiency to these factors. It is the purpose of this section to develop such a model.

Prior to the development of the mathematical model, an understanding of the heat transfer mechanisms occuring in the stove is essential. These mechanisms are briefly described in this section. They are then related to the above factors. The model is subsequently developed; parameters in the model are evaluated by fitting the model to the experimental results shown in the previous sections. With the obtained values of the parameters, the model is used to predict the change of efficiency due to variation of one of the factors.

Mechanisms Occuring in the Stove

A known amount of charcoal is loaded into the stove grate and ignited. Air flows in by natural convection through the inlet opening to accelerate combustion; this operation is continued until all the charcoal is burned. During the cooking operation, most of the heat from the combustion is consumed to raise the temperature of the charcoal to its burning point; if the process is assumed adiabatic, the combustion temperature will vary depending on the geometrical structure of the stove, the supply of air, and the arrangement and the amount of charcoal loaded.

Air is naturally drawn into the stove due to the difference in pressure from the outside to the inside. The flow rate of air is, hence, dependent on the pressure difference and also on the air inlet area.

In the combustion chamber, oxygen in the air oxidizes carbon in the charcoal, producing heat. The amount of heat produced varies with the condition of combustion: if a large quantity of charcoal is loaded and the air supply is not sufficient, the combustion is incomplete; on the other hand, if air is sufficiently supplied or oversupplied, the combustion is complete. The former condition yields less heat than the latter. However, oversupply of air tends to bring the stove temperature down. Consequently, heat produced by the combustion depends on the amount of charcoal and the flow rate of air.

Heat from the combustion of charcoal dissipates by three modes: conduction, convection, and radiation (see Thomas, 1980). The conductive heat transfers through the wall of the stove and the wall of the pot. During the transient state some heat is stored in the stove material, resulting in an increase of the temperature. This amount of stored heat varies directly with the mass and the temperature increment from its initial value to the steady-state value. At the steady state, according to the Fourier law of heat conduction, heat, conduced through the stove wall, varies inversely with the wall thickness and directly with the temperature gradient across the wall.

The air, after combustion with the charcoal, has a low density due to the increase in temperature. As a consequence, the exhaust air, carrying some heat with it, rises and leaves the stove through the gaps between the stove and the pot. A portion of the heat is released to the pot by conduction when the exhaust air (or the flame) comes into contact with the pot bottom; the remainder,accompanying the exhaust air out of the stove, can be considered as a loss. The whole mechanism here is actually natural convection. The flow rate of the exhaust air, hence, depends on the gap area and the pressure gradient.

The third form of heat transfer in the stove is radiation. It is the most important mode among the three since, according to the Stefah-Boltzmann law, the radiative energy from a surface, having an absolute temperature higher than 0°K, varies with the temperature to power four. With the temperature of the charcoal or the flame much higher than the temperature of the pot, the net flux of radiative energy from the flame to the pot is enormous. However, the net energy flux intercepted by the pot bottom decreases as the distance between the flame and the pot increases. The change in the net flux due to the change in the distance is commonly explained by the concept of view factor, which is simply defined as the ratio of the radiation from one surface intercepted by another surface to the total radiation from the first surface. The pot bottom, as the second surface in this definition gains the radiative energy from the charcoal, which acts as the first surface, by the amount proportional to the view factor from the charcoal to the pot. If the radiation is envisaged as energy particles or photons propelled outward from the flame in a random manner, the chance that the photons will hit the pot bottom diminished when the distance increases and the view factor decreases. Consequently, the radiative energy gained by the pot decreases with increasing distance.

The above view of the heat transfer mechanisms in the stove lays the basis of modelling. It will include all the essential characteristics of the stove studied in experiments: the grate hole area A_g, relating to the natural convection of inlet air; the stove mass weight M_S, connected to the heat stored in the material of the stove; the gap height G, associated with the natural convection of the exhaust air; the wall thickness D, related to the heat conduction; and the distance from grate to pot H, pertaining to the radiation (see Fig. 6.1).

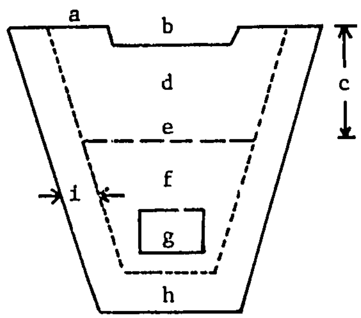


Fig. 6.1 Structure of the ideal Biomass cooking stove:
a - pot stand;
b - exhause gap;
c - grate to pot distance;
d - combustion chamber;
e - grate;
f - ash compartment;
g - opening for inlet air;
h - stove base;
i - stove width.

Mathematical Modelling

Heat from the combustion dissipates, as previously explained, by conduction, natural convection, and radiation. Heat fluxes resulting from these modes of heat transfer may be estimated from some mathematical relations available in many standard textbooks concerning heat transfer. Examples are books by Bird et al. (1960), Thomas (1980), Bennett and Myers (1974).

For conduction of heat through solid slab, heat flux can be calculated from the Fourier's law of heat conduction. If the slab has a thickness of D, the two surfaces at different temperature T_1 and T_2 ($T_1 > T_2$), and its thermal conductivity of k, heat flux q_{cond} at steady state, according to the Fourier's law, can be expressed as:

$$q_{cond} = k(T_1 - T_2)/D \qquad (1)$$

In the process of natural convection, it has been known that this mode of heat transfer is strongly dependent on the value of Grashof number, which is proportional to the temperature difference. The analysis of natural convection of fluid between two parallel infinite plates at different temperatures, aligned with the gravitation direction, shows the velocity of the buoyant fluid to vary directly with the Grashof number (Bird et al, 1960). Undoubtedly, the natural convection between two plates is quite different from what actually occurs in the stove. However, it exemplifies the aforementioned fact that natural convection is a function of the Grashof number, or, as a consequence, due to the definition of the Grashof number, a function of temperature difference, that is:

$$v_{conv} = f(Gr) \qquad (2)$$

in which v_{conv} is the velocity of the buoyant gas and Gr is the Grashof number.

Heat fluxes due to radiation between two isothermal surfaces 2, σ is factors between the surfaces are known, can be calculated from

$$q_{rad} = \sigma F_{12}\ (T_1^4 - T_2^4) \qquad (3)$$

in which q_{rad} is the radiative heat flux from surface 1 to surface 2, σ is Stefan-Boltzmann constant, F_{12} is the view factor from surface 1 to surface 2, and T_1 and T_2 are the respective temperatures of surfaces 1 and 2.

For radiation between two circular discs of equal diameter, the view factors between the two discs have been calculated analytically and plotted against the ratio of the diameter to the distance between the discs (Thomas, 1980). If the diameter is unchanged, the view factor is approximately proportional to the inverse of the distance H:

$$F_{12} = 1/H \qquad (4)$$

To simplify the modelling, the following assumptions are made:

1. Flame temperature is constant (about 800°C).

2. Time and fuel required to increase the temperature of the fuel bed from its initial value (i.e. ambient temperature) to the final temperature at 800°C are negligible.

3. The rate of combustion is proportional to the air mass flow rate into the bed.

4. Density of the stove material ρ, and heat capacity $\hat{c}_p$, thermal conductivity k are constant.

5. The wall thickness is uniform.

6. The diameter of the grate and the diameter of the pot are constant.

7. Only part of the radiation is considered as useful in heating, the other modes of heat transfer contribute to heat loss.

Since the air flow into and out of the stove is by natural convection, the velocity of the air is a function of the Grashof number. The relation between v_{conv} and Gr in this situation can be obtained experimentally. However, no experiments with the purpose of procuring such relations have been performed. In order that the modelling can proceed, the relationship has to be assumed. For simplicity, a linear relationship between the velocity of buoyant gas and the Grashof number is adopted:

$$v_{conv} = (\text{constant})\ Gr \tag{5}$$

or

$$v_{conv} = (\text{constant})\ (T_{flame} - T_{amb}) \tag{6}$$

in which T_{flame} and T_{amb} are the respective temperatures of the flame and the surroundings.

Due to assumption 1, that the flame temperature T_{flame} is constant, Fig. 6 indicates that the velocity of the upflow gas is constant:

$$v_{conv} = \text{constant} \tag{7}$$

For air inlet, the air has to pass the grate holes before it is consumed in the combustion process. With constant air velocity, the volume flow rate is proportional to the grate hole area A_g. Consequently, the mass flow rate of the inlet air is also in proportion to the grate hole area.

Assumption 3 and the argument in the previous paragraph give the consumption rate of charcoal in the following form:

$$-\ dm_c/dt = \alpha A_g \tag{8}$$

in which m_c is the mass of charcoal, t is time, and α is a constant.

Similarly, the volume flow rate of exhaust gas, which leaves the stove through the gap, varies directly with the gap area. It was found later that the gap area changes in a linear fashion with the gap height G. Thus, volume flow rate, or, in other words, the mass flow rate of the exhaust gas is proportional to the gap height G. Since the flame temperature is assumed constant, the heat loss due to this process then varies linearly with the gap height G. If $\dot{Q}_{conv}$ is the rate of heat loss,

$$\dot{Q}_{conv} = BG \tag{9}$$

in which B is a constant.

At the initial time the temperature of the stove material is the same as the ambient temperature; the temperature increases to a certain value at steady state. The constancy of thermal conductivity indicated in assumption 4 assures a linear temperature profile across the stove wall when the system is steady. Since the flame temperature is constant for any thickness of the wall, the temperature difference across it is also constant. Heat stored in the stove material can, hence, be calculated from the average temperature, which is unchanged for any stove. With the assumption of constant heat capacity, the total heat absorbed by the stove mass Q_{abs} is proportional to the mass m_s. Dividing the total absorbed heat with the total heating time yields the rate of heat absorption $\dot{Q}_{abs}$:

$$\dot{Q}_{abs} = \varepsilon m_s \tag{10}$$

in which ε is a function of time and physical properties of stove material. For convenience, ε is assumed constant.

The rate of heat transferred through the wall by conduction $\dot{Q}_{cond}$ is estimated from E_q (1):

$$\dot{Q}_{cond} = kA(T_{flame} - T_{amb})/D \tag{11}$$

in which A is the total surface area of the stove wall.

Since the density of the stove material is ρ, and the wall thickness is uniform, the area A can be related to the mass m_s and the thickness D:

$$m_s = \rho AD \tag{12}$$

Substitution of E_q (12) in E_q (11) gives

$$\dot{Q}_{cond} = k(T_{flame} - T_{amb})m_s/\rho D^2 \tag{13}$$

or

$$\dot{Q}_{cond} = \delta m_s/D^2 \tag{14}$$

in which

$$\delta = k(T_{flame} - T_{amb})/\rho \tag{15}$$

Total heat generated by the combustion is proportional to the rate of combustion if heat of combustion is constant: If $\dot{Q}_{comb}$ is the rate of heat generated, equation (8) gives

$$\dot{Q}_{comb} = \alpha^* A_q \qquad (16)$$

in which α^* is the product of α and the heat of combustion per mass of charcoal consumed.

Subtraction of conductive heat and convective heat from the total heat generated from the combustion would give the radiative heat:

$$\dot{Q}_{rad} = \alpha^* A_g - \beta G - \varepsilon m_s - \delta m / D^2 \qquad (17)$$

in which $\dot{Q}_{rad}$ is the rate of heat transfer by radiation.

Not all the radiative heat is used in boiling water. The amount of this heat varies with the view factor between the pot and the charcoal, which, according to Eq (4), is approximately in proportion to the inverse of the distance between the grate and the pot bottom H. If $\dot{Q}_h$ is the rate of heat supplied to the water,

$$\dot{Q}_h = \gamma \dot{Q}_{rad}/H \qquad (18)$$

in which γ is a constant.

Substitution of equation (17) into equation (18) gives

$$\dot{Q}_h = \gamma(\alpha^* A_g - \beta G - \varepsilon m_s - \delta m_s/D^2)/H \qquad (19)$$

Fig. 19 will be used as a means of estimating the heat in bringing the temperature of water from the initial state to the state of boiling, and in evaporating water.

Period of heating water

In this period, water is heated from the ambient temperature T_{amb} to the boiling point T_{boil}. Since the cooking pot used in this work is made of aluminium which has the property of good thermal conduction, the heat that is intercepted by the pot is partially transferred to heat the water and the remainder is lost through the pot surface. If $\dot{Q}_w$ and $\dot{Q}_1$ are the rates of heat absorbed by water and heat loss respectively, then

$$\dot{Q}_h = \dot{Q}_w + \dot{Q}_1 \qquad (20)$$

Part of the heat that is absorbed by the water prior to its boiling is given by:

$$\dot{Q}_w = m_{wo} c_{pw} dT_w/dt \qquad (21)$$

in which m_{wo} is the initial mass of water, c_{pw} is the heat capacity of water, and T_w is the water temperature at time t. The heat loss through the pot surface is given by:

$$\dot{Q} = hS(T_w - T_{amb}) \qquad (22)$$

in which h is the heat transfer coefficient, and S is the surface area of the pot.

Substitution of Eqs (21) and (22) into Eq (20) give

$$\dot{Q}_h = m_{wo}c_{pw}dT_w/dt + hS(T_w - T_{amb}) \quad (23)$$

The solution of this differential equation is

$$T_w = B_1/B_2 + (T_{amb} - B_1/B_2)\ e^{-B_2 t} \quad (24)$$

in which

$$B_1 = (\dot{Q}_h - hST_{amb})/m_{wo}c_{pw} \quad (25)$$

$$B_2 = hS/m_{wo}c_{pw} \quad (26)$$

Substitution Eqs (19), (25), and (26) into Eq (24), and then rearranging the result of substitution, one gets

$$T_w = T_{amb} + \frac{\gamma(\alpha^* A_g - \beta G - \epsilon m_s - \delta m_s/D^2)}{hSH}(1 - e^{-B_2 t}) \quad (27)$$

Eq (27) is used to estimate the time required to increase the temperature of water from the ambient value to its boiling point.

Period of boiling

At boiling, the water molecules begin to move turbulently and become loosely bound. Eventually, some of the water molecules with enough kinetic energy will be able to escape from the water surface in the form of vapor. If the rate of heat consumed in evaporating water is $\dot{m}_v h_{fg}$, the overall energy balance is

$$\frac{\gamma}{H}(\alpha^* A_g - \beta G - \epsilon m_s - \delta m_s/D^2) - hS(T_{boil} - T_{amb}) = \dot{m}_v h_{fg} \quad (28)$$

in which $\dot{m}_v$ is the rate of evaporated water and h_{fg} is the latent heat of vaporization.

If t_2 is the total time used in the experiment and t_1 is the time required in heating the water from its initial state to boiling, then the total heat consumed in boiling can be obtained by multiplying Eq (28) with $t_2 - t_1$:

$$\left[\frac{\gamma}{H}(\alpha^* A_g - \beta G - \epsilon m_s - \delta m_s/D^2) - hS(T_{boil} - T_{amb})\right](t_2 - t_1)$$
$$= \dot{m}_v h_{fg}(t_2 - t_1) \quad (29)$$

The results in parts A and B are used to estimate the efficiency of the stove.

Efficiency of stove

The heat utilization or the efficiency of the cooking stove η is defined as the ratio of the heat consumed in heating and boiling water to the total heat input into the system. Since the rate of combustion is not a function of the charcoal mass as seen in Eq (8), the efficiency η can be expressed as

$$\eta = \frac{Q_{sens} + \dot{m}_v h_{fg}(t_2 - t_1)}{\alpha A_g \Delta H\ t_2} \quad (30)$$

in which ΔH is the heat of combustion, and Q_{sens} is the sensible heat of water in increasing the temperature from the ambient to the boiling point.

The time required to increase the temperature of water, in the experiment, is usually less than the time required to reach the boiling point. Although the difference between the heating time and the boiling time is not really insignificant, the sensible heat will be excluded from Eq (30). This action is done for two reasons: one, the mass of water is not taken as one of the variables in this work; two, including the sensible heat adds at least one more variable, which not only complicates the evaluation of parameter, but may also obscure the effect of other variables. Furthermore, heat loss through the pot surface will be neglected in Eq (29). Hence, the efficiency of the stove becomes

$$\eta = \frac{\gamma(\alpha^* A_g - \beta G - \varepsilon m_s - \delta m_s/D^2)\ (t_2 - t_1)}{\alpha A_g H \Delta H\ t_2} \quad (31)$$

Eq (31) can be simplified where the constants are lumped together:

$$\eta = a\ (\frac{t_2 - t_1}{Ht_2}) - a_2 G(\frac{t_2 - t_1}{A_2 Ht_2}) - a_3 m_s(\frac{t_2 - t_1}{A_2 Ht_2}) - a_4 \frac{m_s}{D^2}(\frac{t_2 - t_1}{A_g Ht_2}) \quad (32)$$

in which

$$a_1 = \gamma \quad (33)$$

$$a_2 = \gamma\beta/\alpha\Delta H \quad (34)$$

$$a_3 = \gamma\varepsilon/\alpha\Delta H \quad (35)$$

$$a_4 = \gamma\delta/\alpha\Delta H \quad (36)$$

Eq 32 is actually linear with respect to the parameters. This fact can facilitate the method of evaluating the parameters.

B. EVALUATION OF PARAMETERS

Since Eq 32 is linear, the least square method or the method of multiple linear regression would be appropriate in evaluating the parameters a_1, a_2, a_3, and a_4. However, with either method, Eq 32 has to be rearranged into the standard form:

$$\eta = a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 X_4 \quad (37)$$

in which

$$X_1 = (t_2 - t_1)/Ht_2 \quad (38)$$

$$X_2 = X_1 G/A_g \quad (39)$$

$$X_3 = X_1 m_s/A_g \quad (40)$$

$$X_4 = X_3/A_g D^2 \quad (41)$$

The method of multiple linear regression, which can be found in many textbooks on Statistics (e.g. Walpole and Myers, 1972; Hoel, 1971), is adopted in this work. The input data of those physical factors described earlier are selected from the previous baseline survey which consists of thirty-six bucket-type stoves. All the calculations are done by an INTRA microcomputer; the program is written in BASIC. The correlation coefficient from the calculation with boiling time of 30 minutes is found to be very small, indicating the fluctuation of the data. This fluctuation is believed to be due to the fact that the stoves, obtained from thirty-six different locations throughout the country, have variable properties and composition which violates one of the assumptions.

Another reason for poor fitting can be due to some of the assumptions used in developing the model. For example, ε, which is the function of time and physical porperties of the stove, may have a severe effect on the stove behavior. This function is, however, difficult to obtain. The number of parameters in the model of the bucket stove, which is a complicated system, may not be sufficient; and some of the other effects such as the sensible heat excluded from the equation of efficiency may be required. But too many parameters obscure the effect of variables under investigation and can, in some situations, lessen the value of the model. Another violation of the assumptions is the nonuniformity of the wall thickness; the Thai bucket stove generally has its wall area thicker near the base than that near the top of the stove.

An alternative approach for the application of the model is to group the stoves that have similar effects, such as a group that would give a correlation coefficient greater than 90%. This is done with the INTRA microcomputer, the grouping is carried out randomly. The result from this analysis shows that the maximum of fifteen stove combinations would compromise the requirement. One of such groups is shown in Table 1 for which the correlation coefficient is 94%; the values of a_1, a_2, a_3, and a_4 are 653.8 cm, 5,717.01 cm^2, 26.23 cm^2/kg, and 5,282.13 cm^5/kg, respectively. This group is used in the next step; i.e. studying the performance of the stove when one of the variables is changed while others are kept constant.

C. MODEL APPLICATION

The model developed in the preceding sections is kept as simple as possible; it requires minimum knowledge of the stove characteristics. In this section, the simulation of the model is carried out to investigate the effect of each variable on the efficiency of the stove.

Prior to simulation, owing to the geometrical variation of the hand-made stoves sold in the Thai market, an ideal stove is required to represent the actual ones. The stove is simply idealized as being enclosed by two coaxial truncated cones as illustrated in Fig. 6.2; the stove thickness (i.e. the distance between the cones) is assumed uniform. When the concept of similar triangles is applied to the ideal stove (see Annex 3), the following relationships are obtained:

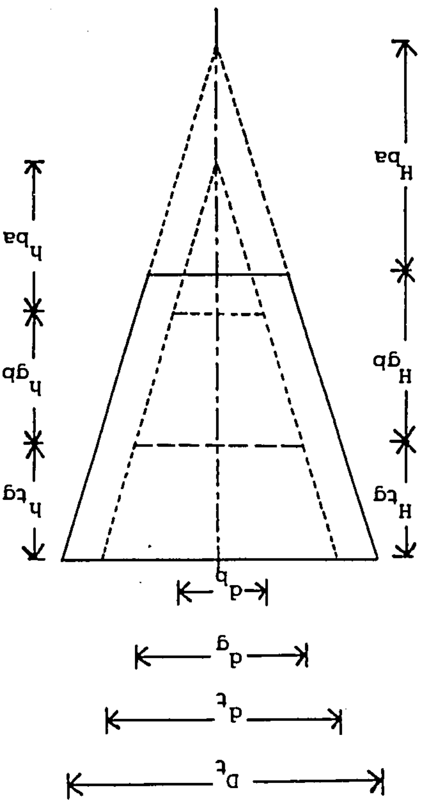


Fig. 6.2 Geometry of the ideal stove: the dimension of the outer and the inner cones are respectively symbolized by capital and small letters.

$$m_s = [\frac{\pi H}{12\ (D_t - D_g)} \{(D_t^3 - d_t^3) - (D_b^3 - d_b^3)\} - (A_e + A_1)D] \qquad (42)$$

$$D_t = d_t + 2D \qquad (43)$$

$$D_b = d_b + D - \frac{D(d_t - d_g)}{H} \qquad (44)$$

$$D_g = d_g + 2D \qquad (45)$$

in which D_t, d_t are the respective outside and inside diameters of the stove at the pot stand,

D_b, d_b are the respective outside and inside diameters of the stove at the bottom,

D_g, d_g are the respective outside and inside diameters of the stove at the grate position,

A_e is the gap area,

A_1 is the area of opening for the inlet air.

There are seven variables that completely fix the geometry of the stove; they are: the three inside diameters d_t, d_g, and d_b; the wall thickness D; the grate-to-pot distance G; the gap area A_e; and the area of the opening for the inlet air A_1 (the dimensions of D, H, A_e and A_i are shown in Fig. 61.). Among these seven varibles, A_e and A_i are not the variables in the model. Therefore, they have to be related to other variables. Fig. 6.3 and 6.4 illustrate the relationship between the air inlet area A_i and the grate hole area A_g, and between the gap area A_e and the gap height G, respectively. When straight lines are drawn through these points, it is found that $A_i = 0.82\ A_g$ and $A_e = 48\ G$. Substitution of these relationships in Eq (42) gives

$$m = [\frac{\pi H}{12(D_t - D_g)} \{(D_t^3 - d_t^3) - (D_b^3 - d_b^3)\} - (48G + 0.82A_g)D] \qquad (46)$$

The efficiency of the stove in Eq (32) also depends on the time t_1 required to heat the water to the boiling point. From Eq (27), the estimation of t_1 can be achieved if B_2 is known. This implies the necessity of evaluating B_2. There are two ways that the value of B_2 can be estimated: one way is to employ the relation in Eq (26), and the other is to utilize the available experimental data. The first method requires the values of the heat transfer coefficient h and the heat transfer area S; both values have to be estimated. To avoid such approximation of h and S, and in order to fully utilize the experimental results, the second method is chosen.

Substituting t and T_w in Eq (27) by t_1 and T_{boil}, and then rearranging it, one gets:

$$t_1 = -\frac{1}{B_2} \ln [1 - \frac{(T_{boil} - T_{amb})\ hSH}{\gamma(\alpha^* A_g - \beta G - \varepsilon m_s - \delta m_s/D^2)}] \qquad (47)$$

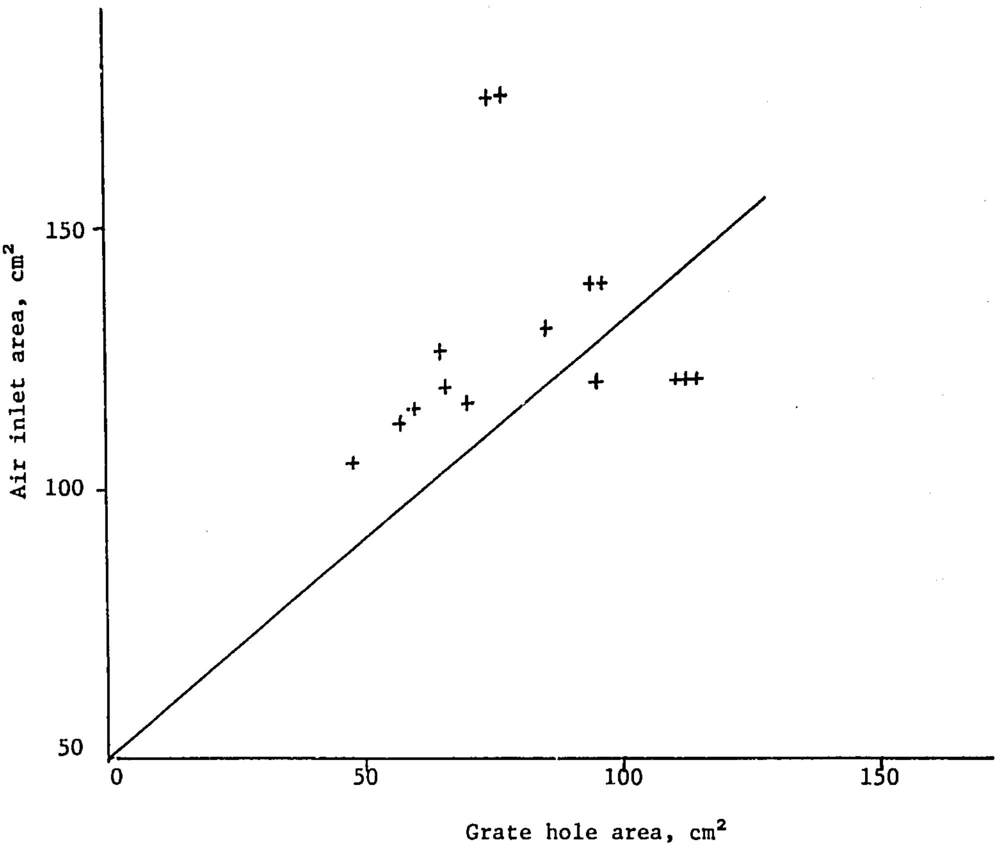


Fig. 6.3 Relationship between the area of the opening for inlet air and the grate hole area.

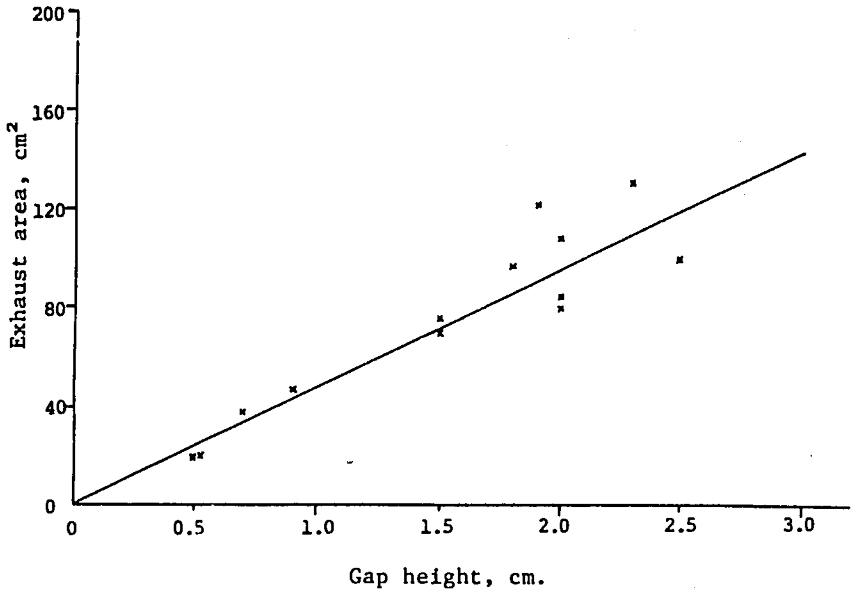


Fig. 6.4 Relationship between exhaust area and gap height.

With the relationships in Eq. (33) to (36) and the fact that $\alpha^* = \alpha\Delta H$, Eq (47) can be expressed as:

$$x = (1 - e^{-B_2 t_1})/\rho \qquad (48)$$

in which $x = H/(a_1 A_g - a_2 G - a_3 m_s - a_4 m_s/D^2)$ (49)

$$\rho = (T_{boil} - T_{amb}) hs/\alpha\ \Delta H \qquad (50)$$

Eq. (48) indicates that x increases from zero to $1/\rho$ as t_1 increases from zero to infinity. With the values of a_1, a_2, a_3, and a_4 obtained in the section of parameter evaluation, x can be calculated for each pot in Table 6.1 and then plotted against the heating time t_1. An exponential curve is drawn through the points as shown in Fig. 6.5; it appears to approach the value of $x = 3.5 \times 10^{-4}$ when t_1 approaches infinity. Hence, $1/\rho$ equals 3.5×10^{-4}. B_2, evaluated at t_1 of 18 minutes, is found to have the value of 0.07; this value, according to Eq. (26), implies that in the heating period, energy stored in the water is much greater than heat lost through the pot surface. Since the time to heat water is usually less than the boiling time, energy used in heating would be less than energy used in boiling. Consequently, the loss of heat through the pot surface, in the period of boiling, is much smaller than the energy consumed in evaporating water. Neglecting the heat loss in deriving the equation of efficiency is, therefore, approved and acceptable.

To estimate the mass of stove by Eq. (46), the density of the stove material, which is fired clay, is required. But, as the stoves tested in this work come from various places in Thailand, each stove would have been subject to particular and different treatment during the process of manufacture. This, of course, would cause a variation of density. Moreover, the stoves, after being tested, are still in good condition, so they are kept for further use. The density of the stove material, necessarily, has to be estimated from other clay products of similar make such as bricks. It is found that bricks have densities ranging from 103 to 128 lb/ft^3 (Perry and Chilton, 1973). As an illustration of model simulation, the density of the stove material is taken to be 110 lb/ft^3 or equivalent 1.76×10^{-3} kg/cm^3.

The following dimensions are chosen to represent the standard dimensions of the stove: H = 10 cm, D = 5 cm, G = 1.8 cm, d_g = 15 cm, d_t = 20 cm, d_b = 10 cm, and A_g = 80 cm^2. These values are in the range of the dimensions of the stoves investigated in the present work. The stove with this standard structure has the efficiency of 28.73% when boiling is kept for 30 minutes, the mass of 10 kg and the time to boil of 19.9 minutes.

With the above standard values of geometrical dimensions, and the values of the parameters previously obtained (i.e., a_1 = 653.8 cm, a_2 = 5,717.01 cm^2 a_3 = 36.23 cm^2/kg, a_4 = 5,282.13 cm^5/kg, and B_2 = 0.07), the simulation is carried out to study the effect of each variable on the efficiency, the mass of the stove, and the time to boil.

Table 6.1 Group of stoves that have similar behavior

Stove No.	Time to Boil (min)	Grate-to Pot Distance (cm)	Grate hole area (cm^2)	Gap Height (cm)	Stvoe Weight (kg)	Wall Thickness (cm)	Efficiency (%)
2	21.7	12	112	2	12.2	6.3	24.96
3	22.3	12	112	1.8	8.7	3.9	25.7
4	18.8	12.2	112	1.5	12.8	6.3	28.19
6	18	12	69	1	8.6	6	28.83
8	27	9	48	1.5	8.1	4.5	24.07
12	22.6	9	65	2	7.2	4.8	29.02
15	24.6	9	65	2	10	6	27.21
19	23.8	11	94	2.5	10.5	6.8	23.94
22	23.3	11	85	0.7	9.5	3.3	28.11
28	20.1	10	74	2.3	12.2	4.5	25.1
29	20	11.5	74	2	13.2	6	25.85
31	16.7	12	94	0.5	11.8	6	32.39
33	18.3	12	94	0.5	6.7	3.3	30.51
35	20	10	70	1.9	10	4	27.7
36	17	9.7	57	0.9	8	4.5	33.35

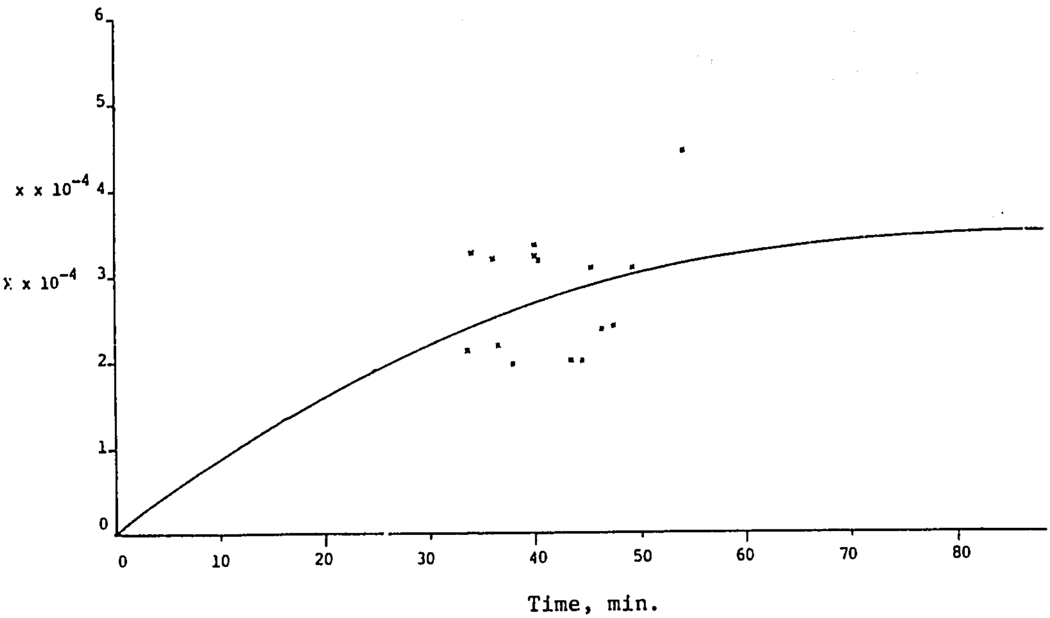


Fig. 6.5 Relationship between variable X, defined in Equation (49), and time to boil.
X....Experimental data; solid line.....fitted curve.

Effect of the grate-to-pot distance H

When the distance between the grate and the pot increases, the model predicts a rapid drop of efficiency, increases of stove material and time to boil Fig. 6.6. As previously mentioned, the decrease in efficiency (curve η) when H increases, can be explained with the concept of view factor. As H increase the view factor decreases, causing the reduction of radiative heat being intercepted by the pot from the flame; most of the heat is lost when the charcoal is very far from the pot. Since the rate of heat supplied to the water in the pot is reduced due to the increase of H, the water in the pot will require a longer time to reach the state of boiling (curve t_1).

Geometrically, any increase of the distance between the grate and the pot, while keeping other characteristics unchanged, results in a comparatively larger increase in the total height of the stove. This implies a bigger size of stove; consequently, more stove material is required as predicted by the model (curve m_s). The increase of the mass also affects the efficiency of the stove: more energy would be accumulated as heat in the stove material when the mass increases. Moreover, with the constant wall thickness, it means larger heat transfer area for the conduction; hence, more heat is lost to the environment. This effect, in addition to the effect of the reduction of view factor, further lessens the efficiency of the stove.

Fig. 6 gives another impression that the model is improper at low values of H where the efficiency appears very high. However, such a condition is not likely to happen in practicé, since a low H implicates a small combustion chamber, which, if too small, cannot hold sufficient charcoal to run the test. Hence, reality will set the limitation of the model.

Effect of the stove wall thickness D

As illustrated in Fig. 7, an increase of wall thickness, up to a certain value, tends to improve the performance of the stove (curve η). Further increase in the thickness causes a slight reduction of the efficiency. Heat loss due to conduction across the wall is high in the stove with thin walls. Increasing the thickness hinders the conductive heat transfer, but, at the same time, promotes the loss of energy to be stored in the wall material. These two phenomena work simultaneously and antagonistically. The initial increase in wall thickness in Fig. 1.7 indicates the reduction of conduction is greater than the increase in energy stored in the material. As the thickness is increased, the relative rate of heat conduction is lower than the rate of energy being accumulated, resulting in the drop in efficiency.

The choice of wall thickness not only helps improve the stove performance, but it will also help in saving raw material which, in this case, is clay. The increase in wall thickness means more clay is required in making the stove (curve m_s). An increase of the wall thickness from 2 to 10 cm causes the mass of the stove to increase from 5 kg to more than 45 kg: an increase of wall thickness by 5 times induces an increase of the mass by about 10 times. If the wall thickness is kept at 6 cm instead of at 10 cm, two stoves can be manufactured instead of one. Moreover, the two stoves with the thickness of 6 cm have higher efficiency of performance than the one stove with the thickness of 10 cm.

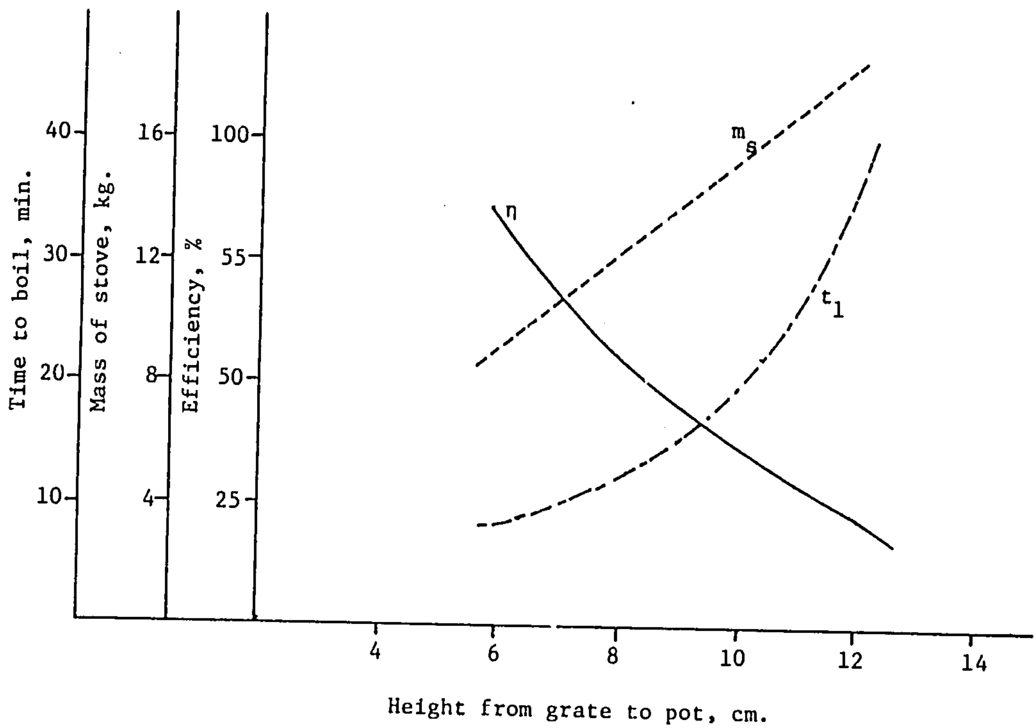


Fig. 6.6 Model prediction of the effect of grate-to-pot distance on the stove efficiency (η), stove mass (m_s), and time to boil (t_1).

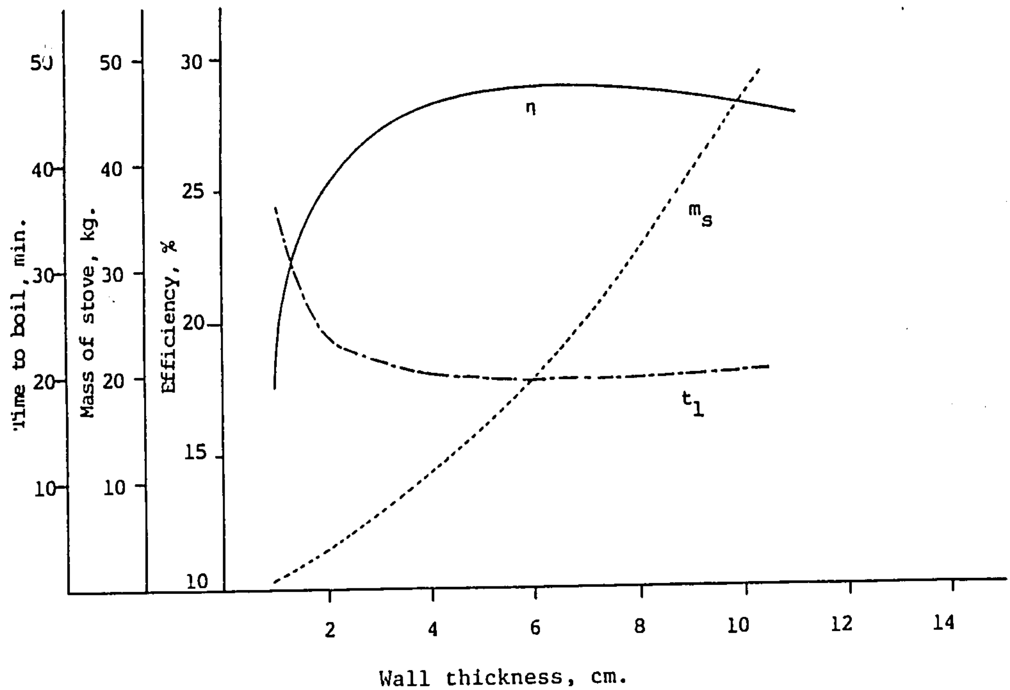


Fig. 6.7 Model prediction of the effect of wall thickness on the stove efficiency (η), stove mass (m_s), and time to boil (t_1).

Curve t_1 shows the change of time as the thickness of the wall changes. The increase of the thickness from 1 to 4 cm reduces the time to boil from 36 to 20 minutes. A slight increase of time to boil is seen when the wall thickness is larger than 6 cm. This behavior can be explained by the concept of antagonism between the heat conduction across the wall and the heat accumulated in the wall material as described before.

Effect of the inside diameter of stove at the bottom d_b

As the inside diameter of the stove at the bottom d_b increases, the model predicts only a slight increase in efficiency, a slight decrease in time to boil, and a reduction of stove mass (see Fig. 6.8). Geometrically, the change of only d_b will mainly affect the ashing compartment without having any effect on the combustion chamber, which is the major part of the stove supplying heat to the water. An increase in d_b reduces the ashing chamber and, consequently, the stove mass. When d_b increases from 7 to 15 cm, the stove weight decreases from 15.9 to 14.3 kg (curve m_s) - about 1% decrease in mass. The change of efficiency in this case is, conclusively, caused by the change in the amount of energy stored in the mass of stove.

Although the increase in the inside diameter of the stove at the bottom lessens the raw material, the choice should depend on the structural strength and the area of the opening for the inlet air.

Effect of inside diameter of the stove at the pot stand d_t

The model prediction of the effect of inside diameter of the stove at the stand d_t on the stove performance, the mass of stove, and the time required to increase the water temperature to its boiling point is illustrated in Fig. 6.9. When the inside diameter at the pot stand is slightly greater than the grate diameter (d_g = 15 cm), the efficiency is low (curve η), the mass of the stove (curve m_s) and the time to boil (curve t_1) are high; at this value of d_t, the distance between the bottom and the grate is very large, resulting in high requirement for raw material and, as a consequence high accumulation of energy in the stove material. The high loss of energy from the combustion due to the stove material causes the reduction of energy supplied to the stove; hence, the time required to boil is high. The increase in d_t will reduce the distance between the grate and the bottom, which simultaneously reduces the stove material. Consequently, less energy is stored in the stove material and the time required to boil is less.

Effect of Gap Height G

The model prediction in Fig. 6.10 indicates that as the gap height G increases, the efficiency η (curve η) decreases linearly at first and more rapidly at a later stage. The decrease of efficiency implies the increasing loss of energy carried out by exhaust gases due to the process of free convection. The larger the gap height, the larger the gap area, and the greater the loss of energy through convection. However, this loss is counteracted by the loss of energy accumulated in the mass of the stove, which decreases linearly wit' the increase of 6 (curve m_s). The rate of change of

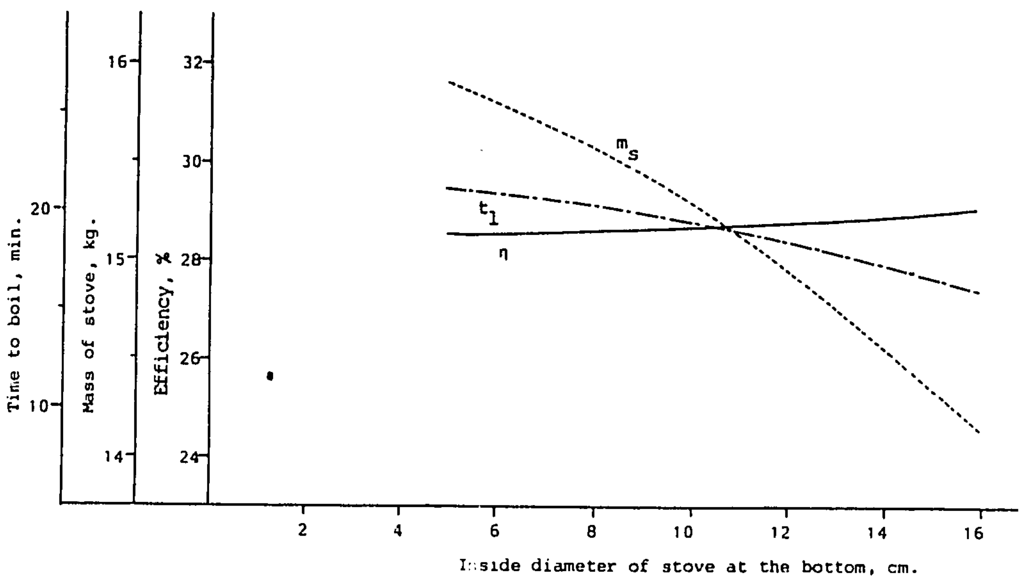


Fig. 6.8 Model prediction of the effect of inside diameter of stove at the bottom on the stove efficiency(η), stove mass (m_s), and time to boil (t_1).

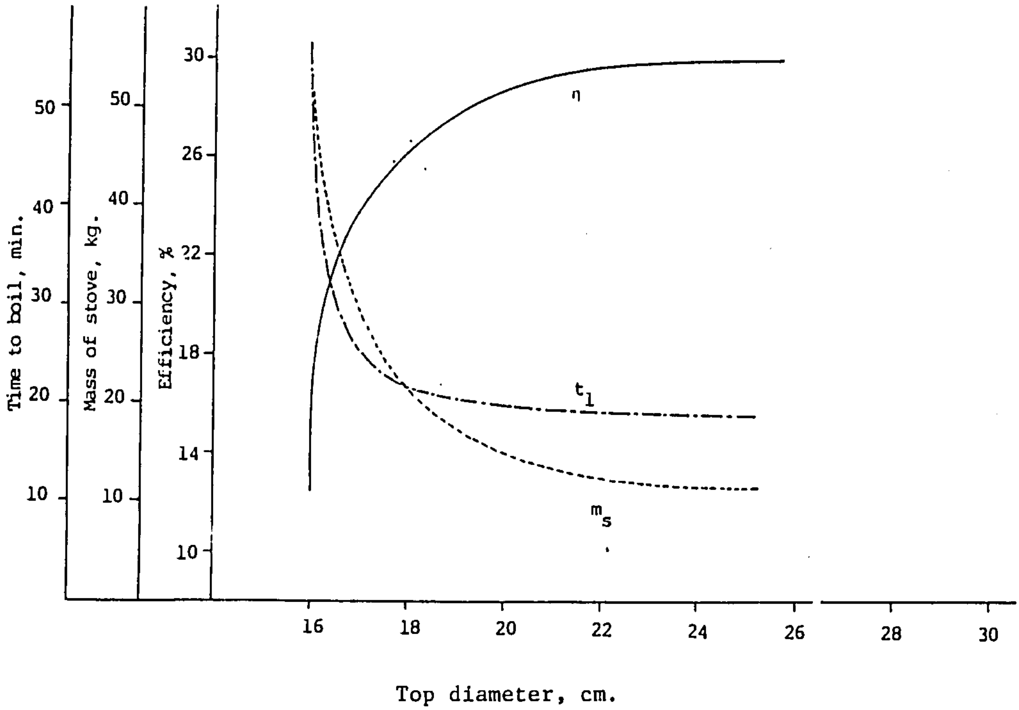


Fig. 6.9 Model prediction of the effect of inside diameter of stove at the pot stand on the stove efficiency (η), stove mass (m_s), and time to boil (t_1).

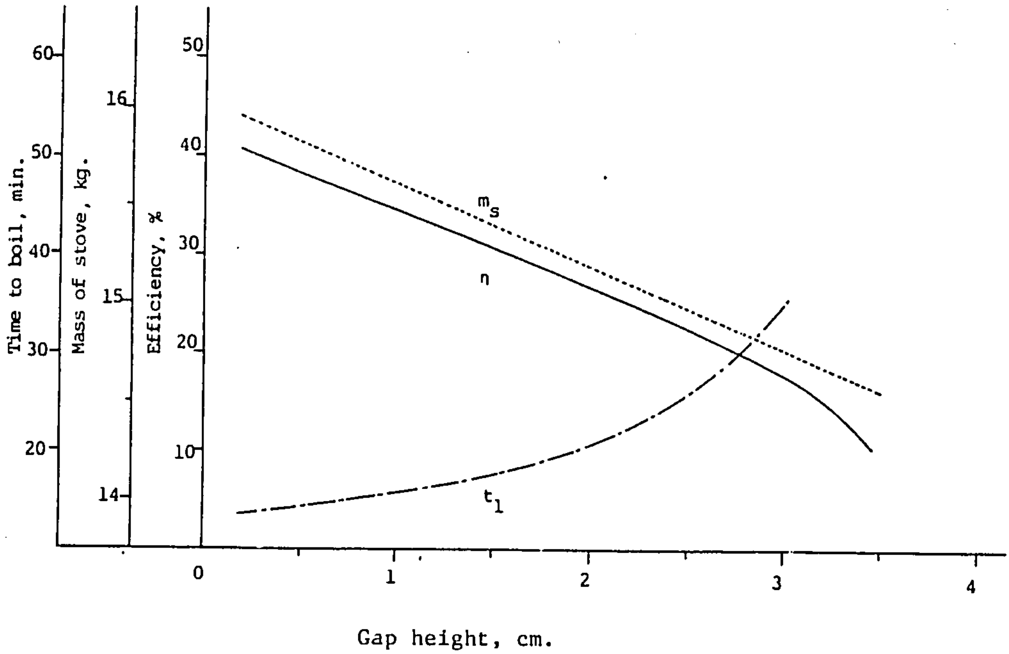


Fig. 6.10 Model prediction of the effect of gap height on the stove efficiency (η), stove mass (m_s), and time to boil (t_1).

these losses is relatively constant at small G; but at large G, the natural convection becomes dominant and causes the rapid drop of the efficiency. Since loss of energy increases when G is increasing, the time to boil under these conditions will increase with G (curve t_1).

Effect of grate diameter d_g

Fig. 6.11 illustrates the effect of grate diameter on the stove efficiency, stove mass, and time to boil. At the grate diameter of 10 cm, the efficiency is about 32% which is approximately 3% greater than the efficiency of the standard stove; the efficiency drops slowly from 32% to 28.7% when the grate diameter increases from 10 to 15 cm (curve η). As d_g is greater than 15 cm, the efficiency rapidly diminishes to 20% at d_g = 18 cm.

The change in efficiency can be explained in relation to the change in mass (curve m_s). When the value of d_g is 10 cm, the stove mass is small, about 18 kg. At this value of d_g the volume of the ashing compartment is very small, and in effect it represents a stove without an ashing compartment. This results in the fresh surrounding air coming into direct contact with the flame. The efficiency is improved not only by good combustion, but also by the reduction of energy stored in the stove material. Providing the area of the opening for the inlet air has no effect on the air supply to the flame, an increase in grate diameter will increase the size of the ashing chamber and consequently, the stove mass is increased. Energy accumulated in the stove material increases. Moreover, the increase in material causes the increase in heat transfer area, which promotes heat loss due to conduction through the wall. These effects reduce the efficiency of the stove and at the same time increase the time to boil (curve t_s).

Effect of grate hole area A_g

The grate hole area, according to the assumption in modelling, controls the rate of air supply to the combustion. An increase in grate hole area thus improves the air supply which results in better combustion and, as consequence, good performance of the stove (curve η in Fig. 6.12). The stove mass decreases as A_g increases. This reduces the energy stored in the stove material (curve m_s). Due to good heat supply to water, the time to boil decreases (curve t_1).

It should be noted that the grate hole area cannot be increased without limit. The grate diameter, and the strength of the grate are factors that will constrain the grate hole area. Since the diameter of the grate of standard stove is 15 cm, the maximum area provided by the grate is about 176 cm^2; the value of A_g greater than 176 cm^2 would be impractical. If the strength of the grate is considered, the grate hole area will be much less than 176 cm^2.

The comparative study, illustrated in this simulation, is based on the assumption that the flow rate of air depends only on the total area of grate holes; this, of course, implies that A_g increases because of the increase in the number of grate holes without altering the hole diameter. If the hole

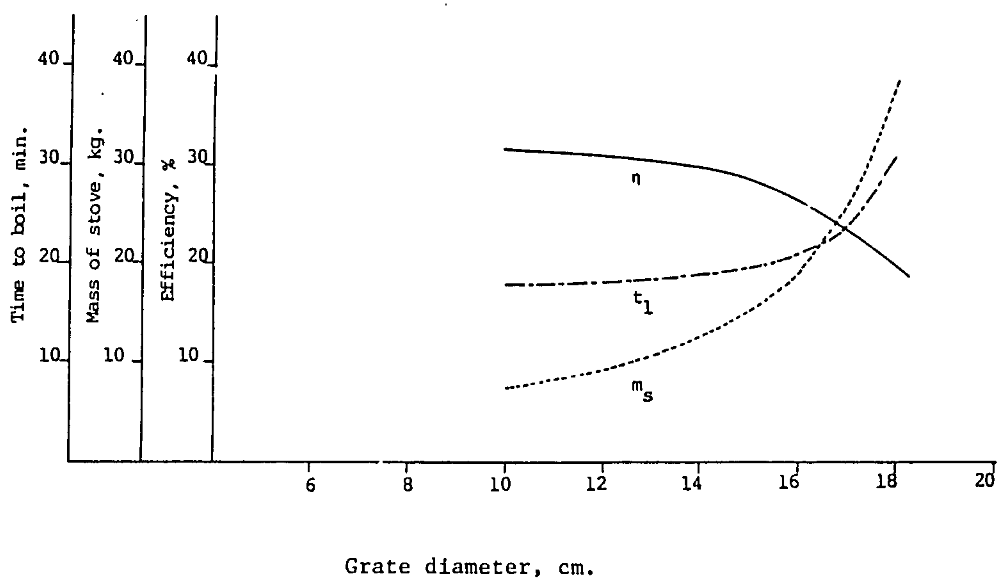


Fig. 6.11 Model prediction of the effect of grate diameter on the stove efficiency (η), stove mass (m_s), and time to boil (t_1).

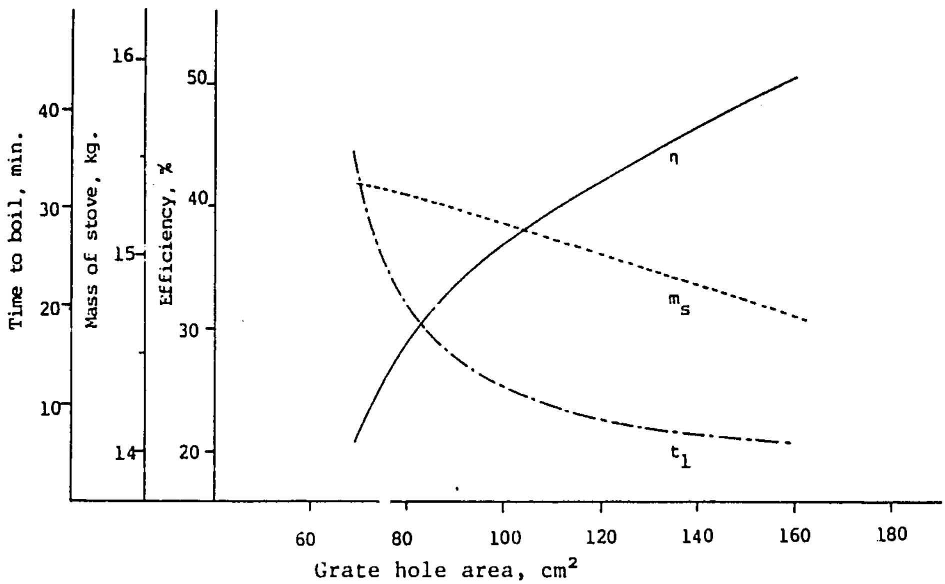


Fig. 6.12 Model prediction of the effect of grate hole area on the efficiency(η), stove mass (m_s), and time to boil (t_1).

diameter changes, the resistance of the hole to the air flow will be affected; the parameter in Eq (8), therefore, has different values at different hole $\propto$ diameters. This point should be noted in comparing any stove efficiency.

D. DISCUSSION AND EVALUATION

Many assumptions have been introduced in developing the model and the bucket stove in this section. These assumptions are proposed to simplify the mathematical complexity and to relate major factors that are studied experimentally. As a consequence, the model prediction deviates from observation under some experimental conditions. This preliminary model, in the future, will be modified to provide a more detailed explanation.

The process of combustion is very complex; the composition of the combustion products and the heat of combustion are strongly affected by the amount of air supplied to the stove. In the model, it is assumed that heat of combustion and the composition of the exhaust gas are not changed--regardless of any variation in air supply. This assumption is valid only when combustion is complete. Such complete combustion, however, in achieved only if sufficient air is provided to the stove. If air is undersupplied (which is caused by a small total grate hole area) heat of combustion is reduced and efficiency is also reduced. But if the grate hole area is too large, the air to oversupplied. Although the combustion is complete for this condition, a large amount of energy generated by the combustion is lost in increasing the temperature of the excess air. Consequently, a drop of efficiency is expected. As the model does not account for this effect, the predicted efficiency keeps on increasing with the grate hole area. A detailed study of the combustion mechanism in relation to the grate hole area is necessary for any modifications of the model.

In modelling the stove, the effect of the grate diameter on the view factor has been neglected. It has already been mentioned that the view factor between two circular discs with equal diameters varies with both the diameter and the distance between the discs. Since radiation is the major energy supply for cooking, the inclusion of the grate diameter into the equation for view factor estimation might stress the importance of the grate diameter on the efficiency.

Another point that needs to be considered in improving the model is the energy required to increase the water temperature to its boiling point. The present model assumes that the time to boil is small and hence not much energy would be utilized in this process. However, the model predicts that the time to boil in some cases is large, indicating that a massive amount of energy has been consumed. For example, if the time to boil and the boiling time are 20 and 30 minutes, respectively, providing that the rate of heat supply from the combustion is constant and heat loss is small, then the ratio of heat used in heating up water and in boiling is 2 to 3. With a long time to boil, it is important to include heat consumed in increasing the water temperature when efficiency is being calculated.

Although the present model is based on many assumptions, it can shed light on the understanding of interactions among the stove characteristics that influence stove performance. This model should give some basic idea of how the stove would perform. For example, the model predicts that the grate-to-pot distance, which contributes the major part of efficiency, strongly affects the performance of the stove. If it is large, the efficiency decreases, but if it is small, the stove will perform better. However, result from the experiment show that this is not exactly true: the performance becomes poor when the grate-to-pot distance is smaller than a certain value. This is mainly due to radiative loss through the gaps.

The thickness of the stove wall also strongly affects stove performance. If the wall is too thick, the efficiency is reduced. The same effect is predicted if the wall is too thin. The stove will exhibit the best performance at a particular value of thickness.

With a large grate hole area, the stove performs better than that with a small grate hole area. This is due to the assumption that air flows into the stove at constant velocity; hence, the volume or mass flow rate of air is proportional to the grate hole area. The model, however, neglects to take into account the insulation effect of the grate. A large grate hole area implies a high loss of radiative heat from the combustion chamber to the ash chamber. As a consequence, a stove with a grate hole area larger than a certain value could perform poorly. The insulation effect of the grate should be considered in the model improvement.

Conclusions

The model, although based on many assumptions, can give us an understanding of the interactions of stove geometry on the performance. The dependence of stove efficiency on the grate-to-pot distance can be explained in terms of radiative heat obtained by the pot. Increasing gap height causes a poor stove performance, indicated by the model as the result of high convective heat loss through the gap. Conductive heat loss, predicted by the model, is severe in the case of insufficient thickness of the stove wall; the stove would perform better if wall thickness is increased. However, if the wall is too thick, the model indicates that a large amount of heat is stored in the stove material, resulting in a drop in stove efficiency.

As already discussed, the model can be modified to yield better predictions. The modifications should be performed according to the recommendations in the previous section.

Chapter 7

Stove Models Developed

STOVE MODELS DEVELOPED

This chapter presents the results of improvement of five generic types of biomass household cooking stoves.

Based on commercial stove testing and analysis of results, experience gained during stove collections, stove construction and modifications in the laboratory, and numerous contacts with stove users and manufacturers, the general requirement for the improved cooking stove concept, particularly within Thailand, can be stated as follows:

a) That the improved stove shall be designed to accommodate as many various sizes and shapes of pots and pans as possible.

b) That the improved stove shall reduce the time duration of cooking or at least keep it constant. No stove with prolonged cooking time can be accepted, no matter how fuel efficient it may be.

c) That the improved stove shall be made to have longer service life or durability.

d) That the improved stove's portability, and construction with a single pothole, are desirable components.

e) That the improved stove shall consume less fuel or at least equal amounts to the existing good models.

f) That the improved stove operation shall be conducted with ease and safety, including the stove's ignition, frequency of attendance, heat output control, refueling and fire extinguishing.

Development then strictly followed such requirements. The design, testing and production of improved prototypes have yielded hardwares whose features and performances are presented in following sections.

A. IMPROVED STOVE'S TERMINOLOGY

In previous chapters, numerous discussions were made in reference to various stove terms. In order to avoid misunderstanding and to promote future stove development and standardization, drawings illustrating terminology are presented in Fig. 7.1 to 7.5. The five types are the charcoal stove, wood stove without chimney, wood stove with chimney, rice husk stove without chimney, and rice husk stove with chimney. All stoves, however, are of the single pothole type as desired by most Thai users.

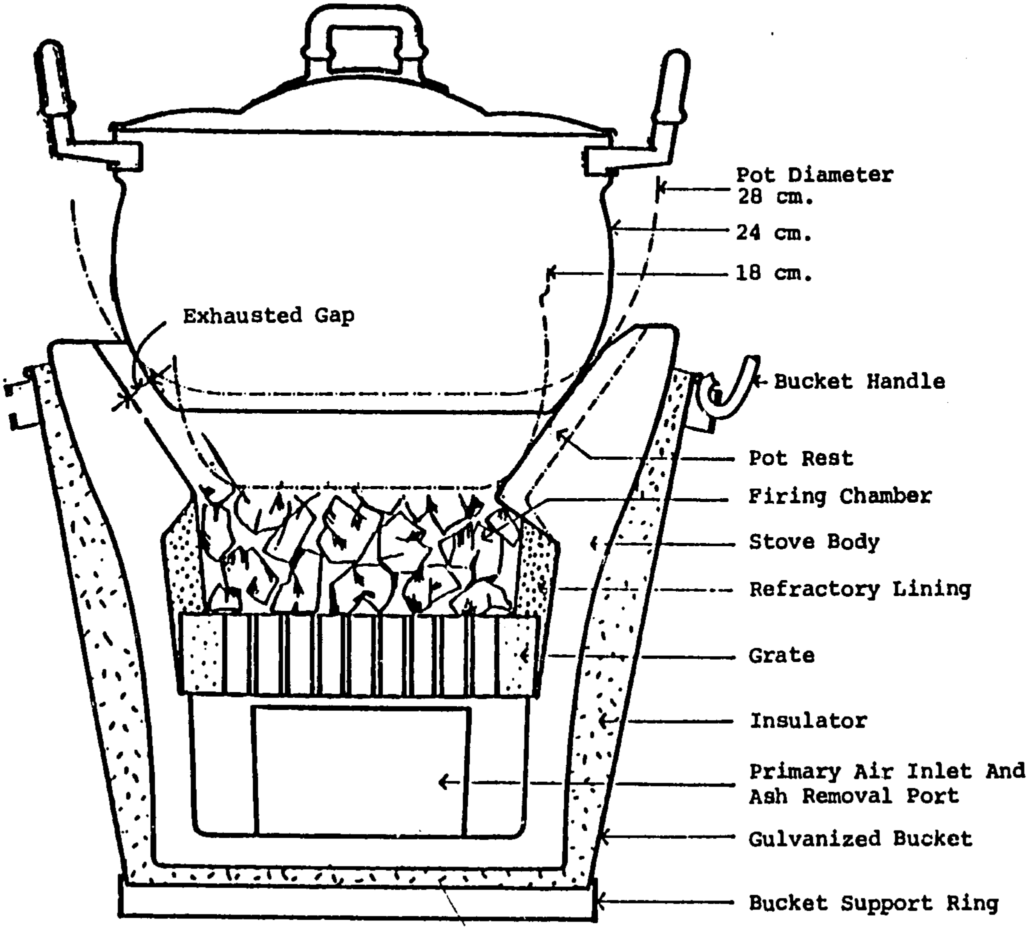


Figure 7.1 Drawing of improved charcoal bucket stove showing various parts of the construction and terminology.

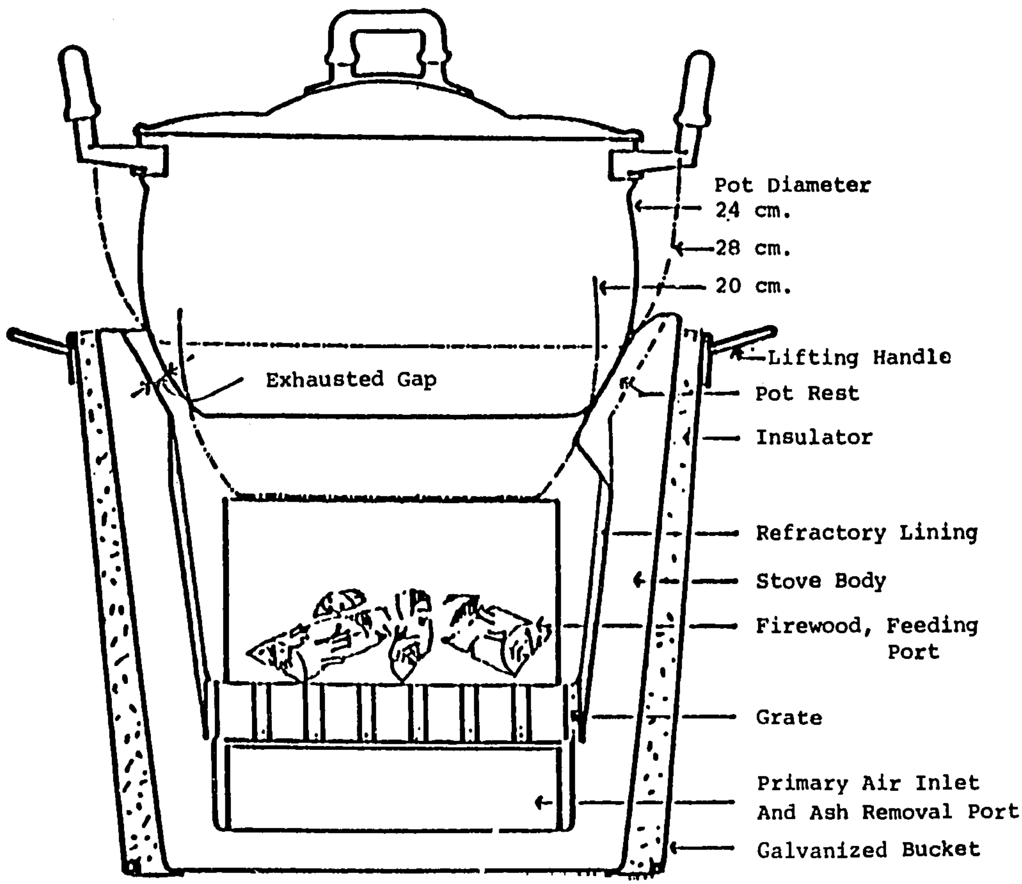


Figure 7.2 Drawing of improved nonchimneyed wood stove showing parts of the construction and terminology.

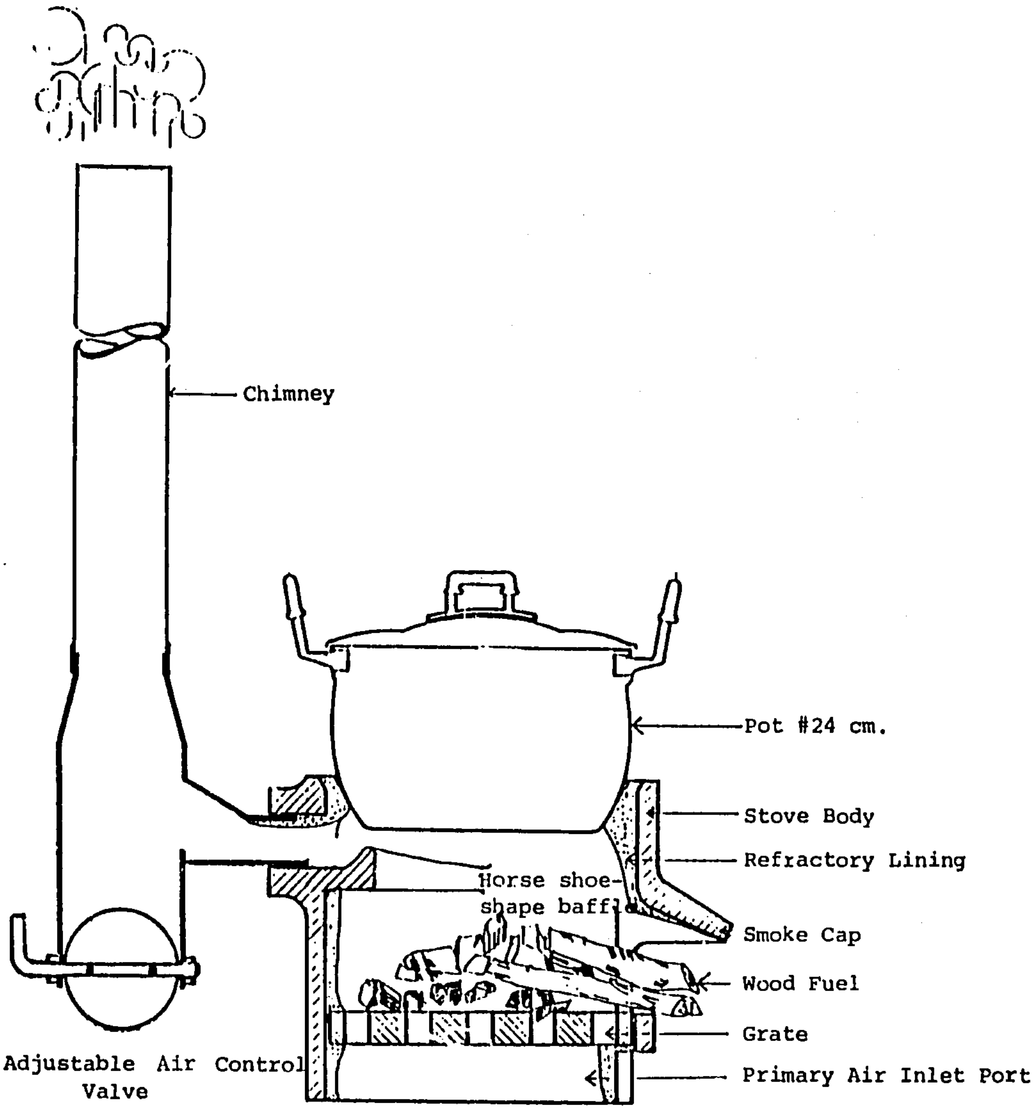


Figure 7.3 Drawing of developed chimneyed wood stove prototype showing the construction and terminology.

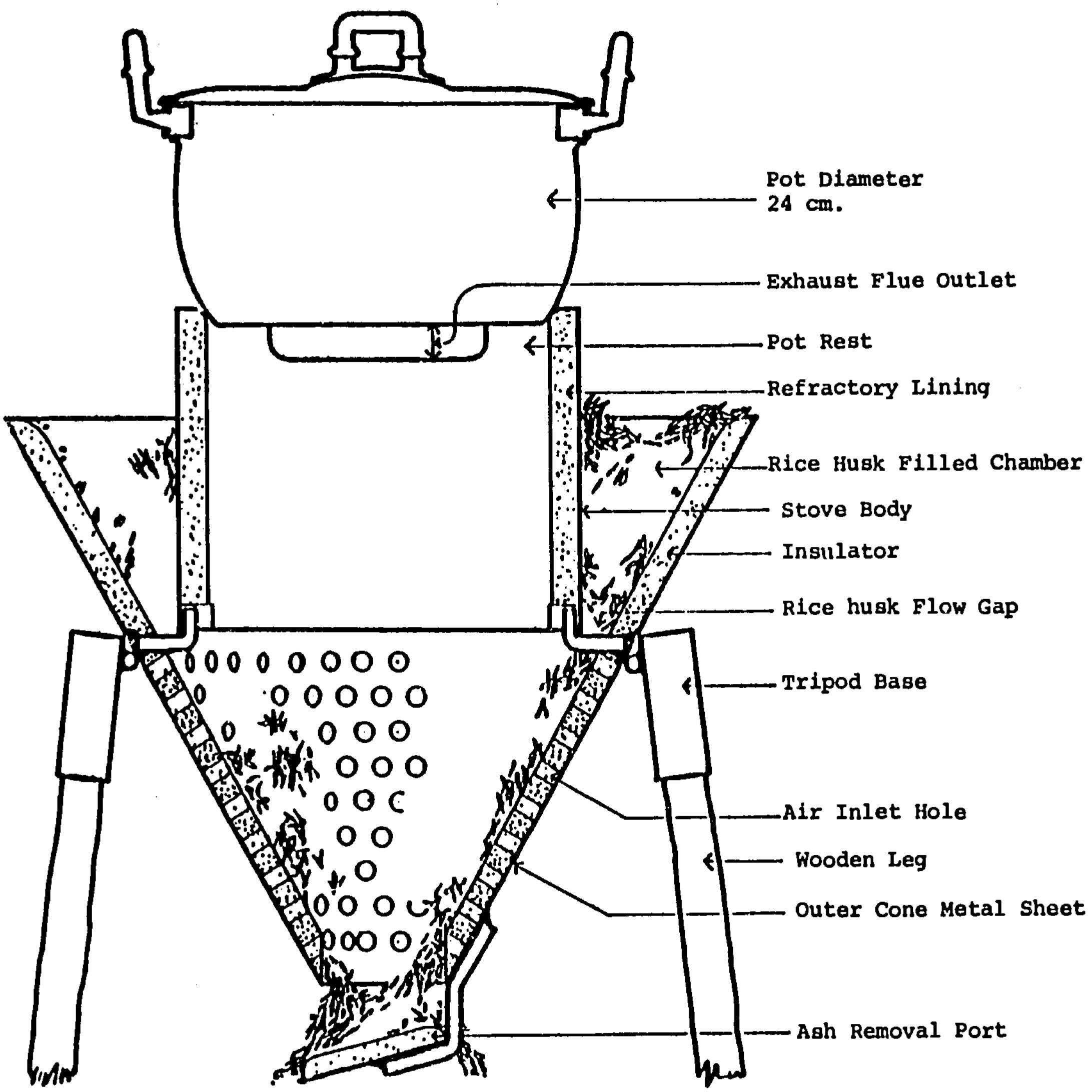


Figure 7.4 Drawing of improved nonchimneyed rice husk stove showing the construction and terminology.

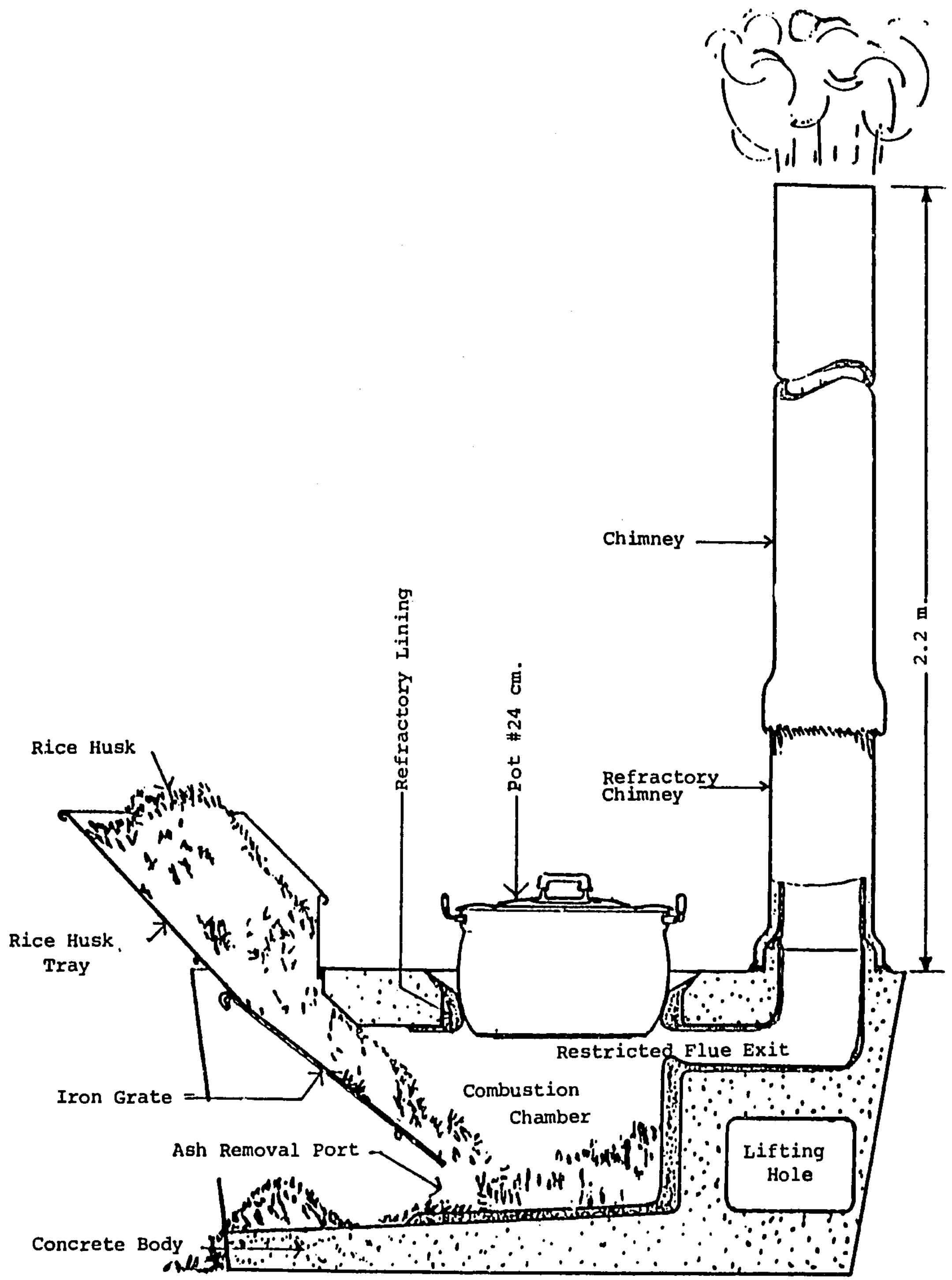


Figure 7.5 Drawing of improved chimneyed rice husk stove showing the construction and terminology.

B. IMPROVED CHARCOAL STOVE MODEL RFD-1

The physical dimensions and characteristics of the latest improved charcoal stove called "RFD-1" can be described as follows:

a)	Stove weight, fired-clay body only	5.9	kg.
	fully fabricated (with bucket included)	10.1	kg.
b)	Stove height (no bucket)	25.0	cm.
c)	Top diameter (no bucket), outside	30.0	cm.
	inside	26.5	cm.
d)	Bottom diameter (no bucket), outside	19.0	cm.
	inside	16.0	cm.
e)	Vertical height from grate top to stove rim	15.0	cm.
f)	Vertical height of the pot rest portion	6.5	cm.
g)	Pots accommodation, pot diameter	16-32	cm.
h)	Firing chamber capacity after refractory lining,		
	normal full charcoal load	1,240	cm^3
	extra charcoal load for large cooking	2,000	cm^3
i)	Grate, diameter	17.5	cm.
	thickness	4.0	cm.
	weight	0.7	kg.
	hole diameter (taper up)	1.2-1.4	cm.
	number of hole	61	
	hole area	94	cm^2
	hole area/grate area	39	%
j)	Average thickness of inside refractory lining	1.0	cm.
k)	Exhausted gap (for flue gas outlet)	1.0	cm.
l)	Air inlet port, 5 x 11 cm.	55	cm^2
m)	Average stove wall thickness (including insulation and bucket	5.2	cm^2
n)	Bucket weight	1.1	kg.

The relationship of physical characteristics to external variables such as pot size, charcoal load, pot position relative to the top rim is shown in Table 7.1.

Table 7.1 Physical characteristics of RFD-1 charcoal stove relating to external variables

Pot Ø cm	Grate-to-pot distance, cm	Charcoal load* gm	Charcoal top layer-to-pot distance, cm	Exhausted area, cm^2	Pot position relative to the stove rim, cm
16	7	250	2	43.5	-7.0
18	7.5	310	2	45.7	-6.3
20	9	390	3	48.0	-5.5
22	10	440	3	52.0	-4.3
24	11	480	3	58.5	-3.2
26	12	550	3	62.0	-2.2
28	13	690	3	67.5	-1.0
30	14	740	4	75.5	+0.6
32	15	770	5	75.5	+1.0

* the load based on high density mangrove charcoal prepared to the average size of 5 cm in length and 2 cm in cross-sectional width.

Test results of developed charcoal stove (RFD-1) are shown in Table 7.2.

Table 7.2 Average test results of RFD-1 charcoal stove under different use conditions*

Pot Ø cm	No. of test	Charcoal load, gm	Initial water wt gm	Charcoal remained gm	Average burning rate gm/min	Time to boil	HU %
16	3	130	1,180	16.7	2.4	17	21.6
20	6	240	2,190	34.0	4.2	19.5	25.4
24	3	400	3,700	50.0	7.4	17.3	32.1
28	3	640	5,920	90.0	10.6	22	34.2
32	3	800	7,400	93.3	12.6	26	30.2

* In this test, the ratio of charcoal load to initial water weight was kept constant at 1:9.25 based on standard tests where 400 gm of charcoal and 3,700 gm of water were used. The water occupies approx. 3/4 of the pot capacity. Test durations are 30 minutes plus time to boil, all starting from a cold stove.

From Table 7.2 the heat utilization efficiency is lowest when a very small load of charcoal (130 gm) is used. This should be expected because a large percentage of heat from charcoal input is absorbed by the stoves but even with such a small charcoal fuel, 1.18 liters of water can be brought to boil in 17 minutes. The HU begins to peak when operating the stove at 400-640 gm charcoal, with a 24 - 28 cm pot diameter, and the amount of water between 3,700 - 5,900 gm. This particular range of operation represents the conditions used in cooking by most rural Thai families. Time to boil achieved by this stove based on standard comparison tests (pot #24, water 3,700 gm, charcoal 400 gm) is 17.3 minutes which is equal to the best top-line model in the market, as previously shown in Table 5.6. In those tests, the time to boil of existing commercial bucket stoves ranged from 16.7 - 32.0 minutes and averaged 22.8 minutes.

Regarding the stove durability, the RFD-1 improved model is considered superior to all commercial models since the fired clay body is made of refractory material which can withstand thermal shock without cracking much better than commercial models. For details of improved charcoal stove production please refer to Chapter 8.

Recalling the six criteria of user's requirements stated earlier, it can be concluded with a high degree of confidence that the RFD-1 improved model has met all those requirements.

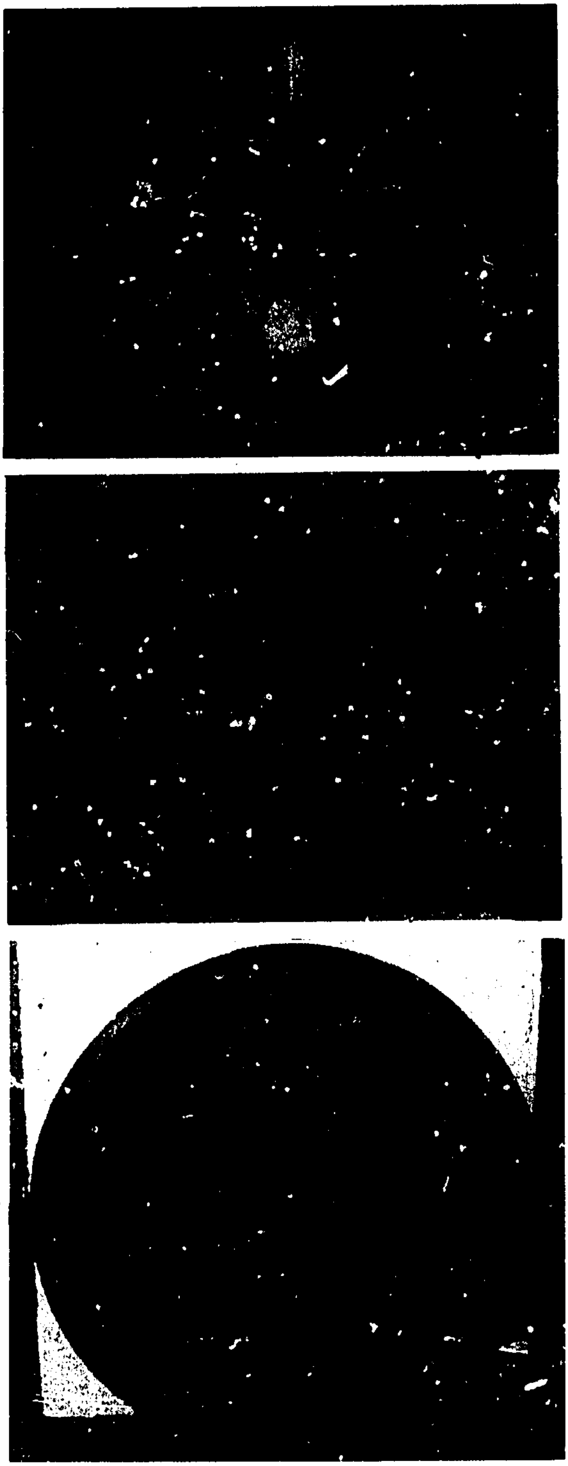
Fig. 7.6 and 7.7 are photo-illustrations of the sample stove made from actual production by a group of retrained local stove makers in Roi-et Province.

C. IMPROVED NON-CHIMNEYED WOOD STOVE MODEL RFD-2

This nonchimneyed wood stove, model RFD-2, has the designed purpose of overcoming weaknesses in physical features of commercial wood bucket stoves, particularly its too wide exhausted gap, too small combustion chamber, too restricted firewood feeding port, and poor stove rim design to fit pots and pans properly. Besides, the improved design is intended to replace the three-stone stoves which are ranked second in popularity among rural Thai users.

After a long process of attempting to make a dual purpose stove both for charcoal and wood, test results have indicated that such a stove would greatly compromise on charcoal fuel used and would make the operation more difficult when using firewood. This conclusion, therefore, has led to the development of a separate wood burning stove and charcoal burning stove.

The improved nonchimneyed wood stove model RFD-2 was previously illustrated in Fig. 7.2. Its physical dimensions and characteristics can be described as follows:

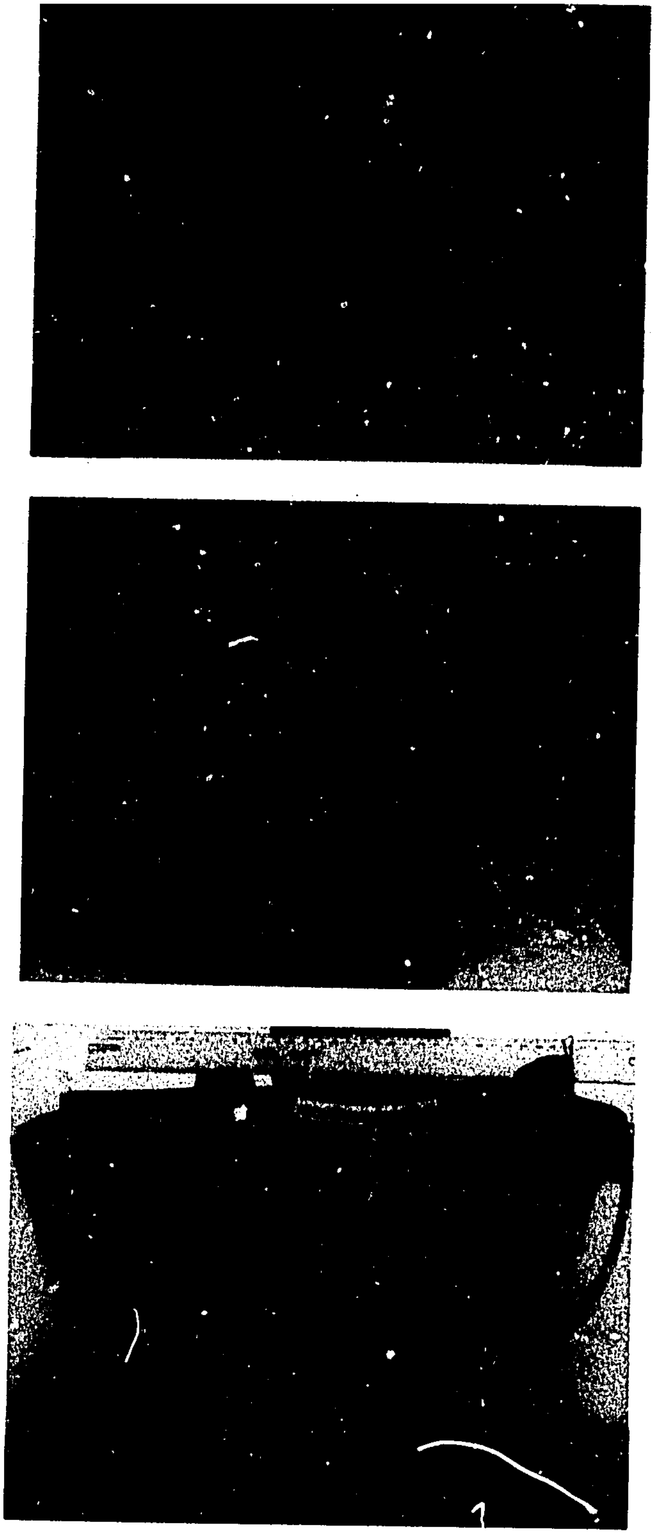


(a)

(b)

(c)

Figure 7.6. Improved charcoal stove model"RFD-1"showing : (a) fire-resistant body,(b) with grate and door and (c) inside of fabricated stove.



(a)

(b)

(c)

Figure 7.7 Improved charcoal stove model"RFD-1"showing : (a) stove external ready for use, (b) and (c) sectional views showing different pa s of construction.

a)	Stove weight, fired clay body only	6.9	kg.
	fully fabricated	9.8	kg.
b)	Stove height	23.5	cm.
c)	Top diameter, outside	28.0	cm.
	inside	24.0	cm.
d)	Bottom diameter, outside	25.0	cm.
	inside	21.0	cm.
e)	Vertical height from grate top to stove rim	13.5	cm.
f)	Pots accommodation, pot diameter	18-32	cm.
g)	Firing chamber capacity	3,040	cm^3.
h)	Grate, diameter	21.0	cm.
	thickness	3.0	cm.
	weight	0.9	cm.
	hole diameter	1.6	cm.
	number of holes	37	
	hole area	60	cm^2.
	hole area/grate area	21	%
i)	Exhausted gap (for smoke outlet)	1.0	cm.
j)	Average stove wall thickness, body only	2.0	cm.
	with insulation and bucket	5.3	cm.
k)	Primary air inlet port (4 x 12.5 cm)	50	cm^2.
l)	Firewood feeding port (9 x 12.5 cm)	100	cm^2.

Test of the performance of the RFD-2 stove conducted in the laboratory (based on standard testing method as described in Chapter 4) are as shown in Table 7.3.

Table 7.3 Test results of improved non-chimneyed wood stove model RFD-2 with bucket.

Test run no.	Firewood used, gm	Charcoal produced at end of test, gm	Average fuel burning rate gm/min	Time to boil min	HU%
515	820	20	18.2	15	27.4
516	810	20	18.0	15	28.8
517	750	20	17.4	15	28.1
601	780	30	17.0	16	28.7
604	790	25	18.4	13	28.9
606	740	30	18.1	11	30.4
average	781.7	24.0	17.9	14.2	28.7

From the above Table, the heat utilization efficiency of RFD-2 is considered high when compared with all commercial model test results (previously presented in Table 5.7 and in Fig. 5.3 where the HU ranged from 14.2 - 25.9% and averaged 19.8%). The time to boil of the RFD-2 seems to fluctuate somewhat; the average feeding rate for each run is almost the same (17 - 18 gm/min). This reflects the intrinsic characteristic of wood stoves where duplications of actual feeding are difficult. At any rate, the average time to boil of 14.2 min for this stove is very satisfactory when considering the burning rate figure. The RFD-2 consumed firewood only 17.9 gm/min while that of commercial models ranged from 22.6 - 35.4 gm/min and averaged 28.4 gm/min (See Table 5.7). This means that the RFD-2 model would save approximately 59% of firewood over those commercial models on the average, while maintaining the same average time to boil (14 minutes).

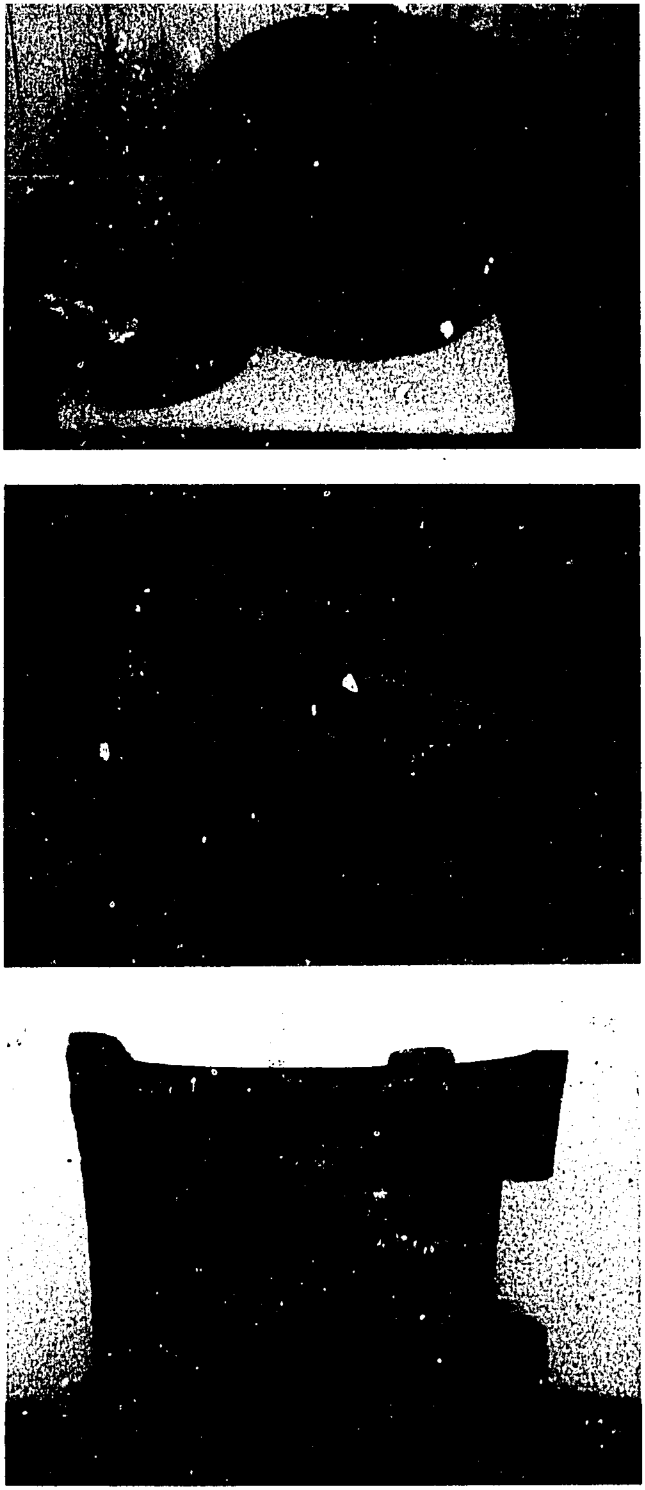
Figs. 7.8 and 7.9 show the RFD-2 stove from the actual production by a group of retrained local stove makers in Roi-et Province. Since the heat released from burning wood inside the combustion chamber is not so intense as in the case of the charcoal stove, the RFD-2 model can be produced either with or without a bucket and insulation restraint outside. This option shall be decided by consumers according to their ability to pay, preference for a neat appearance, together with ease of cleaning. The performance of RFD-2 of both options is the same within 45 min of operation under the standard test.

D. IMPROVED CHIMNEYED WOOD STOVE

The second type of wood stove developed is the chimneyed wood stove. However, only three commercial models exist with one pothole as discussed in Chapter 5 and illustrated in Annex III. Even though the stove is not popular and finds very limited use in rural Thailand, it could compete with the charcoal stove in certain applications if it could be developed to attain the efficiency level of up to 20 - 25%. Recalling that heat utilization efficiency (HU) of the improved charcoal stove is 32% and the maximum efficiency in conversion of wood to charcoal is 60% (see report of charcoal improvement component), the absolute efficiency of the charcoal stove as calculated directly from wood raw material, therefore, is equal to 19.2%.

The development of the one pothole chimneyed wood stove has faced problems; namely, a) fitting of various sizes of pots and pans is not possible b) directing the flame toward the pots' bottom and around their side wall is very difficult. Too much draft and improper baffling will direct most of the flame toward the flue gas exit hole. On the other hand, too weak a draft and too restricted a baffling will cause the smoke to come out from the firewood feeding port.

A compromise was made on the above problems. Designs and various modifications were then made and tested. The prototype selected is shown in Fig. 7.3 and 7.10. Physical dimensions and characteristics are as follows:

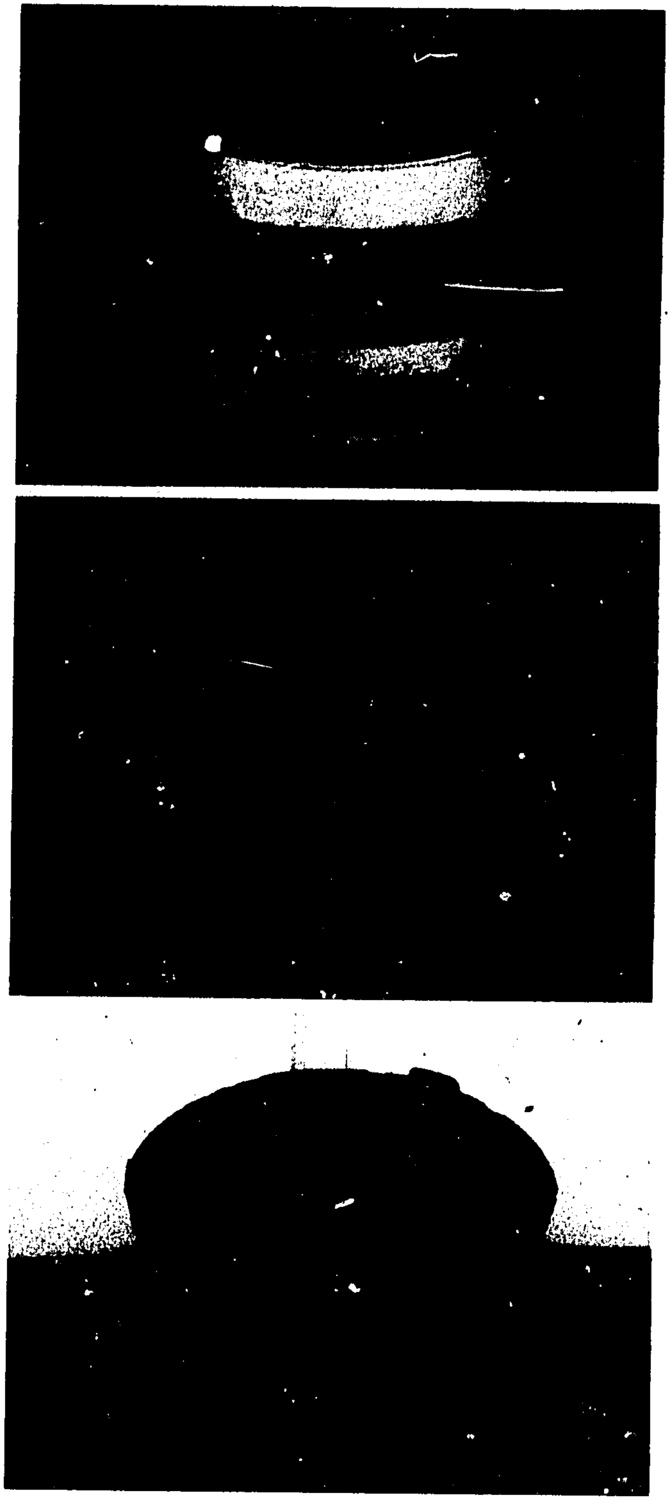


(a)

(b)

(c)

Figure 7.8 Improved nonchimneyed wood stove model"RFD-2"
(a) fire-resistant body with grate (b) fabricated model without bucket and (c) Sectional view showing parts of construction.



(a)

(b)

(c)

Figure 7.9 Improved nonchimneyed wood stove model"RFD-2"showing : (a) and (b) fire resistant stove fabricated model with bucket (c) sectional view showing parts of construction.

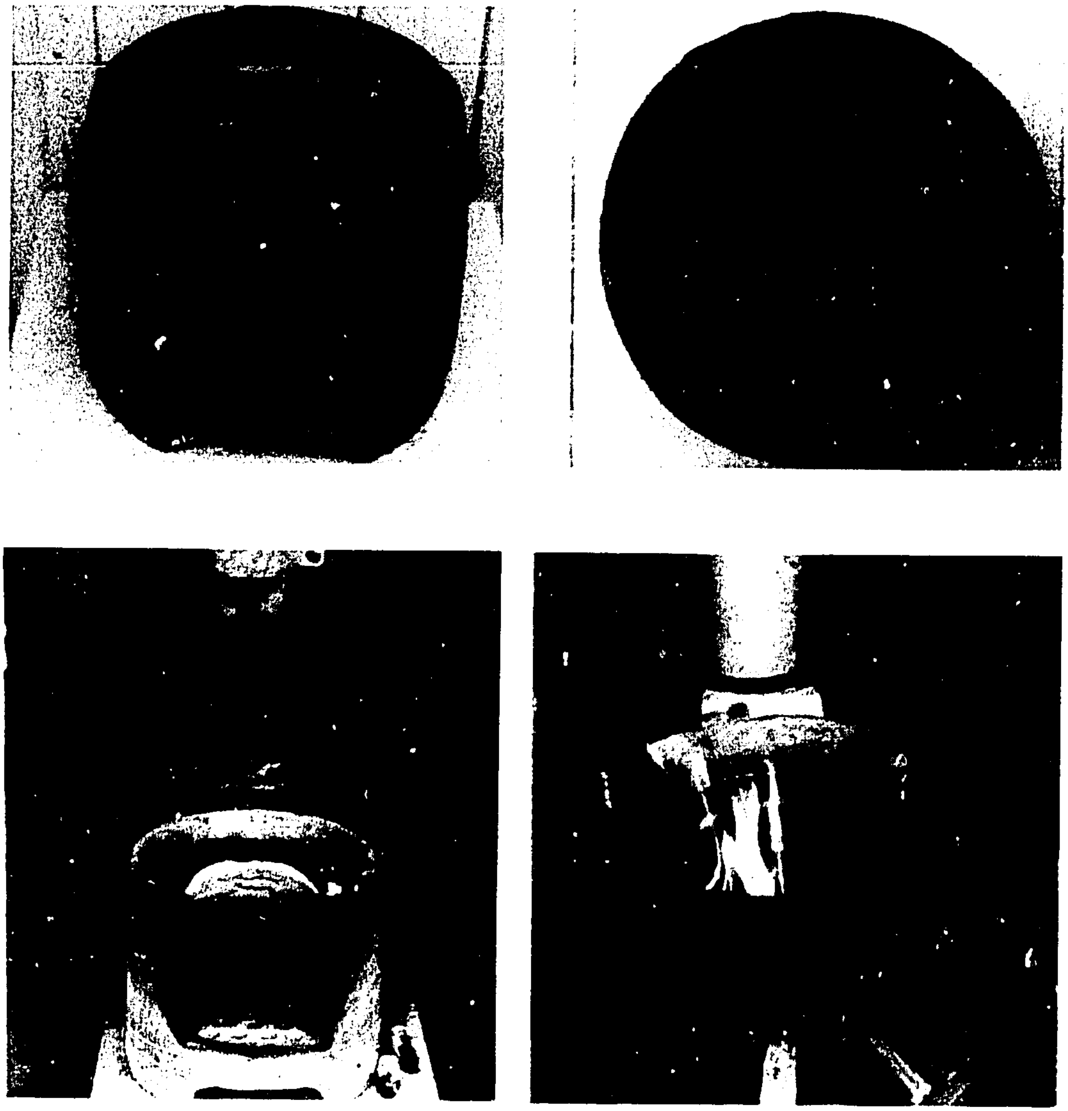


Figure 7.10 Prototype of developed chimneyed wood stove showing different parts of construction.

a)	Stove weight	7.9	kg.
b)	Stove height	23	cm.
c)	Pot hole diameter (fit best only one size)	24	cm.
d)	Firing chamber capacity	4,400	cm^3
e)	Grate, diameter	23	cm.
	hole diameter	2	cm.
	number of holes	38	
	hole area	60	cm^2
f)	Grate-to-pot distance (pot #24)	13.5	cm.
g)	Average stove wall thickness	3.5	cm.
h)	Primary air port	50	cm^2
i)	Firewood feeding port (8 x 15 cm.)	120	cm^2
j)	Flue gas outlet hole (4 x 10 cm.)	44	cm^2
k)	Baffle, half-ringed length	30	cm.
	flue gas trough, height x width	3 x 1.5	cm.
l)	Chimney, diameter	10	cm.
	height	2.2	m.

m) Adjustable external damper at lower end of chimney below the flue gas exit hole level.

Test results of an improved chimneyed wood stove prototype are shown in Table 7.4.

Table 7.4 Performance of the prototype improved chimneyed wood stove

Run no.	Firewood use, gm	Charcoal produced at end of test, gm	Average fuel burning rate, gm/min	Time to boil min	HU%
494	1,025	25	20.1	21	19.6
495	970	40	19.4	20	18.5
496	950	20	18.6	21	18.5
499	1,080	20	21.6	20	19.0
503	1,130	20	21.3	23	17.3
505	1,110	30	21.8	21	21.8
average	1,044	25.8	20.6	21	19.1

Test results from Table 7.4 indicate that HU increased by approximately 4.6% over the average existing models shown in Table 5.8, (that is, from 14.5 to 19.1%). Time to boil increased from 17.7 to 21 minutes on the average. The major contribution of this prototype is that the firewood use is considerably less than the commercial models; i.e. 1,044 gm versus 1,583 gm or 34% less on the average.

Since the original aim was to raise the efficiency of this chimneyed wood stove to 20 - 25% while maintaining at least the same time to boil, this prototype stove still has not met with requirements. Therefore, this stove should receive more improvement in the future before trial promotion or commission of the production.

E. IMPROVED NON-CHIMNEYED RICE HUSK STOVE

The nonchimneyed rice husk stove from Khao-I-Dang refugee camp (also called the "Meechai stove") is quite unique in its design and operating efficiency. Therefore, only a little improvement and modification need to be done. Possible modifications include the material of construction, air inlet hole size and number, the inner cylinder height and exhausted flue gas area, and the outer cone insulation. The final design has the following features:

a)	Outer cone, mild steel gauge	0.70	mm.
	upper diameter	45	cm.
	lower diameter	10	cm.
	cone angle	60	deg.
	vertical height	30.5	cm.
b)	Air inlet hole, diameter	0.9	cm.
	number of holes	274	
c)	Inner cylinder, diameter	21	cm.
	height	19	cm.
	exhausted area 3(3 x 13 cm)	117	cm^2
d)	Fuel flow, gap	2	cm.
	gap area	163	cm^2
f)	Outer cone insulation thickness	0.5	cm.

This improved model has the heat utilization efficiency of 19 - 20% and a time to boil of 11 - 13 minutes under standard tests. Rice husk used for one test (approximately 40 - 45 min operation) is 1.7 - 1.8 kg at 10 - 13% moisture content. The insulation of the outside cone with rice husk ash-clay mixture, even though offering only 1 - 2% increase in HU over the uninsulated one, has greatly helped in keeping the cone metal from repeated extreme heat exposure and rust. In so doing, however, the flow friction (the husk on clay mixture surface) is also increased. To correct it, the rice husk ash-clay mixture insulating surface must be made as smooth as possible to avoid rice husk sticking at the flow gap. Future development to smooth this surface should be tried, particularly with cheap glazing material such as a salt solution. The operation of this stove is only suitable for a well-ventilated area such as around the yard. A container to receive hot rice husk ash from the ash port is necessary. In case of windy conditions, the stove will not operate well unless a shield is improvised.

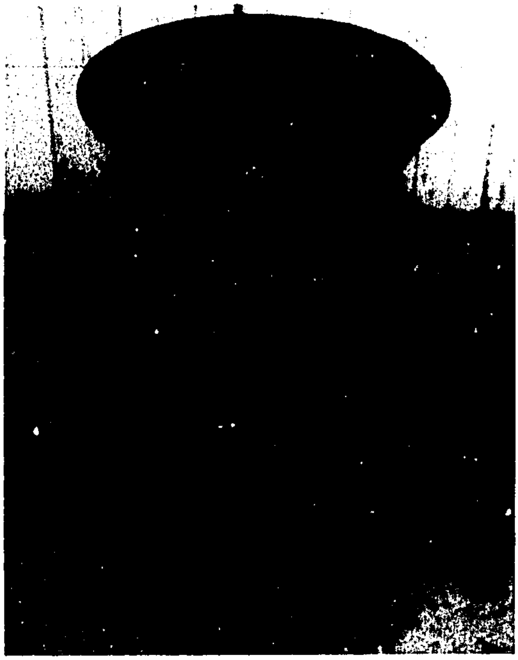
Fig. 7.11 shows part of construction and operation of this stove.

F. IMPROVED CHIMNEYED RICE HUSK STOVE MODEL "RFD-3"

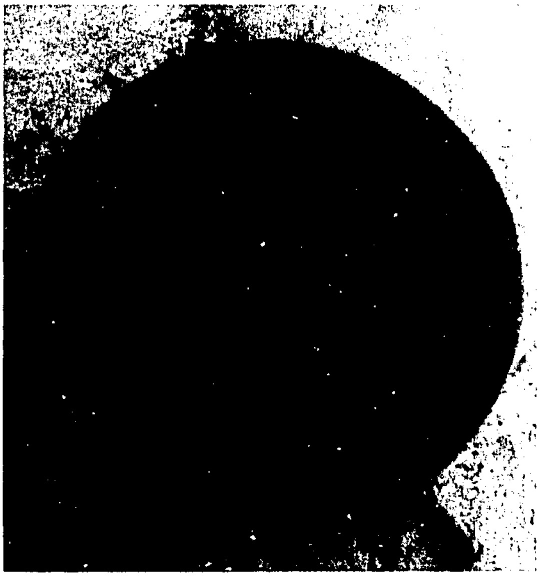
The design of the RFD-3 chimneyed rice husk (and other residues of similar form) stove has the purpose of correcting the following weaknesses of commercial models: a) stove and chimney cracking because of an intense heat and flame generated in both cement and fired-clay constructions, b) poor conversion efficiency due to lack of baffling, too large flue gas exit hole and too far a distance from combustion zone to the pot bottom, c) too large a pot hole diameter so that the common family pot size (#22 - 36) cannot be used, d) weight of models (most are too heavy to be moved by two persons), and e) frequency of fire attendance during operations of some fuel efficient models.

The development of the RFD-3 model has resulted in the design of physical structures and characteristics as follows:

a)	Stove weight, stove body only	68	kg.
	with insulation	75	kg.
b)	Stove height	33	cm.
c)	Pot hole diameter, no insulation	28	cm.
d)	Pot accommodation (only one size of pot has to be decided by users prior to insulation lining of the stove)	22-32	cm.
e)	Firing chamber capacity, no insulation	14,800	cm^3
	with insulation for 24 cm pot	10,000	cm^3
f)	Iron grate, slope	43	deg.
	rod diameter	6	mm.
	finished length	36	cm.
g)	Air inlet area	450	cm^2
h)	Ash removal port	60	cm^2
i)	Flue gas exit hole uninsulated	50	cm^2
	insulated	32	cm^2
j)	Base to pot distance for pot #24	19	cm.



a



b

c

Figure 7.11

Nonchimneyed rice husk stove, the "Improved Meechai" model showing: a) an insulated outside cone sitting on the steel ring with three wooden legs, the inside cylinder with three exhausted gaps for flue gas exit, and the ash removal port at bottom of the cone, b) the stove's top view before flue loading and c) the stove during operation.

Previous Page Blank

k) Average insulation thickness 1.2 cm.

l) Chimney, inside diameter 10 cm.
total height 220-240 cm.
length of refractory bottom portion 50 cm.

Tests of the performance of the RFD-3 model (based on the standard method previously described) are as shown in Table 7.5.

Table 7.5 Test results of improved chimneyed rice husk stove model RFD-3

Run no.	Rice husk use, gm	Average burning rate, gm/min	Time to boil min	HU %	Remarks
142	2,830	61.5	16	10.0	Operated at the
143	2,930	65.1	15	10.5	chimney height
146	3,300	68.8	18	9.4	of 220 cm.
151	3,310	66.2	20	11.6	
152	3,330	62.8	23	10.7	
average	3,140	64.9	18.4	10.4	

From Table 7.5 the heat utilization efficiency of the RFD-3 reached an average of 10.4%. This increase was quite considerable when compared with the original commercial models in Table 5.9 (where HU was only 4.2 - 7.1%). The time to boil for commercial stoves without any modifications ranged from 18.5 - 27.0 minutes and averaged 22.4 minutes. The RFD-3 performance in this respect (average 18.4 min) is quite satisfactory. The fuel consumption of the commercial models ranging from 65.6 - 160.7 gm/min (with a mean of 108.0 gm/min) was considerably higher than the RFD-3 stove which consumes only 64.9 gm/min.

Regarding the stove cracking problem, the inside insulation lining using an inexpensive rice husk ash-clay mixture has proven to be very effective and also serves the purpose of fitting a particular size of pot to the stove well. This insulation application (including some repairs later) should be done by users, however.

The reception of the chimneyed rice husk stove in certain areas of Central and Northeastern Thailand is, at present, quite good though still not as popular as charcoal and wood stoves. Based on trial promotions, many groups of village people seem to accept the RFD-3 readily and claim that its construction cost of 200 baht (excluding the chimney) is much cheaper than the price of commercial models.

Fig. 7.12 shows the RFD-3 improved chimneyed rice husk stove from actual production by one rice husk stove manufacturer at Rangsit, Phatumtani Province.

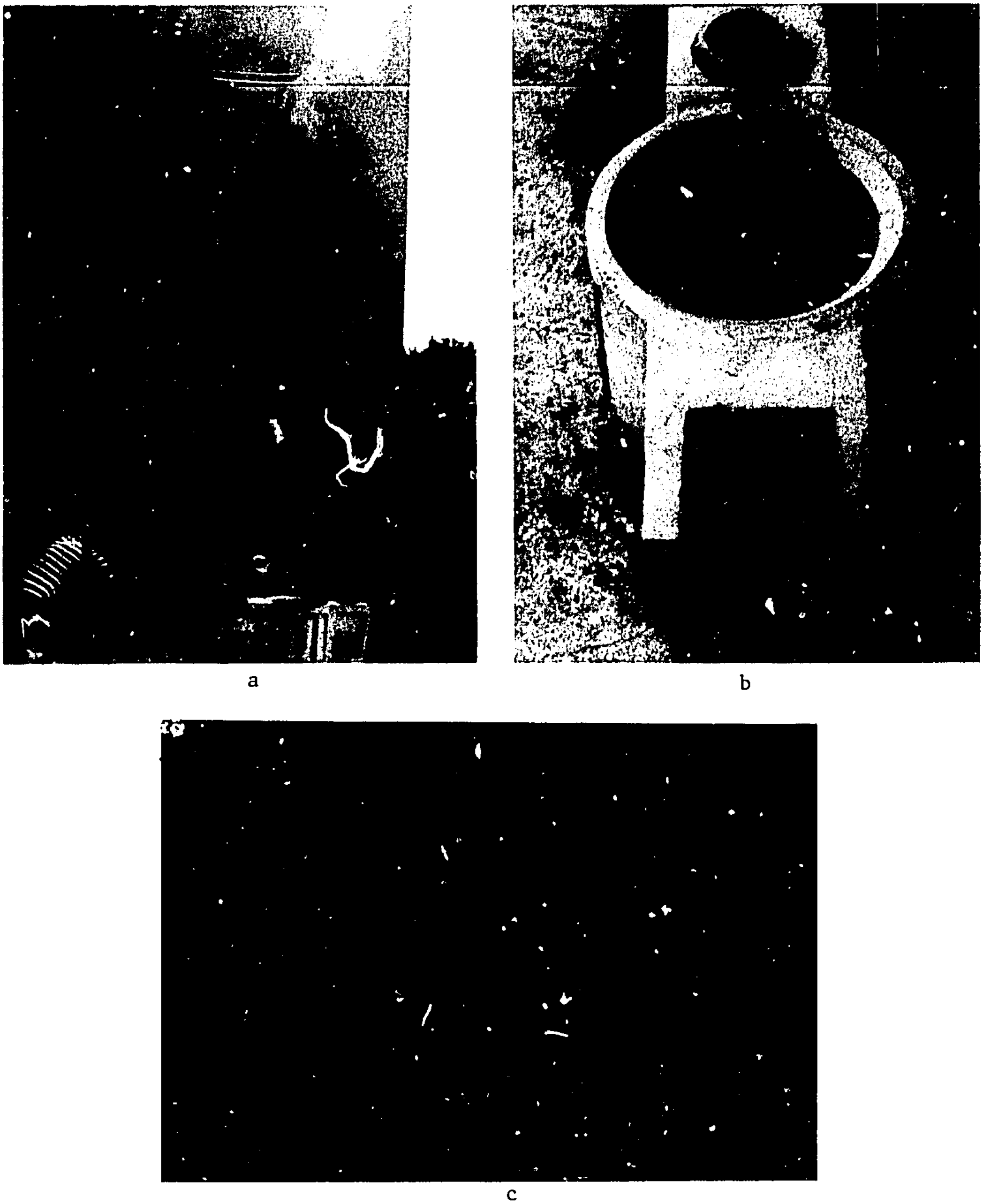


Figure 7.12 Improved rice husk stove with chimney, the "RFD-3" model: a) an example of installation during a demonstration with inside insulation for 24 cm pot diameter, two portions of chimney, a refractory at bottom and an ordinary drain pipe at top; b) cement cast body with uninsulated firing chamber, flue gas exit hole and tunnel, sloping iron-grate and ash removal port under; c) side view with sleeves and hole to reduce its weight.

Chapter 8

Improved Stove Designs and Production

IMPROVED STOVE DESIGNS AND PRODUCTION

The design and construction of a cooking stove are critical. Factors that influence stove performance must be fully recognized. In producing a stove, therefore, the technical drawings, the construction instructions and the methods for mass production should be closely followed.

A. TECHNICAL DRAWINGS OF IMPROVED STOVES

Figs. 8.1 - 8.4 are the drawings of the 4 improved stove models developed within the framework of this study. They are the charcoal bucket stove, the non-chimney wood stove, the non-chimney rice husk stove, and the chimney rice husk stove.

B. CONSTRUCTION INSTRUCTIONS

In producing efficient cooking stoves (which will be used daily for at least 1,000 hours a year) long-term service and durability must be taken into account. In order to construct such a stove, the clay body must be chosen carefully, formed properly and dried and fired under the correct conditions. Further, the grate, the bucket, and the insulation must be fabricated and put together correctly. And, finally, the stove must be inspected for quality control at various stages in its production.

Clay Material for Pottery Lined Stoves

A refractory clay body must be used for cooking stove production since the operating temperature (particularly of the charcoal stove) can reach 1,000 - 1,200 °C. The project investigated a number of clay bodies and found a refractory clay body very suitable for charcoal and wood stove production in the Panomprai district, province of Roi-et. Local artisans have been using this kind of clay for limited wood stove production for at least one generation. The dark brown sedimentary clay from the central lowlands that is widely used for stove and pottery production is unfortunately not refractory. A stove made from this kind of material will normally crack the first or second time it is used because of thermal shock. Further operation will cause further degradation. Refractory clay bodies require a high alumina content as well as some amount of iron oxide to facilitate a lower firing temperature. Silica, a major component of the clay body that gives strength to the final fired-product, must also be present in the proper proportion to the alumina & iron oxide. Weight loss after firing indicates the presence of organic or humus matter in the clay body. (The humus matter creates the porosity necessary in the final product that improves the stove's insulating properties and makes it light weight.) However, too much organic matter will greatly reduce plasticity and the handling strength of the wet clay during forming. Table 8.1 shows compositions and fire-resistant properties of some local clay materials used for stove and pottery manufacturing.

Clay Preparation

Since the project mainly used clay for improved stove production from the source at Roi-et, the following discussion covers only this clay type; however, the information is applicable to the preparation of clay for making stoves in other situations, given that a properly refractory clay body has been found.

The dried clay raw material was soaked with water in a pit and left standing for at least 12 hours. After 12 hours the wet clay was separated into two parts ($\frac{2}{3}$ and $\frac{1}{3}$). Two-thirds would be used later as a main mix. One-third was further mixed with an equal volume of fresh rice husk and hand formed into biscuits. After air drying, these biscuits were open fired with fuelwood for 6-12 hours until all pieces were evenly baked. The baked biscuits were pounded into small granules (with the bigger size not more than 1 mm in diameter). The prepared substance (or so-called "caking powder") was added to the main mix (two-thirds of the original clay) previously set aside. These two components were then mixed as thoroughly as possible with enough water added to ensure that the wet clay mixture would retain its shape during forming and/or throwing.

Forming the Stove from Wet Clay

In practice, forming a stove from clay is carried out using three different methods as follows:

Using of potter's wheel and external mold

Using a potter's wheel with an external mold is the most popular method used in bucket stove making, particularly in Central Thailand in areas such as Rajaburi, Nakorn Pathom, Pathumthani, and Chachoengsao. The clay is quite soft and can be formed easily on the potter's wheel with an external mold acting as a restraint shell. This method, at present, gives the highest production rate but yields poor accuracy of the critical inside dimensions of the stove. Therefore, it is not a suitable method for improved stove production.

Using of wooden spatter and hand forming

The wooden spatter and hand forming method is still practiced by Panomprai stove makers. By hand, the potters form the hard clay into the shape of the stove desired. Thereafter, a wooden spatter is used for beating around the outer surface to ensure final integrity and strength. This method is considered a very poor method for commercial production since the production rate is low and there is poor control of the stove's dimensions.

Table 8.1

Compositions and fired resistant property of some local clay materials used for stove and pottery productions

Clay source and/or mixture	Major clay composition %					Fire resistance °C
	Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	Others	
1. Panomprai Roi-et, an original raw material sample	9.8	61.5	24.5	2.4	1.8	1632
2. Panomprai Roi-et, a final mixture sample prior to throwing	8.6	61.7	23.8	2.6	3.3	1621
3. Banmor Mahasarakarm, a river bed sample	6.2	77.4	11.9	2.0	2.5	1501
4. Pakred Nondhaburi, a dark brown central lowland sample	8.9	59.0	19.2	6.9	6.0	na
5. Pakplee Prachinburi, a white clay or kaolin sample	12.3	56.1	25.9	3.0	2.7	na

Source: Clay samples no. 1-3 were analyzed and tested by Department of Science Service, Ministry of Science Technology and Energy.

Data on compositions of clay samples no. 4 and 5 were obtained from Industrial Service Division, Department of Industrial Promotion, Ministry of Industry.

Using the internal mold in cooperation with a potter's wheel and spatter

Using an internal mold, a potter's wheel and spatter was a method developed by project personnel as a combined technique to improve the above two methods and control the stove's internal dimensions, integrity, and provide a reasonable production rate. A detailed production process is shown in the following photographs (Figs. 8.5 - 8.8). After the Pranomprai stove makers were trained briefly in this production method, the production rate, precision and stove quality greatly improved. Using this technique more than 3,500 charcoal and wood pottery liner stoves were produced in three months (for the project's initial dissemination) employing four molds and eight workers from four families.

Stove Drying

Stoves newly formed from wet clay require shaded air drying for several days (approximately 3 - 5 days in the dry season and 10 - 12 days in the rainy season). During this drying stage, the clay stove form will shrink. Therefore, care should be taken to ensure uniform and gradual drying to avoid stove distortion and/or cracking. When the clay stove form has become "leather hard" it can be placed in the sun for a final 1 - 2 days of drying.

Stove Firing

After stoves have been properly dried in both stages, a quality check must be performed. Stoves with severe defects such as cracking, distortion, and dimension discrepancies (due to excessive shrinkage) will be rejected. (The clay can be re-wet for reuse as raw material in another batch.) Firing of stoves is carried out in an old-fashioned manner. Local stove makers employ an open-firing technique. Open-firing requires that a level ground area of 8 - 10 sq meters be laid with dried rice straw approximaterly 3 - 4 cm thick. Dried firewood sticks (approximately diameter 3 - 4 cm) are placed horizontally as the first layer on the straw bed. Then the second layer of firewood (slightly larger in size, approximately 5 - 10 cm) is horizontally stacked on top, with the length perpendicular to each other. Altogether, 3 - 5 layers of firewood are required to make the pile approximately 40 cm high. The amount of firewood required for this size of a pile is 700-800 kg (at 12 - 15% wood moisture content). This pile will accommodate 100 stoves per firing.

Stoves to be fired are carefully placed on the firewood pile as close to each other as possible in one single layer. The rice straw around the pile is then ignited. After the first layer of firewood starts catching fire, the operator will throw rice straw on top and around the pile. As the straw keeps on burning it will release heat and provide insulation to the top and sides of the stove pile. The firewood inside will continue burning for approximately 2 - 4 hours. Then the pile will be left alone for self curing and cooling for 12 - 15 hours more. Stoves are normally unloaded from the pile the following day.

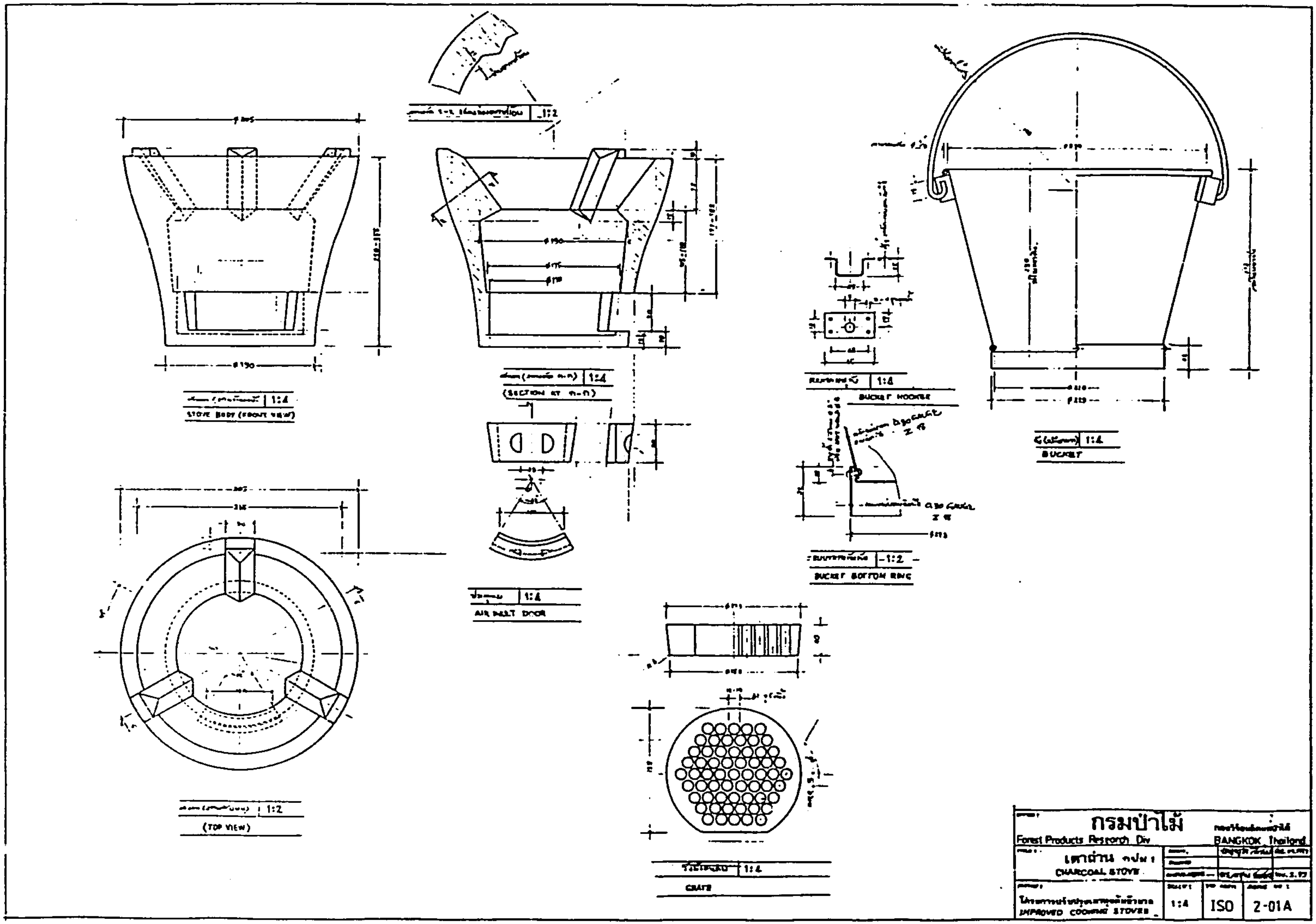


Figure 8.1 Technical Drawing of the Improved Charcoal Stove

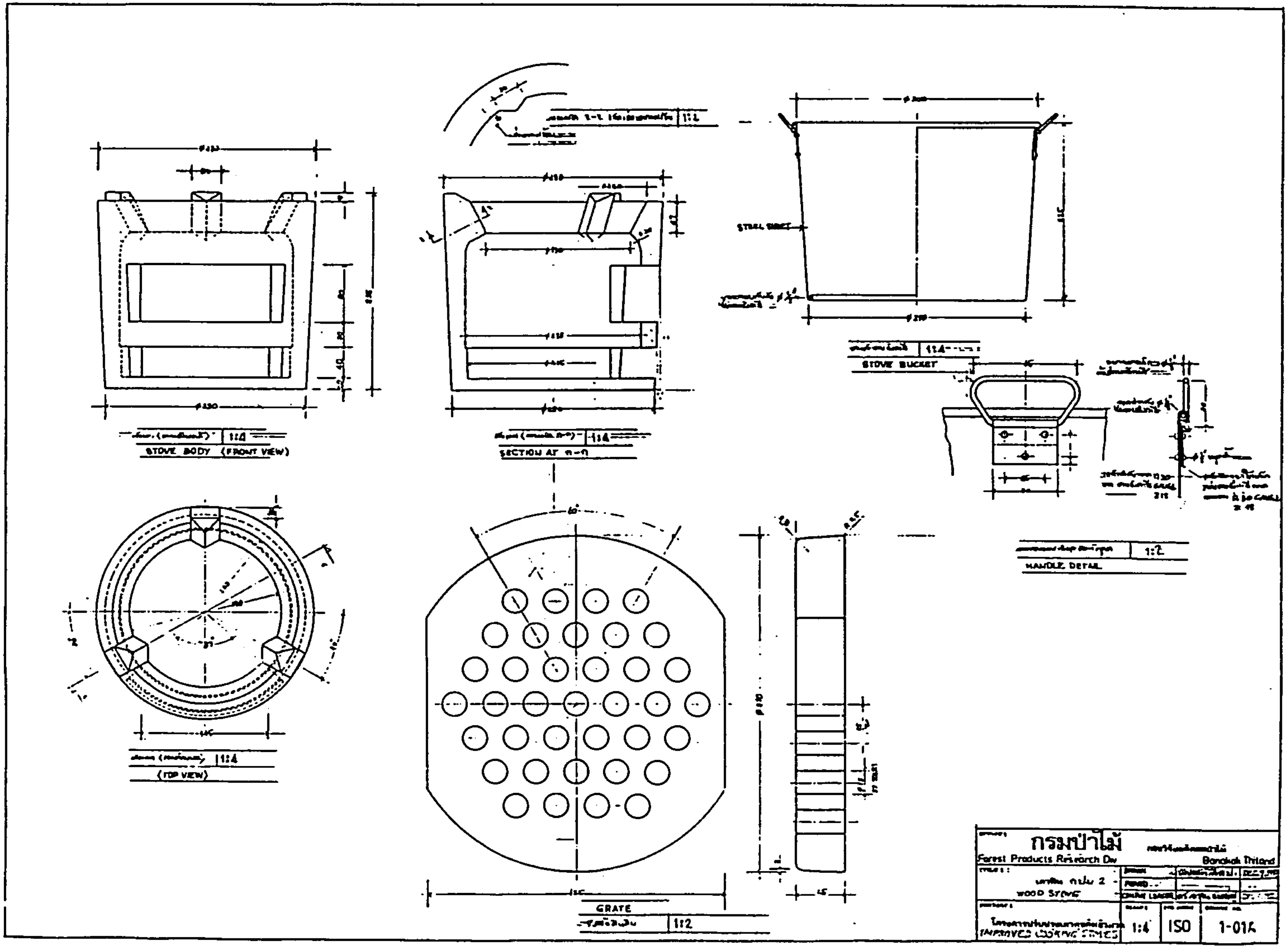


Figure 8.2 Technical Drawing of the Improved Wood Stove

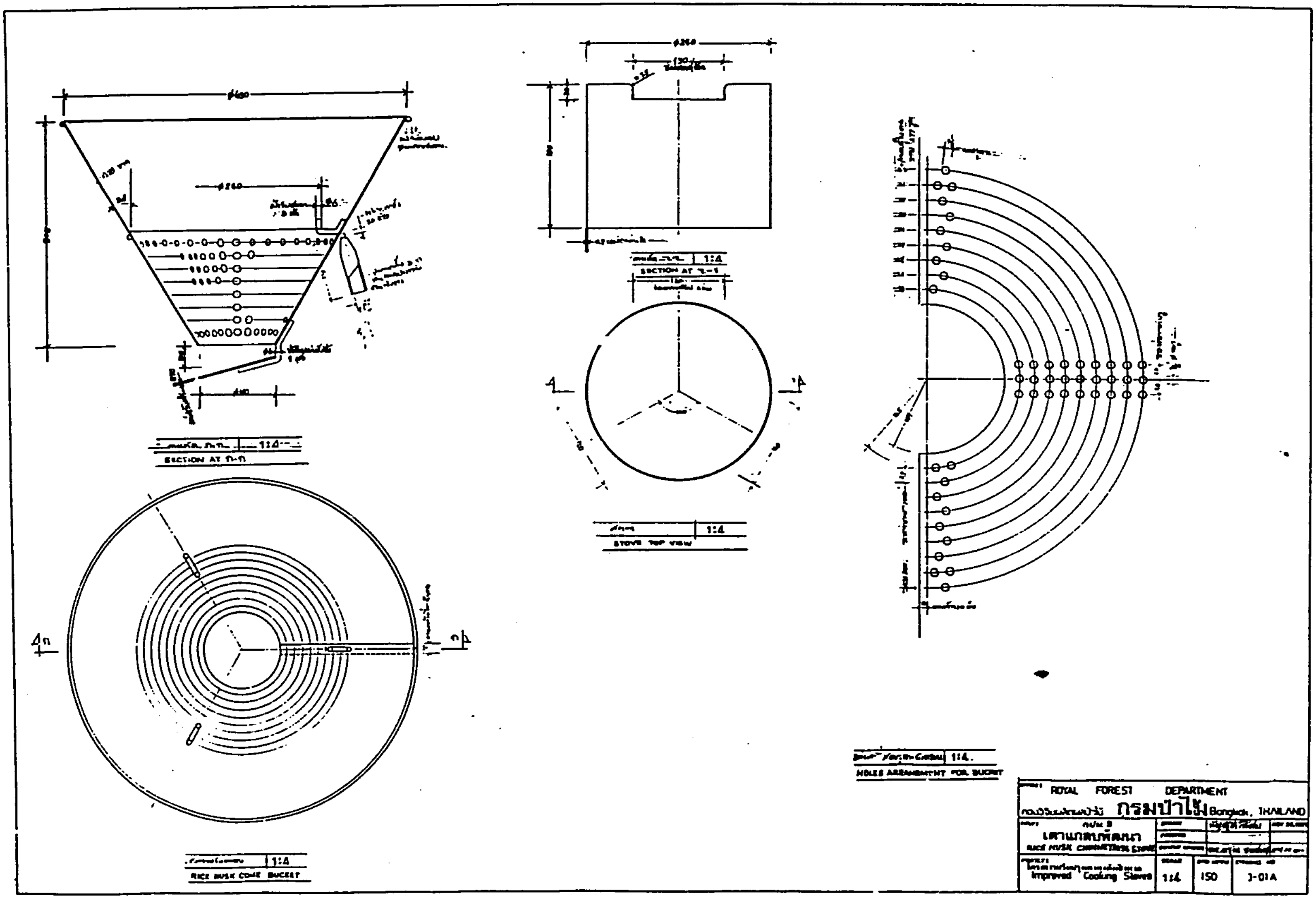


Figure 8.3 Technical Drawing of Improved Rice Husk Non-chimney Stove

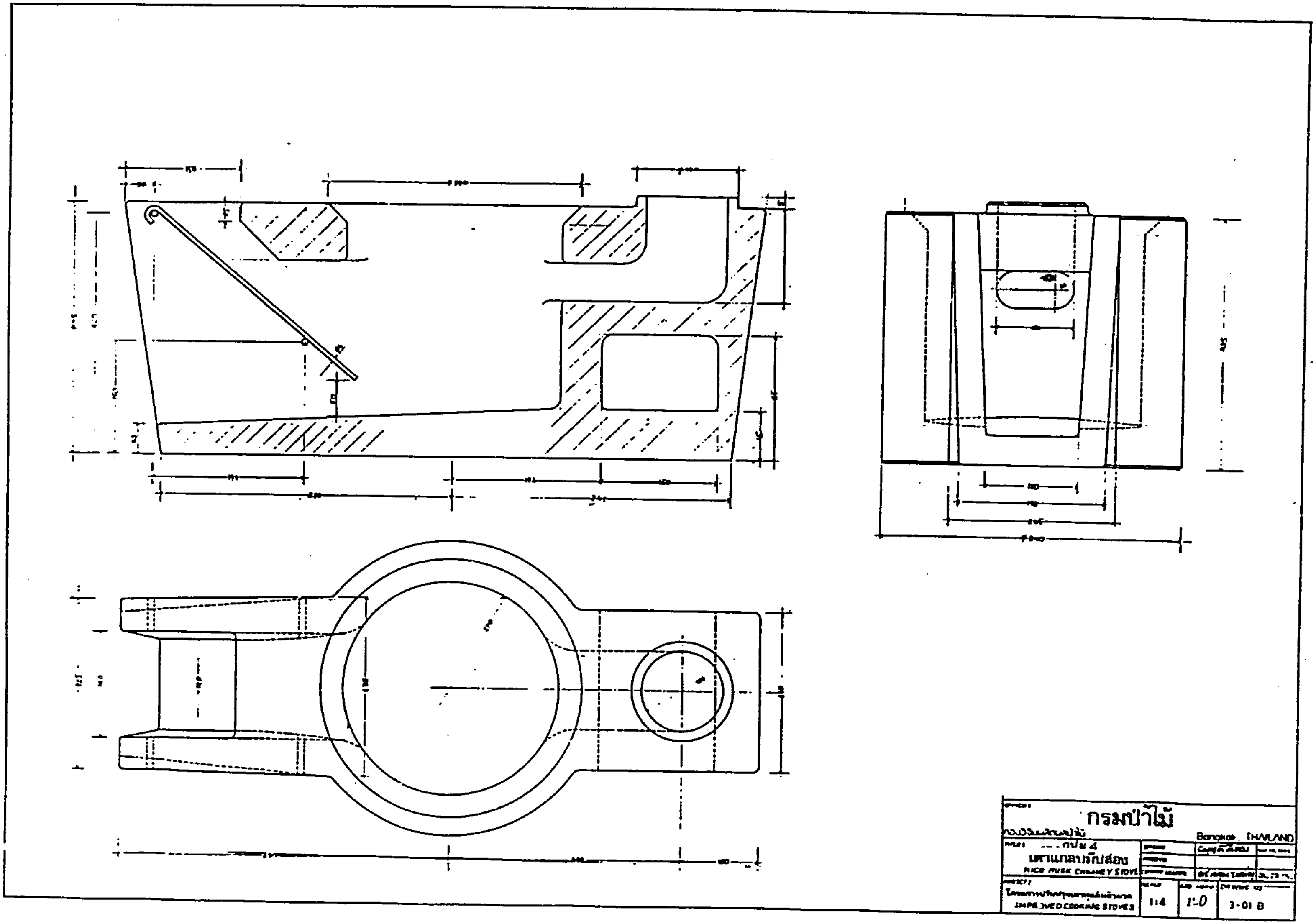


Figure 8.4 Technical Drawing of Improved Rice Husk Stove with Chimney

Figure 8.5 Preparation of biscuits and firing to be later used for clay mixture.

Figure 8.6 Production of charcoal stove on the potter's wheel using the internal mold.

Figure 8.7 Disassembling of the internal mold from a newly made charcoal stove.

Figure 8.8 Improved charcoal and wood stoves after finished firing and ready for further fabrication.

Stove's Quality Inspection

Even when firing is carried out by experienced local stove makers, some defects may occur due to non-uniform heat and cooling at certain spots in the pile. The final inspection will reject the stoves that are underfired, cracked and distorted. Normally, however, our results show a rejection of less than 7%.

Stove's Grate Making

Pottery liner stoves, as well as charcoal wood stoves, need grates for efficient combustion. However, the design for each is slightly different. See their detailed dimensions in Figs. 8.1, 8.2, 8.9. The clay composition used for making the grate is different from the clay mixture used to make the stove body. The rice husk ash content is higher in the grate body to reduce shrinkage during production and to enable the grate to withstand high thermal stress during use.

The normal composition of a thick charcoal grate is approximately 2-parts clay to 3-parts refined white rice husk ash by volume. The grate is hand-formed in a ringed-mold and hand-punched by a tapered tube with the help of a hole template. After air drying for approximately 15 days, this type of grate need not be fired since it becomes cured during use and has enough initial strength to withstand a charcoal load.

A wood stove grate, on the other hand, is thinner and larger in diameter. Therefore, prior to use, it must be fired first to become strong. In addition, a wood stove grate is made with a rougher clay body 1-part clay body and 3 parts black rice husk ash (which has not been refined and/or sieved).

Stove Bucket Making

Long term servicability and heat conservation within the stove rely heavily on the outside bucket. A good bucket is designed to fit the stove properly, so that the gap for packing the insulation between the stove and the bucket is 1.5-2.0 cm around the tapered wall. The bucket height will be 0.5 cm shorter than that of the stove to facilitate insulation filling and sealing with cement. A standard galvanized iron sheet of 0.3 mm gauge is considered the suitable size for the prototype stove. This material can withstand the alkalinity of rice husk ash insulating material reasonably well; it can withstand external rusting due to moisture and other factors. A handle is an essential part of the bucket and must be able to withstand the normal stove weight of 10 - 12 kg in long-term service. A good quality bucket can be ordered in quantity (and therefore at less cost) from a water bucket manufacturing plant.

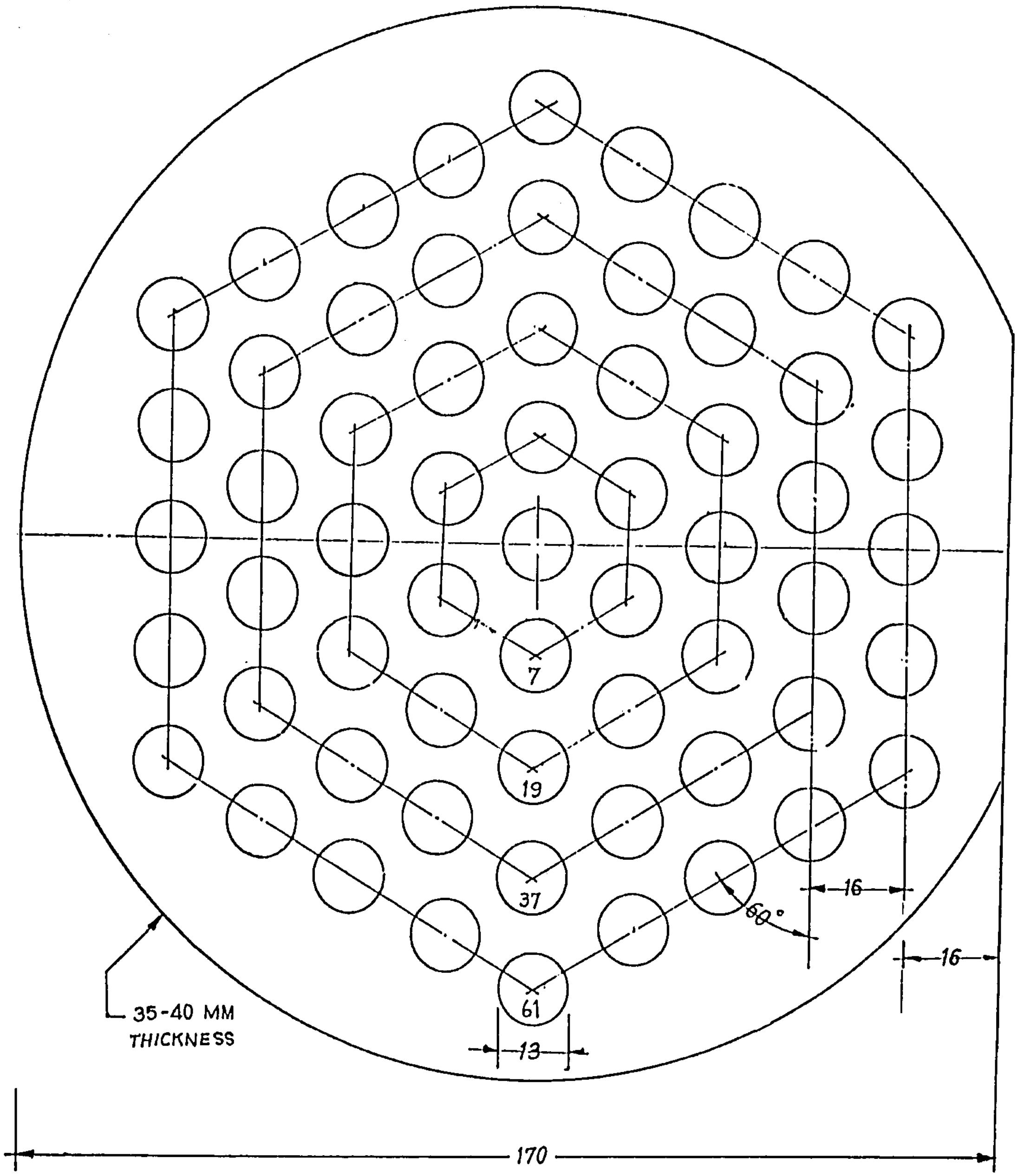


Figure 8.9 Grate hole design for charcoal stove : hole diameter 1.3 cm., with 61 holes in 5 shells around the center hole.

Stove Fabrication

Essentially, pottery lined stoves (wood and charcoal) consist of four separate components as follows:

- The fired clay body;
- The grate;
- The bucket; and
- The refractory and insulation linings.

The composition of material for the interior refractory lining is 5 - 6 parts common rice husk ash and one-part clay. That for exterior insulation lining is 12-parts ash and 1-part clay. Both must be thoroughly mixed.

The fabrication is completed by first pouring the insulation mix into the bucket bottom (about 1.5 cm). The stove body is then positioned inside the bucket. More insulation mix is added to the gap and then is tightly packed inside the gap between the stove body and the bucket. The stove's top rim and the edge around the air inlet door are then sealed off by cement mortar (3 parts fine sand and 1 part Portland cement). The grate is then positioned and fixed with refractory mix inside the stove body in such a way that the bottom edge of the grate is in line with the upper rim of the air inlet door. Finally, the refractory mix is lined around the combustion chamber approximately 1 cm thick to seal the edge between the grate and the stove body. The whole stove is then air-dried for at least 24 hours before use to avoid cracking of the refractory lining.

C. A MASS PRODUCTION SCHEME TO MAKE CHARCOAL AND WOOD STOVES USING THE HYDRAULIC PRESS

In the section on "Forming the Stove From Wet Clay" three forming methods were discussed. However, these methods cannot meet the stove production criteria of high production rate, precision of internal and external stove dimensions, and high uniform forming pressure of hard clay to withstand high thermal stresses. In order to meet all three requirements, it is envisaged that a hydraulic press with an internal mold and an external mold would provide a better method for long-term commercial production. The need for this kind of simple equipment for local production cannot be overemphasized if the "improved stove promotion program" hopes to see the quick replacement of 5 - 6 million poor charcoal and wood stoves throughout rural Thailand.

The prototype of such a hydraulic press in forming the clay bucket (including molds) has been designed and individual parts have been made. Fabrication and testing of this machine are underway at the present time. It is hoped that this device will work out well and out-perform those stove manufacturing techniques presently employed in Thailand. A detailed sketch of the hydraulic press for stove molding is shown in Fig. 8.10.

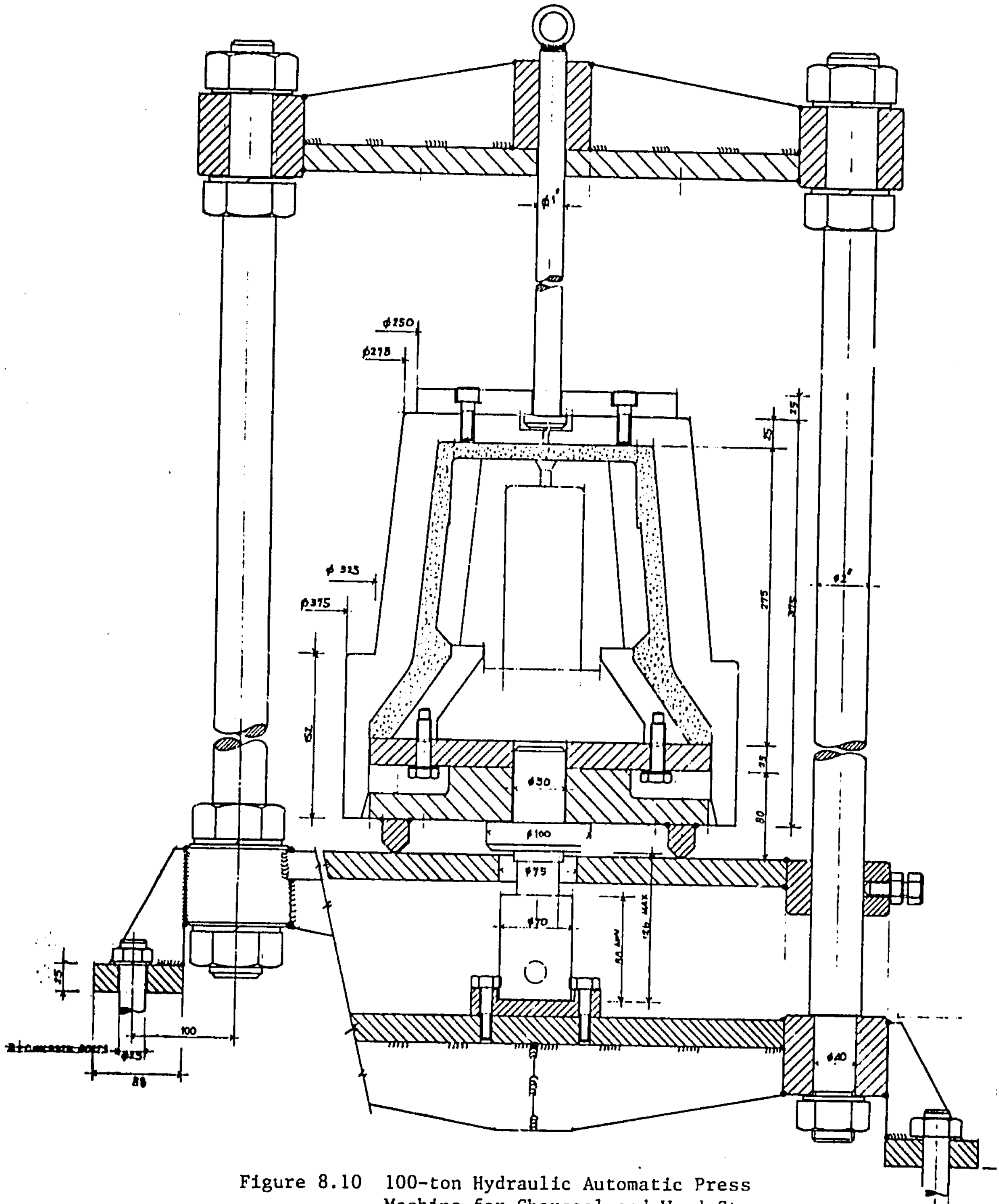


Figure 8.10 100-ton Hydraulic Automatic Press Machine for Charcoal and Wood Stove.

SCALE 1:5
B.SRISOM
JANUARY 84

Chapter 9

Improved Stove Promotion

IMPROVED STOVE PROMOTION

Laboratory research and development of highly efficient biomass cooking stoves were carried out for approximately 2 years. As a result, four types of improved biomass cooking stoves were proposed for trial promotion. They were the: charcoal bucket stove, the wood stove without a chimney, and the rice husk stove with and without a chimney. The four improved types gave satisfactory performance. Their absolute efficiencies increased approximately 5 - 7% on the average. Furthermore, performance tests on durability (long service life), ease of operation (easy to start up the fire and continuously give high heat output with equal or little attendance), accommodation of various pot sizes (one stove fits pot diameter from 16 to 32 cm), and portability (light weight) were satisfactory. Only the wood stove with a chimney requires further improvement of efficiency and to accommodate a variety of pot sizes.

Any problems that arise during stove development can usually be solved in the laboratory. However, problems dealing with the introduction of the newly developed stoves to users need to be solved in the field. Stove promotion is a most important project task. The work involved in research and development will have been wasted if improved models are not accepted by users. Hence,the promotion of improved stoves is one of the main concerns of this project.

This chapter presents some activities and field work involved in introducing improved stoves to rural families.

A. OVERALL TARGET OF STOVE PROMOTION

The population of Thailand is approximately 50 million. The average number persons in a family is 6 persons. Approximately 80% of Thai families live in rural areas. Thus, there are roughly 6 million biomass cooking stoves used by rural families. This presumes that each family has only one cooking stove. (In fact, a large number of rural families have 2 - 3 stoves in their possession). The main problem of promotion then becomes how to get all of the stoves replaced within a certain time frame. If Thailand were to replace all 6 million inefficient stoves within say, 5 years, approximately 1.25 million improved stoves must be produced. The activity involved in producing this many improved stoves is tremendous. It is not possible for a government agency to carry on such a heavy task alone. Stove manufacturers throughout the country must be involved in the production process. However, to begin this implementation program, the government must initiate and stimulate stove promotion activities so that stove replacement time will be shortened.

This project had only 6 months to begin the campaign. Stove promotion and training schedules have been established. There are two projects under the same component leader: Charcoal Improvement and Stove Improvement.

Therefore, both projects have been combined into one promotional campaign. Each promotion activity generally takes 5 - 10 days. Improved stoves are introduced during the first 1 - 2 days and charcoal production is demonstrated during the remaining time. The subjects present in the promotion activity depend on the level of education and the capability of participants. For representatives of government agencies and rural development associations, promotion activity elaborates both theoretical and practical details (since this group is more knowledgeable and is directly responsible for carrying out this development program in rural areas). Another group of participants consists of people who live in the villages. Hence, the promotion activity is less technical, and emphasizes only the practical, specific features of good stoves and their proper care. A prepared time-schedule for promotion activities is presented below:

1. The first trial promotion of the charcoal and stove improvement projects.
   Place: Regional Energy and Technology Center for Rural Development
   Muang District, Mahasarakarm, Northeastern
   Date: 9 - 16 December 1983

2. Technology of charcoal production and introduction of developed stove--the first official training course for government and rural development agencies.
   Place: Charcoal Research Center
   Muang District, Saraburi, Central
   Date: 9 - 20 January 1984

3. Improved production of charcoal and introduction of developed stoves to rural families--a training course for villagers and officials of the Mobile Military Development Unit.
   Place: Mobile Military Development Unit #32
   Pannanikorm District, Sakolnakorn, Northeastern
   Date: 1 - 11 February 1984

4. Improved production of charcoal and introduction of developed stoves to rural families--a training course for villagers.
   Place: Regional Energy and Technology Center for Rural Development
   Muang District, Pitsanulok, Northern
   Date: 5 - 9 March 1984

5. Technology of charcoal production and introduction of developed stoves to rural families--the second official training course for Government and Rural Development agencies.
   Place: Charcoal Research Center
   Muang District, Saraburi, Central
   Date: 13 - 23 March 1984

6. Improved production of charcoal and introduction of developed stoves to rural families--a training course for villagers.
   Place: Khao Hin Sorn
   Educational Development Center,
   (under H.M. the King's direction)
   Panomsarakarm District, Chachoengsoa
   Date: 16 - 20 April 1984

7. Improved production of charcoal and introduction of developed stoves to rural families--a training course for villagers.
   Place: Ban Thatoom Secondary School
   Muang District, Maharasakarm, Northeastern
   Date: 30 April - 4 May 1984

8. Technology of charcoal production and introduction of developed stoves to rural families--the third official training course for the Mobile Military Development Unit.
   Place: Charcoal Research Center
   Muang District, Saraburi, Central
   Date: 14 - 25 May 1984

9. Improved production of charcoal and introduction of developed stove to rural families--a training course at the Mobile Military Development Unit.
   Place: Mobile Military Development Unit #22
   Poa District, Nan, Northern
   Date: 3 - 10 June 1984

To achieve this project goal, it must be emphasized that the promotion of newly developed stoves is not just to distribute the stoves to users. A variety of aspects must be considered. For example, stove production, stove fabrication, repair and maintenance, and criteria for selection of good stoves from the markets should be included in promotional workshops. The intention of this field work is, therefore, to educate users on the above subjects as well. In fact, trainees are required to participate in stove fabrication. They install the stove grate, prepare insulating materials, line the inside refractory part, fill the stove bucket with insulation and seal the stove rim. Overall promotional activities are summarized in the subsequent section.

B. CREATION OF PUBLIC AWARENESS

In order to distribute 1.25 million improved stoves to rural families throughout the country (in addition to promotional activities carried out by this project), the government must step in to initiate various kinds of campaigns such as press conferences, radio interviews, distribution of leaflets and posters, etc.

The first introduction of cooking stoves (and related subjects) to the public was conducted by the National Energy Authority on 3 - 4 August 1983. Cooperating closely with the Stove Improvement Project, the meeting included a seminar, demonstration, and exhibition of cooking stoves. The participants consisted of representatives from government institutions such as universities, the Agricultural Department, the Rural Development Department, the Welfare Department, the Ministry of Education, etc., and the private sector such as the Population and Social Development Assoication, VITA company, Appropriate Technology Association, and a number of stove manufacturers, etc. The purpose of this campaign was to bring together the researchers, users, and manufacturers to join in a panel discussion in order to share points of view on several aspects of the project such as standard methods of stove testing, special features of highly efficient stoves, experience in stove manufacturing, marketing, and quality control.

Another promotional effort was the press conference on newly developed biomass cooking stoves which was held in February 1984 at the Ministry of Science and Technology. Representatives from radio and television stations and representatives from various newspapers were invited to the meeting. Leaflets, posters, T-shirts as well as a user's guide on stove maintenance and repairs were distributed.

It should be emphasized that the work involved in promoting improved stoves to users and manufacturers is extensive and should be continued with the support of various government agencies.

C. INTRODUCTION/TRAINING ON EFFICIENT STOVES

The introduction/training on improved stoves for local rural develoment officials, school teachers, village leaders, etc. has been carried out following the program described in section A of this chapter. The training activities include:

1. Instruction on the five proposed types of biomass cooking stoves on the fundamentals of stove design and construction (see Fig. 9.1);

2. Efficiency test comparison between the developed stoves and the currently marketed stoves (see Fig. 9.2);

3. Demonstration and trainee participation in installing the grate into the stove body, lining refractory material around the combustion chamber, and placing the insulating materials between the bucket and the stove body, etc. (see Fig. 9.3)/ and

4. Distribution of the finished stoves (fabricated by trainees) to those who have participated in building their own selected stoves (see Fig. 9.4).

The training activities are discussed in the following section.

Table 9.1 Comparison test for efficiency between developed and commercial stoves in Mahasarakarm

Condition	Charcoal stove			Nonchimneyed wood stove		Chimneyed rice husk	Nonchimneyed rice husk
	developed	comm. 1	comm. 2	developed	comm. (pranomprai)	developed	developed
Fuel wt, gm	400	400	400	1,520	1,490	3,800	3,070
Half time to boil (64°C), min	9	14	17	7	9	9	14
Time to boil, min	17	27	27	12	14	29	22
Water evaporated, gm	810	420	450	1,310	1,210	1,400	1,160
Fuel remaining, gm	60	40	40	25;570[1]	45;330	550	1,050
Fuel use, gm	340	360	360	950	1,160	3,250	2,020
Efficiency, %	31.01	20.59	21.27	24.90	19.90	9.60	13.67

Note: 1. Charcoal remaining; wood remaining

The First Promotion Trial for the Charcoal and Stove Improvement Projects, 9 - 16 December 1984, Muang District, Mahasarakarm

The purpose of this trial was to provide the trainers with experience in stove promotion training. There were 35 trainees, they included:

- 5 Officers from the Regional Energy and Technology Center for Rural Development
- 2 Officers from the NEA Training Center
- 4 Promotors and researchers
- 4 District agriculture officers
- 2 Sub-district development officers
- 15 Village leaders
- 2 Primary school teachers
- 1 Public health reporter

The training program consisted of the four activities described at the beginning of this section. The results of the comparison between the improved charcoal bucket stove, the improved non-chimneyed wood stove and the commercial ones are shown in Table 9.1.

Thirty-two questionnaires were distributed to the trainees after the end of the program. The results are summarized below.

Within this district in Mahasarakarm, the charcoal bucket stove was the most popular stove type. The non-chimneyed wood stove, the chimneyed wood stove, the non-chimneyed rice husk stove, and the chimneyed rice husk stove were less popular--in that order. 93% of the trainees said they knew more about the specific features of the highly efficient stoves as well as criteria for selecting good stoves after the training. 56% of the trainees increased their knowledge of building and designing good stoves. 84% of the trainees felt they had a better understanding of stove care and maintenance. However, only 50% of the trainees said they could transfer this training to others. Responding to length of training, 66% said the timing was convenient and the length of training was adequate. Other comments were personal that additional training on the method of making the developed stoves for use was needed; more promotion and distribution of stove samples to other villages, more training should be offered to other private and government agencies as well as to interested outsiders; and there was a request for construction blueprints of the five developed stoves.

Stove Promotion in Saraburi on 9 - 20 January 1984

The stove promotion workshop in Saraburi was the first official training course and the opening of the Charcoal Research Center. The ceremony was witnessed by the following representatives:

- 1 Representative from the National Energy Administration
- 4 Chief engineers and officers from USAID office, Thailand
- 2 Representatives from Food and Agriculture Organization, Asia and Pacific Region

2 Representatives from the Forestry Department
1 Representative from Kasetsart University
1 Chief of a biogas development project
1 Chief of a renewable energy project, from the support office
2 Representatives from the Regional Forestry Office, Saraburi
1 Representative from the Provincial Forest Office, Saraburi

The trainees consist of:

5 NEA officers from the Regional Energy and Technology Center
2 Training officers from the National Security High Command
4 Field officers from the Community Development Department
2 Field officers from the Family Planning and Population Development Association
2 Field officers from the Land Development Department

The formal training program was carried out as outlined in the beginning of this section. The charcoal stove comparison was performed and the results are shown in Table 9.2.

Since this training program was devoted mainly to charcoal production, stove promotion was only minimally presented to participants. Only the stove charcoal stove comparison was demonstrated. See Table 9.2.

No stove questionnaires were distributed

Table 9.2

Comparison Test for Efficiency
between developed and commercial stoves in Saraburi

Condition	Developed	Charcoal Stove Rangsit	Charcoal Stove Cholburi	Boobparam
Fuel wt, gm	400	400	400	400
Half time to boil (64°C), min	11	12	13	14
Time to boil, min	17	24	27	31
Water evaporated, gm	790	450	410	400
Fuel remaining, gm	40	35	45	35
Fuel use, gm	360	365	355	365
Efficiency, %	29.16	21.40	20.48	19.73

Stove Promotion in Sakolnakorn on 1 - 11 February 1984

The participants consisted of:

17 Training personnel from the Mobile Military Development Unit
5 Officers from the District Development Section
1 Teacher from the Nonroau school
3 Village leaders
19 Villagers

The training program was conducted as previously described. The results of the stove comparison between the developed models and the commercial stoves are shown in Table 9.3.

The results were obtained from 45 questionnaires, From analysis of the questionnaire responses, the following can be concluded.

Non-chimneyed wood stoves made up 68% of all stoves used by the trainees at home. Within this region, 56% of rural families used the non-chimneyed type. 88% of the trainees believed that they had learned more about the criteria for selection of good stoves by the end of the training. 94% of the trainees improved their knowledge on proper care and maintenance of stoves. All participants (100%) agreed that the developed stoves performed better than the commercial ones.

33% of the trainees preferred the charcoal bucket stove, 32% preferred the non-chimnened wood stove, 19% preferred the non-chimneyed rice husk stove, and 16% preferred the chimneyed rice husk stove.

At the end of training, each participant received a stove. The number of stoves distributed: 43 charcoal bucket stoves, 27 non-chimneyed wood stoves, 4 non-chimneyed rice husk stoves, and 15 chimneyed rice husk stoves. Out of the total number of stove distributed, 45 stoves were given to villagers, 2 stoves were given to a youth group from Moungkai village, and 42 stoves were given to the Mobile Military Development Unit.

Stove Promotion in Pitsanulok, 5 - 9 March 1984

The Pitsanulok training was held at the Regional Energy and Technology Center. There were 33 participants involved; they are:

5 Officers and workers from the Regional Energy and Technology Center
4 Lecturers from the Educational College and teachers from the primary school
9 Sub-district senior personnel and assistants, village assistants and leaders of village committees
14 Farmers and people from the region

The results of the stove comparison between the improved model and the commercial stoves are shown in Table 9.4.

Table 9.3

Comparison test for efficiency between developed and commercial stoves in Sakolnakorn

Condition	Charcoal stove		Nonchimneyed wood stove				Chimneyed rice husk
	developed	commercial	developed	commercial 1	commercial 2	commercial 3	developed
Charcoal wt, gm	400	400	1,100	1,050	2,275	1,240	2,800
Time to boil, min	22	–[1]	14	15	22	31	19
Water evaporated, gm	640	110	1,240	1,140	950	600	1,440
Fuel remaining, gm	45	25	40;230[2]	25;0	265;170	50;365	300
Fuel use, gm	355	375	870	1,050	2,105	865	2,500
Efficiency, %	29.2	14.7					12.7

Note: 1. not boil (windy on the test day)
2. charcoal remaining; wood remaining

The results of training are summarized below. The basic information on the type of stoves used among the trainee's families revealed that 75% had: charcoal bucket stoves, 8% had non-chimneyed wood stoves and 17% had chimneyed and non-chimneyed rice husk stoves. 97% of the trainees chose the charcoal bucket stove as their preferred model. 38% chose the non-chimneyed wood stove as their second preference. All trainees gained confidence in their knowledge of how to select good stove. 50% of the participants were in favor of the present desing and the other 50% preferred the new design. All trainees agreed that they better understood stove care and maintenance.

This training was highly successful. The trainees showed great interest and cooperated well during fabrication and discussion. At the end of each day, trainees gathered around the training site and discussed the problems that had arisen during the day. All 71 participants received a developed stove.

Stove Promotion in Saraburi on 13 - 23 March 1984

The March 1984 workshop was the second official training course at the Charcoal Research Center in Saraburi.

A total of 11 persons from various government agencies and private associations participated in the stove promotion program. These included:

3 Training officers from Military Central Security
2 Workers from the Family Planning and Population Development Association
4 Workers from Community Development Department
1 Worker from the Land Development for Agriculture Division
1 Worker from the Thai-German Center, Welfare Department, Lopburi

The training course was carried out according to the program previously mentioned. The stove comparison for efficiency is shown in Table 9.5.

Evaluation of this training from the responses on the returned questionnaires can be summarized as follows: 82% of the participants used charcoal bucket stoves and 18% used gas stoves. All trainees (100%) said they had a better understanding of the criteria for selecting a good stove. 82% of the trainees (moderately) believed that they could transfer their stove knowledge to rural people.

Stove Promotion in Chachoengsoa on 16 - 20 April 1984

The training in Chachoengsoa was set up at the Khao Hin Sorn Educational Development Center under His Majesty the King's direction in Panomsarakarm district, Chachoengsoa Province. There were 36 participants; they included:

6 Agricultural workers from the Land Development Division, Khao Hin Sorn Development Center
2 Field officers from the Community Development Department, Khao Hin Sorn Development Center

3 Field officers from the Forest Nursery Plant Center, Forestry Division
9 Students from the Rachaburi Agricultural Institute, Rachaburi
16 Villagers from Khao Hin Sorn region and nearby

The results of comparison between the improved model and commercial stoves are shown in Table 9.6.

At the end of the training program, 34 questionnaires were distributed to participants. The results are presented below.

The charcoal bucket was the most popular types of stove. 71% of the participants chose it as their preference. The other choices were non-chimneyed wood stove--18%, non-chimneyed rice husk stove--5%, chimneyed rice husk stove--3%, and chimneyed wood stove--3%.

All participants (100%) agreed that their knowledge about selecting highly efficient stoves had increased significantly. 97% stated that their understanding of stove use, care, and maintenance had also increased; 41% of the participants have confidence in their ability to transfer their stove knowledge to others. In addition, many participants requested more elaborate details for stove making.

At the end of training, 24 charcoal bucket stoves, 9 non-chimneyed wood stoves, and 4 non-chimneyed rice husk stoves were given to participants. Another 18 stoves were donated to the Land Development Center, the Forest Nursery Center and representative students from the Agricultural Institute for future use in stove promotion activities.

Stove Promotion in Mahasarakarm on 30 April - 4 May 1984

56 people participated in this training:

2 Teachers from Ban Thatoom school
1 Teachers from Ban Dotangarm school
1 Teacher from Ban Napangdonhi
2 Officers from the Regional Energy and Technology Center
3 Village leaders
1 Assistant village leader
44 Villagers
2 Observers from the External Educational Center

The results of the comparison between the improved stoves and the commercial ones are presented in Table 9.7.

From the responses on the questionnaires, it was determined that 67% of the participants used charcoal bucket stoves and 29% used non-chimneyed wood stoves at home. 73% preferred charcoal bucket stoves while 21% preferred non-chimneyed wood stoves. 97% of the participants believed that their knowledge in selecting good stoves had increased, as had their ability to repair and maintain stoves in good condition. 50% believed that they could transfer this knowledge to other people. There were also many requests for complete instructions on how to make the stove for one's own use--starting from nothing. The training course only lets each participant place a pre-shaped and fired stove body into a bucket. He then places the grate, lines it with the refractory material, and fills it with insulating materials. This request is similar to other previous training course. However, the method of making stove body is rather complicated, time-consuming, and requires high skill; hence, this function needs to be performed by stove manufacturers. Instead it was suggested that the participants take the stove samples to stove manufacturers in their villages for trial production.

There were altogether 137 stoves distributed at the end of training. 56 stoves were given to participants, 81 stoves were given to Ban Thatoom school. The distributed stoves included 80 charcoal bucket stoves, 50 non-chimneyed wood stoves, 5 non-chimneyed rice husk stoves, and 2 chimneyed wood stoves.

Stove Promotion in Saraburi on 14 - 25 May 1984

The May 1984 training took place at the Charcoal Research Center in Saraburi. There were 19 participants; they included:

3 Military officers from the Central Security Division
5 High-ranking military officers from the Mobile Military Development Unit
6 Noncommissioned officers from the Mobile Military Development Unit
5 Participants from the Regional and Voluntary Self-defense Association

The results of the stove comparison are shown in Table 9.8.
Questionnaire evaluation showed that 88% of the participants used charcoal bucket stoves and 6% used gas stoves at home. Their increased ability to identity and select highly efficient stoves was reported to be 94%. The ability of participants to transfer this training knowledge to other people was 50%, and the trainer's capability of interpretating and monitoring the stove training course was 72%.

At the end of the training program, participants received 19 newly developed charcoal stoves.

Improved Stove Promotion in Nan on 2 - 8 June, 1984

This program was the last training course of the project. The training was coordinated by Colonel Dusit Menapothi, Chief of Training division, Central Security High Command and Special Colonel Padej Amwong, Commander of the Military Mobile Development Unit #22, Nan. There were 54 participants. They included:

2 Training officers from the Military Mobile Development Unit #21, Uttaradit
20 Training officers from the Military Mobile Development Unit #22, Nan
4 Field officers from the Battalion Cavalry, Nan
3 Workers from the external Education Center, Nan
4 Noncommissioned officers
21 Villagers

Table 9.4

Comparison test for efficiency between developed and commercial stoves in Pitsanulok

Condition	Charcoal stove			Nonchimneyed wood stove	
	Developed	Commercial 1	Commercial 2	Developed	Commerical
Fuel wt, gm	400	400	400	-	-
Time to boil, min	24[1] (17)	-[2]	24	11	13
Water evaporated, gm	720	460	540	1,340	1,240
Fuel remaining, gm	30	20	25	20	15
Fuel use, gm	370	380	375	890	1,160
Efficiency, %	29.5	22.1	24.5	26.8	19.1

Note: 1. The value is somewhat higher due to trainees' lack of skill in lighting the fuel. The same test was repeated on the next day and a new time to boil was quoted in the parenthesis.
2. Not boiling.

Table 9.5

Comparison test for efficiency between developed and commercial stoves in Saraburi

Condition	Charcoal stove		Non-chimneyed wood stove		
	Developed	Commercial	Developed	Commercial 1	Commercial 2
Fuel wt, gm	400	400	-	-	-
Time to boil, min	19	23	20	27	18
Water evaporated, gm	610	510	1,310	1,210	1,000
Fuel remaining, gm	40	30	50	55	25
Fuel use, gm	360	370	1,030	1,170	1,020
Efficiency, %	28.4	24.5	23.8	19.7	19.2

Table 9.6

Comparison test for efficiency between developed and commercial stoves in Chachoengsoa

Condition	Charcoal Stove		Nonchimneyed Wood Stove		
	Developed	Commercial	Developed	Commercial 1	Commercial 2
Fuel wt, gm	400	400	-	-	-
Time to boil, min	17	32	17	16	15
Water evaporated, gm	620	410	1,130	1,100	1,250
Fuel remaining, gm	40	45	55	50	50
Fuel use, gm	360	355	820	920	1,210
Efficiency, %	26.33	21.64	24.86	21.75	18.0

* Very windy condition during the test day

Table 9.7

Comparison test for efficiency between developed and commercial stoves in Mahasarakarm

Condition	Charcoal stove			Nonchimneyed wood stove		
	Developed	Commercial 1	Commercial 2	Developed	Commercial 1	Commercial 2
Fuel wt, gm	400	400	400	1,390	1,410	1,570
Time to boil, min	24	26	-[1]	14	19	19
Water evaporated, gm	560	480	60	1,260	960	1,140
Fuel remaining, gm	65	65	110	505	720	635
Fuel use, gm	335	335	290	885	690	935
Efficiency, %	31.14	28.79	22.15	25.06	23.97	21.28

The results of the comparison between the improved models and the commercial stoves are shown in Table 9.9.

54 questionnaires were returned. The result are summarized below.

The most popular type of biomass cooking stover trainees was the charcoal bucket stove; used them at home 68%. The next popular type was the non-chimneyed wood stove accounting for 29%, and the chimneyed rice husk stove 3% ccounting for all participants received a stove.

At the end of the training, 54 developed stoves were distributed.

D. INTRODUCTION AND DISTRIBUTION OF SAMPLE STOVE TO HOUSEHOLD USERS

The trial promotion and training course in improved stoves should include free distribution of stove samples to rural villagers under the condition that the promotors follow up and record the results. Thus, any problems that may arise during the application of the new models can be addressed and improvements made. Free distribution of sample stoves must be supported by the government, particularly in the trial promotion and monotoring phases.

E. ORGANIZATION OF STOVE MANUFACTURERS TO PRODUCE IMPROVED DESIGN STOVES

Introduction to manufacturers of the improved stoves is a very difficult task because of lack of concern and cooperation among local stove manufacturers. These problems are believed to exist because they:

- Have little credibility with the government agency;
- Believe that the stoves they are making are best (due to lack of scientific knowledge);
- Believe that the stove making profession is doomed because of strong competition from gas stoves and their LPG fuel government subsidies.
- Believe that Thailand is running out of wood and charcoal. Many state that they will give up stove manufacturing when there is no more wood.

Hence, government agencies should focus on educating local stove manufacturers to better understand Thailand's precious, indigenous and reproducible source of energy--wood--and by providing them with guidance and useful scientific knowledge on improved stove technology. This can be achieved by the following government efforts:

1. Publication and distribution of documents describing the important features of good stoves.

Table 9.8

Comparison test for efficiency between developed and commerical stoves in Saraburi

Condition	Charcoal stove			Nonchimneyed wood stove		
	Developed	Commercial 1	Commercial 2	Developed	Commercial 1	Commercial 2
Fuel wt, gm	400	400	400	1,670	1,710	1,500
Time to boil, min	20	21	26	14	22	16
Water evaporated, gm	360	345	360	950	710	1,020
Fuel remaining, gm	40	55	40	40;720[1]	55;1,000	35;480
Fuel use, gm	730	550	440	1,360	920	1,260
Efficiency, %	30.32	27.50	23.52	26.23	28.33	22.83

Note: 1. charcoal remaining #; wood remaining

Table 9.9

Comparison test for efficiency between developed and commercial stoves in Nan

Condition	Charcoal stove			Non-chimneyed wood stove		
	Developed	Commercial 1	Commercial 2	Developed	Commercial 1	Commercial 2
Fuel wt, gm	400	400	400	1,440	1,460	1,440
Time to boil, min	-	-	-[1]	-	-	-
Water evaporated, gm	600	410	-	1,280	1,060	1,020
Fuel remaining, gm	40	35	-	40;300[2]	60;190	50;215
Fuel use, gm	360	365	-	1,140	1,410	1,225
Efficiency, %	27.7	22.6	-	20.7	14.9	16.6

Note: 1. not recorded
2. charcoal remaining; wood remaining

2. Methods of selecting stove materials such as fire resistant clay, insulating material, etc. and how to improve such materials.

3. Government development and provision of the stove mold for mass production of the improved stoves.

4. Government advertising campaigns to boost sales and marketing of the new stoves.

5. Providing awards and incentives to cooperative manufacturers. Stove competitions and awards to manufacturers producing the most efficient stoves are highly recommended. Stoves that pass a standard test for efficiency and ruggedness should be given a government guarantee certificate. This will give the users confidence enough to buy and motivate manufacturers to produce good stoves.

Figure 9.1 Introduction of developed stoves to participants

Figure 9.2 Stove contest for efficiency comparison between commercial stoves and developed models

Figure 9.3 Trainee participation in installing stove's parts

Figure 9.4 Distribution of developed stoves to all participants

Chapter 10

Conclusions

CONCLUSIONS

As a result of the implementation of the Improved Biomass Cooking Stove Component, many activities and achievements took place. Accomplishments can be described as follows:

1. As a part of institution strengthening, the component has succeeded in establishing a cooking stove testing laboratory at the Forest Products Research Division, Royal Forest Department. Through project funding, the laboratory was equipped with invaluable, basic test instruments and facilities--including a microcomputer system for future applications.

2. Long-term training of project personnel to increase their future capabilities was minimum because time was short (30 months) and they were needed on site to carry out project tasks. Therefore, all technical personnel were indispensable for project implementation. They could not be spared for long term training.

3. The component has produced five generic types of improved cooking stoves: namely, the charcoal bucket stove, wood stoves with and without chimneys, and rice husk stoves with and without chimneys. The absolute heat utilization for charcoal and both types of wood stoves increased up to 7% over that of the average commercial models. Further, an increase of 5 and 3% was achieved with rice husk stoves with and without chimneys respectively. In terms of comparative efficiency increases, the charcoal stove reached a 26% increase over the average commercial models, while for wood stoves with and without chimneys they were 58 and 35% respectively. The increase for the rice husk stove with chimney was 100%, or double the efficiency of the average commercial models. The rice husk stove without chimney had the least increase--15 - 16%.

4. The investigation conducted on existing commercial stoves revealed that fuel efficient cooking stoves for charcoal, wood, or rice husk are rare. The laboratory tests have led to the identification of the stoves' critical physical parameters. They consist of stove weight; exhausted gap/area; combustion chamber capacity; rim design for proper fit of variously-sized pots and pans; grate-to-pot distance; grate parameters such as hole area, hole size and distribution, and thickness; height of chimney, and flue gas baffle (for chimneyed stoves). Other strong factors also influencing stove performance are external variables--fuel load or fuel feeding rate, amount of water to be boiled, and the wind factor. The information obtained was later used for redesigning the improved stove models.

5. Good quality clay material suitable for stove manufacturing has been identified and a production technique has also been developed for small-scale and home industries. Local stove manufacturers in one district of Roi-et Province were trained without any difficulty in this technique of stove production. Improved stoves, particularly charcoal and nonchimney wood models, are heat refractory and can withstand thermal shock much better than present

commercial ones. In addition, the application of the internal mold has greatly improved the precision necessary to control the critical internal dimensions. This method was found to be superior to the traditional one using an external mold which hardly controlled the internal dimensions.

6. The production cost of the improved models as described in (2) above presently is approximately 2.5 times more than the cost of the poorer quality commercial models. However, when compared with top quality charcoal bucket stoves sold in the market, the improved models' cost is 25 - 30% lower. Therefore, in long-term commercial production, the improved models will be competitive when production increases and more improved stoves reach the market.

7. So far, nine improved stove promotion and training programs have been carried out among villagers at various places around the country. The reception for the charcoal bucket and the non-chimney wood stoves was very good, while the good reception of the rice husk chimneyed stove was limited to a few localities where only rice husk is available. The chimneyed wood and non-chimneyed rice husk stove are of less interest to rural users than the charcoal bucket and the non-chimneyed wood and the rice husk chimneyed stove. It is believed that with good follow-up and promotional effort, some of the improved developed models will withstand harsh use and serve users well in rural kitchens. However, these long-term results are yet to be seen.

8. Because of time constraints, the project had a limited time to approach manufacturers on a large scale. However, among a few large manufacturers in the Central area, the response to the idea of mass production of the developed models was not enthusiastic. This lack of enthusiasm is perhaps a result of stove manufacturers being accustomed to the production of their rough products and being reluctant to manufacture stoves with which they have little or no experience. Moreover, they probably want to see the market for high quality, efficient stoves develop first before committing their resources to their production. Therefore, more time and more education are needed for them to change their attitude and adapt their production techniques.

Chapter 11

Recommendations

RECOMMENDATIONS

On the basis of the overall work of this project, some recommendations are presented below:

1. Because stove development and promotion involve the social customs and habits of millions of people in Thailand and around the world, it is highly recommended that stove research and development be carried on to further improve present designs and find more alternatives for users.

2. Stove development should emphasize each generic type of stove; namely, charcoal, wood with and without chimney, and agriresidue stoves with and without chimney so that users have choices.

3. Stove research and development must not only emphasize the good conversion efficiency, but it must also facilitate ease of use and other cooking functions, without causing undue change in people's cooking habits.

4. Stove promotion is a most difficult activity. It will take a great deal of time and resources. Therefore, continuous effort must be made for at least five years with reasonable financial and human resource support in order to see a real impact among 6 million rural users.

5. In Thailand there are quite a few researchers and interest groups working on stove development and promotion. Unfortunately, all lack guidelines and coordination. For national stove programs to be directed toward this common goal, leading government agencies are needed to provide close coordination.

6. During the course of stove development, many contacts were made with experienced stove manufacturers. It was found that, regardless of their long experience, their basic understanding of good stove configuration, design and its performance was very much lacking. This problem was also manifested in the presence of a large majority of poor quality and less efficient commercial stoves in the market. Therefore, it is strongly recommended that concerned government agencies take an initiative toward arranging formal training programs for the promotion of the essential, scientific knowledge required among stove manufacturers. Incentives or approaches such as offering a certificate and/or reward to manufacturers of efficient stoves would be a highly motivating factor.

7. The lack of understanding among users on the criteria for selection and use of efficient cooking stoves was also evident. Therefore, the concerned government agency should establish a long-range,adequately funded educational campaign program for efficient stoves--particularly through primary and secondary school systems.

8. The cost of improved design stove production is still high. If simple hydraulic molding can be developed and employed at the village level, production costs can be greatly reduced. Under these conditions stove dimensions will be more precise and the production rate will be increased significantly.

9. Selection of clay raw material and improvement of the clay mixture and firing to attain a product with fire resistant characteristics (particularly, the charcoal stove body) are essential to a stove's long service life. The weight of the stove also needs further reduction (to achieve peak performance with even lower charcoal loads).

10. The improved non-chimneyed wood stove is quite efficient for the present developed model. It can conveniently be used to replace three-rock stoves. However, the same problems exist in its mass production techniques as exist for the charcoal stove.

11. Smoke in the kitchen is a problem inherent in non-chimneyed wood stoves including the three-stone and open fire. Research should be carried out in Thailand to determine whether smoke from undeveloped and even developed stoves (which noticeably gives less smoke over the undeveloped ones), has any significant effect on long-term health of users.

12. Up to the present time, the one hole chimneyed wood stove has attained an efficiency up to only 18-19%. In addition, there are problems fitting pots and pans to this stove. Therefore, it is recommended that development on this type of stove be continued in order to improve both heat utilization efficiency and compatability with various pots and pans. Moreover, the stove material (as in the case of the non-chimneyed wood stoves and the charcoal stove) should also be investigated.

13. Even though, at present, the chimneyed rice husk stove is still not popularly used in Thailand, the chance for this stove to become popular in certain regions is high. This is because it can use granulated fuels other than rice husk (such as sawdust, peanut shell, seed waste, household biomass scraps, etc). There are several further improvements that need consideration. These include the improvement of the stove's configuration to fit various pots and pans and reduction of its weight so that sometimes it can be moved around the house (yard) when needed. For two people to carry the stove, the weight should not exceed 50 kg.

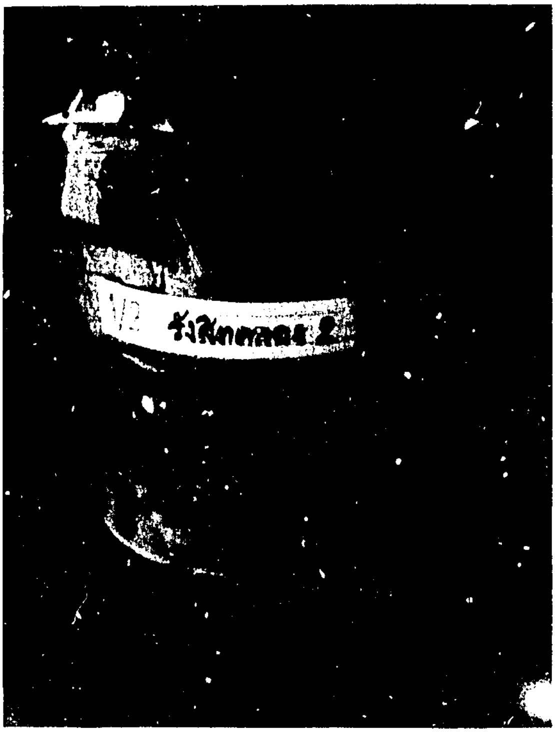
14. The experience gained from the stove promotional campaigns among rural users, even in its short duration, strongly indicated that there is a good chance of success in replacing relatively inefficient stoves among 6 million rural Thai families with efficient stoves. It is, therefore, recommended that the government support a nationwide efficient stove promotional campaign for users and manufacturers as soon as possible.

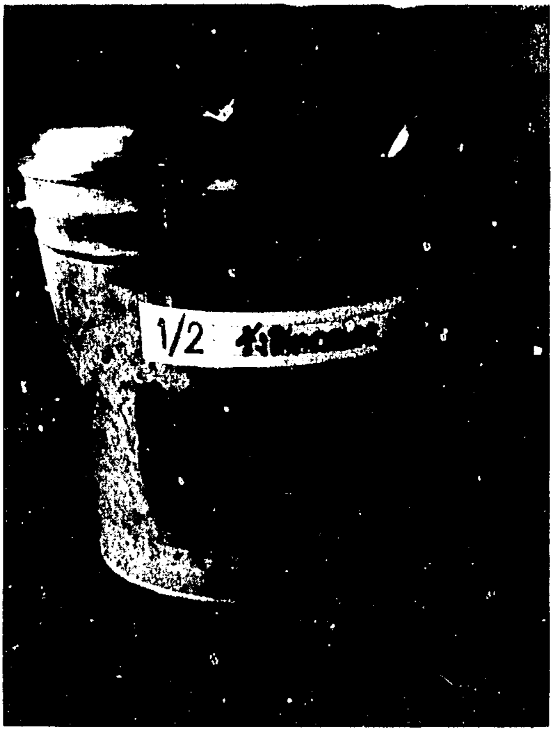
15. Since better biomass cooking stoves, in part, mean better living for millions of rural families around the world, the idea of continuous development to attain even better performance than the present developed models should be the challenging subject among applied research scientists and concerned institutions.

ANNEX I

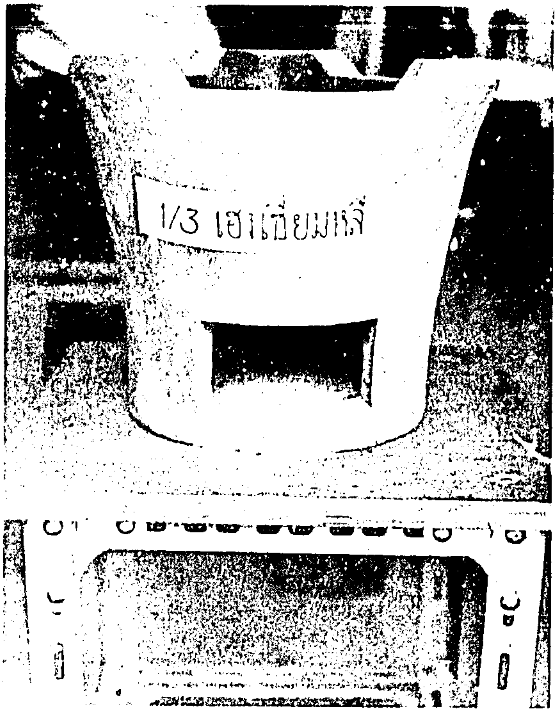
Commercial Charcoal Bucket Stove Investigated

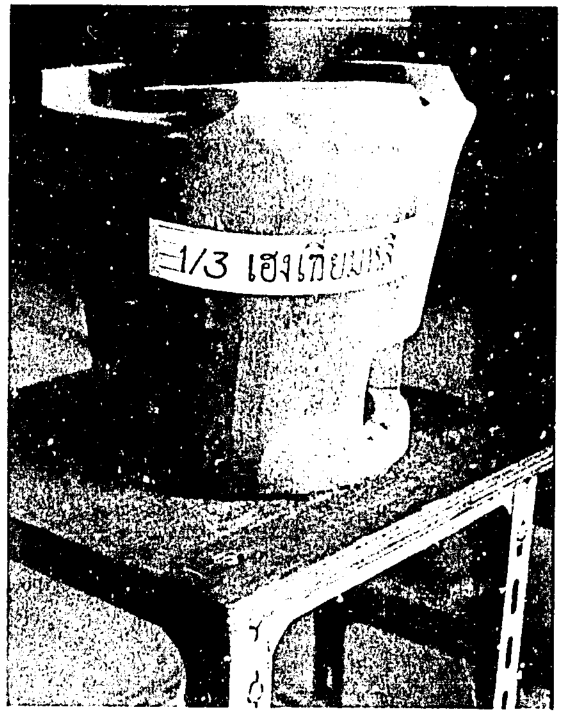
243

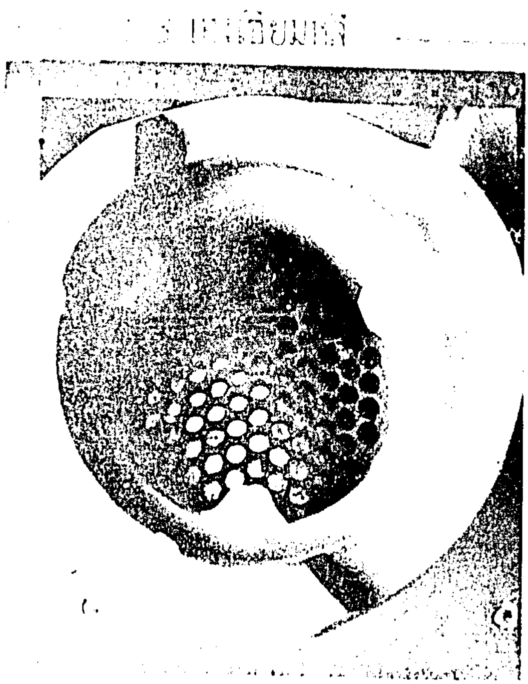




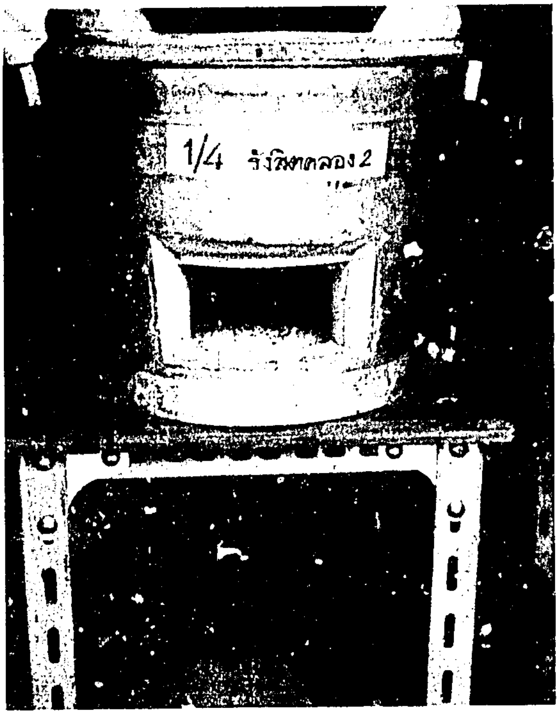
Stove No.	1/2	(Charcoal & wood)
Name	<u>Heng Siem Lee</u>	
Pot hole diameter	19, 23	cm
Weight	12.2	kg
Exhaust gap	2	cm
Exhaust area	96	cm^2
Grate hole area	112	cm^2
Grate: grate hole area	1:0.46	
Fuel chamber size	2426	cm^3
Time to boil	21.7	min
HU	24.96	%

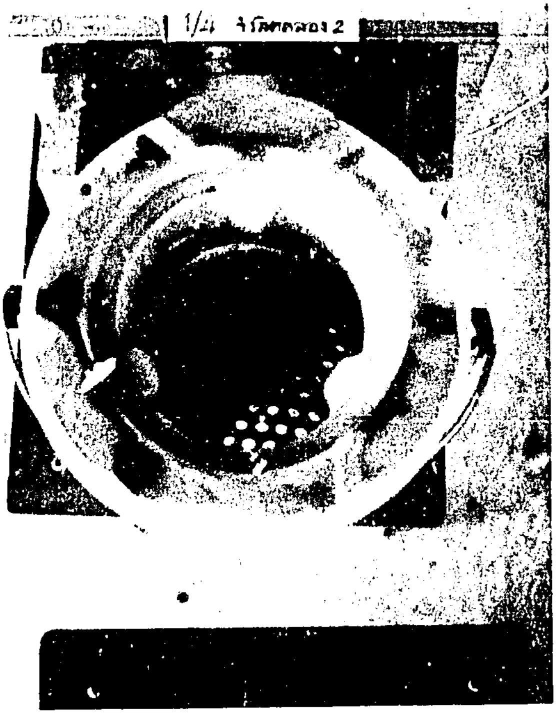




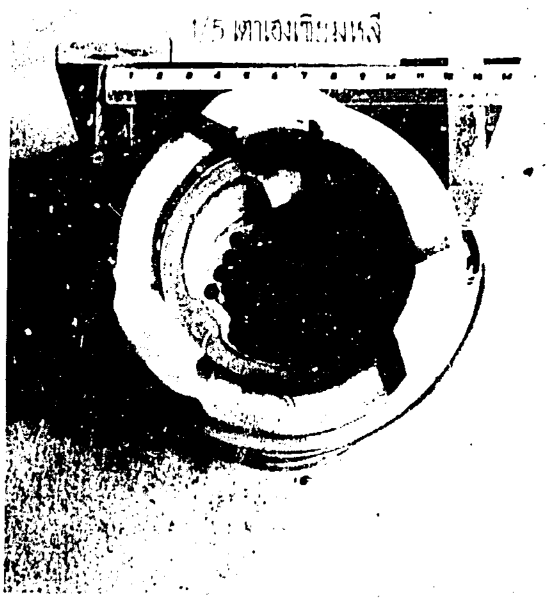


Stove No.	1/3	(Non insulated)
Name	Heng Siem Lee	
Pot hole diameter	19,24	cm
Weight	8.7	kg
Exhaust gap	1.8	cm
Exhaust area	[illegible]7	cm^2
Grate hole area	112	cm^2
Grate: grate hole area	1:0.46	
Fuel chamber size	2426	cm^3
Time to boil	22.3	min
HU	25.70	%

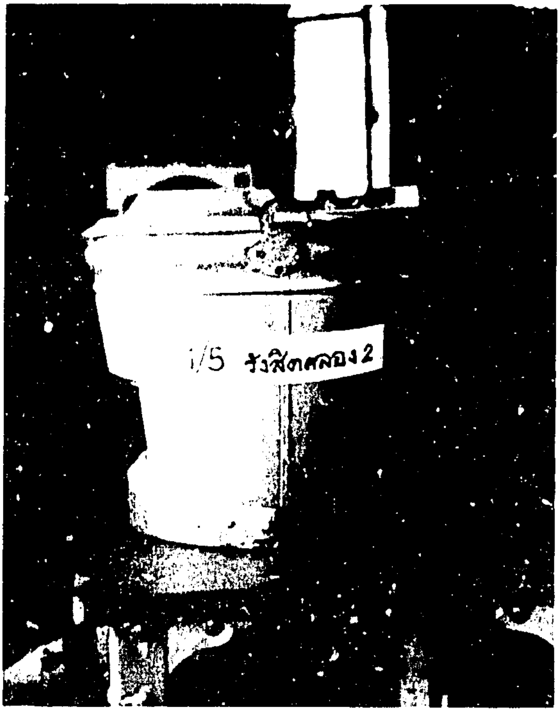


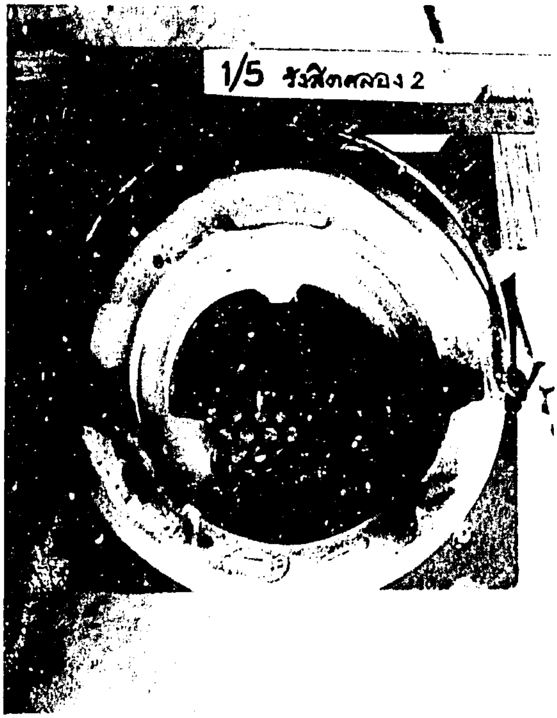


Stove No.	1/4	
Name <u>Rungsit</u>		
Pot hole diameter	19,23.5	cm
Weight	12.8	kg
Exhaust gap	1.5	cm
Exhaust area	76	cm^2
Grate hole area	112	cm^2
Grate: grate hole area	1:0.46	
Fuel chamber size	2426	cm^3
Time to boil	18.8	min
HU	28.19	%

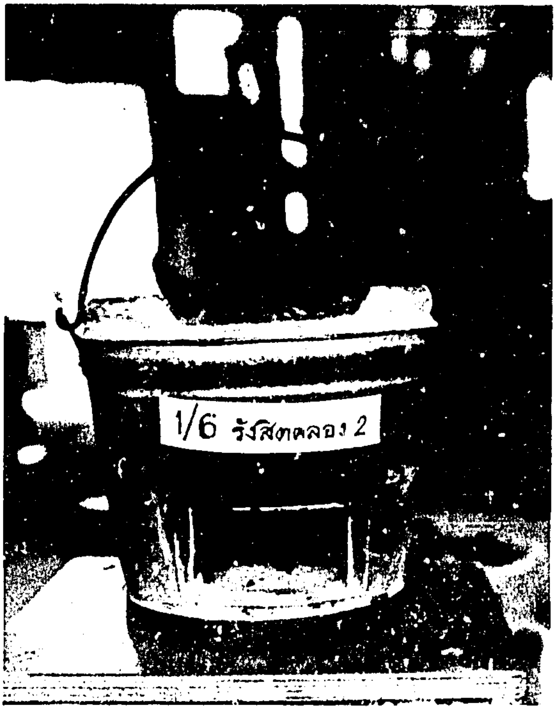


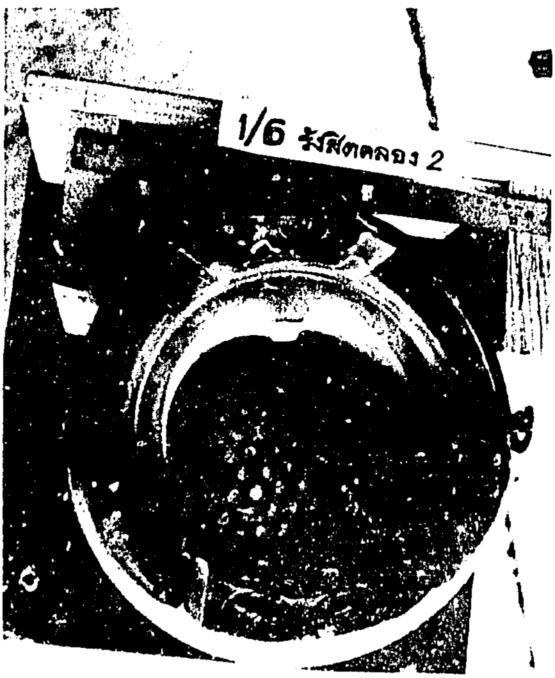
Stove No.	1/5	(Stainless bucket)
Name	Rungsit	
Pot hole diameter	16,20	cm
Weight	9.3	kg
Exhaust gap	1.0	cm
Exhaust area	41	cm^2
Grate hole area	80	cm^2
Grate: grate hole area	1:0.45	
Fuel chamber size	1575	cm^3
Time to boil	21.1	min
HU	30.53	%



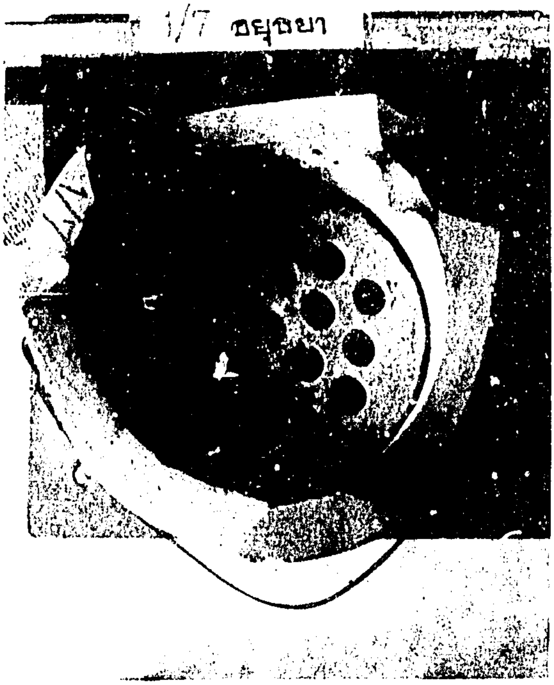


Stove No.	1/5	
Name	Rungsit	
Pot hole diameter	16,20	cm
Weight	9.3	kg
Exhaust gap	1.0	cm
Exhaust area	41	cm^2
Grate hole area	80	cm^2
Grate: grate hole area	1:0.45	
Fuel chamber size	1575	cm^3
Time to boil	21.1	min
HU	30.53	%

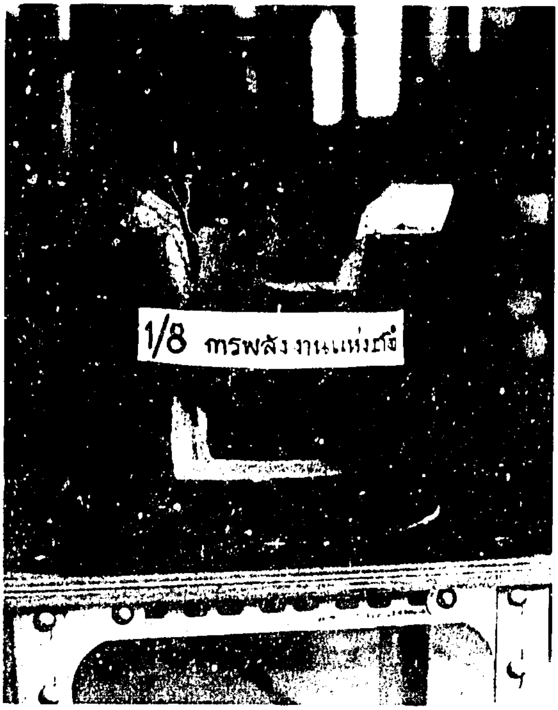


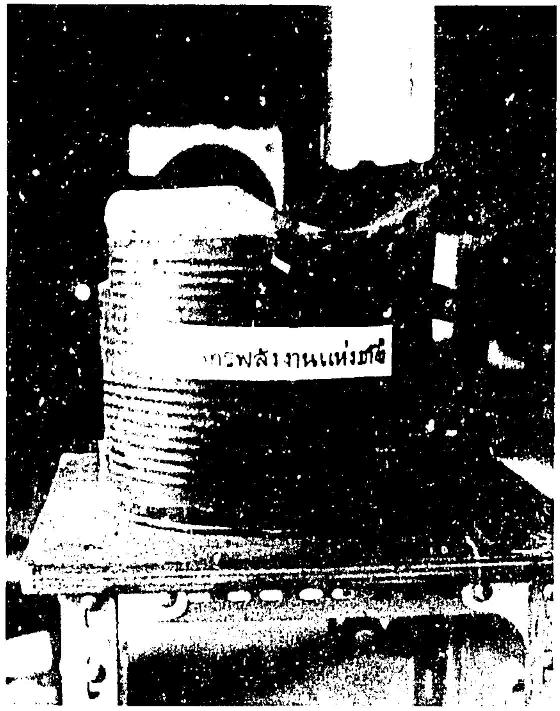


Stove No.	1/6	
Name <u>Rungsit</u>		
Pot hole diameter	20,0	cm
Weight	8.6	kg
Exhaust gap	1.0	cm
Exhaust area	41	cm^2
Grate hole area	69	cm^2
Grate: grate hole area	1:0.36	
Fuel chamber size	2065	cm^3
Time to boil	18.0	min
HU	28.83	%



Stove No.	1/7	
Name Ayudthya		
Pot hole diameter	21	cm
Weight	6.4	kg
Exhaust gap	2	cm
Exhaust area	63	cm^2
Grate hole area	66	cm^2
Grate: grate hole area	1:0.23	
Fuel chamber size	1931	cm^3
Time to boil	28	min
HU	25.61	%

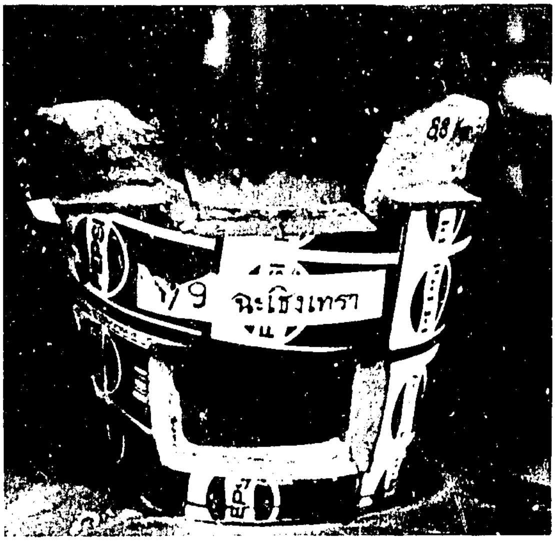




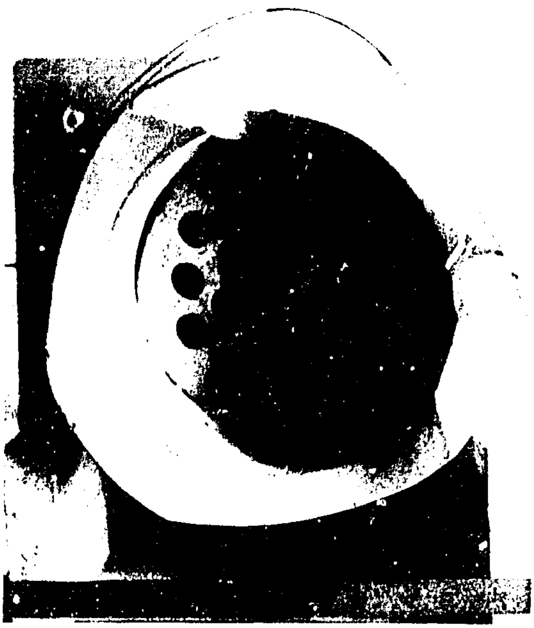
Stove No. 1/8

Name unknown

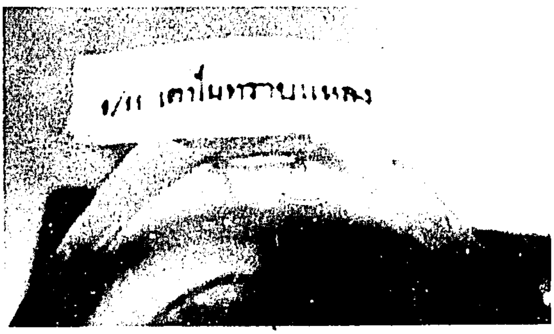
Pot hole diameter	18	cm
Weight	8.1	kg
Exhaust gap	1.5	cm
Exhaust area	70	cm^2
Grate hole area	48	cm^2
Grate: grate hole area	1:0.2	
Fuel chamber size	1832	cm^3
Time to boil	27	min
HU	24.07	%



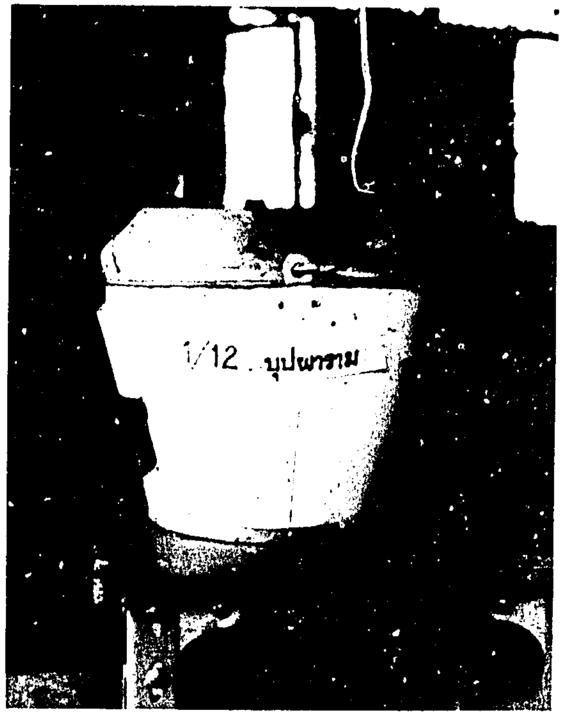
Stove No.	1/9	
Name	Chacherngsac	
Pot hole diameter	23	cm
Weight	8.7	kg
Exhaust gap	3	cm
Exhaust area	66	cm^2
Grate hole grea	94	cm^2
Grate: grate hole area	1:0.28	
Fuel chamber size	3232	cm^3
Time to boil	23	min
HU	28.42	%

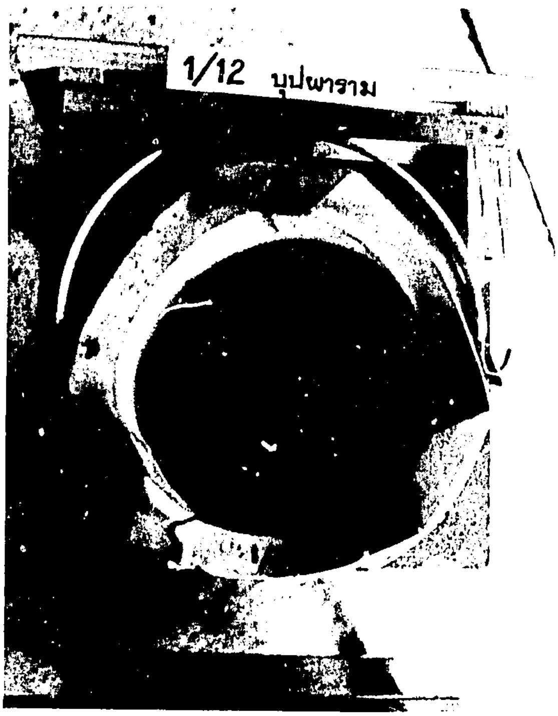


Stove No.	1/10	
Name	unknown	
Pot hole diameter	21	cm
Weight	4.2	kg
Exhaust gap	2	cm
Exhaust area	80	cm^2
Grate hole area	54	cm^2
Grate: grate hole area	1:0.21	
Fuel chamber size	2176	cm^3
Time to boil	31.7	min
HU	26.54	%



Stove No.	1/11	
Name <u>unknown</u>		
Pot hole diameter	20	cm
Weight	4.2	kg
Exhaust gap	2	cm
Exhaust area	80	cm^2
Grate hole area	85	cm^2
Grate: grate hole area	1:0.21	
Fuel chamber size	2176	cm^3
Time to boil	22.3	min
HU	26.52	%





Stove No. 1/12

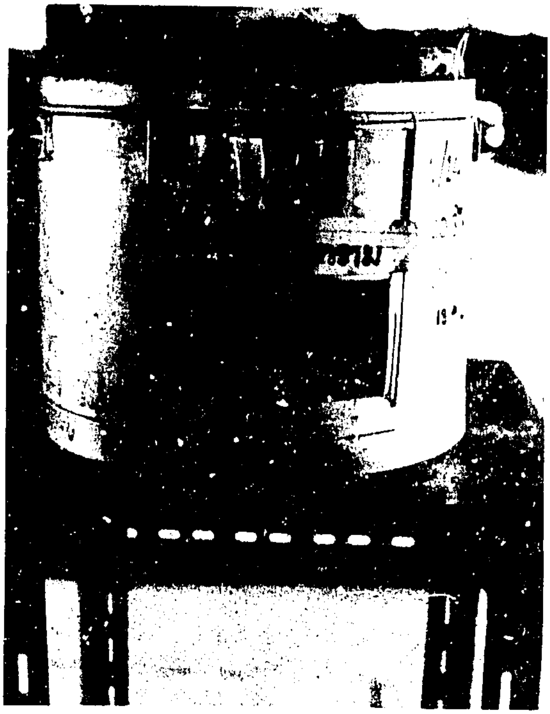
Name Booppararm

Pot hole diameter	21	cm
Weight	7.2	kg
Exhaust gap	2	cm
Exhaust area	80	cm^2
Grate hole area	65	cm^2
Grate: grate hole area	1:0.22	
Fuel chamber size	2856	cm^3
Time to boil	22.6	min
HU	29.02	%

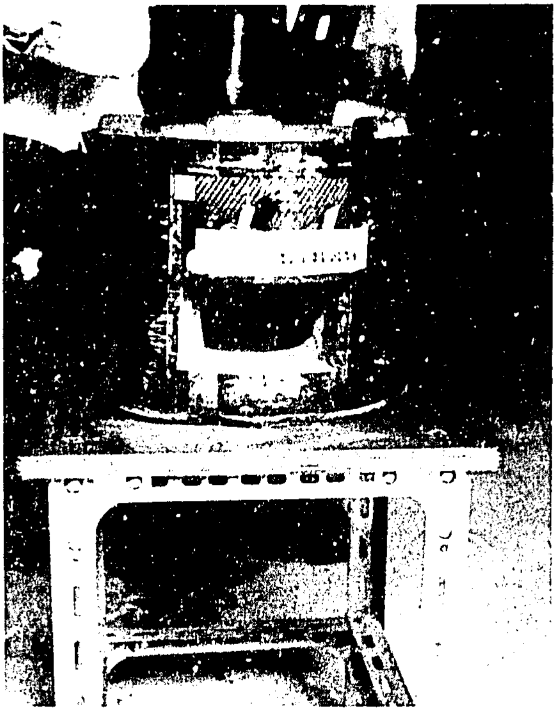
Stove No. 1/13

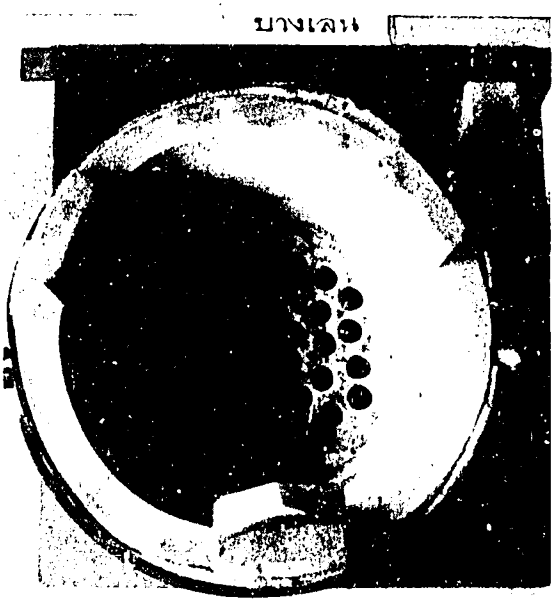
Name <u>Samyakphicharg</u>

Pot hole diameter	22	cm
Weight	10.7	kg
Exhaust gap	1.6	cm
Exhaust area	74	cm^2
Grate hole area	76	cm^2
Grate: grate hole area	1:0.28	
Fuel chamber size	2390	cm^3
Time to boil	23.9	min
HU	26.12	%

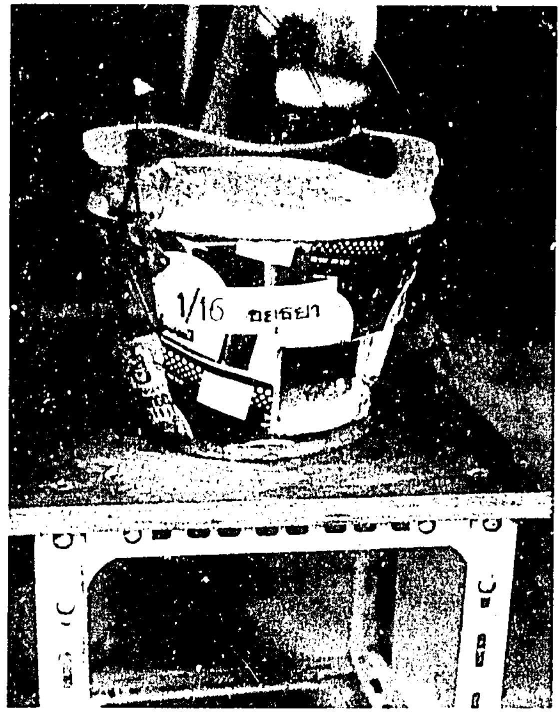


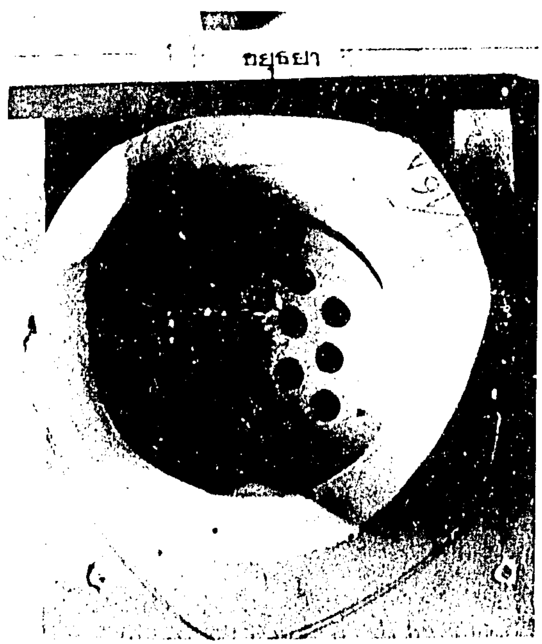
Stove No.	1/14	
Name	Boopparam	
Pot hole diameter	20	cm
Weight	19	kg
Exhaust gap	2.5	cm
Exhaust area	113	cm^2
Grate hole area	65	cm^2
Grate: grate hole area	1:0.23	
Fuel chamber size	3464	cm^3
Time to boil	27.2	min
HU	23.53	%



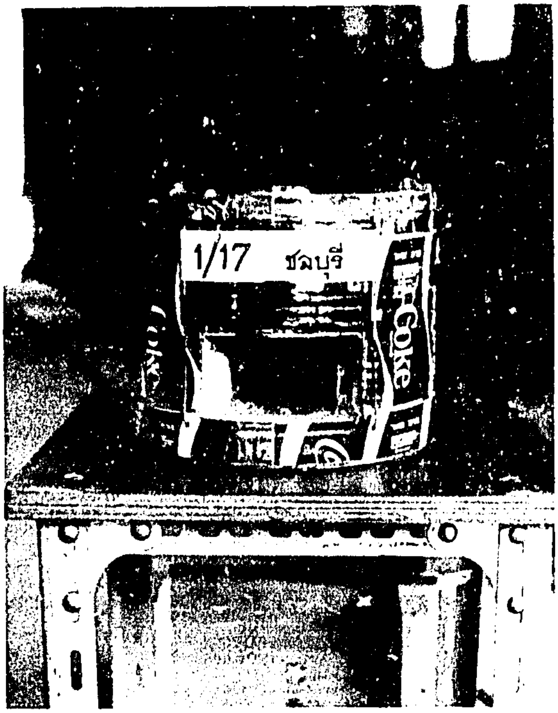


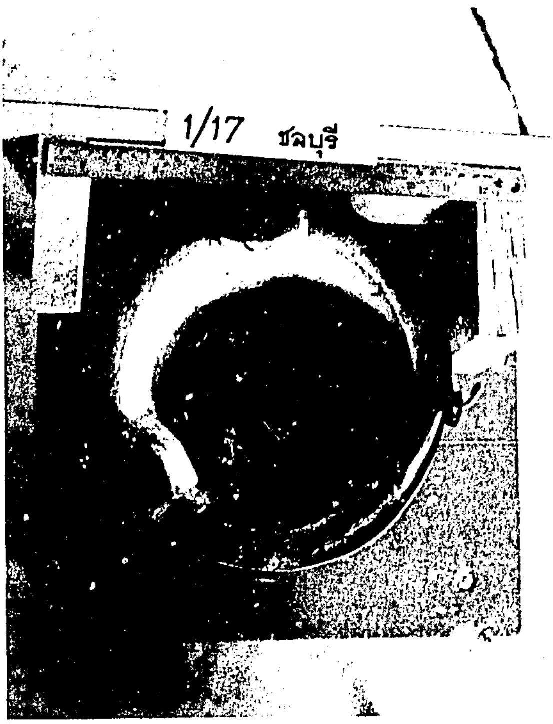
Stove No.	1/15	
Name	Banglane	
Pot hole diameter	20	cm
Weight	10.0	kg
Exhaust gap	2	cm
Exhaust area	108	cm^2
Grate hole grea	65	cm^2
Grate: grate hole area	1:0.23	
Fuel chamber size	2865	cm^3
Time to boil	24.26	min
HU	27.21	%





Stove No.	1/16	
Name	Ayudthya	
Pot hole diameter	21	cm
Weight	6.6	kg
Exhaust gap	1.0	cm
Exhaust area	45	cm^2
Grate hole area	59	cm^2
Grate: grate hole area	1:0.2	
Fuel chamber size	2618	cm^3
Time to boil	27.2	min
HU	27.45	%

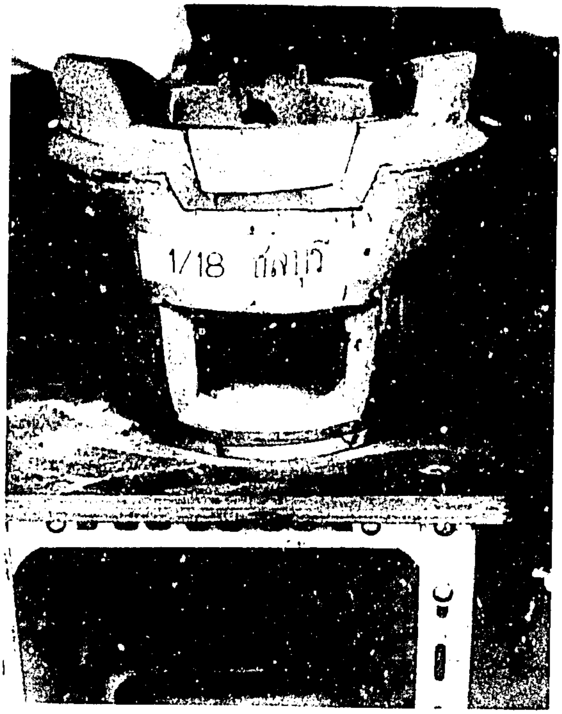




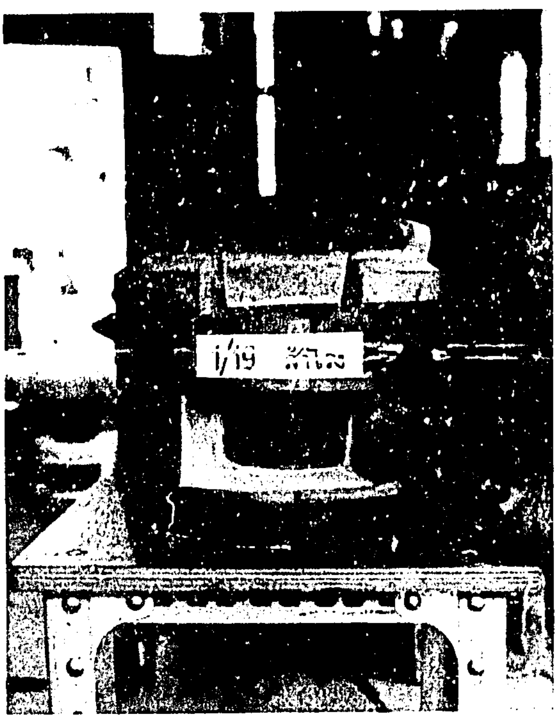
Stove No. 1/17

Name Cholburi

Pot hole diameter	17	cm
Weight	5.9	kg
Exhaust gap	1.2	cm
Exhaust area	50	cm²
Grate hole area	54	cm²
Grate: grate hole area	1:0.31	
Fuel chamber size	2013	cm³
Time to boil	20	mir
HU	32.30	%



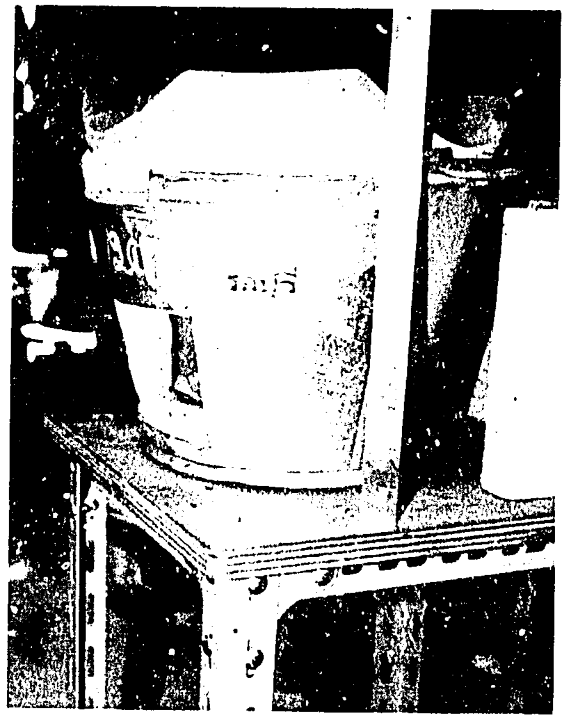
Stove No.	1/18	
Name	Cholburi	
Pot hole diameter	21	cm
Weight	7.2	kg
Exhaust gap	2	cm
Exhaust area	96	cm^2
Grate hole area	68	cm^2
Grate: grate hole area	1:0.25	
Fuel chamber size	3202	cm^3
Time to boil	23.6	min
HU	26.85	%

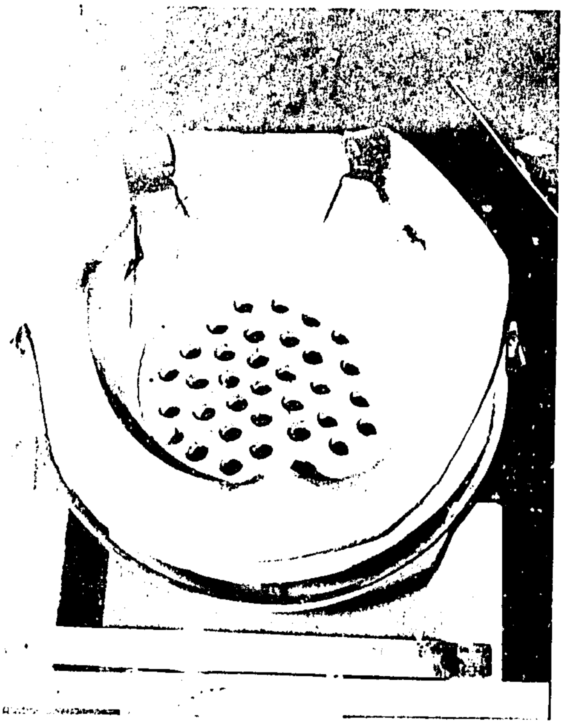


Stove No. 1/19

Name Samrong

Pot hole diameter	18	cm
Weight	10.5	kg
Exhaust gap	2.5	cm
Exhaust area	105	cm^2
Grate hole area	94	cm^2
Grate: grate hole area	1:0.5	
Fuel chamber size	3[illegible]42	cm^3
Time to boil	23.8	min
HU	23.94	%

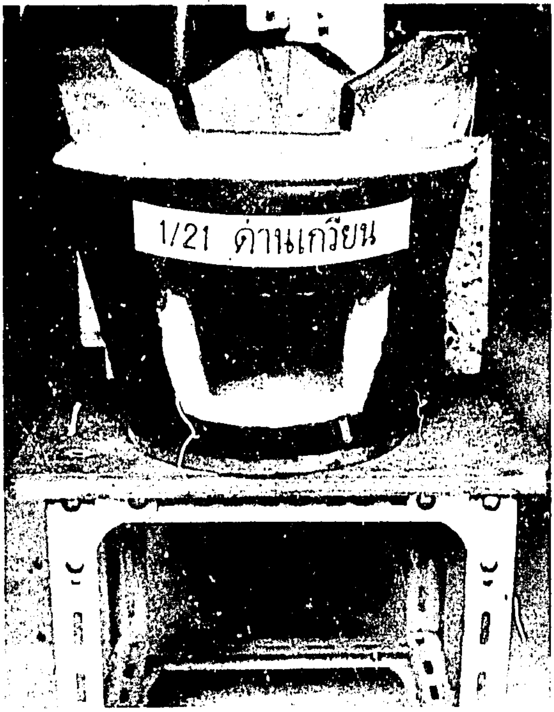


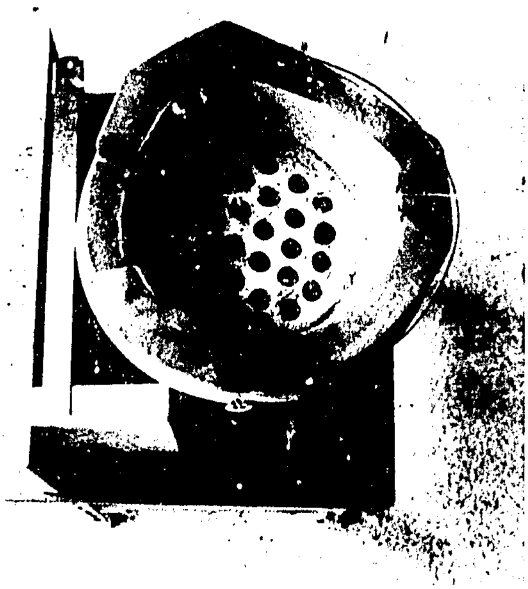


Stove No. 1/20

Name Cholburi

Pot hole diameter	23	cm
Weight	10.2	kg
Exhaust gap	2	cm
Exhaust area	102	cm^2
Grate hole area	94	cm^2
Grate: grate hole area	1:0.30	
Fuel chamber size	2516	cm^3
Time to boil	30.3	min
HU	24.49	%

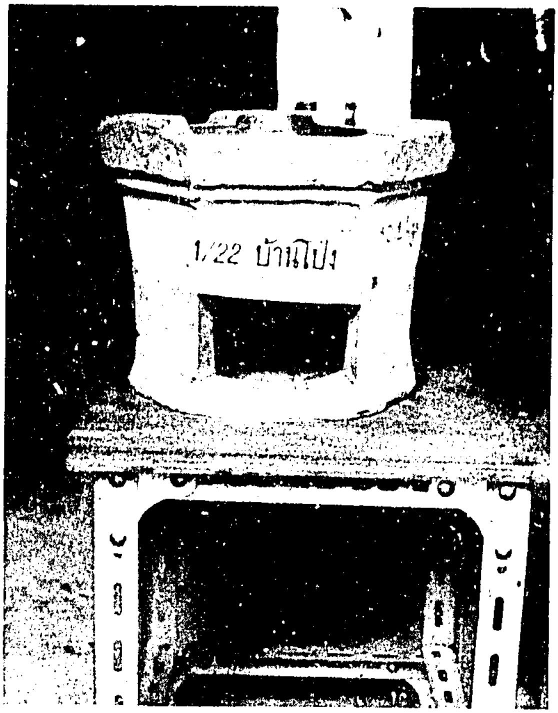


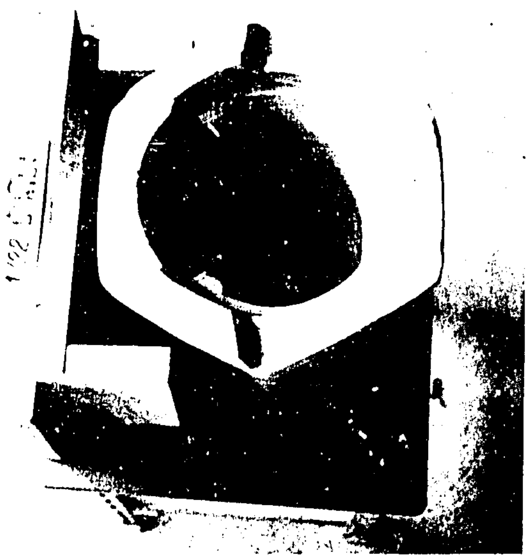


Stove No. 1/21

Name Darnkwian

Pot hole diameter	22.5	cm
Weight	11.1	kg
Exhaust gap	3	cm
Exhaust area	107	cm^2
Grate hole grea	68	cm^2
Grate: grate hole area	1:0.22	
Fuel chamber size	2414	cm^3
Time to boil	32.7	min
HU	24.13	%

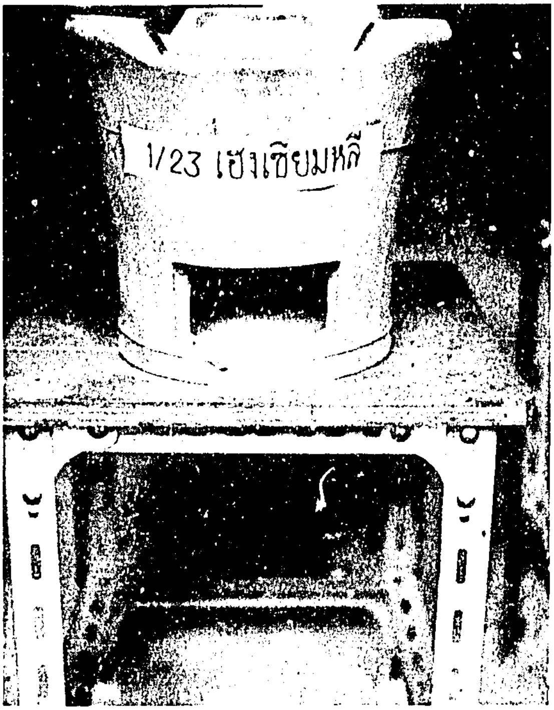


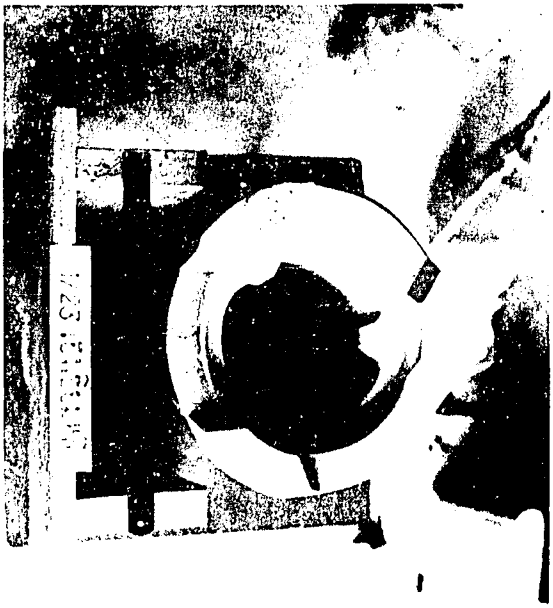


Stove No. 1/22

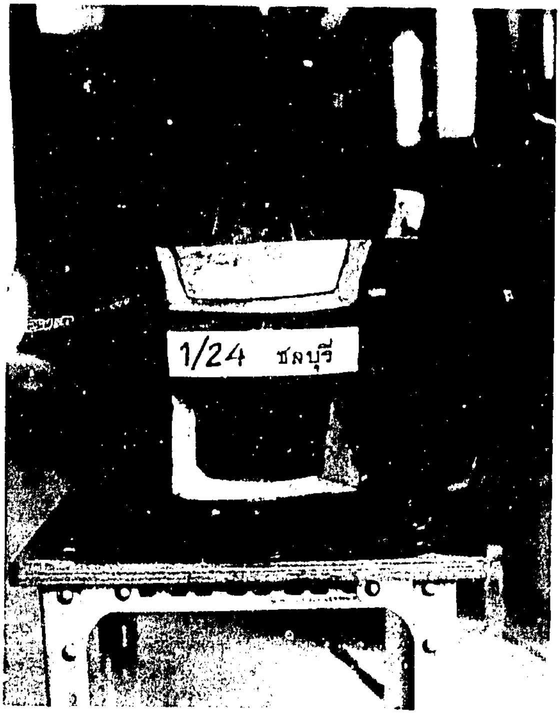
Name <u>Barnponge</u>

Pot hole diameter	20	cm
Weight	9.5	kg
Exhaust gap	0.7	cm
Exhaust area	38	cm^2
Grate hole area	85	cm^2
Grate: grate hole area	1:0.29	
Fuel chamber size	3155	cm^3
Time to boil	23.3	min
HU	28.11	%

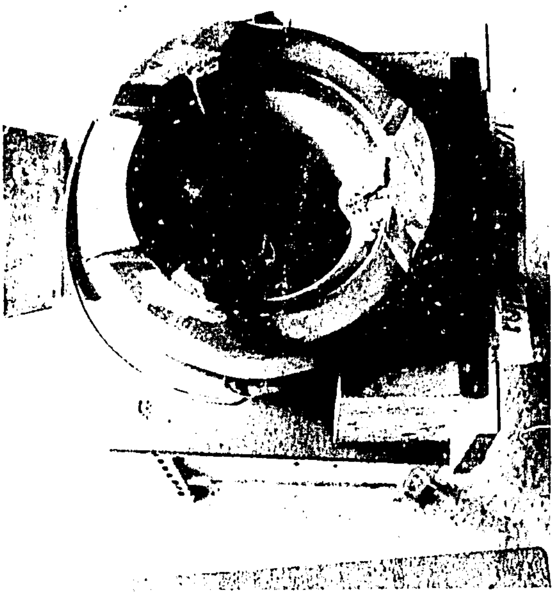




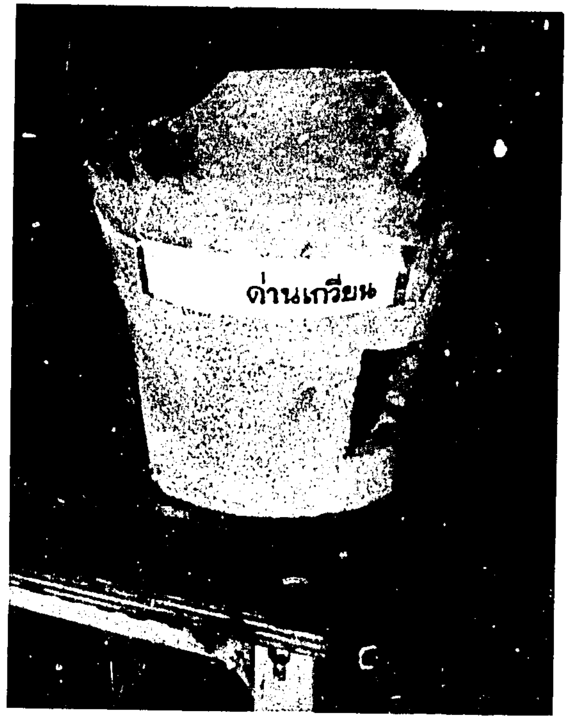
Stove No.	1/23	(non insulated)
Name	<u>Heng Siem Lee</u>	
Pot hole diameter	16,20	cm
Weight	7.2	kg
Exhaust gap	1	cm
Exhaust area	41	cm^2
Grate hole area	80	cm^2
Grate: grate hole area	1:0.45	
Fuel chamber size	1575	cm^3
Time to boil	21.5	min
HU	29.17	%

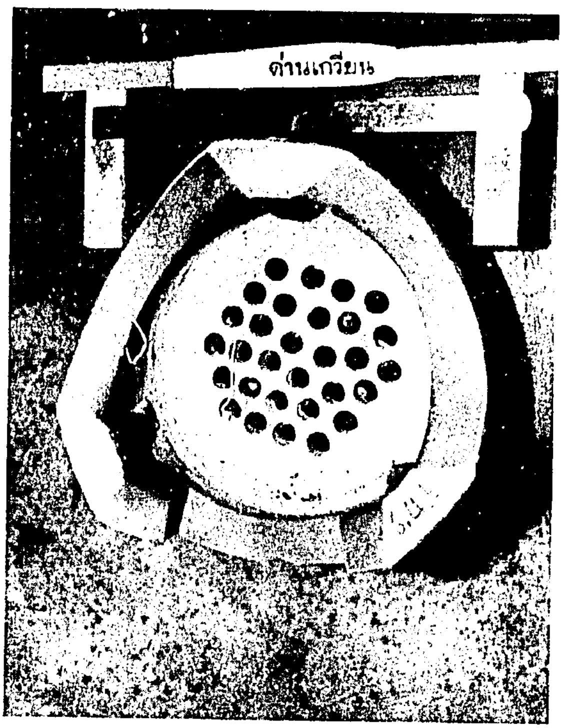


Stove No.	1/24	(Charcoal & wood)
Name <u>Cholburi</u>		
Pot hole diameter	22	cm
Weight	13.8	kg
Exhaust gap	2.2	cm
Exhaust area	112	cm^2
Grate hole area	77	cm^2
Grate: grate hole area	1:0.23	
Fuel chamber size	3815	cm^3
Time to boil	22.7	min
HU	25.9	%



Stove No. 1/25	(Charcoal & wood)	
Name Heng Siem Lee	modified	
Pot hole diameter	19,23	cm
Weight	13.2	kg
Exhaust gap	2	cm
Exhaust area	96	cm^2
Grate hole area	112	cm^2
Grate: grate hole area	1:0.46	
Fuel chamber size	2426	cm^3
Time to boil	11.8	min
HU	26.59	%



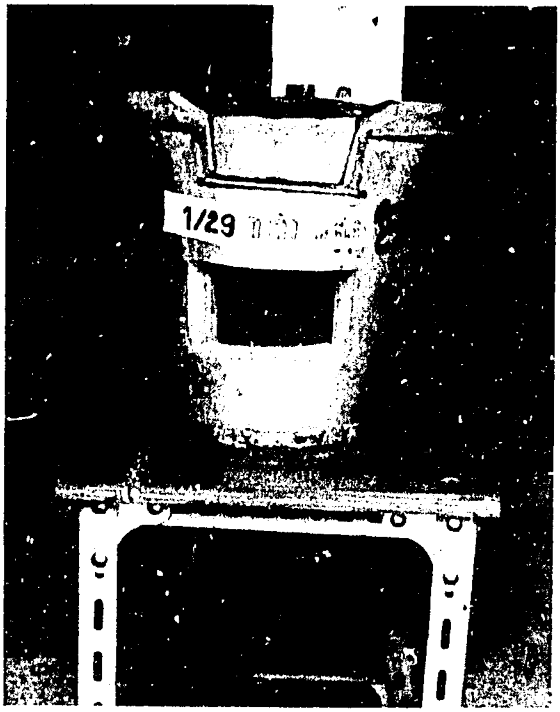


Stove No. 1/26 (non insulated)

Name Darnkwian

Pot hole diameter	23	cm
Weight	6.6	kg
Exhaust gap	1.5	cm
Exhaust area	90	cm^2
Grate hole area	75	cm^2
Grate: grate hole area	1:0.24	
Fuel chamber size	2700	cm^3
Time to boil	23.7	min
HU	24.35	%

Stove No.	1/28	
Name	Sa Sua	
Pot hole diameter	23	cm
Weight	12.2	kg
Exhaust gap	2.3	cm
Exhaust area	131	cm^2
Grate hole area	74	cm^2
Grate: grate hole area	1:0.24	
Fuel chamber size	4261	cm^3
Time to boil	20.1	min
HU	25.10	%



Stove No. 1/29

Name Sa Sua, modified

Pot hole diameter 19 cm.

Weight 13.2 kg.

Exhaust gap 2 cm.

Exhaust area 85 $cm.^2$

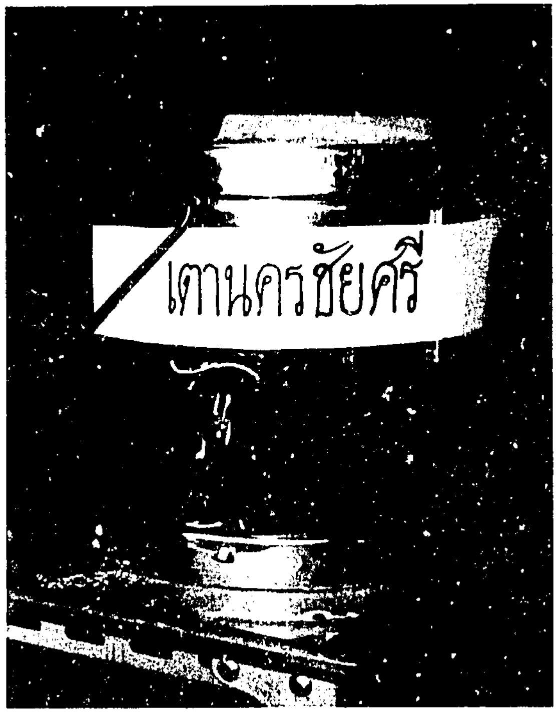
Grate hole area 74 $cm.^2$

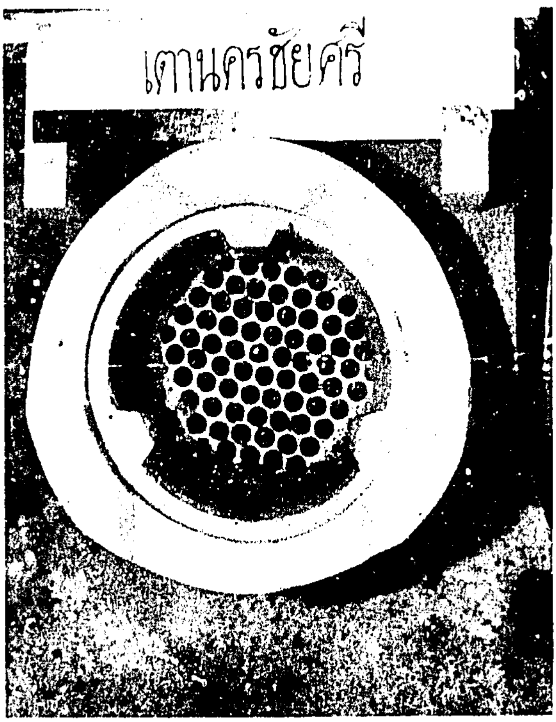
Grate: grate hole area 1:0.33

Fuel chamber size 3414 $cm.^3$

Time to boil 20 min.

HU 28.85 %

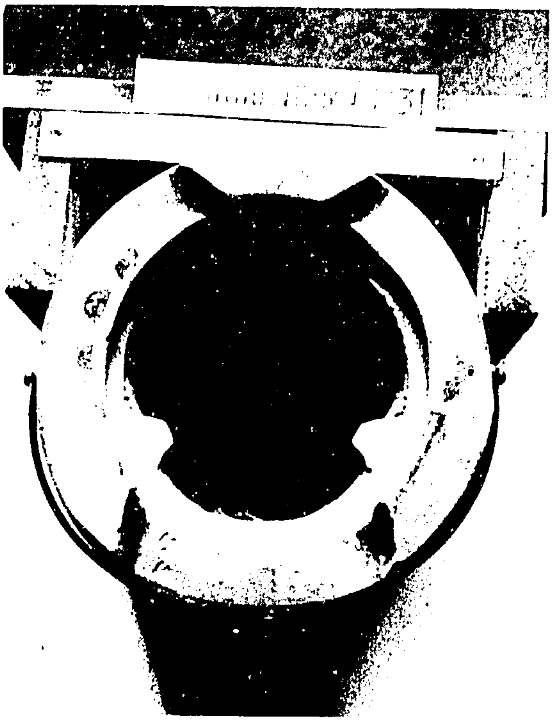




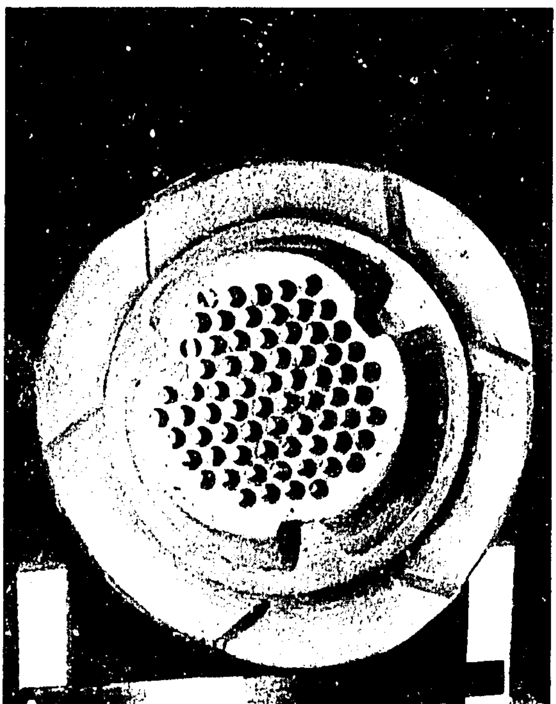
Stove No. 1/30

Name Nakornchaisee

Pot hole diameter	20,24	cm
Weight	18	kg
Exhaust gap	1.5	cm
Exhaust area	72	cm^2
Grate hole area	131	cm^2
Grate: grate hole area	1:0.46	
Fuel chamber size	2992	cm^3
Time to boil	16.9	min
HU	24.25	%

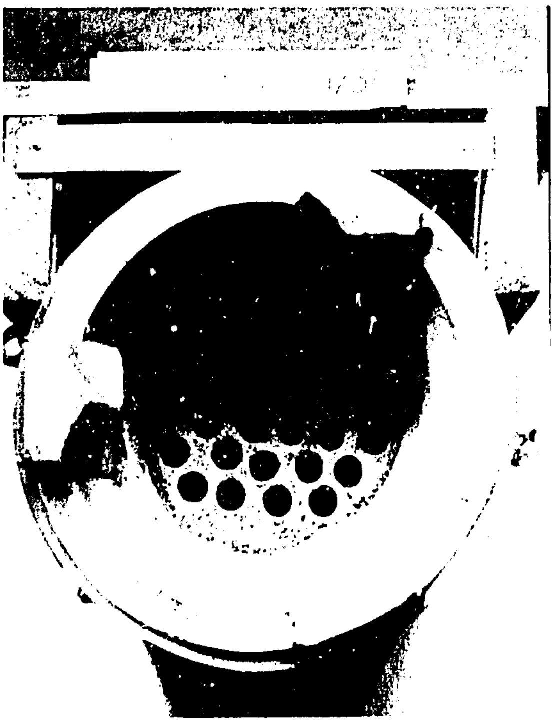


Stove No.	1/31	
Name	nakornchaisee	
Pot hole diameter	17,20	cm
Weight	11.8	kg
Exhaust gap	0.5	cm
Exhaust area	20	cm^2
Grate hole area	94	cm^2
Grate: grate hole area	1:0.44	
Fuel chamber size	2250	cm^3
Time to boil	16.7	min
HU	32.39	%

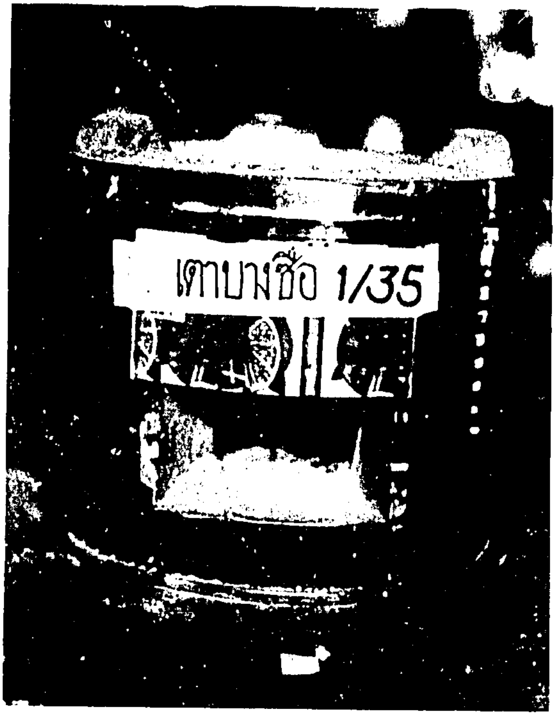


Stove No.	1/32	
Name	Nakornchaisee	
Pot hole diameter	20,24	cm
Weight	8.2	kg
Exhaust gap	2	cm
Exhaust area	102	cm^2
Grate hole area	131	cm^2
Grate: grate hole area	1:0.46	
Fuel chamber size	2992	cm^3
Time to boil	17.6	min
HU	24.61	%

Stove No.	1/33	
Name	<u>Nakornchaisee</u>	
Pot hole diameter	17,20	cm
Weight	6.7	kg
Exhaust gap	0.5	cm
Exhaust area	20	cm^2
Grate hole grea	94	cm^2
Grate: grate hole area	1:0.41	
Fuel chamber size	2550	cm^3
Time to boil	18.3	min
HU	30.51	%



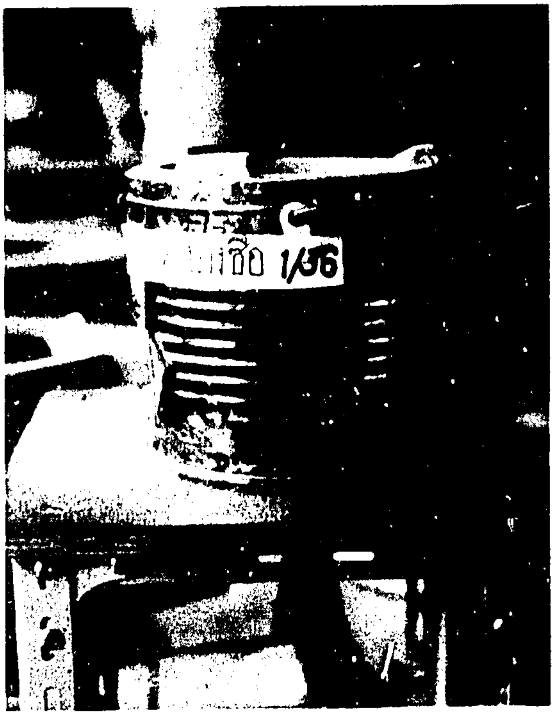
Stove No.	1/34	
Name	Bang Sue	
Pot hole diameter	30	cm
Weight	10.4	kg
Exhaust gap	1.8	cm
Exhaust area	103	cm^2
Grate hole area	68	cm^2
Grate: grate hole area	1:0.27	
Fuel chamber size	2829	cm^3
Time to boil	21.2	min
HU	26.07	%



Stove No. 1/35

Name Bang Sue

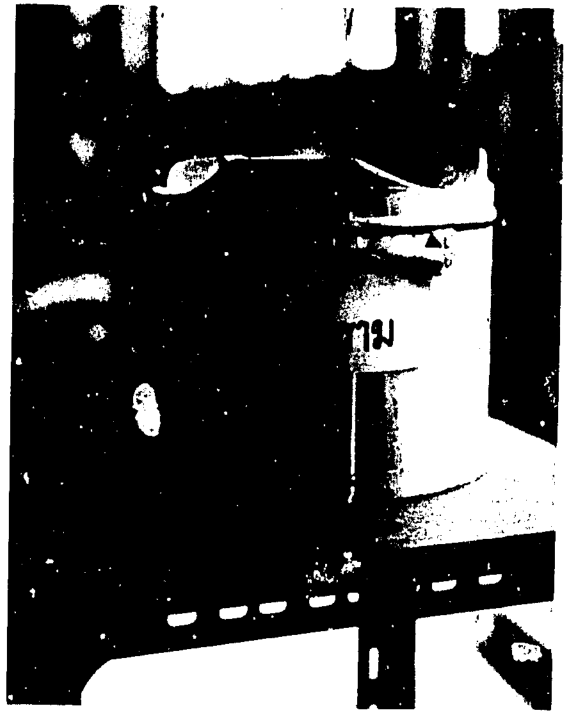
Pot hole diameter	17	cm
Weight	8	kg
Exhaust gap	1.7	cm
Exhaust area	82	cm^2
Grate hole area	54	cm^2
Grate: grate hole area	1:0.27	
Fuel chamber size	2176	cm^3
Time to boil	19.8	min
HU	27.22	%

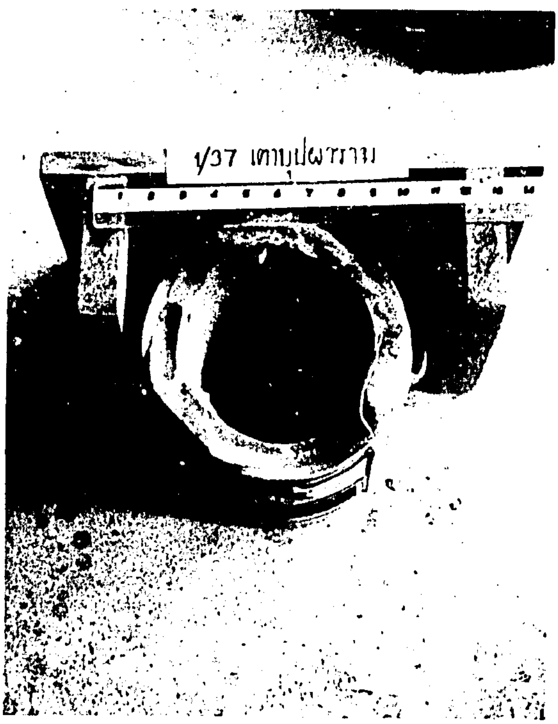


Stove No. 1/36

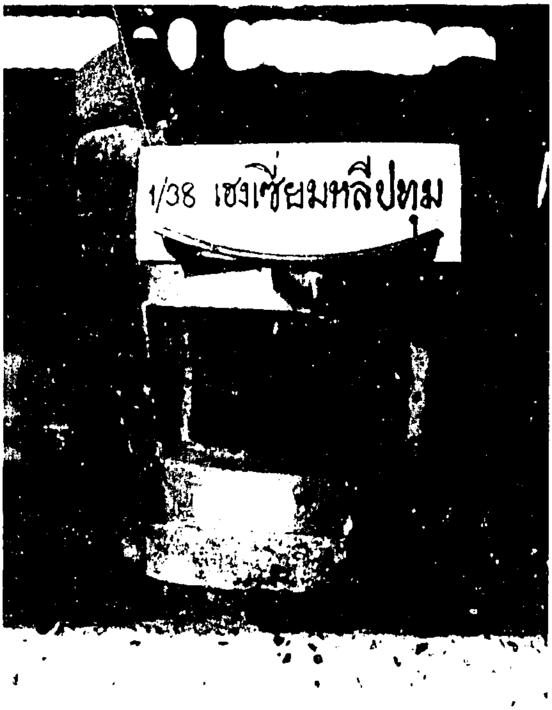
Name Bang Sue

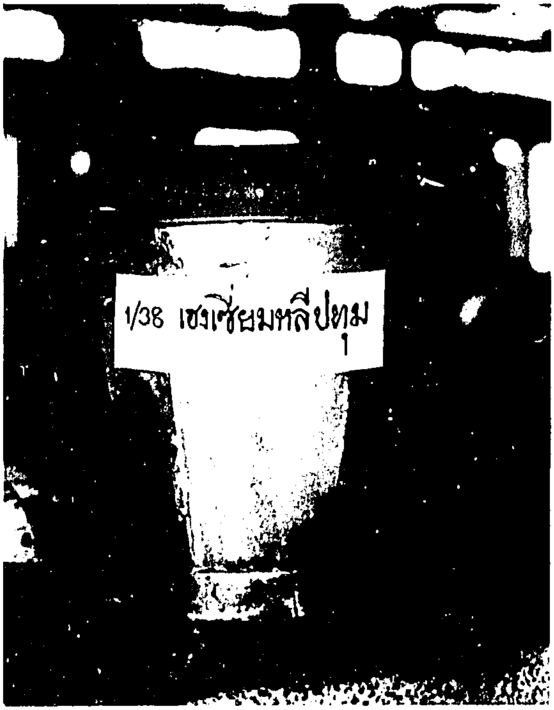
Pot hole diameter	15	cm
Weight	6.5	kg
Exhaust gap	1.5	cm
Exhaust area	56	cm^2
Grate hole area	44	cm^2
Grate: grate hole area	1:0.31	
Fuel chamber size	1568	cm^3
Time to boil	20.8	min
HU	30.67	%

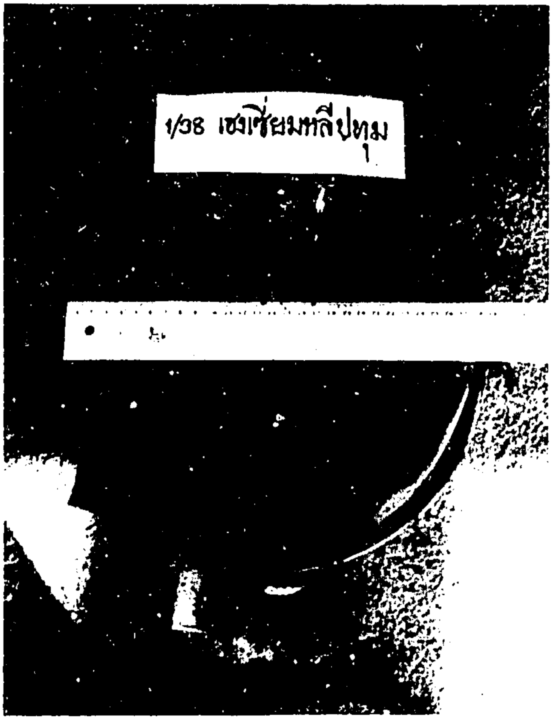




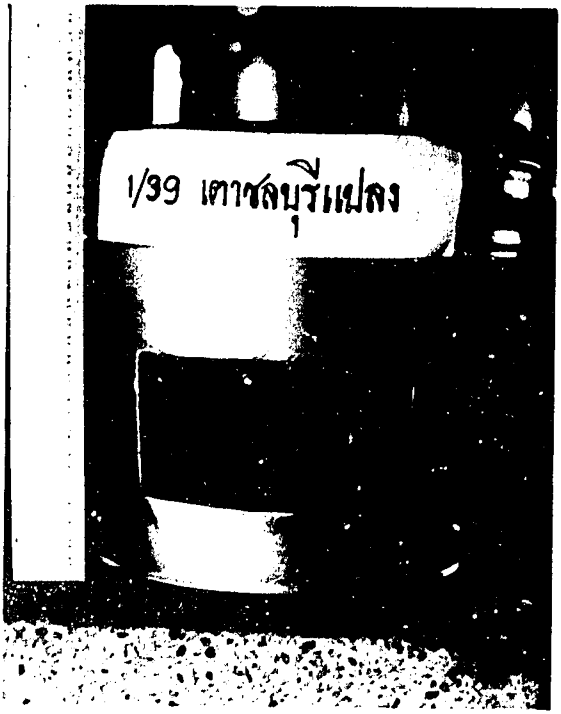
Stove No.	1/37	
Name	<u>Booppararm</u>	
Pot hole diameter	15	cm
Weight	6.5	kg
Exhaust gap	0.7	cm
Exhaust area	30	cm^2
Grate hole area	25	cm^2
Grate: grate hole area	1:0.14	
Fuel chamber size	1140	cm^3
Time to boil	26	min
HU	28.07	%







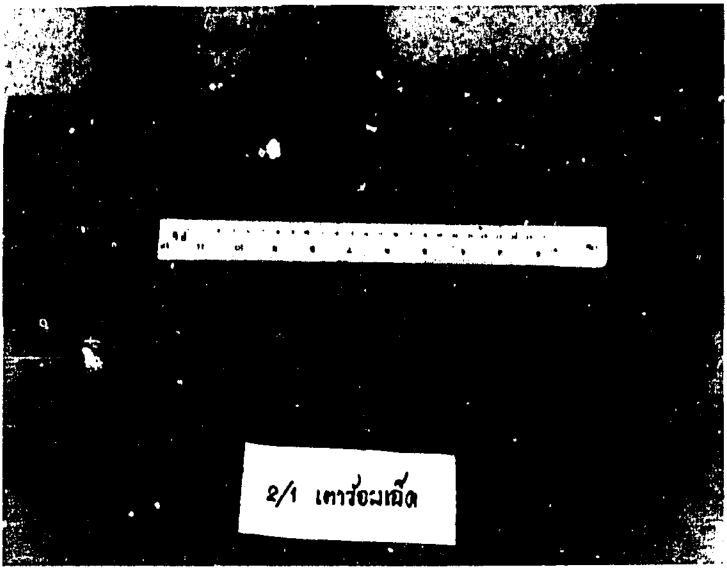
Stove No.	1/38	
Name <u>unknown</u>		
Pot hole diameter	19,22	cm
Weight	10	kg
Exhaust gap	1.9	cm
Exhaust area	122	cm^2
Grate hole grea	70	cm^2
Grate: grate hole area	1:0.35	
Fuel chamber size	2000	cm^3
Time to boil	20	min
HU	27.7	%



Stove No.	1/39	
Name	Cholburi Lab.modified	
Pot hole diameter	22.5	cm.
Weight	8	kg.
Exhaust gap	0.9	cm.
Exhaust area	47	$cm.^2$
Grate hole area	57	$cm.^2$
Grate: grate hole area	1:0.28	
Fuel chamber size	2800	$cm.^3$
Time to boil	17	min.
HU	33.35	%

ANNEX II

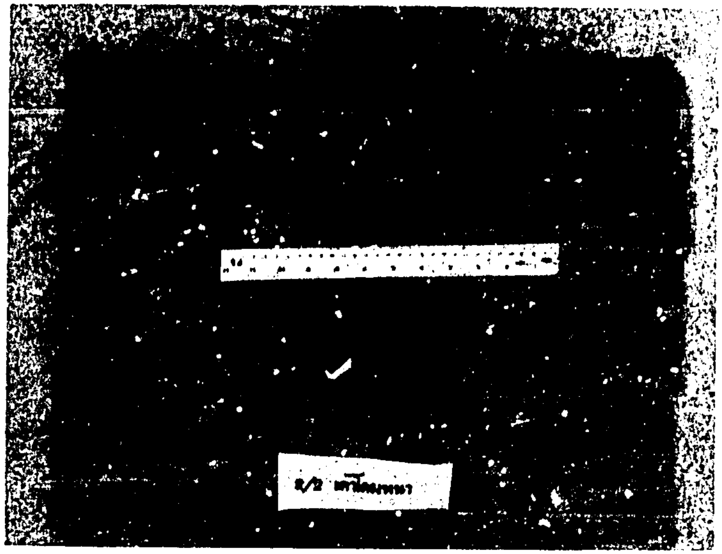
Commercial and User Built Wood Stove Without Chimney Investigated

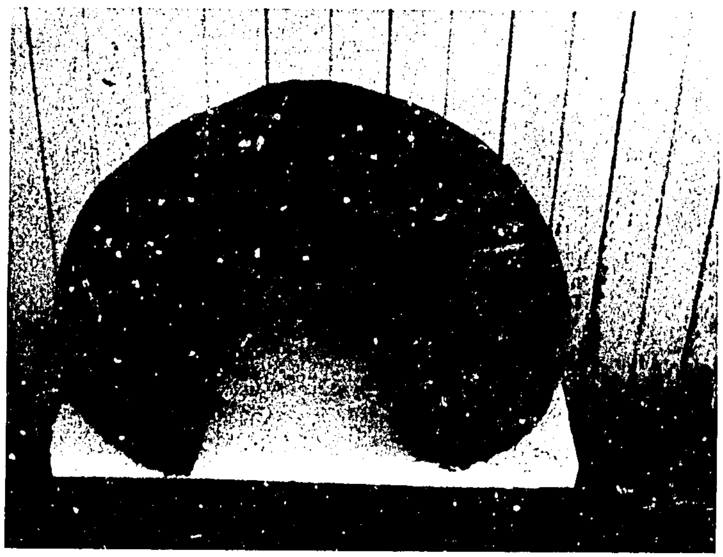


Stove No. 2/1

Name Roi-et (Original)

Pot hole diameter	22	cm
Weight	5.9	kg
Exhaust gap	1.3	cm
Exhaust area	25.3	cm^2
Grate hole area	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	7600	cm^3
Time to boil	12	min
HU	17.59	%

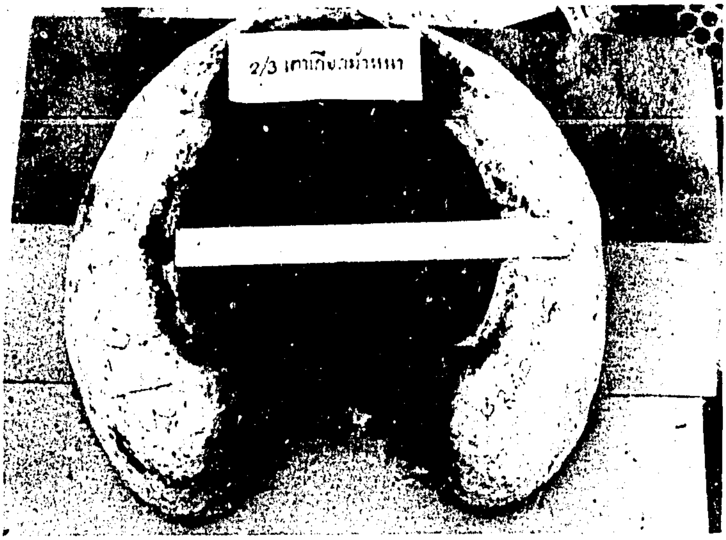




Stove No. 2/2

Name Thick dome, clay

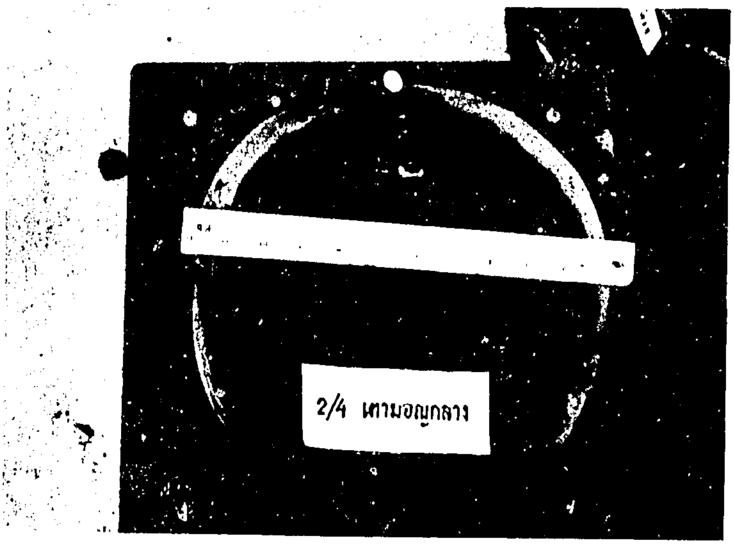
Pot hole diameter	23	cm
Weight	11.8	kg
Exhaust gap	2.1	cm
Exhaust area	18.2	cm²
Grate hole area	-	cm²
Grate: grate hole area	-	
Fuel chamber size	5800	cm³
Time to boil	14	min
HU	19.25	%



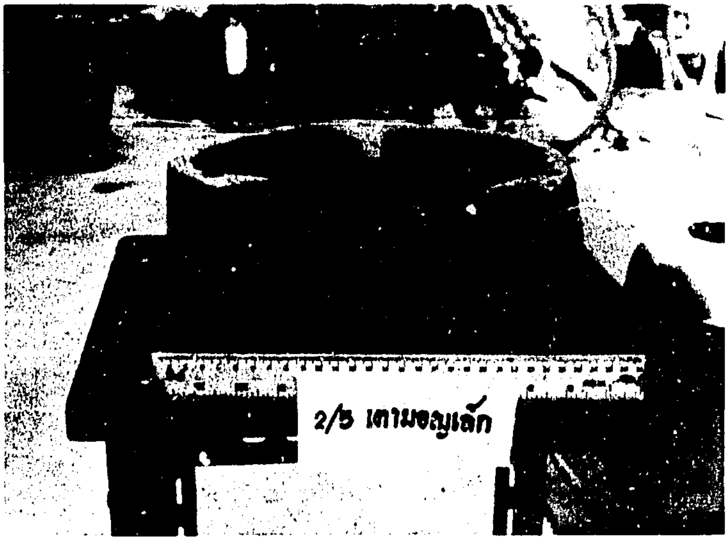
Stove No. 2/3

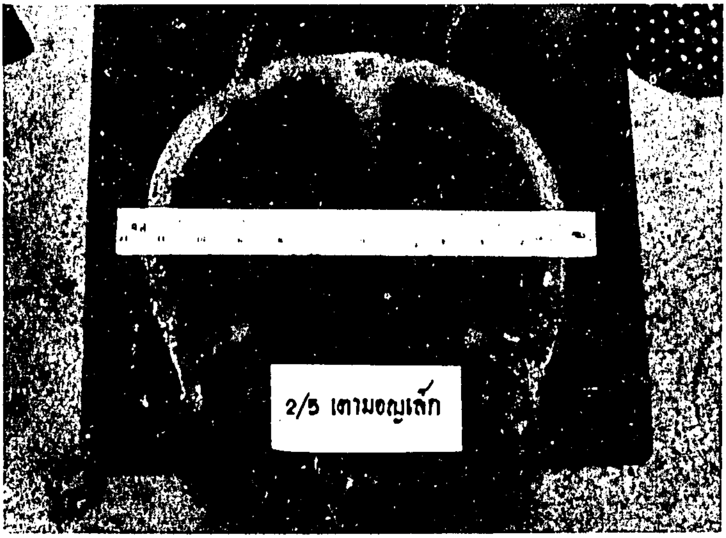
Name <u>Thick horse shoe, clay</u>

Pot hole diameter	25	cm
Weight	13.2	kg
Exhaust gap	1.9	cm
Exhaust area	86.7	cm^2
Grate hole area	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	6870	cm^3
Time to boil	13.7	min
HU	19.08	%



Stove No.	2/4	
Name	Morn Pakred, modified	
Pot hole diameter	27	cm
Weight	2.5	kg
Exhaust gap	2.6	cm
Exhaust area	90.7	cm^2
Grate hole area	160.9	cm^2
Grate: grate hole area	1:0.34	
Fuel chamber size	7440	cm^3
Time to boil	14	min
HU	20.94	%

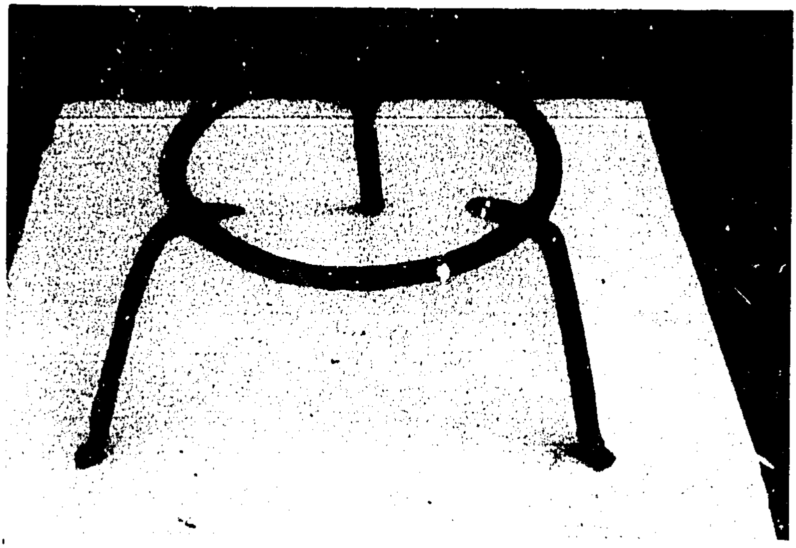


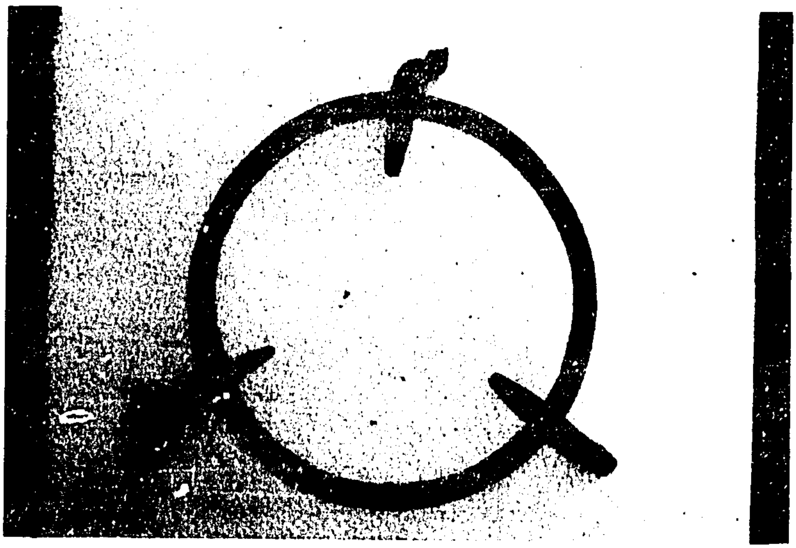


Stove No. 2/5

Name Morn Pakred, small

Pot hole diameter	18	cm
Weight	12	kg
Exhaust gap	5.0	cm
Exhaust area	210	cm²
Grate hole area		cm²
Grate: grate hole area	-	
Fuel chamber size	3600	cm³
Time to boil	17	min
HU	23.27	%

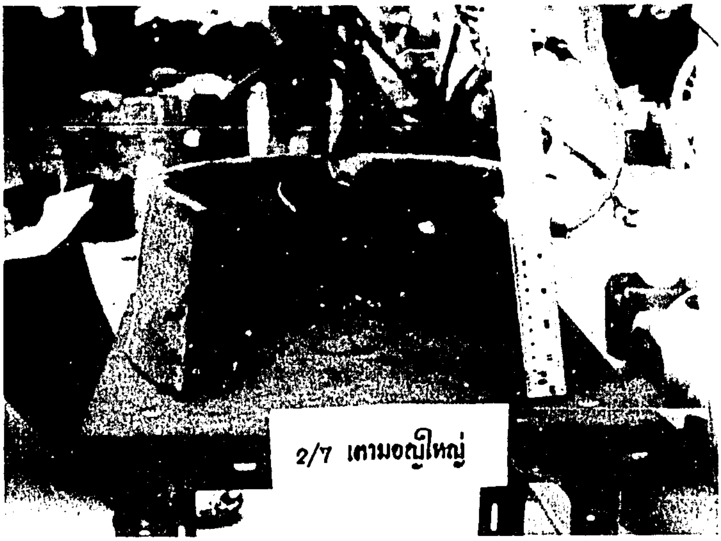


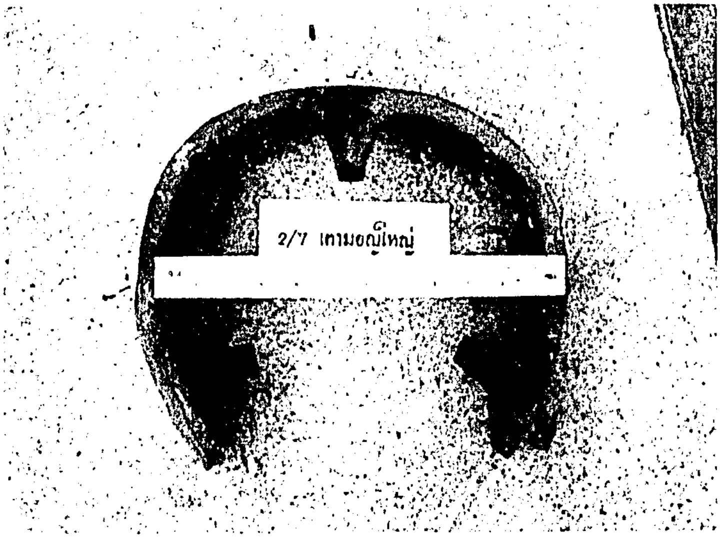


Stove No. 2/6

Name <u>Tripod</u>

Pot hole diameter	-	cm
Weight	0.7	kg
Exhaust gap	-	cm
Exhaust area	-	cm^2
Grate hole area	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	-	cm^3
Time to boil	16.2	min
HU	14.2	%

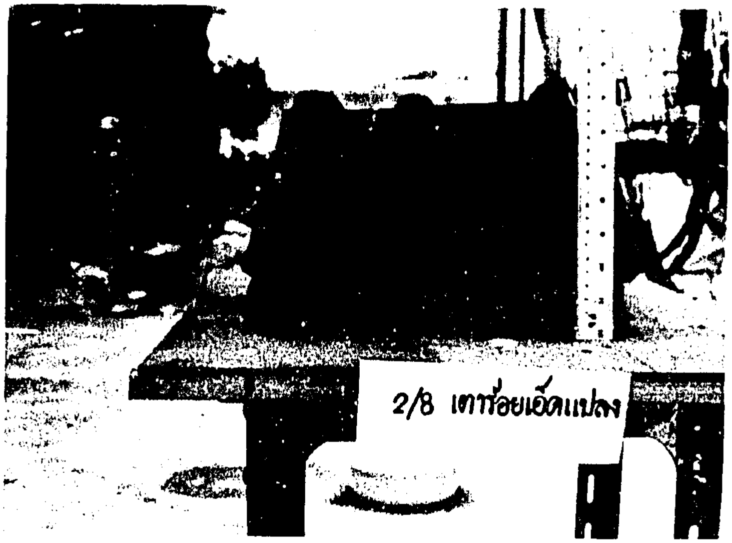


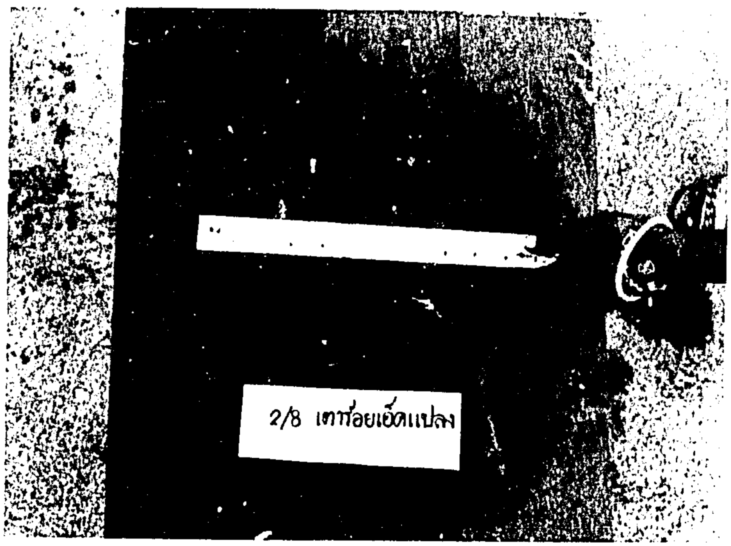


Stove No. 2/7

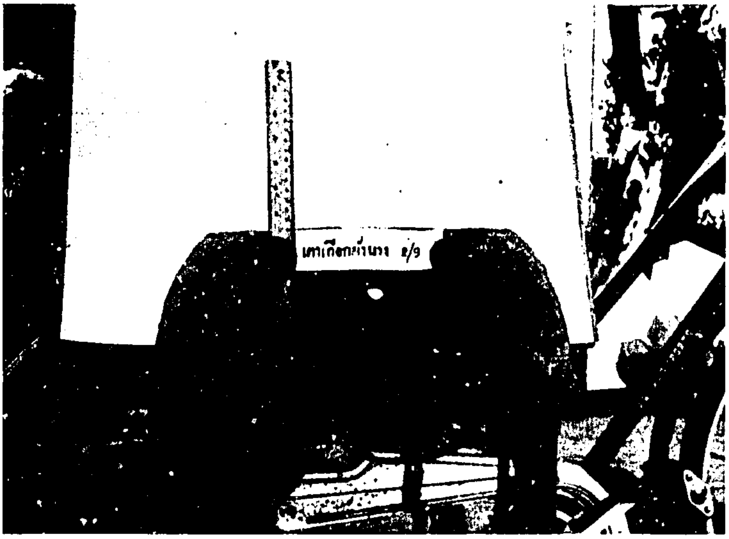
Name Morn Pakied, large

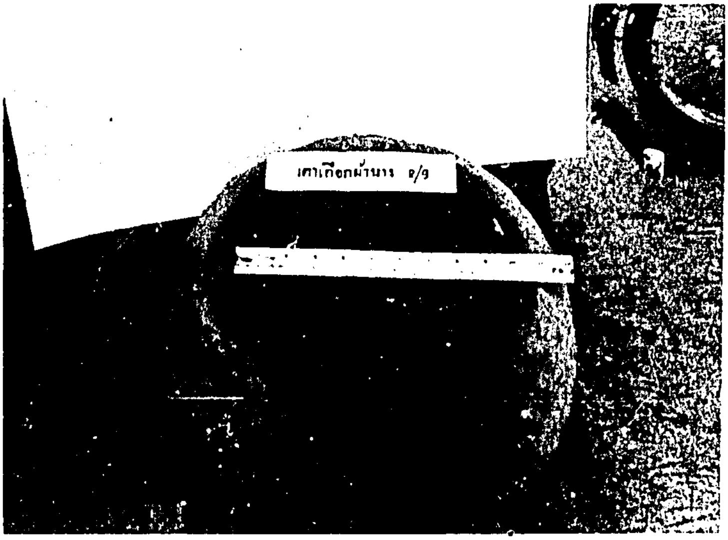
Pot hole diameter	-	cm
Weight	3.3	kg
Exhaust gap	5.4	cm
Exhaust area	222.6	cm^2
Grate hole grea	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	7440	cm^3
Time to boil	18.7	min
HU	15.39	%





Stove No.	2/8	
Name	Modified Roi-et, clay	
Pot hole diameter	22	cm
Weight	6.6	kg
Exhaust gap	1	cm
Exhaust area	55.5	cm^2
Grate hole area	99.6	cm^2
Grate: grate hole area	1:0.23	
Fuel chamber size	4560	cm^3
Time to boil	15	min
HU	20.92	%

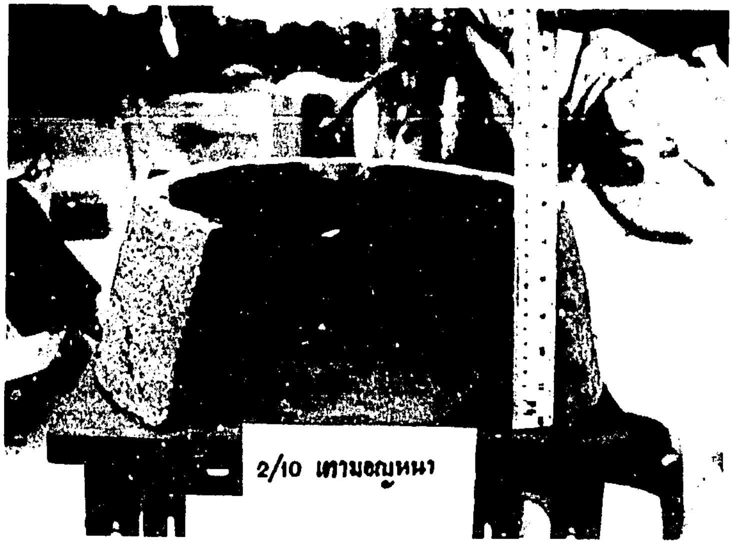


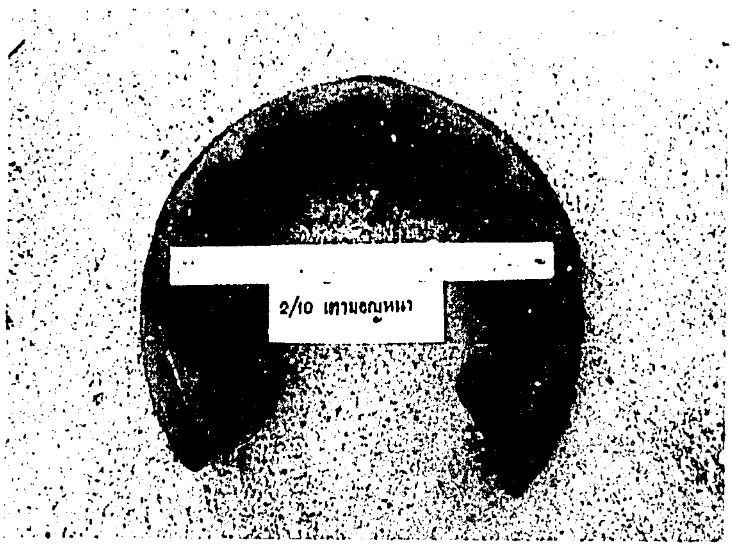


Stove No. 2/9

Name <u>Horse shoe, clay</u>

Pot hole diameter	25	cm
Weight	8.1	kg
Exhaust gap	2.5	cm
Exhaust area	197.1	cm^2
Grate hole area	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	6380	cm^3
Time to boil	15.5	min
HU	19.48	%

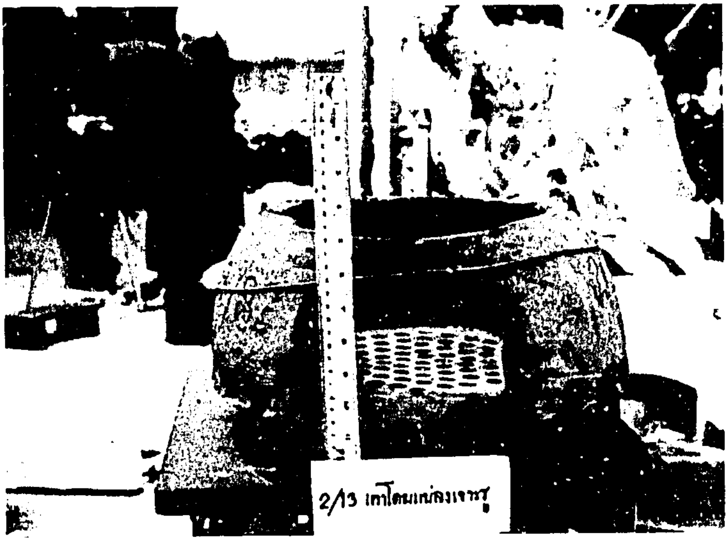


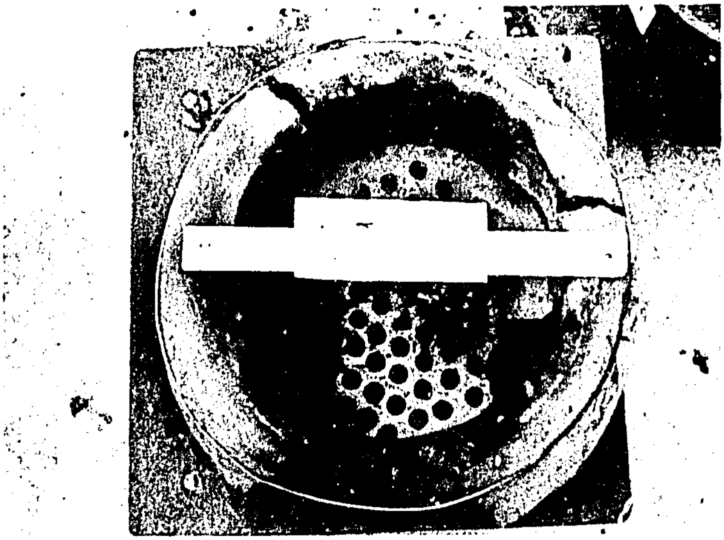


Stove No. 2/10

Name Thin horse shoe, clay

Pot hole diameter	22	cm
Weight	7.4	kg
Exhaust gap	3.6	cm
Exhaust area	77.6	cm^2
Grate hole area	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	4560	cm^3
Time to boil	15.3	min
HU	16.77	%

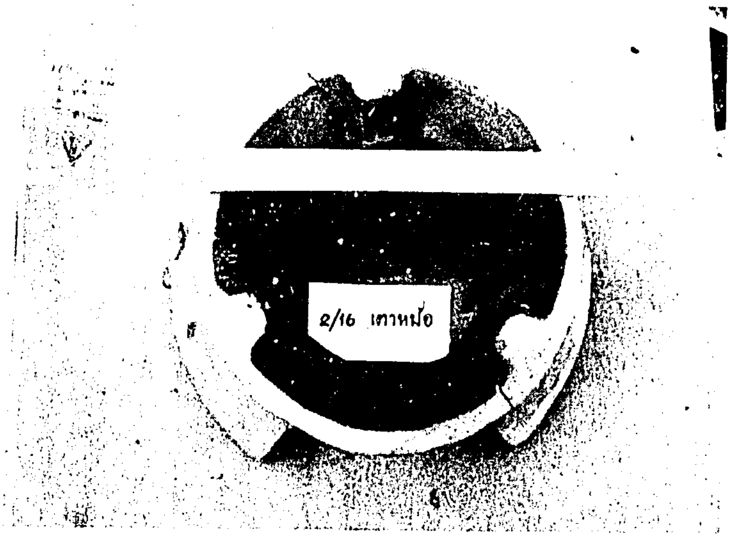




Stove No. 2/13

Name Dome, clay

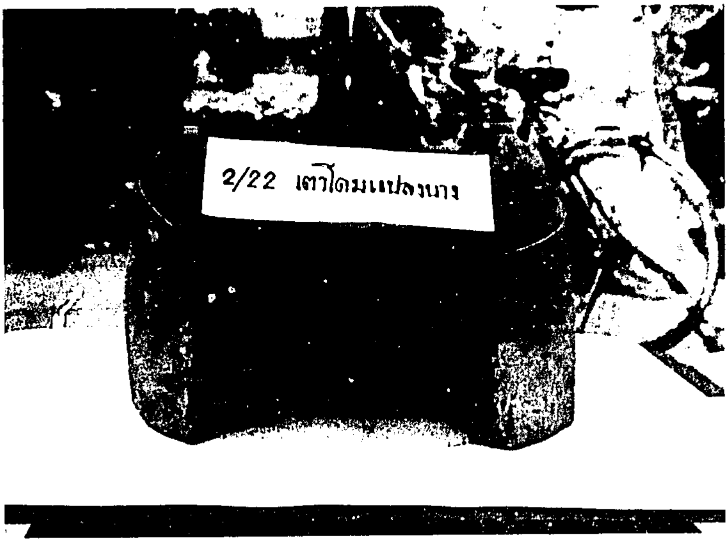
Pot hole diameter	24	cm
Weight	15	kg
Exhaust gap	1.3	cm
Exhaust area	62.4	cm²
Grate hole area	160.9	cm²
Grate: grate hole area	1:0.34	
Fuel chamber size	5400	cm³
Time to boil	17	min
HU	20.2	%

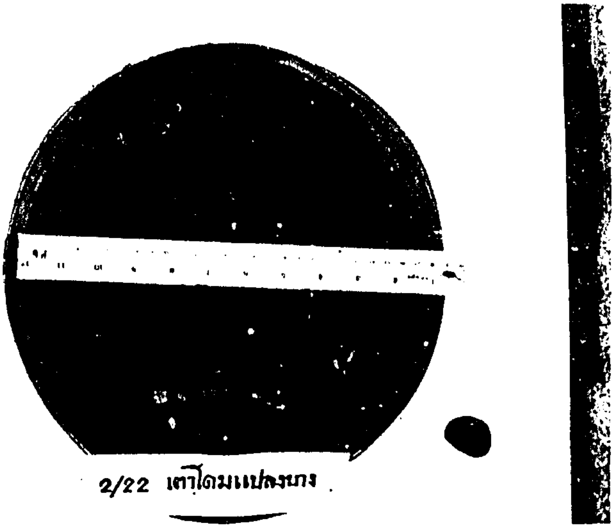


Stove No. 2/16

Name <u>Pot shaped, clay</u>

Pot hole diameter	22	cm
Weight	10.3	kg
Exhaust gap	1.8	cm
Exhaust area	86.4	cm^2
Grate hole area	-	cm^2
Grate: grate hole area	-	
Fuel chamber size	7030	cm^3
Time to boil	16.7	min
HU	14.37	%

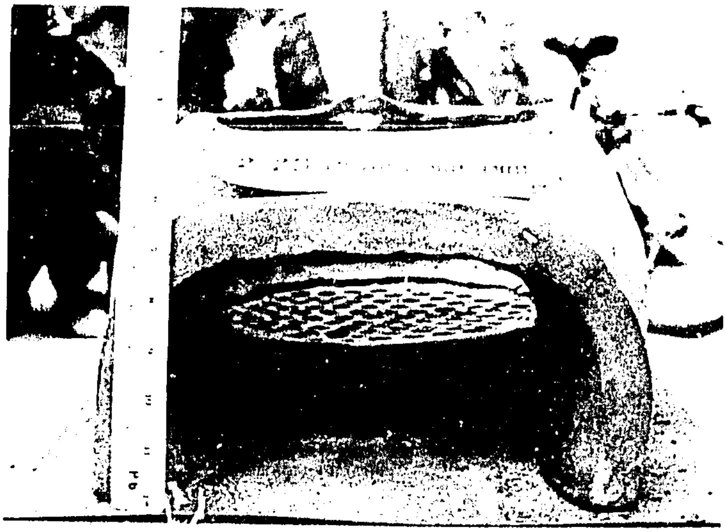


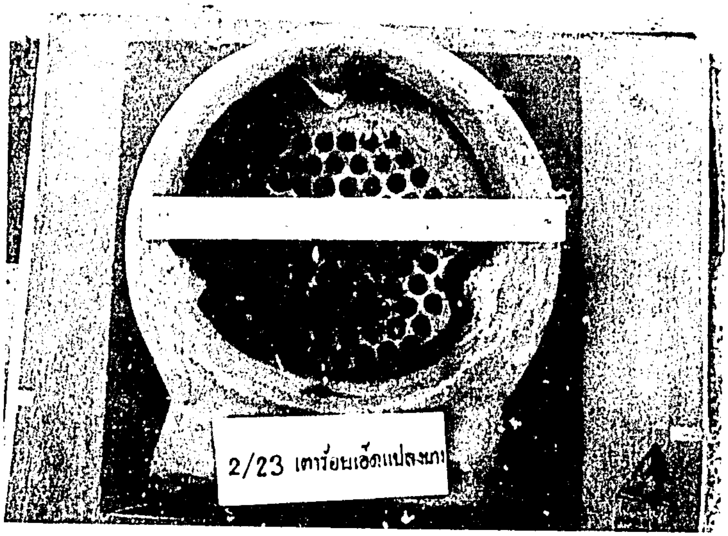


Stove No. 2/22

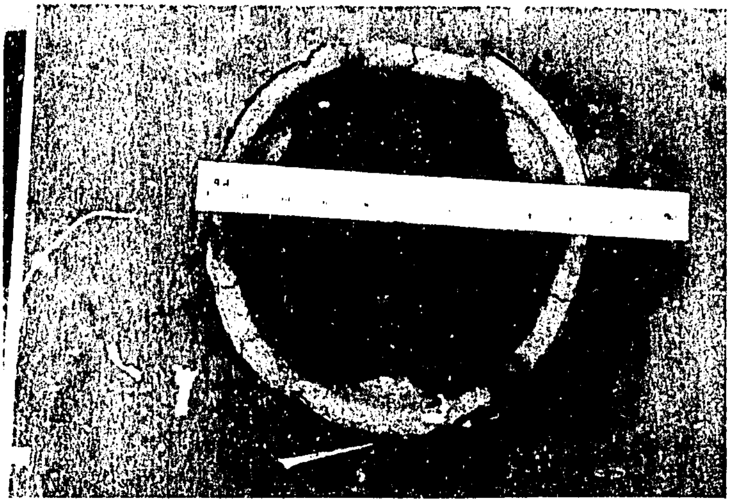
Name <u>Dome with cap, clay</u>

Pot hole diameter	22	cm
Weight	11.3	kg
Exhaust gap	1.5	cm
Exhaust area	73.1	cm^2
Grate hole grea	160.9	cm^2
Grate: grate hole area	1:0.34	
Fuel chamber size	6840	cm^3
Time to boil	14	min
HU	24.4	%





Stove No.	2/23	
Name	<u>Modified Roi-et, clay</u>	
Pot hole diameter	22	cm
Weight	14	kg
Exhaust gap	1.8	cm
Exhaust area	86.6	cm^2
Grate hole area	160.9	cm^2
Grate: grate hole area	1:0.34	
Fuel chamber size	4950	cm^3
Time to boil	14.5	min
HU	23.2	%

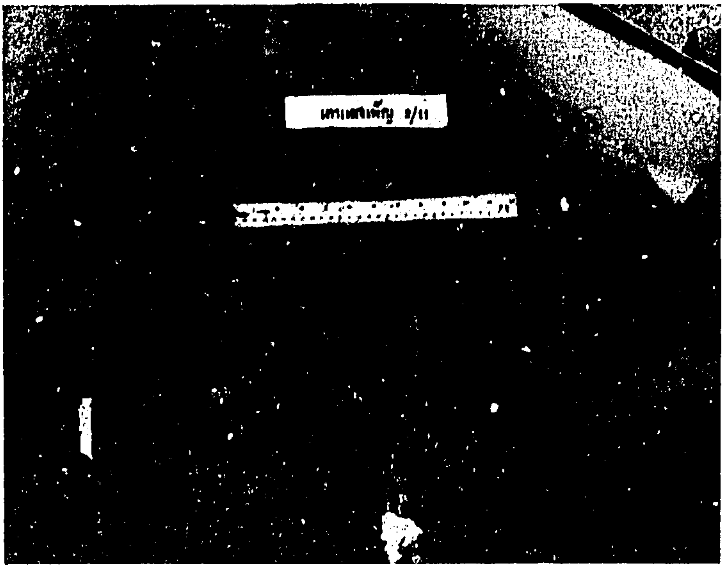


Stove No.	2/24	
Name	Cylinder, steel	
Pot hole diameter	17	cm
Weight	3.7	kg
Exhaust gap	0.6	cm
Exhaust area	32.2	cm^2
Grate hole area	99.6	cm^2
Grate: grate hole area	1:0.23	
Fuel chamber size	2040	cm^3
Time to boil	13.5	min
HU	25.93	%

ANNEX III

Commercial Wood Stove with Chimney Investigated

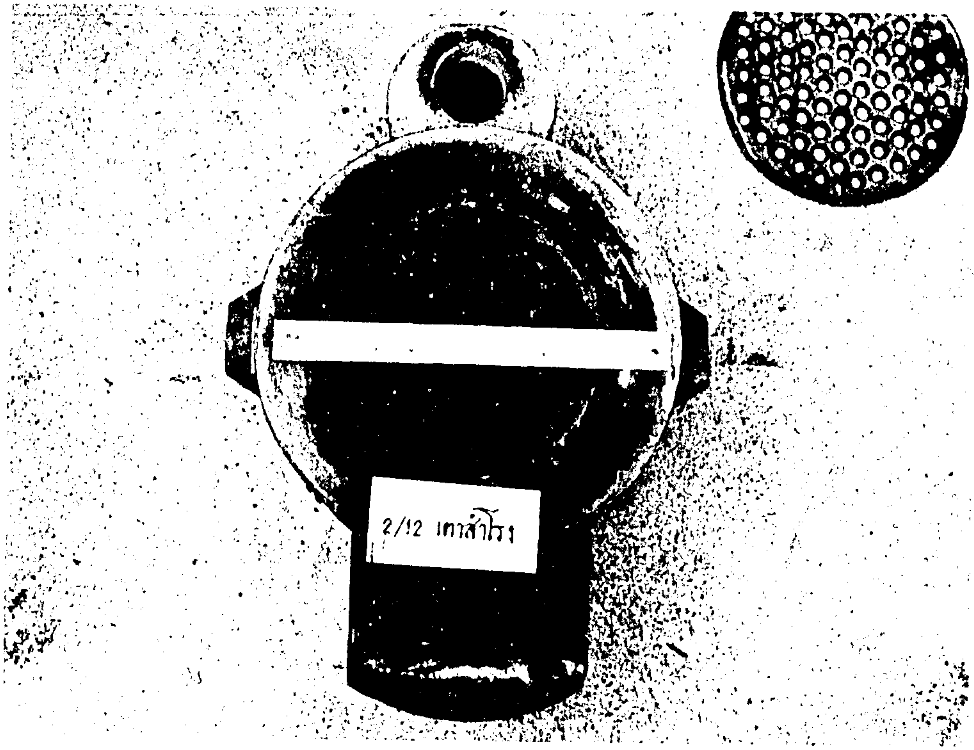
301

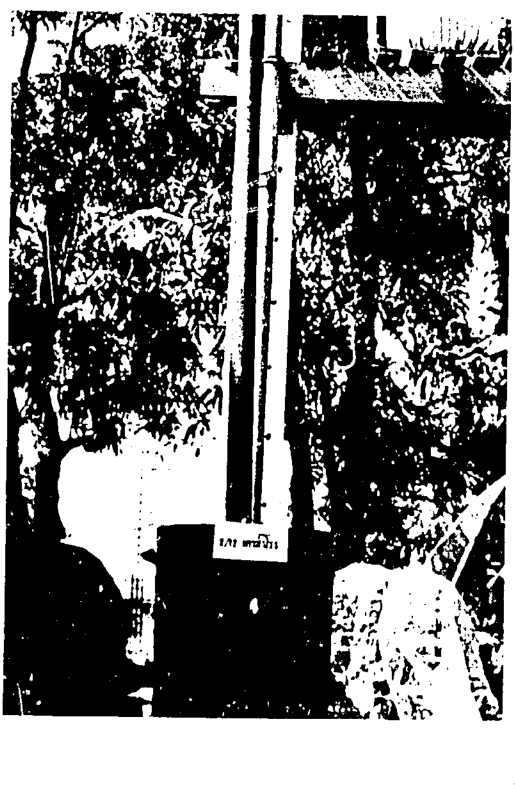


Stove No. 2/11

Name <u>Saengpen, Narn</u>

Pot hole diameter	19	cm
Weight	24.8	kg
Exhaust gap	-	cm
Exhaust area	72.3	cm^2
Grate hole area	72.3	cm^2
Grate: grate hole area	1:0.19	
Fuel chamber size	5190	cm^3
Time to boil	20	min
HU	13.88	%

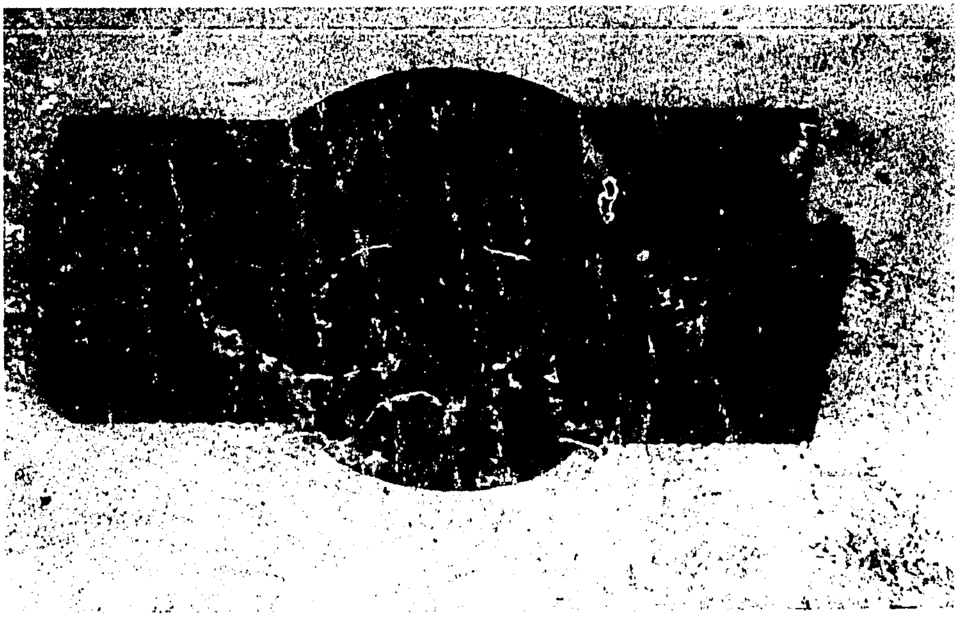




Stove No. 2/12

Name Samrong, Samutprakarn

Pot hole diameter	20	cm
Weight	24.8	kg
Exhaust gap	-	cm
Exhaust area	23.6	cm^2
Grate hole area	65.4	cm^2
Grate: grate hole area	1:0.20	
Fuel chamber size	4400	cm^3
Time to boil	19.5	min
HU	11.99	%



Stove No.	2/15	
Name	Ban Pong, Rajaburi	
Pot hole diameter	29.0	cm
Weight	69.5	kg
Exhaust gap	-	cm
Exhaust area	23.8	cm^2
Grate hole grea	94.3	cm^2
Grate: grate hole area	1:0.20	
Fuel chamber size	5890	cm^3
Time to boil	16.7	min
HU	11.01	%

ANNEX IV

Commercial Rice Husk Stove with Chimney Investigated

Stove No. 3/2

Name Ngo Gew Ha

Pot hole diameter 32.0 cm.

Weight 85.0 kg.

Flue gas outlet area 78.0 cm^2

Fuel chamber size 19,000 cm^3

Chimney height 240 cm

Pot used, ∅ 24 cm, HU 5.48%, TTB 20.0 min

Stove No. 3/4A

Name Thai charoen

Pot hole diameter 33.0 cm.

Weight 96.7 kg.

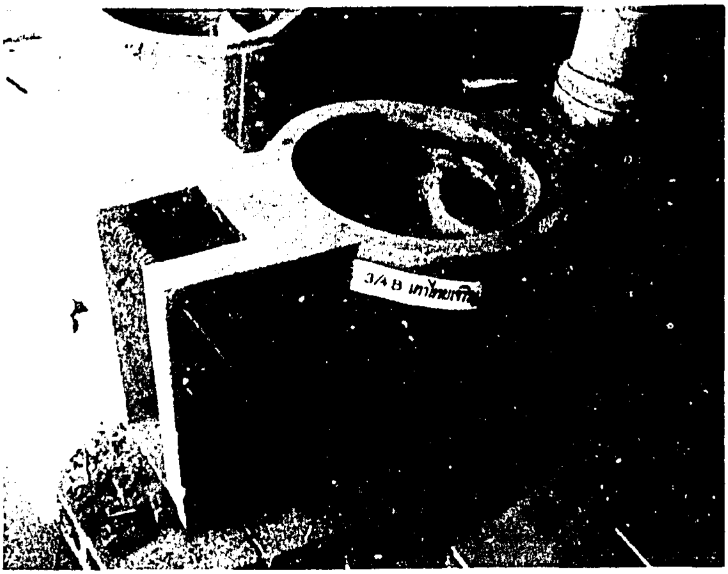
Flue gas outlet area 47 cm^2

Fuel chamber size 16,400 cm^3

Chimney height 240 cm.

Pot used, ϕ 24 cm, HU 6.24%, TTB 23 min.

Pot used, ϕ 30 cm, HU 9.26%, TTB 24.3 min.



Stove No. 3/4B

Name Thai Charoen

Pot hole diameter 30.0 cm.

Weight 95.5 kg.

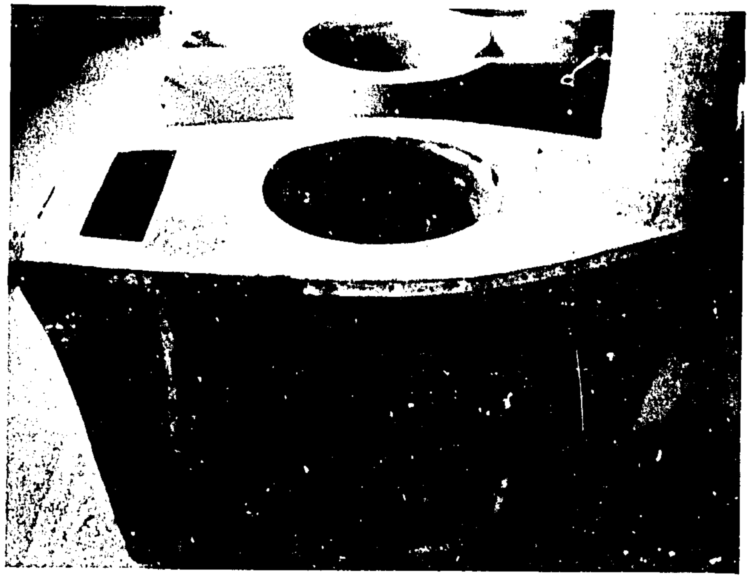
Flue gas outlet area 95 cm^2

Fuel chamber size 12,600 cm^3

Chimney height 240 cm.

Pot used, ø 30 cm,HU 8.53%,TTB 28.3 min

Pot used, ø 24 cm,HU 7.23%,TTB 25 min.



Stove No. 3/5

Name Banglane

Pot hole diameter 30.0 cm.

Weight 95.5 kg.

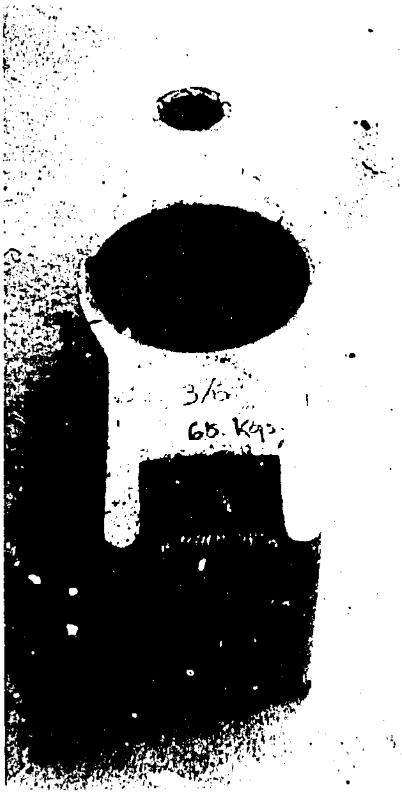
Flue gas outlet area 113.0 cm^2

Fuel chamber size 19,100 cm^3

Chimney height 230 cm

Pot used, ø 30 cm,HU 11.14%,TTB 20.3 min.

Pot used, ø 24 cm,HU 4.24%,TTB 28.5 min.



Stove No. 3/6

Name Sayan

Pot hole diameter 27 cm.

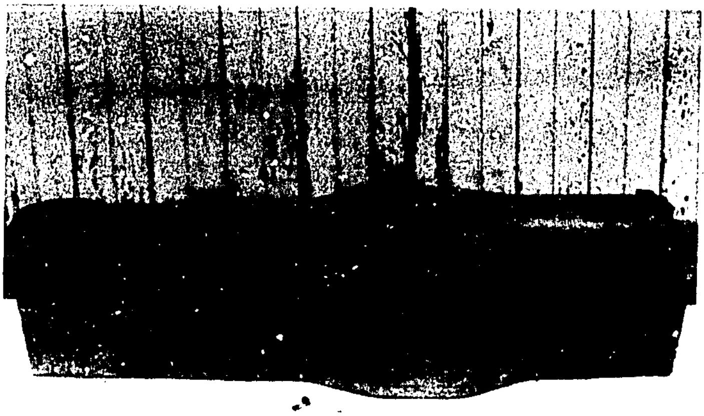
Weight 65.0 kg.

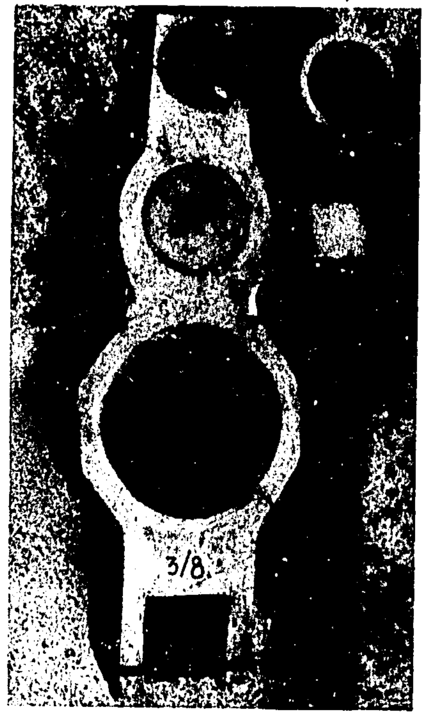
Flue gas outlet area 28.0 cm²

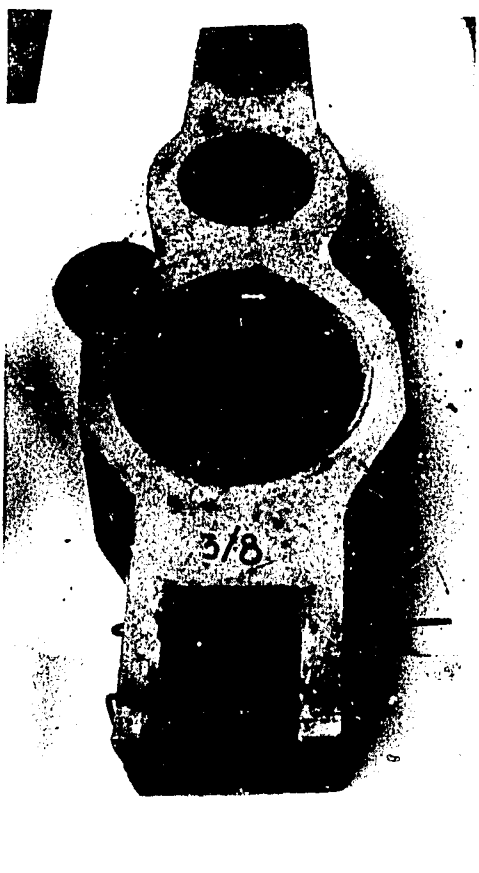
Fuel chamber size 6,200 cm³

Chimney height 240 cm.

Pot used, ø 24 cm,HU 7.13%,TTB 27.0 min.







Stove No. SC2

Name Sooksunt

Pot hole diameter 28 cm.

Weight 62 kg.

Flue gas outlet area 71.0 cm^2

Fuel chamber size 10,600 cm^3

Chimney height 160 cm.

Pot used, ø 24 cm, HU 9.23%, TTB 21.7 min.

ANNEX V

List of Staff for Stove Improvement Component

ANNEX 3

List of Staff and Personnel for Stove Improvement Component

1.	Dr. Aroon Chomcharn	Component leader, RFD
2.	Mr. Arkom Vejsupasuk	Assistant comp. leader, RFD
3.	Mr. Songdham Jaikwang	Project officer, RFD
4.	Ms. Malee Rungsrisawadh	Project officer, RFD
5.	Mr. Piroj Uttarapong	Project consultant, Kasetsart Univ.
6.	Ms. Pojanee Jongjitirat	Project consultant, King Mongkut's Institute of Technology
7.	Mr. Banyat Srisom	Project consultant, Temp. employee
8.	Ms. Nongluck Thong-in	Project researcher, Temp. employee
9.	Mr. Wattanapong Woottha	Project researcher, Temp. employee
10.	Ms. Sudarat Ngamkajohnwiwat	Project researcher, Temp. employee
11.	Mr. Pratya Kanapoosed	Project researcher, Temp. employee
12.	Ms. Kevalee Musikapong	Project coordinator, Temp. employee
13.	Mrs. Kunthon Santudkarn	Supporting service, RFD
14.	Mrs. Lek Ninmanee	Stove fabricator, RFD
15.	Mrs. Hame Krisangsri	Stove fabricator, RFD

REFERENCES

REFERENCES

Bennett, C., Myers, J.E., *Momentum, Heat and Mass Transfer*, McGraw Hill International Book Co., Singapore, 2nd ed., 1974.

Bird, R.B., Stewart, W.E., Lightfoot, E.N., *Transport Phenomena*, Wiley International Edition, New York, London, John Wiley and Sons, Inc., 1960.

Bronowski, J., *The Ascent of Man*, Little, Brown and Company, Boston, 1973.

Bumroong, T., *Economical Stove*, Appropriate Technology for Education, Institute of Educational Promotion for Science and Technology, Ministry of Education, Bangkok, pp. 61 - 65, 1981.

Catlyn, A., Joseph, S., and Shanahan, Y., *Testing of the Zip Stove*, Intermediate Technology Development Group, Stoves Project, Technical Notes No. 3, 1983.

Chomcharn, A. et. al., *Energy from Wood (5): Test for Efficiency of Fuel and Bucket Stove*, Forestry Meeting Annual Report, Forest Products Research Division, pp. -29 - 254, 1981.

Cookstove Bulleting, *Priyagni: A New Stove from CPRI*, Tata Energy Documentation and Information Center, Bombay, pp. 4 - 5, 1984.

Cookstove Handbook, Pilot edition, Tata Energy Research Institute Documentation Center, Bombay, 1982.

Deeammart, L., *Economical Stove*, A Report on Stove Testing and Evaluation Using Agriresidue, Military Research and Development Center, Supreme Command Headquarter, pp. 61 - 63, 1981.

Dunn, P. et al., *Traditional Thai Cooker*, Energy from Biomass: 2nd E.C. Conference, pp. 748 - 752, 1982.

Forestry Statistics 1982, Forest Statistics Section, Planning Division, Royal Forest Department, p. 9.

Foley, G. and Moss, P., *Improved Cooking Stove in Developing Countries*, Earthscan, Energy Information Programme, Technical Report No. 2, ITED, London, 1983.

Gupta, C.L., Usha, K., *Energy Vol. 5*, pp. 1213 - 1222, 1980.

Hoel, P.G., *Introduction to Mathematical Statistics*, Wiley International Edition, John Wiley and Sons, Inc., New York, London, Sydney, Toronto, 4th ed., 1971.

Joseph, S., *Stove Testing*, ITDG, 1979.

Joseph, S., Shanahan, Y., Trussell, J., and Bialy, J., *Compendium of Tested Stove Designs*, ITDG Stoves Programme for the UN Food and Agricultural Organization, 1980.

Kaufman, M., *From Lorena to a Mountain of F[illegible]*, A case study of Yayasan Dian Desa's fuel efficient stove program 1978 - 1983.

De Lepelaire, G., Prasad, K.K., and Verhart, P., *A Wood Stove Compendium*, Prepared for the Technical Panel of Fuelwood and Charcoal, UNERG, Nairobi, 1981.

Madon, G., L. DIOP and E. Lagandre, *Les Consommations de Combustibles Domestiques au Senegal Sur Foyers Traditionnels et sur Foyers Ameliorees*, CERER, University of Dakar and USAID, Undated.

Meechai: Economical Stove, Papers from Family Planning and Public Development Association, 8 Sukhumvit Rd., BKK 11, undated.

Noi, P., *Economical Stove and Charcoal Fuel*, Appropriate Technology for Education, Institute of Educational Promotion for Science and Technology, Ministry of Education, Bangkok, pp. 115 - 129, 1981.

Omar, K.J., *Chula-Need for Improvement*, Dept., of Chemical Engineering, BUET, Dacca, Bangladesh, Undated.

Openshaw, K., *A Comparison of Metal and Clay Charcoal Cooking Stoves*, Division of Forestry, Faculty of Agriculture, Forestry and Veterinary, Science, University of Dar es Salaam, Morongoro, undated.

Osuwasn S. and Booyakiat, K., *Study of Variables Affecting Charcoal Stove Efficiency*, Journal of Chemical Engineering Food and Fuel Technology, pp. 5 - 95, Bangkok, 1982.

Perry, R.H., Chilton, C.H., *Chemical Engineers' Handbook*, McGraw Hill Co., 5th ed., 1973.

Ponnoum, S., Wongopalert, A., Arnold, J., Jr., *Stove Experiments and Cooking Observations*, Meat Systems Inc., Thai Group, February, 1982.

Prasad, K.K., *Some Performance Tests on Open Fires and the Family Cooker*, Woodburning Stove Group, Department of Applied Physics and Mechanical Engineering, Technical University of Eindhoven and TNO, Apeldoorn, Netherlands, 1980.

Prasad, K.K., *A Study on the Performance of Two Metal Stoves*, Woodburning Stove Group, Technical University of Eindhoven and TNO, Apeldoorn, Netherlands, 1981.

Prasad, K.K., *Some Studies on Open Fires, Shielded Fires and Heavy Stoves*, the Woodburning Stove Group, Eindhoven University of Technology and TNO, Apedoorn, Netherlands, 1981.

Sherman, M. and Srisom, B. et al., *Thailand National Renewable Energy Project, Interim Report of 1982*, Activity Stove Improvement Component, 1983.

Singer, H., *Report to the Government of Indonesia on Improvement of Fuelwood Cooking Stoves and Economy in Fuelwood Consumption*, Report No. 1315, FAO, Rome, 1961.

Sooksant, S., *Economical Stove for Rural Village*, Appropriate Technology for Education, Institute of Educational Promotion for Science and Technology, Ministry of Education, Bangkok, pp. 71 - 89, 1981.

Suwat, T. and Paitoon, M., *Cooking Stove Using Agriresidues as Fuel*, Department of Mechanical Engineering, Songkhla University, undated.

Tata Energy Research Institute, Documentation Center, Bombay, 1979.

Thomas, L.C., *Fundamentals of Heat Transfer*, Prentice Hall, Inc., Englewood Cliffs, New Jersey 07632, 1980.

Vita News, *Report from Upper Volta, New Direction in Wood Stoves*, pp. 8 - 9, 1984.

Walpole, R.E., Myers, R.H., *Probability and Statistics for Engineers and Scientists*, McMillan Publishing Co., Inc., New York, Collier McMillan Publishers, London, 1972.