EFFICIENCY IMPROVEMENT OF TRADITIONAL GAS BURNER

A THESIS

SUBMITTED TO THE DEPARTMENT OF CHEMICAL ENGINEERING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF

MASTER OF SCIENCE IN ENGINEERING (CHEMICAL)

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY, DHAKA

RAHIMA AKTER LUCKY

MAY, 1999

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY, DHAKA

DEPARTMENT OF CHEMICAL ENGINEERING

CERTIFICATION OF THESIS WORK

We, the undersigned, certify that **Rahima Akter lucky**, candidate for the degree of master of science in Engineering (chemical), has presented her thesis on the subject "**Efficiency improvement of traditional gas burner**" that the thesis is acceptable in form and content, and that the student demonstrated a satisfactory knowledge of the field covered by this thesis in the oral examination held on the 23th MAY, 1999.

(Dr. Ijaz Hossain) — Chairman
Associate Professor
Department of Chemical Engineering
BUET, Dhaka

akma Quader

(Dr. A. K. M. A. Quader) — Member
Professor & Head
Department of Chemical Engineering
BUET, Dhaka

(Dr. Sabder Ali) — Member
Professor
Department of Chemical Engineering
BUET, Dhaka

(Dr. M. Eusuf) — External Member
Senior fellow, BCAS
(Bangladesh Center for Advanced Study)
House 620, Road-10A
Dhanmondi, Dhaka

ABSTRACT

From the beginning of civilization, people have been using different types of fuels for preparing their meals. Nowadays a number of cooking stoves for different fuels are available in Bangladesh and all over the world. The main objectives of this project were to study the efficiency of all types of cooking stoves available in Bangladesh and to improve the efficiency of the best available traditional gas burner. All available models were collected and studied. The standard water-boiling test was used to measure the efficiency of the stoves. Experimental results are comparable with published results. A new model for the natural gas burner was developed by placing a guard around the vessel to restrict the flow of the flue gas. The performance of this model was evaluated. The results showed that the guard increased the efficiency by 4% - 10% depending on the shape and the model of the gas burner. A comparative study has been performed to identify the most suitable cooking stove. This was done by estimating the economic cost of the fuels used by the various cookstoves. The efficiencies found in this study was used in this estimation. The improved biomass-cooking stove was found to be suitable for rural areas and the improved gas burner with the guard (the model developed in this study) was found to be suitable for urban areas.

ACKNOWLEDGMENT

The author acknowledges with great thanks and gratitude Dr. Ijaz Hossain, Associate Professor, Chemical Engineering Department, Bangladesh University of Engineering and Technology (BUET), under whose supervision this work has been carried out. The author is particularly grateful for the encouraging advice and help she received. The author extends her thanks to all of her colleagues especially Dr. Dil Afroza Begum, at the Chemical Engineering Department, for providing assistance at different stages of the work.

The author is indebted to Dr. M. U. Amin, Director of IFRD, BCSIR and Dr. A.M. Hasan Rashid Khan, Chief Scientific Officer, for their co-operation in completing a major part of this work. Thanks are also extended to Dr. Lulu Bilquis Banu and Ms. Sheply Rahman for their willing contribution and co-operation.

The author wishes to express her thanks to all of the staff of this department especially to Mr. Jahangir, Mr. John Biswas, Mr Habibur Rhaman and Mr Mahabub for their co-operation during the work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

Page no

Chapter 1

INTRODUCTION

Per capita energy consumption is a measure of quality of life. The more a country is developed, the more it uses energy. In developed countries, the higher consumption of energy is mainly for home heating, transportation and industries; cooking consumes only a small portion of the total energy. Analyzing the data of energy consumption in Bangladesh for the year 1990 (Fig. 1.1), it can be seen that approximately 65% of the total energy is used for cooking or domestic purpose.

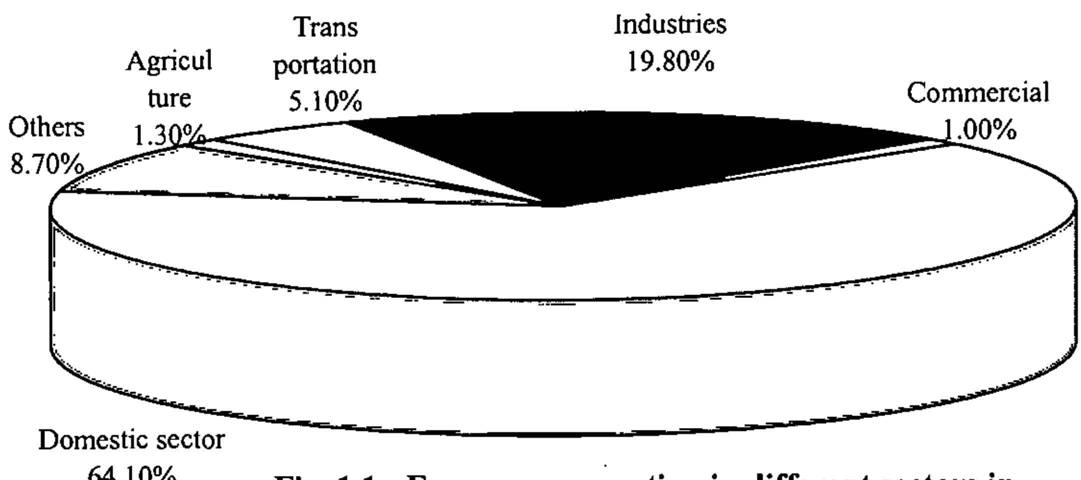

Fig. 1.1: Energy consumption in different sectors in Bangladesh (1990)

Different fuels such as natural gas, electricity, kerosene, coal, firewood, crop residues, animal excreta and urban refuse/waste are used for cooking and other domestic purposes. The contribution of different fuels in the total energy consumption is shown in Fig. 1.2. Energy for cooking in Bangladesh is derived largely from biomass and are predominantly in the form of firewood, crop residues and animal excreta.

Biomass is a renewable energy source if it is used commensurate with its production. The existing methods of extracting energy by direct combustion suffer from several disadvantages. As heating value of biomass is low, the quantity of biomass required is high, especially when crop residues are used. As it is bulky, transportation becomes costly. It is used for cooking in rural areas of LDCs in traditional cooking stoves, which are very poor with respect to thermal efficiency. Complete combustion is not accomplished in these stoves, and therefore, carbon monoxide and particulates are emitted causing severe pollution in the vicinity of the cookstove.

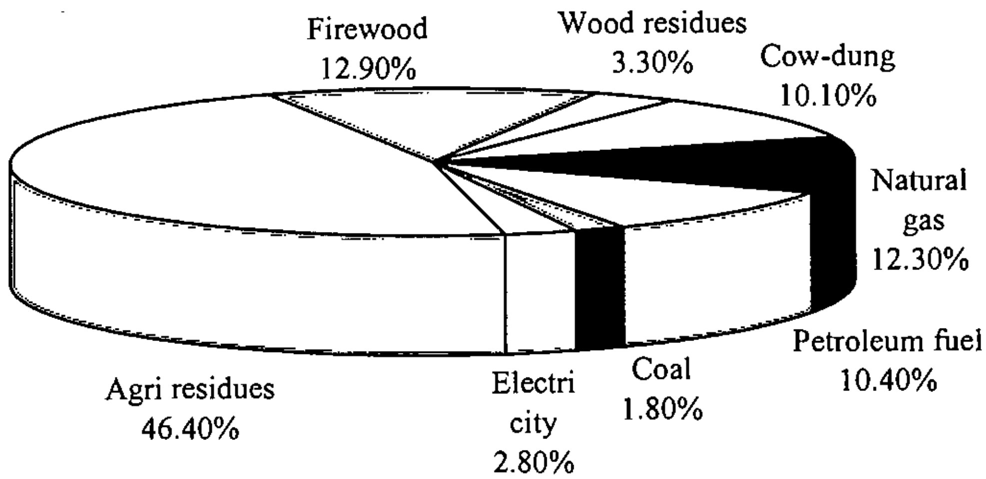

Fig. 1.2: Different types of fuel used in Bangladesh (1990)

Many respiratory problems are found among rural women and children of Bangladesh who are exposed to biomass smoke for significant portion of the day. Despite the dangers of biomass smoke, millions of people will continue to burn biomass because no better option exists for them. The use of cleaner and dryer biomass, improved cooking stoves, better ventilation of kitchen and changes in habits could lessen the adverse effects of the burning of biomass.

In Bangladesh, the consumption of commercial energy, especially natural gas is increasing rapidly because of population growth and economic development. As more and more gas fields are being discovered the government is trying to meet most energy needs from natural gas. Natural gas consumption is increasing at a rate of about 10 percent annually. In major urban areas natural gas is used for cooking. Natural gas is the only significant natural resource of the country. Its judicious use through conservation is critical for a poor country like Bangladesh. Thus, even a small efficiency improvement in the existing devices is important for the country. It is imperative therefore to develop technology to make better use of energy as well as to improve devices to have better thermal efficiency. Different governmental and non-governmental organizations are trying to improve the efficiency of cooking stoves. The contribution of IFRD in BCSIR is notable among these. Nowadays along with the traditional biomass cookstove the improved cookstove developed by IFRD is available in Bangladesh. The problem with the biomass cookstove is dissemination; but in the case of the natural gas burner, not enough research has been conducted to improve its efficiency. The improved models available needs evaluation. The purpose of the proposed research is to conduct a systematic investigation of all types of cookers used in the country including the improved cooker developed by BCSIR and to improve the efficiency of the best natural gas cooker available in the market.

1.1 Statement of the problem

Food, fuel and fertilizer are the major problems for Bangladesh. These problems are interrelated. Irrigation, tilling and fertilizer can increase food production. Production of fertilizer and power generation is dependent on fuel. But in Bangladesh about 65% of the total energy are used for cooking or domestic purpose. So using more efficient stoves for cooking can save a lot of fuel, which can be used for boosting economic growth. Moreover, as a poor developing country, Bangladesh has to raise its low per capita energy consumption as well as conserve its limited sources of non-renewable energy. Natural gas is the major source of non-renewable energy. So increasing even a small percentage of the gas burner efficiency will bring potential benefit for Bangladesh.

1.2 Objectives of the study

The following were the major objectives of the present research:

(1) To conduct a systematic investigation on the efficiencies of existing cookers being used in Bangladesh

(2) To study the efficiency of the improved natural gas burner developed by BCSIR

(3) To improve the efficiency of the best available (in the market) natural gas burner by simple modification.

(4) To investigate the financial implications of using different types of cookstoves.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Energy can conveniently be divided into two categories - commercial or non-renewable energy and non-commercial or renewable energy. Commercial energy includes electricity, petroleum fuels, coal and natural gas. Non-commercial energy includes firewood, crop residues, animal excreta and urban refuse/waste. These energy sources are biomass, which is created by photosynthetic process in which solar energy is converted into more useful forms. Biomass cooking stove has been used for cooking and heating from the beginning of civilization soon after fire was discovered about five hundred thousand years ago. After the discovery of commercial fuels, the use of biomass fuels dwindled. Nowadays, biomass, as well as commercial fuels are used for cooking, and several different types of stoves for each type of fuel are used around the world.

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. This chapter briefly discusses the evolution of cooking stoves in the world, stove construction and design, methods of testing stove performance and the factors affecting stove performance.

2.2 Evolution of cooking stoves

Evidence of the use of biomass fuels, particularly wood, has been found within the caves of Peking man as early as 500,000 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 have changed very little in structure and performance from their ancient predecessors.

When compared with modern stoves of oil, gas and electricity, the biomass cooking stoves are far less efficient. The efficiency of kerosene or LPG fueled stoves can be as high as 40-48%, while that of a wood stove averages only 10-25%. Even though the gap in efficiency is partially explained by the lower calorific value of the woodfuel, 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 woodfuel has risen sharply. The increase in demand coupled with the rapid loss of forestland 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.

2.3 Biomass stove construction and design

Various stove configurations can be found the world over. Even in Bangladesh there exists several designs. The variation comes about as a consequence of cooking habits and complexity. 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 stoves, traditional stoves and the improved stoves are described.

Open fire stoves: The open fire stove is a primitive stove that is still widely used in the developing world. Stones, bricks, cement, or lumps of other incombustible material encircle the fire. The open fire stove, sometimes called the three-stone stove 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.

Traditional stoves: The traditional Bangladeshi chula consists of a short, slightly downward-sloping tunnel, digging into the ground, or made upon the ground with a pothole cut in the roof at the end (Fig. 2.3.1). 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).

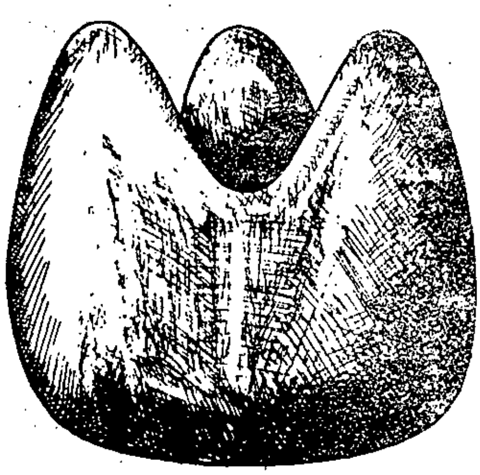

Fig. 2.3.1: Traditional wood burning stove (portable)

Improved biomass stoves: An improved biomass stove now found in rural household of Bangladesh is shown in Fig. 2.3.2. It is like the traditional stove except that a grate is placed at the bottom of the stove. For removal of ash, a door exists at the bottom below the grate. Spaces for flue gas exits are made rectangular for better contract of the flue gas with the utensil. For entry of air 6-8 holes are made on the wall of the stove just below the grate. A considerable increase in efficiency can be achieved by these changes.

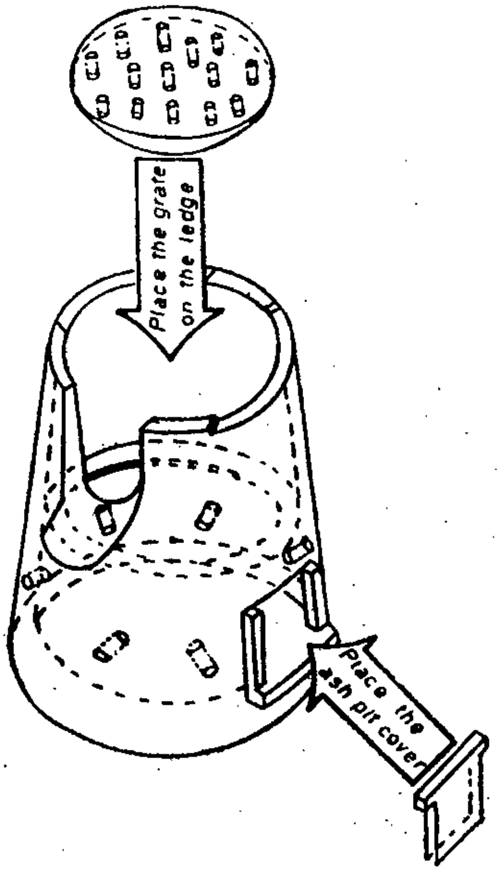

Fig. 2.3.2: Improved biomass domestic cooking stove (Portable)

2.4 Natural gas burner

Natural gas has been known for many centuries but its initial use was probably more for religious purposes than as a fuel. Gas wells were known in Europe in the middle ages and were reputed to eject oil from the wells; e.g. the phenomena observed at the site near the town of Mineo in Sicily. At about 250 A.D. when it was used as a fuel in China, the gas was obtained from shallow wells, and was distributed through a piping system constructed from hollow bamboo stems. Natural gas was used on a small scale for heating and lighting in northern Italy during the early seventeenth century. Natural gas was first discovered in the United States in Fredonia, New York, in 1821. But at that time natural gas had little or no commercial value. After World War II natural gas became a popular fuel commodity. The wide range of uses of gas for domestic, commercial and industrial purposes has led to the development of gas burners. The smallest burners, as used to provide pilot flames, have ratings as low as 30 W whilst the larger burners, as used in some water tube boilers, have ratings up to 60 MW. This is therefore a capacity range of two million to one. Different burner principles are given below.

2.4.1 Natural-draught neat-gas burners

The simplest way to burn gas is by releasing it from an orifice so that combustion occurs at the boundary with the surrounding open air by diffusion. When the velocity of the issuing gas is very low, gas will burn in this manner, but the resulting flame is lambent, is easily disturbed by draughts, and the combustion intensity is very low. Such flames therefore have few practical applications. When the issuing velocity is increased, the rate of mixing with air and consequently the combustion intensity are increased. With natural gas, the velocity, which is necessary to provide useful flames, is greater than the burning velocity of the gases, and as a consequence the flame lifts from the gas port and either becomes unstable or is extinguished.

In order to use the simple neat-gas burner with natural gas many ways of obtaining flame stability have been devised. Fig. 2.4.1 shows a selection of these. They have taken the form of shields or deflectors or impinging jets to promote a low-velocity mixing zone where combustion can be stabilized at the burner port. The need for burners of this type is predominantly for domestic and commercial appliances but they are also used for some industrial purposes where the individual burner ratings are very limited.

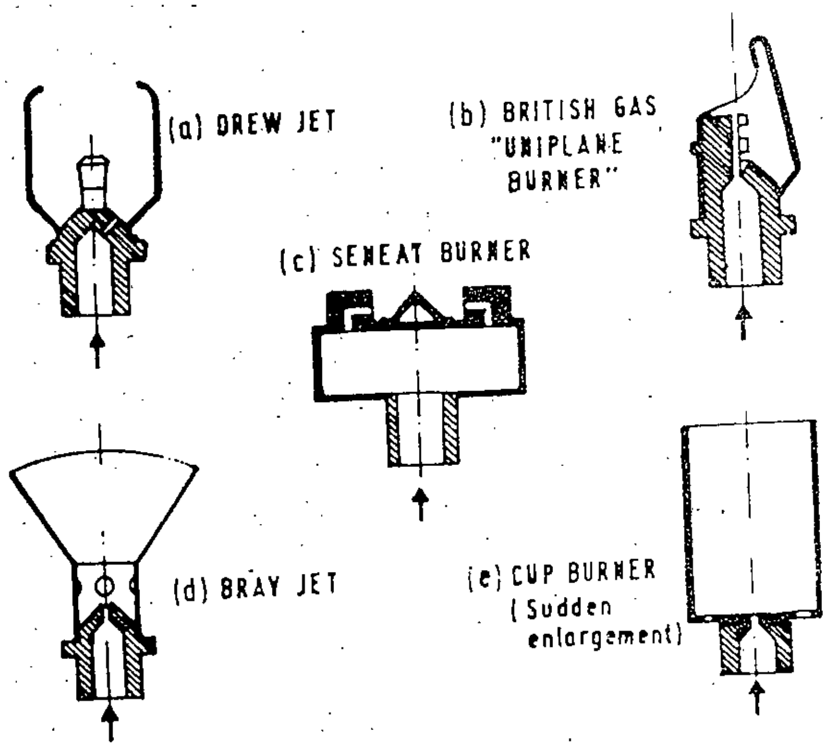

Fig. 2.4.1: Different types of non-aerated burners

2.4.2 Low-pressure aerated or premix burners

This category of burner uses the pressure energy of the gas issuing from the gas port to entrain part of the air required for combustion into a mixing tube or venturi, and the resulting air-gas mixture is burned at one or more burner ports supplied from the injection system. The most familiar example is the bunsen burner, and the most used in terms of numbers are the burners in domestic cookers and other domestic appliances. For larger applications these burners are provided with multiple burner ports in drilled pipes, in pressed steel box and pipe sections, and in castings.

In the majority of these burners, the flames, or the combustion products following the flame zone, are used to transfer heat to the surfaces to be heated or to provide a source of hot gases. Some types use a surface of ceramic or metal gauze, or a fibre pad incorporating a catalyst, in which the air-gas mixture burns on or within the surface layers or ports so that the surface is heated and the resulting radiant heat provides a considerable proportion of the total heat output. Surface temperatures for these units are from 500°C to 800°C when supplied with air-gas mixtures from low-pressure gas supplies of less than 7-kPa gauge (70 mbar). The total or most of the total combustion air is injected by the gas for this application method. Ratings of individual burners are from 500 W to 150 kW or thereabouts.

2.4.3 High-pressure aerated or premix burners

The majority of low-pressure aerated burners operate with up to half of the total air for combustion entrained as primary air, the remainder of the air being supplied as secondary air around the flames. Where burners of the type described in the preceding section are supplied with gas at pressures above approximately 20 kPa gauge (200 mbar) for natural or town gas, or above 70-120 kPa gauge (700-1200 mbar) for LPG, the increased energy available can be used to induce all of the combustion air and provide a mixture pressure suitable for combustion to take place in closed combustion chambers operating at pressures slightly above atmospheric. For example, they can be used for some furnace applications and for burners which are enclosed, and where there is some restriction on the combustion product exit. Because higher mixture pressures are available, higher velocities can be obtained, and consequently the size of the burner equipment is smaller for a given output compared with that for low-pressure equipment. This burner category is not in widespread use as pressure gas supplies are not generally available, although gas compressors can be installed. It can however be useful for small installations where there are a number of burners, and there is an advantage in having simple burner controls.

2.4.4 Nozzle-mixing pressure air burners

This burner category, known also as nozzle-mixing burners, tunnel-mixing burners, or package burners, uses an air supply at pressure, which is discharged through a nozzle or nozzles or through an annulus or annuli at the burner head or face. Gas ports, which again may be of many forms, admit gas into the air stream, and combustion takes place either totally or partially in a burner tunnel or at the burner face. In some designs, part of the combustion air is admitted into the gas stream prior to the main mixing zone so that the resulting flame is of this air-gas mixture, the remaining air completing combustion. These burners are the most commonly used types for industrial processes, and boiler firing up to and including power-station boilers.

2.4.5 Premix pressure air burners

Two categories of premix burners have already been described, i.e., low- and high-pressure types in which the gas pressure is used to inject combustion air. This final type of burner uses air under pressure, which is mixed with gas in an injector; the resulting air-gas mixture is burned either at burner nozzles or in burner tunnels. These burner systems are commonly known as air-blast systems, and it is usual to govern the gas supply to the injectors to zero gauge pressure, so that the air then entrains the correct volume of gas automatically. As such systems are self-proportioning, burner control is simply effected by a single valve in the air supply. However, if the pressure in the combustion chamber varies, a pressure back-loading control may be required. Premix burners provide versatile systems that are used for many industrial processes, but the system is not normally used for boiler firing.

2.5 Standard methods of testing stove performance

Although human beings 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% difference in performance figures.

Joseph and Shanahan (1980) have proposed a few methods of testing. 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. 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. Two types of tests are commonly carried out on stoves; one is the "boiling water" test, and the other is the "cooking food" test. Other tests such as combustion tests are also sometimes used.

2.5.1 Boiling water tests

There exists 4 tests which are being used as standard methods. These are

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.

2.5.2 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).

2.5.3 Combustion test

In combustion tests (Joseph, 1979), gas analysis and measurement of the stack temperature are obtained. These data give a measure of how much heat is lost due to process combustion. According to this test, fuel is burned 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 gas decreases, the amount of air being drawn into the combustion chamber also decreases.

2.6 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 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 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 potholes; 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. Somchai and Kanchana (1983) showed that radiative heat loss could occur through the exhaust gap. 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.

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 rich 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 fueled 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 under supply 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 variable: The initial project study that appeared in the interim report (Sherman and Bunyat, 1983) revealed that the internal variables of the biomass 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 clay, cement, or metal, its efficiency varies. Openshaw (undated) compared metal and clay cooking stoves. He found that households could save 40% of charcoal used if households used clay stove instead of metal stove. In addition, the material chosen more or less reflects the long-term service ability.

2.7 Results of some works on cookstoves

A number of governmental, non-governmental and research institutions have been working on cookstoves. Scientific investigation have been directed, towards improving the efficiency of cookstoves, to get knowledge about the factors which effect burning, to understand the correct procedure for measuring the heat balance and study the heat transfer from stove to cooking vessel. Results of some relevant research are given below.

Bussmann (1981) developed a model to understand the open fire, by which it is possible to obtain the temperatures, velocities, and mass flows in wood fires. These characteristics can serve as a basis for evaluating heat transfer from the flames to different surfaces in a stove. Insight into the behavior of flame characteristics in firewood is required for developing rules for dimensioning the combustion spaces in wood burning stoves.

The theoretical and experimental work of Bussmann (1981) provides a few interesting results. Consider first the influence of power output. Increasing the power output does not influence the maximum temperature in the system, but simply the flame height. What this means is that more air is required for completion of combustion and the entrainment process from the surroundings takes a longer distance to provide this air. The flame height is shown to vary according to

$$H \propto P^{2/5}$$

Experiments show that power output from a fuel bed is essentially controlled by its diameter. Thus

$$P \propto D^2$$

In other words,

$$H \propto D^{4/5}$$

This is very nearly the relation suggested in the wood stove compendium (De Lepeleire et al., 1981). This has far reaching implications on the performance of a given design of a three stone fire. Prasad (1981) illustrated the situation by the following example. He considered a three stone fire with a diameter and height of D_1 and H_1 respectively. The configuration is capable of delivering a power output of P_1. Now the system operates at a power output of P_2, smaller than P_1. As illustrated in Fig. 2.7.1, the gas temperature at the pan location drastically reduces from nearly 1400°C to 650°C. Thus the driving force for convective heat transfer reduces from 1300°C to 550°C. In other words one could expect as much as a halving of convective heat transfer to the pan under these conditions. However, since reduction in power output implies a reduction in fuel bed diameter, this results in increased radiant heat transfer. Thus the loss in convective heat transfer is partially compensated.

Visser (1981) worked on the compendium (De Lepeleire/Van Daele Stove). The first series of tests concern an open fire on a grate, shielded with rings in a number of different configurations. The second series of tests concern a shielded fire on a grate, with controllable primary and secondary air entrance holes, and a shield around the pan. Experiments showed the dramatic impact of shielding on an open fire. The reason for this was Explained by the help of Fig. 2.7.1. Due to dilution by entrained air, the temperature of burned gases drop by about 1000°C over a height of about 20 cm. This dilution is suppressed by shielding thus increasing the convective heat transfer to the sides of the pan, which form nearly 3/4 of the total pan area. Efficiency measurements on open fires (Visser, 1980) showed an efficiency increase of 3 percentage when a grate was used. It was supposed that a better aeration of the fuel bed through the grate might be the cause of this increase, but a good explanation of this phenomenon however was not given.

To understand the burning process of the firewood, Wagner (1978) studied the processes involved in burning of wood. He distinguished four successive periods, in which the temperature of each following period is higher (Fig. 2.7.2). Wagner stated that the volatiles and charcoal do not burn simultaneously because the oxygen cannot reach the charcoal part when the volatiles production is high. This is caused by the expansion of burning gases. Only after the volatiles production has nearly stopped, the charcoal will be converted into CO_2.

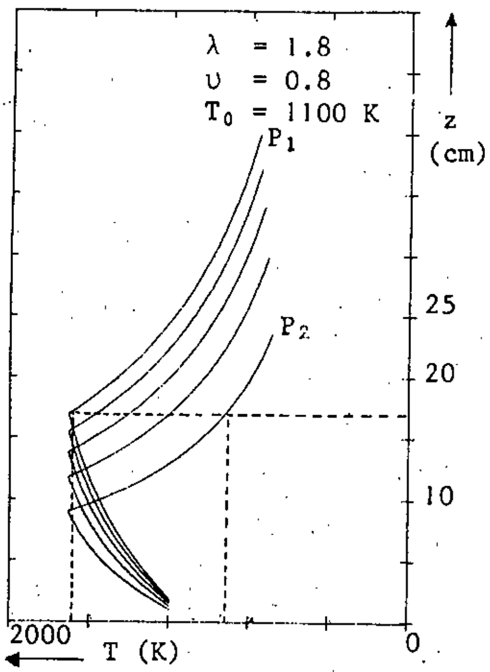

Fig. 2.7.1: Flame height & temperature at various power output

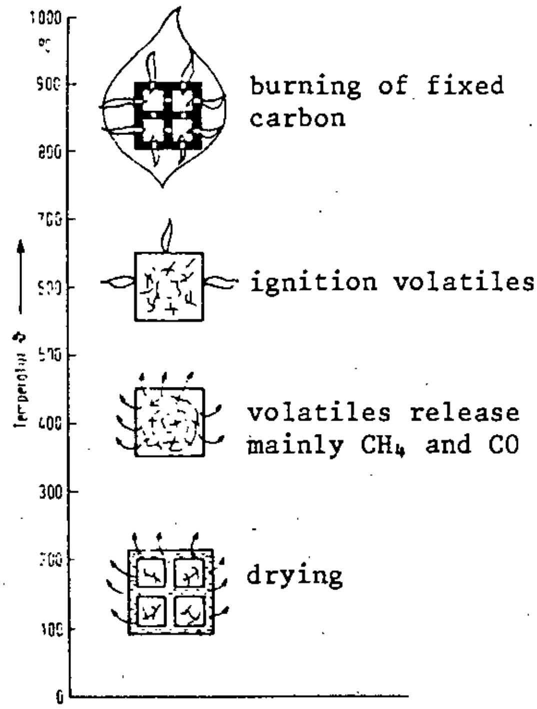

Fig. 2.7.2: Burning process of wood

To check the heat balance calculation procedure, in particular the calculation of the heat loss to the surrounding by convection and radiation, an experiment was done by Nievergeld et al. (1981) using natural gas as a fuel in the De lepeleire/Van Daele stove. This wood stove essentially consists of a fuel supply shaft, a combustion chamber, a flue gas channel and a chimney. There are two potholes on the top of the stove. This first pan is situated directly above the combustion chamber and the second pan above the flue gas channel. In this experiment a small gas burner was installed in the combustion chamber of the stove. Natural gas was chosen as a fuel because of its composition and its combustion characteristics are exactly known and because it can be supplied to the stove at a constant rate. The results of the experiment are given in Table 2.7. For reference, the results of some other natural gas experiments are included in this table. These show that the calculation procedure adopted yields quite satisfactory results. The results of the heat balance calculations particularly confirm the validity of the procedure adopted to calculate the heat loss of the stove to the surroundings.

Finally, Table 2.7 shows that with an ideal fuel like natural gas, efficiencies of about 30% for the first pan and 10% for the second pan can be obtained with the De Lepeleire/Van Daele stove. If the stove is insulated these efficiencies will be higher.

TABLE 2.7: Heat balance of De Lepeleire/Van Daele wood stove with natural gas as a fuel

Run no.	Heat output (kW)	Percentage of heat output of the fire in	
		First pan (%)	Second pan (%)
4	6.16	29.8	10.3
5	6.38	29.6	9.4
6	5.93	32.0	10.5
112	5.74	28.3	9.6
146 (stove insulated)	5.37	35.3	13.6

The effects of swirl in inert and reacting flow systems have been known and appreciated for many years. Experimental studies show that swirl has large-scale effects on flow fields: jet growth, entrainment and decay, flame size, shape, stability; and combustion intensity are affected by the degree of swirl imparted to the flow. The combustion intensity may be greatly enhanced in a swirling flow because of the higher shear stresses that result from the rotating movement of the flow. Moreover, swirling flows are especially appropriate for regulating the residence time distribution in combustion appliances. These considerations have led Elperin and Tamir (1989) to suggest a gas burner with swirling central flame only recently. The essential feature of the new burner is the implementation of a centered, rotating vertical flame rather than of the bandform flame generated by conventional gas burners. The rotating central flame is generated by feeding a mixture of gas and primary air through the ports in burner cap. The axes of the ports are orientated toward the burner center at an angle β with respect to the cap horizontal plane, thus producing tangential projections at the angle α with respect to the cap radius. The jet of the ignited gas and primary air mixture flowing from the cap ports form the vertical rotating flame over the burner cap. This swirling flame impinges on the base of the heated vessel and forms the rotating, radially diverging jet of hot gases. The performance characteristics of a gas burner with a swirling central flame were examined. Result shows that the burner thermal efficiency is higher by 10 to 30% than that of a conventional burner.

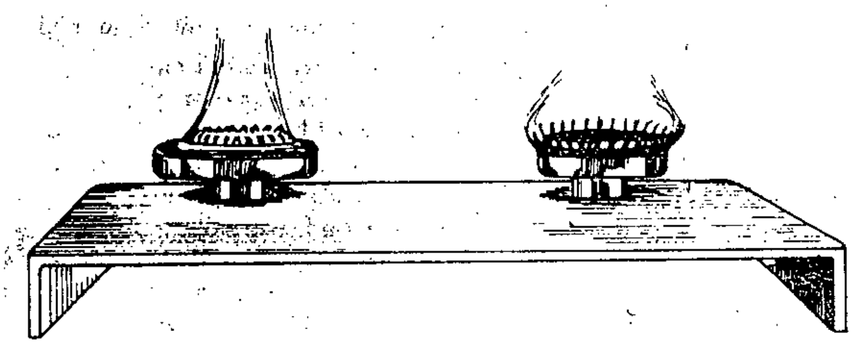

Fig. 2.7.3: Schematic of the new (left) and conventional (right) flames

2.8 Fuels and stoves for cooking

All over the world different types of cooking stoves are available. Variation of cooking stoves depends on the development, culture and fuel availability of a country. To get a clear concept about energy consumption, cost and efficiency of different types of cooking stoves used all over the world especially in the developing countries, a literature search was conducted. From this it is clear that people in the developing countries eat less processed foods, less restaurant foods and more grains. So cooking food is the most important energy service in the developing countries. In rural areas of developing countries, traditional fuels --- wood, crop residues, and dung --- remain the primary cooking fuels, while in many urban areas, charcoal is used also. About 2 billion people depend on these crude polluting biomass fuels for their cooking and other energy needs. Higher incomes and reliable access to fuel supplies enable people to switch to more modern stoves and cleaner fuels such as kerosene, LPG, electricity, and, potentially, to modern biomass --- a transition that is widely observed around the world largely irrespective of cultural traditions (Fig.2.8.1).

These modern stoves are preferred for their convenience, comfort, cleanliness, ease of operation, speed, efficiency, and other attributes. The efficiency, cost, and performance of stoves generally increase as consumers shift progressively from wood stoves to charcoal, kerosene, LPG or gas, and electric stoves (Fig.2.8.2).

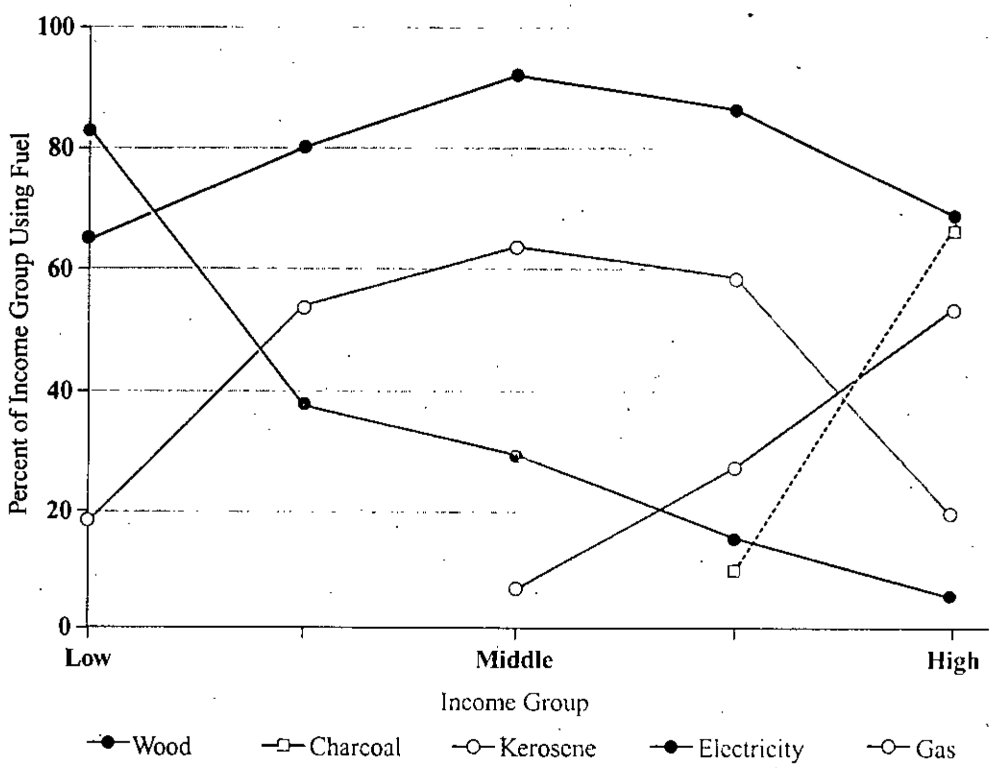

Fig. 2.8.1: Choice of cooking fuel by income for five medium-sized towns in kenya (Soussan, 1987)

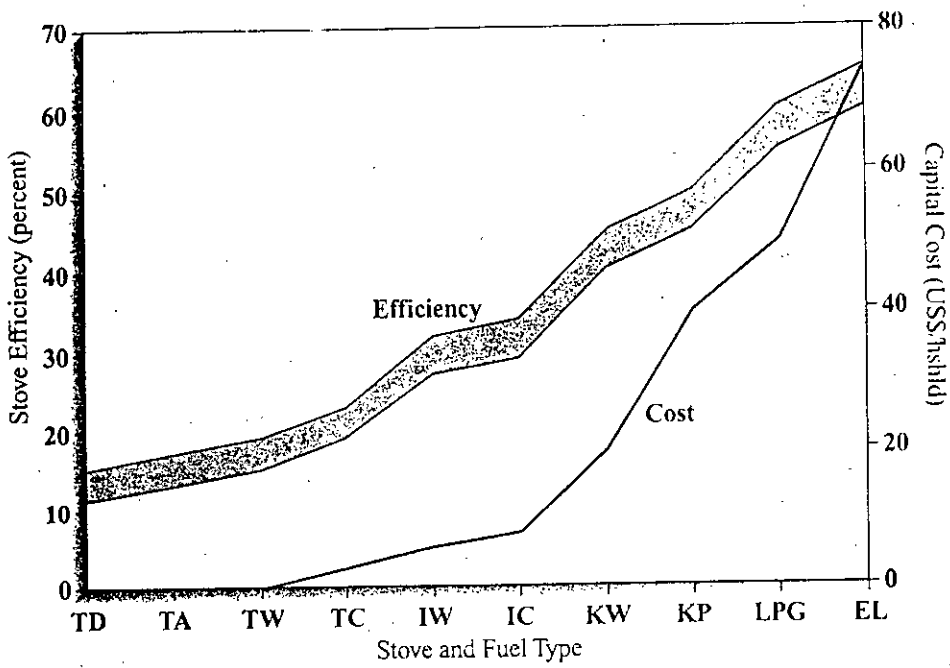

Fig. 2.8.2: Representative efficiencies and capital costs for various stoves (OTA, 1992)

Stoves listed are: TD, TA, TW, TC- traditional stoves using dried animal dung agricultural residues, wood and charcoal, respectively; IW, IC- improved wood and charcoal stoves; KW, KP- kerosene wick and kerosene pressure stoves; LPG- LPG or natural gas stoves; and EL- electric resistance stove.

At the same time, efficiencies and costs tell a much different story when examined from a system, rather than the individual purchaser's perspective. When the energy losses of converting wood to charcoal and fuel to electricity, refining petroleum products, and transporting these fuels to consumers are included, the system efficiency of delivering cooking energy by charcoal and electric stoves drops precipitously (Fig. 2.8.3) because stove efficiency are nominal values for the stove alone; system efficiencies include the energy losses in producing, converting, and delivering fuel to the consumer.

As for the efficiency estimates, there are substantial variations between the capital costs for individual stoves and for the entire cooking system. This is particularly notable in the case of electricity where the upstream costs of generation, transmission and distribution, and other facilities are much larger than the capital cost that the consumer confronts for the stove itself (Fig. 2.8.4). When system costs are included, electric stoves can be seen to be particularly expensive.

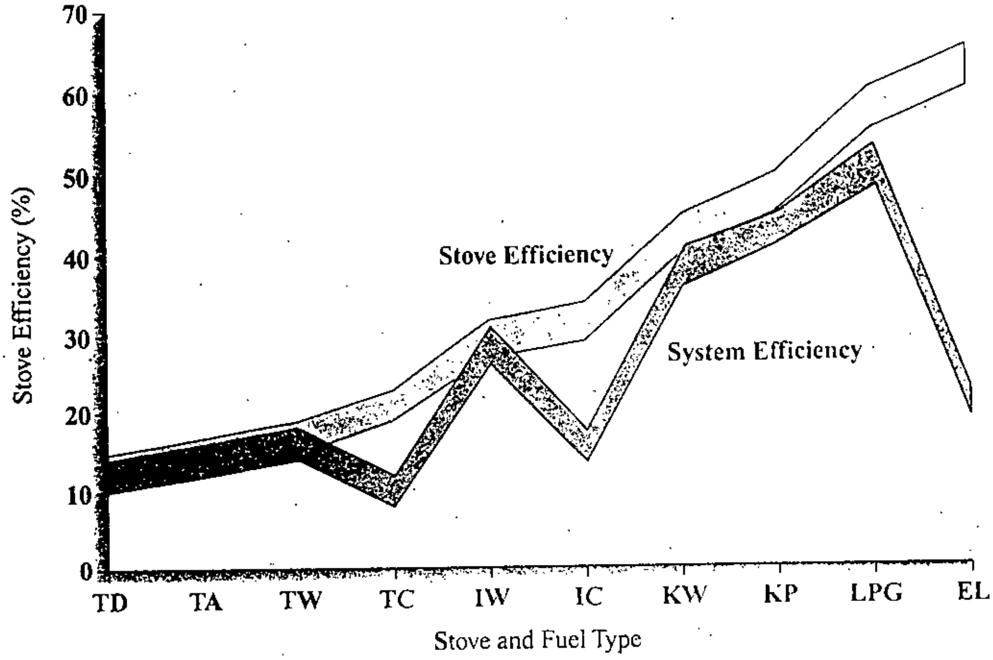

Fig. 2.8.3: Stove and system efficiencies (OTA, 1992)

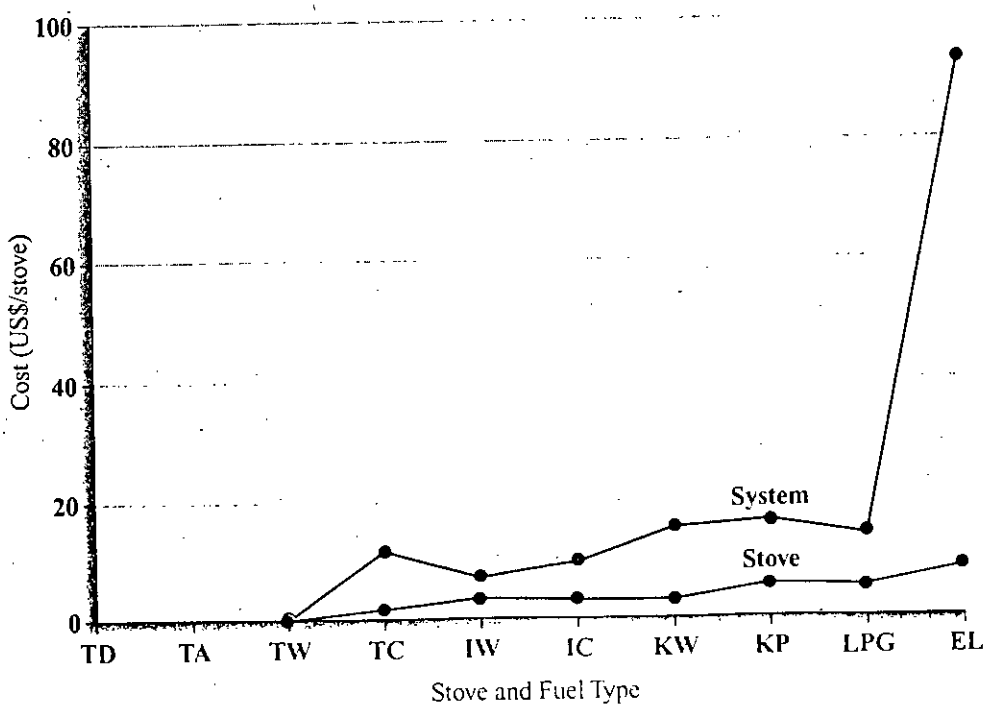

Fig. 2.8.4: Stove and system capital costs (OTA, 1992)

Depending on relative fuel and stove prices, substantial reductions in both operating costs and energy use can be obtained from switching from traditional stoves using commercially purchased firewood to improved biomass, gas, or kerosene stoves (Fig. 2.8.5). There may be opportunities to substitute high performance biomass stoves for traditional ones or to substitute liquid or gas (fossil- or biomass-based) stoves for biomass stoves.

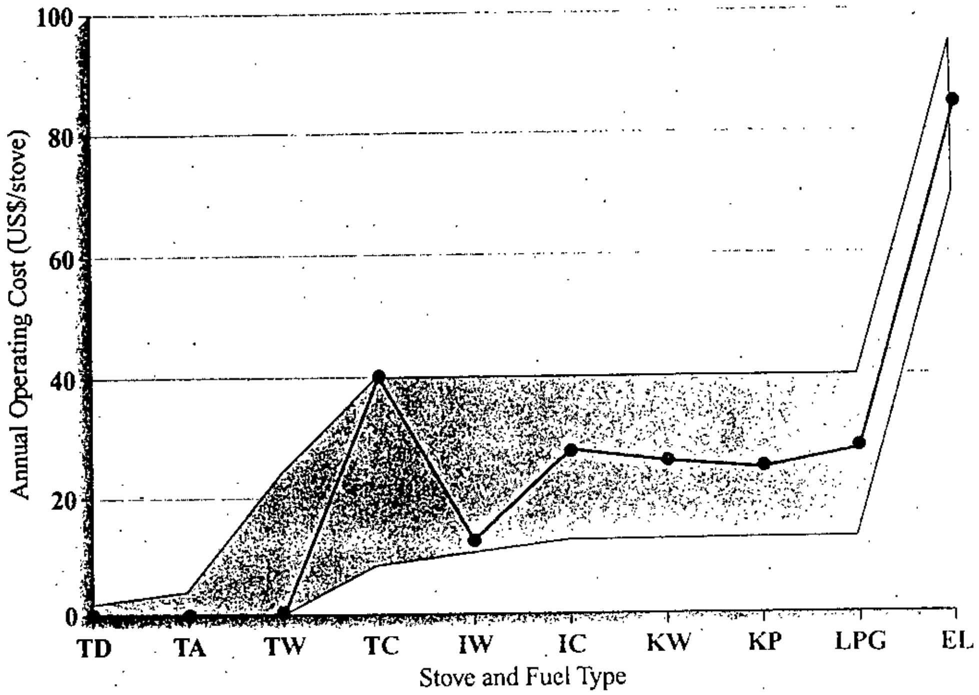

Fig. 2.8.5: Annual cost of cooking for different stoves (OTA, 1992)

Data points show the cost as estimated from the nominal values. The gray band suggests the wide variation in cost using any particular stove depending on local stove and fuel costs, diet, and a host of other factors (OTA, 1992).

Within a given country, public policy can help shift consumers toward the more economically and environmentally promising cooking technologies. In particular, while improved biomass stoves may be the most cost effective option for the near to midterm, they require significant additional work to improve their performance. In rural areas, biomass is likely to be the fuel of necessity for cooking for many years to come. Alternatively, liquid or gas fuelled stoves may offer the consumer greater convenience and performance at reasonable costs, especially in urban areas. However, in order to make improved stove purchases economically feasible to most households, foreign exchange considerations will require that stove and system efficiencies be maximized and that as much as possible of the stove and other system equipment be manufactured in-country.

In the long-term (assuming income growth and the ability to finance imports), the transition to high quality liquid and gas fuels for cooking is inevitable. With this transition, substantial amounts of labour now expended to gather biomass fuels in rural areas may be freed. The time and attention needed to cook when using crude biomass fuels may be reduced substantially. Furthermore, household, local, and regional air pollution from smoky biomass (or coal) fires may be largely eliminated. On the other hand, high quality fuels will increase monetary costs to the individual consumer. Moreover, if fuels or stove equipment are imported, this situation could have significant impacts on national trade balances and foreign exchange holdings. The use of commercial liquid fuels from biomass, advanced gasification designs for stove and other options may be particularly important here. To realise any of these advanced biomass based systems, however, will require a substantial further research and development effort.

The transition to modern stoves and fuels thus offers users many benefits --- including reduced time and labor as well as a potential reduction in cooking fuel inputs and in local air pollution levels. Nevertheless, this transition can be constrained sharply by the higher capital and operating costs of modern stoves and uncertain fuel supplies. Means of lowering both capital and operating costs and ensuring the reliability of supply are needed if the poor are to gain access to these clean, high-efficiency technologies. Further, this transition could impose a substantial financial burden on poor nations.

A large-scale transition to LPG, for example, would require a significant investment in both capital equipment and ongoing fuel costs. Optimistically assuming that the capital cost of LPG systems would average $ 50 per household (including bottling, storage, and transport), the investment would be roughly 3.5 percent of current Gross National Product and 20 percent of the annual value-added in manufacturing for the three billion people in the lowest countries. The LPG used would be equivalent to one-fourth total commercial energy consumption today by these countries and would be a significant fraction of their export earnings. Significant economic growth and a gradual phase-in of these technologies are needed if these costs are to be absorbed. Given these costs and impacts, advanced biomass fuels --- liquids or gases --- could be highly beneficial in meeting cooking requirements for efficiency, cleanliness, and convenience, while minimising greenhouse gas emissions and trade balance impacts, and increasing domestic rural employment. A significant effort in advanced biomass fuels and cooking technologies is highly desirable.

Chapter 3

EXPERIMENTAL

3.1 Introduction

Depending on the fuel, cooking stoves can be divided into 5 broad groups, such as biomass stoves, kerosene cookers, electric heaters, gas burners and solar cookers. Solar cookers are expensive, bulky, and fragile. These may require changes in cooking practice, and materials to repair them may be difficult to obtain. More extensive analysis of field experience and further field trials are needed to independently characterize the performance of the current generation of solar cookers and determine their potential. Thus solar cookers were excluded from this study.

All types of cookers used in Bangladesh were collected and examined. The description of the cookers and the experimental techniques and procedures used in this study are given in the following sections.

3.2 Biomass cookstove

In Bangladesh there is no significant difference among the cooking stoves for different types of biomass fuels. Two cookers used in the country are examined. One is the traditional cookstove (Plate 1) and the other is the improved biomass cookstove (Plate 2).

3.2.1 Fuel characteristics

Mango wood having a net heating value of 18 MJ/kg was selected as the fuel for this experiment. Wood was chopped into small pieces approximately 10-12 cm in length and 2-3 cm in diameter and sun-dried for several days.

3.2.2 Experimental procedure

The experimental procedure to evaluate the Efficiency and the Time to Boil is outlined. The pot was weighed and filled with 3 kg of water. Initial temperature of the water was recorded. Firewood was loaded into the cooker and ignited. The pot was covered with a

Plate 1: Traditional biomass cookstove

Plate 2: Improved biomass cookstove

lid and placed on the stove. Time required to bring the water from its initial state to the state of boiling was noted. When the water started to boil, the lid was removed and boiling was continued for fifteen minutes. After that water remaining in the pot was weighed, as also was any remaining fuel.

3.3 Kerosene cooker

Three types of kerosene cookers, traditional or 10-wicks kerosene cooker, kerosene cooker with inside pump and kerosene cooker with outside pump are now available in Bangladesh (see Plates 3, 4, & 5). All three were examined. Experimental procedure was the same as that for the biomass stove except for the measurement of the amount of fuel used. Kerosene can be measured in different ways, and the simplest method was used in this study. Kerosene was poured into the cooker, and the cooker was weighed before the start of the experiment. After the end of the experiment, the cooker was reweighed to determine the amount of kerosene used.

Plate 3: Traditional kerosene cooker

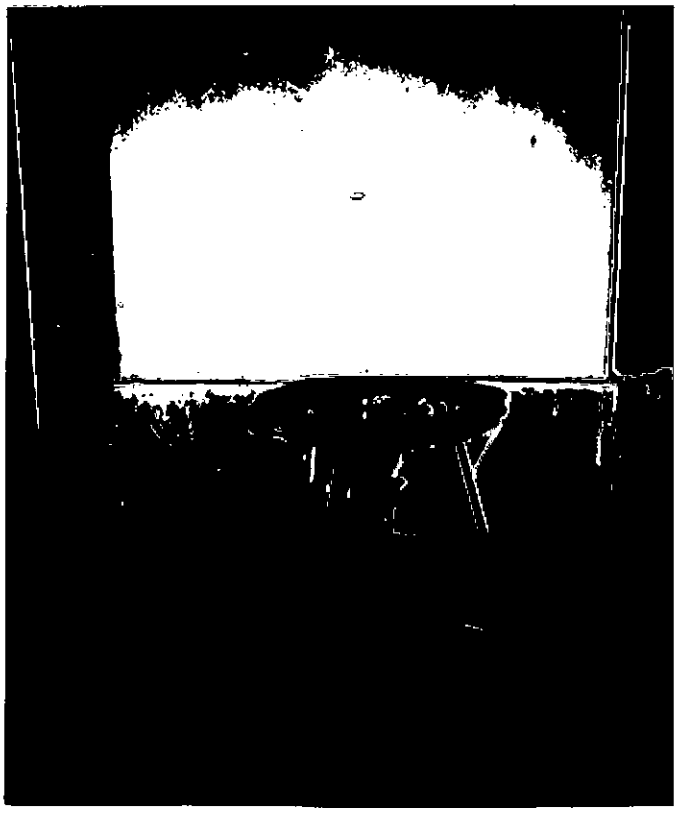

Plate 4: Kerosene cooker (inside pump)

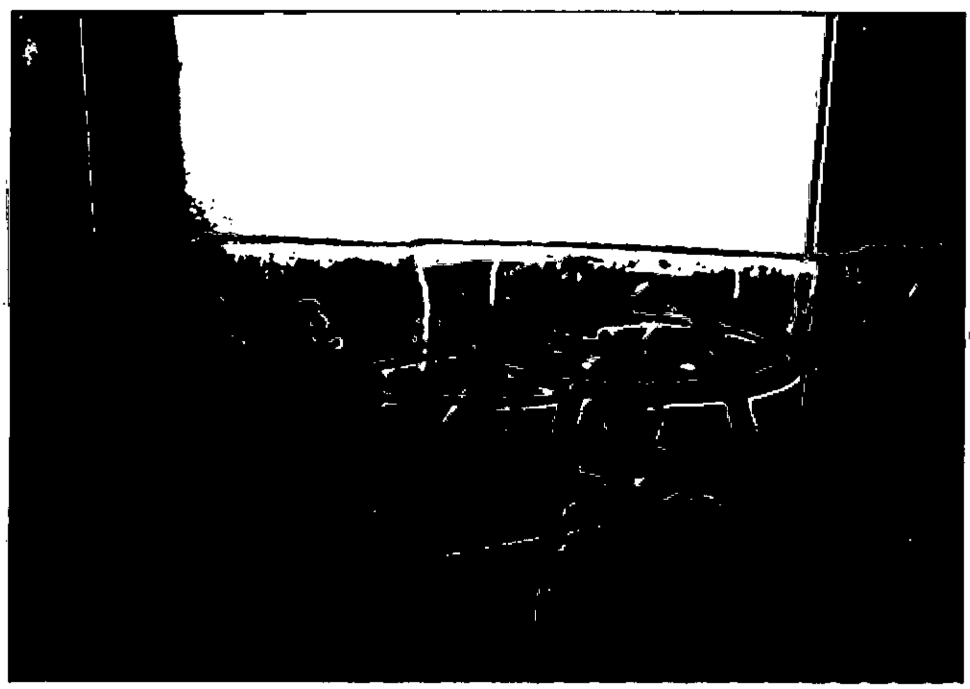

Plate 5: Kerosene cooker (outside pump)

3.4 Electric heater

Electric heater is the most simple and easily controlled cooker. The simplest one was examined. Experimental procedure was the same as that for the biomass cookstove except for the procedure for measuring the amount of electricity used. In this experiment a 800-watt heater was used. By recording the total time required for the experiment, the total kWh was determined.

3.5 Gas burner

There are three types of burners available in the market. An improved type has been developed by BCSIR, but has not been marketed. All four types were examined.

3.5.1 Traditional model

The traditional gas burner consists of a circular burner surface 9.3 cm in diameter. The schematic diagram of the gas burner is shown in Fig. 3.5.1. The burner is fitted on a frame. The distance between the utensil and the burner surface is 4.5-5 cm. The frame is made of iron sheet and the burner is made of cast iron.

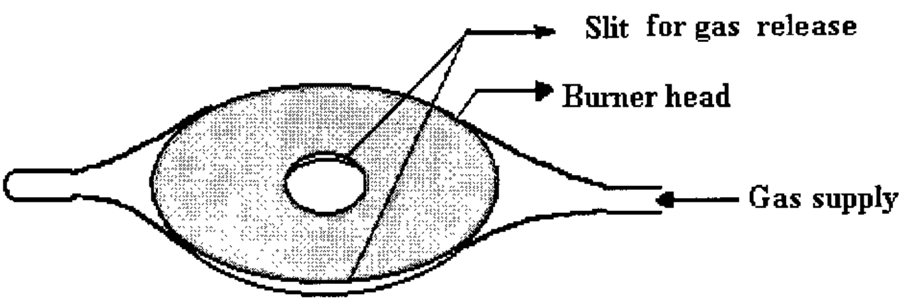

Fig. 3.5.1: Traditional burner

3.5.2 Improved burner-1

Like the traditional burner, the improved burner-1 consists of a circular burner surface 8.5 cm in diameter. The main difference between the traditional burner and the improved burner is in the gas distribution system. In the improved model, gas is distributed through the total burner surface. There are 25-30 holes covering the surface. The distance between the utensil and the burner is 6 cm. The burner is shown in Fig. 3.5.2.

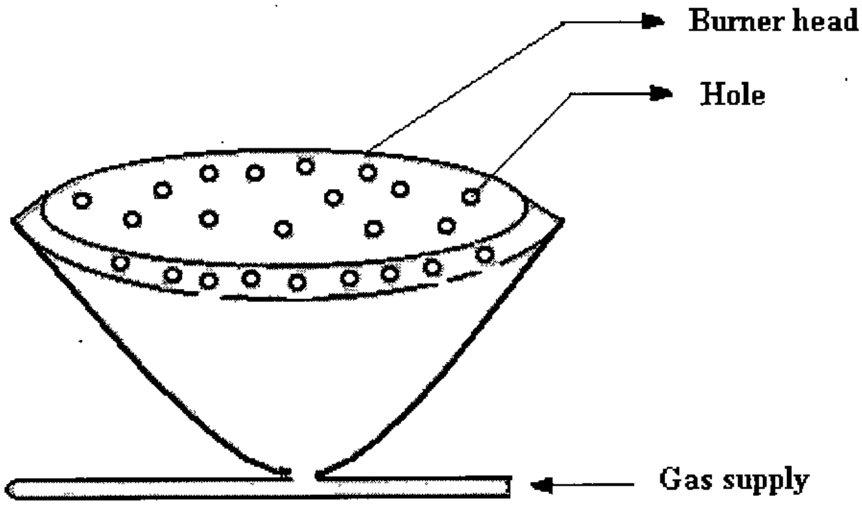

Fig. 3.5.2: Improved gas burner-1

3.5.3 Improved burner-2

The improved burner-2 consists of a circular burner surface 10.5 cm in diameter. It is different from the traditional burner and the improved burner-1. In this burner a large number of holes covers the overall surface of the burner head. The burner head is larger than both the traditional burner and the improved burner-1.

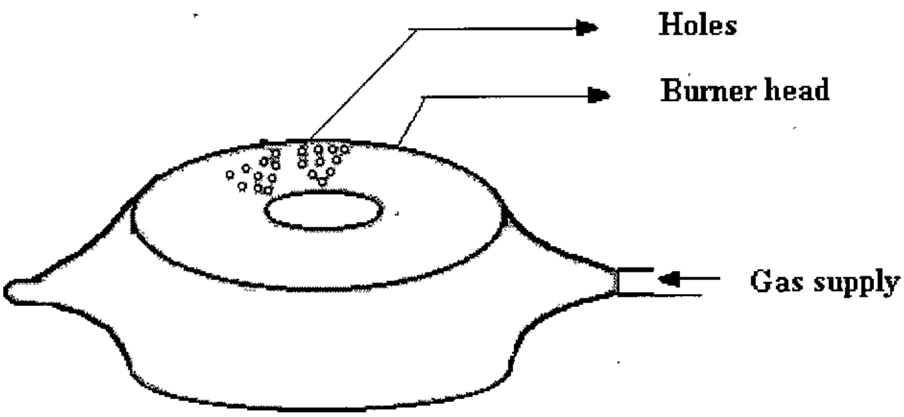

Fig. 3.5.3: Improved gas burner-2

3.5.4 Improved BCSIR gas burner

The stove consists of three parts :-

i) Outer frame

ii) Gas burner

iii) Gas regulating valve with a nozzle.

Outer frame of the stove: The outer frame is made of mud. The frame can also be made of cement, sand, fireclay, M.S. sheet or G.I. sheet. The frame is shown in Fig. 3.5.4(a). The diameter of the frame is 20 cm and height is 23 cm. On the top of the frame there are three raised points as shown in the Fig. 3.5.4(a). The three raised points support the cooking utensil and the space between the risers serve as exit for flue gases. At the bottom of the frame, below the burner, 6-8 holes of 1.3 cm diameter are made for entry of secondary air, so that soot-free combustion can be achieved. At a depth of 12.7 cm. from the top of the riser, two ledges are made on diametrically opposite sides of the frame for holding the burner. On one side, a hole is made just above the ledge for fixing the control valve and nozzle assembly to the burner port.

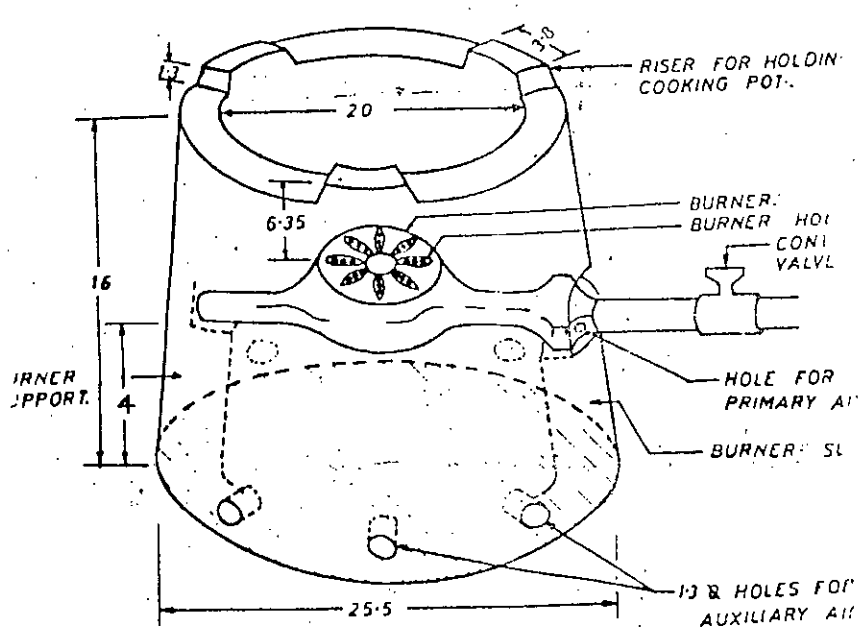

Fig. 3.5.4(a): Outer frame of the stove

Gas burners: Two type of burners have been constructed as shown in Fig. 3.5.4(b) and Fig. 3.5.4(c). The burners, made of mud, is 24 cm long with one end closed. At the open end, there is a burner port of 1.3 cm diameter. Adjacent to the burner port, two holes 0.90 cm diameter each, are made for entry of primary air. The holes are preferably made at diametrically opposite sides 7.5 cm away from the burner port. A circular burner surface, 10 cm in diameter is made, and 25-30 small holes of 0.16 cm diameter are made and arranged like a flower petal as shown in Fig. 3.5.4(b) or in concentric form as shown in Fig. 3.5.4(c). The burner is placed inside the mud frame in such a way that the distance between the top of the riser and the top of the burner surface is 6.35 cm.

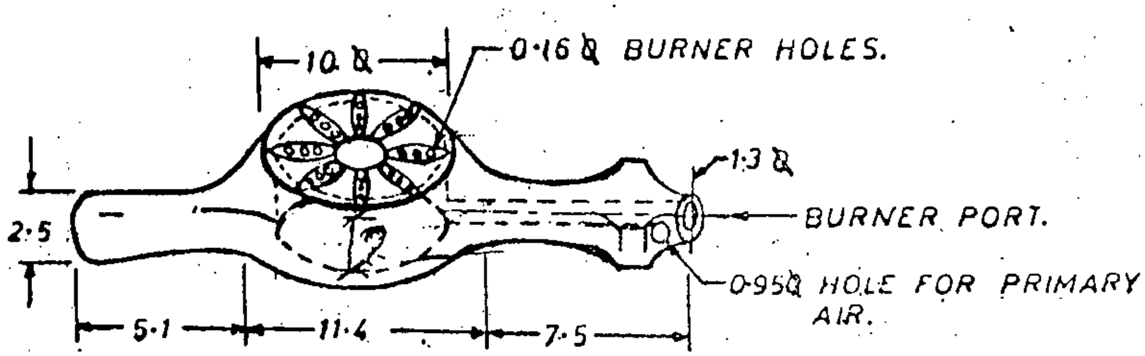

Fig. 3.5.4(b): Burner (flower petal)

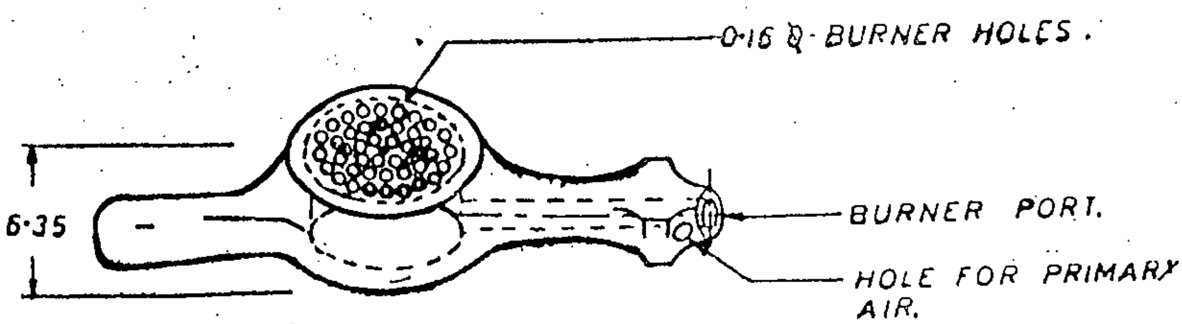

Fig. 3.5.4(c): Burner (concentric)

3.5.5 Characteristics of the utensils

Two types of utensil, namely flat bottomed saucepans (Pan) and round bottomed pitcher-shaped (Pot) vessels were used in this study to determine the effect of shape on the efficiency. Dimensions of the utensils are given below.

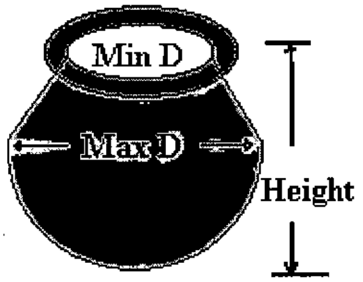

Fig. 3.5.5(a): Pot

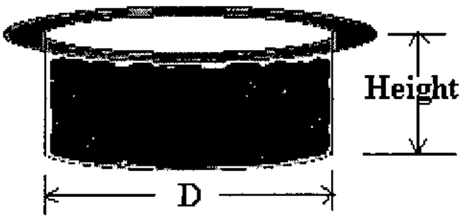

Fig. 3.5.5(b): Pan

a. Pot-1: Diameter -- 26 cm (maximum)

Diameter-- -15.5 cm (minimum)

Height ----17 cm

Volume -- Approximately 5 liters

Weight --- 0.32 kg

b. Pot-2: Diameter---26 cm (maximum)

Diameter--14 cm (minimum)

Height-----15 cm

Volume---Approximately 5 liters

Weight----0.25 kg

c. Pan: Diameter -25 cm

Height ----12.5 cm

Volume --- Approximately 5 liters

Weight --- 0.35 kg

3.5.6 Fuel characteristics

Net heating value of natural gas = 37 MJ/m^3

TABLE 3.5.6: Composition of natural gas

Component	Symbol	Mole percent dry gas
Methane	C_1	97.17
Ethane	C_2	1.89
Propane	C_3	0.29
i-Butane	i-C_4	0.13
n-Butane	n-C_4	0.12
i-Pentane	i-C_5	0.07
n-pentane	n-C_5	0.05
Hexane	C_6	0.04
Heptane plus	C_7^+	0.24

3.5.7 Experimental setup

To measure the efficiency of a gas burner the following equipment were used

1. Cooking vessel
2. Gas burner
3. Rotameter
4. Weight machine
5. Wet test meter

6. Thermometer

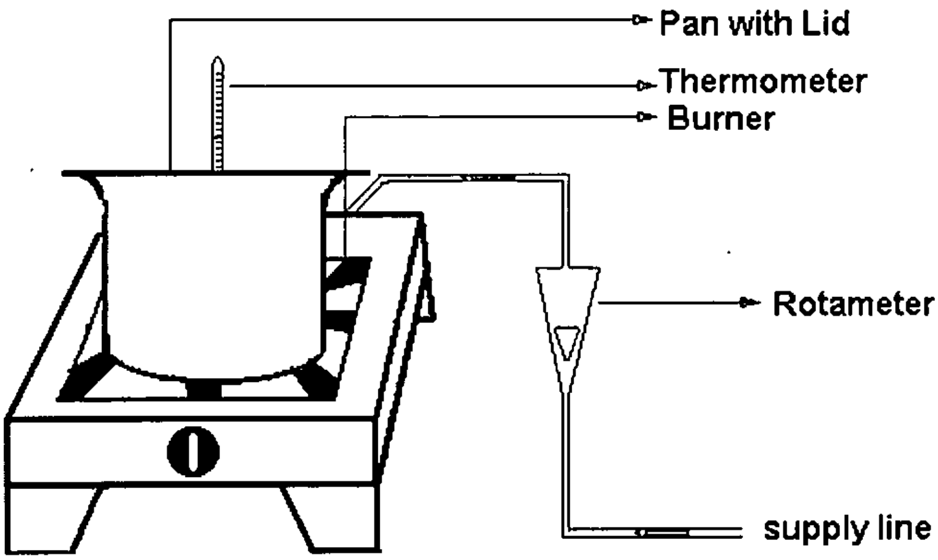

Fig. 3.5.7: Experimental setup

A rotameter was connected to the burner to measure the gas flow rate. First, the rotameter was calibrated by a wet test meter. A schematic diagram of the experimental setup is shown in the Fig. 3.5.7 and Plate 6. To measure the temperature of the water, a thermometer is placed through a hole on the lid.

3.5.8 Experimental procedure

The cooking vessel was first weighed, filled with water and weighed again. The initial temperature was noted. The cooking vessel was covered with a lid and was placed on the stove. The start of the experiment was recorded and the stopwatch was started for time measurement. Time required for taking the water from its initial state to the boiling state was recorded. When the water started to boil, the lid was removed and boiling was continued for a fixed time. After the experiment, water remaining in the cooking vessel was weighed to determine the evaporated water.

The total time was recorded to determine the amount of gas consumption. A calibrated rotameter was used to measure the amount of gas. [Calibration chart is given in Appendix-A. The desired flow rate of gas was fixed by adjusting the rotameter. This procedure was followed to measure the thermal efficiency of all gas burners including the BCSIR model.

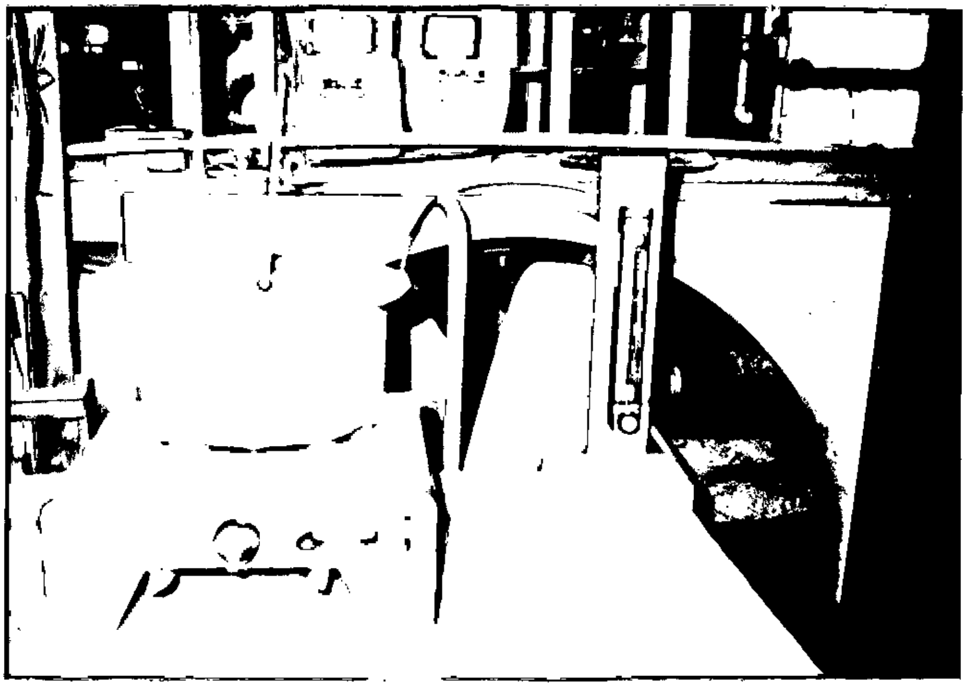

Plate 6: Experimental setup

Chapter 4

RESULTS AND DISCUSSIONS

4.0 Introduction

The two main objectives of this project were to study the efficiency of all types of cookstoves available in Bangladesh and to improve the efficiency of the best available existing natural gas burner. To fulfil the objectives, experiments were performed as described in chapter 3. All the experimental results are presented in the following sections. The improved natural gas burner developed in this study is described in section 4.2 and the results are presented in section 4.2.1. A table summarizing the efficiencies of the different cookstoves is presented in section 4.3.

4.1 Efficiency studies of different cookstoves

The experimental setup and procedure are described in chapter 3. The detailed results for each fuel and cookstove are presented in appendix-D. In this chapter only the final calculated results, which are the efficiencies and the time required for a fixed amount of water to reach the boiling point are presented. The calculation procedure for efficiency is presented in appendix-C. The following cookstoves were collected to study their efficiencies.

1. Biomass (2 types)
2. Kerosene (3 types)
3. Electric heater
4. Gas Burner (4 existing models)

The experimental results and discussion for biomass cookstoves, kerosene cookers, electric heaters and gas burners are presented in sections 4.1.1 to 4.1.4. For the gas burner the effect of gas flow rate and the shape of the cooking vessel were also studied. The results are presented in a graphical form as thermal efficiency versus gas flow rate. At the end of section 4.1.4 the results for BCSIR improved model are presented.

4.1.1 Biomass cookstoves

A number of improved biomass stoves are available in Bangladesh. Among these, the most widely used model was selected and studied. The results are presented in Table 4.1.1. Analyzing the data it is clear that the improved model has much better thermal efficiency than the traditional model. Moreover, the time required to reach boiling point which is a measure of the rate of heat transfer, is lower for the improved model. The literature and all previous experimental data of BCSIR (Eusuf et al., 1990) support this result.

TABLE 4.1.1: Efficiency of biomass cookstoves available in Bangladesh

Model	Weight of water (kg)	Heat utilization efficiency (%)	Time to reach boiling point
Traditional	3	10	21.5 minutes
Improved	3	24	13.5 minutes

Energy for household cooking in Bangladesh is derived largely from biomass fuels. Approximately 80 percent of the population of Bangladesh live in the rural areas. Crop residue and firewood are the main biomass fuels. Biomass fuel has several disadvantages. The main disadvantage is very low thermal efficiency of traditional biomass stoves. The quantity of ash produced is also very high. As the heat content of biomass and efficiency of stoves are low, a large quantity of biomass is required. As it is bulky, transportation becomes costly. Complete combustion is not accomplished, leading to the formation of carbon monoxide and particulates, which cause a considerable amount of air pollution. Many respiratory problems are found among rural women and children who are exposed daily to biomass smoke for a significant length of time. Despite the dangers of biomass smoke, millions of people will continue to burn biomass because no other option exists for them.

As the poor people of developing countries will continue to use biomass for the preparation of their meals, it is necessary to develop technology to make better use of biomass, and to improve the stoves to achieve better thermal efficiency. For this purpose, the Institute of Fuel Research and Development, BCSIR, has been working to design and make available different types of improved biomass stoves in Bangladesh. In rural areas, where biomass is the only source of fuel, the use of improved biomass cookstoves is an attractive proposition because the improved biomass stove has the following advantages.

1. Approximately 40-50% firewood can be saved.
2. Smoke, which is very harmful to the health of those who are exposed for long hours particularly women and children in the kitchen, is much lessened.
3. The cooking time is reduced.
4. The technology is simple and therefore can be built and maintained by the users themselves.
5. The materials for the improved stoves are cheap and readily available.

Statistics on wood consumption in the country reveal that 20 million tons of firewood and other non-commercial fuel sources are being consumed annually, constituting 74 percent of the total energy consumption. The large firewood consumption is causing rapid deforestation leading to erosion and changes in the ecosystem and climate. By using improved biomass cookstoves this problem can be minimized.

The lack of understanding among users of the criteria for selection and use of efficient cooking stoves, is a serious impediment to the widespread dissemination of improved stoves. So the concerned government agency as well as NGOs should establish a long-range, adequately funded educational campaign program for efficient stoves, particularly through the primary and secondary school systems.

4.1.2 Kerosene cookers

People in the semirural areas use firewood, kerosene, and electricity as fuel. Firewood still remains the main fuel. But fast urbanization and deforestation are leading to shortage of biomass fuel. So there is a need for transition from firewood to commercial fuels. This transition is very complex and not yet well understood. But the following factors will increase this transition.

1. Family income increase

2. Dwindling supply of firewood

3. The proximity of firewood

4. Level of education increases

Kerosene is the usual supplement to biomass fuels in the semirural areas. There are three types of kerosene cookers available in Bangladesh. All three models have been studied and the results are summarized in Table 4.1.2.

TABLE 4.1.2: Efficiency of kerosene cookers available in Bangladesh

Model	Weight of water (kg)	Heat utilization efficiency (%)	Time to reach boiling point (min)
Traditional	3	46	24
Improved (Pump inside)	10	42	20
Improved (Pump outside)	10	50	31

The 10-wicks traditional model has higher thermal efficiency than the improved cooker (pump inside); but produces more solid carbon which makes pots dirty and harder to clean. Two improved models in which a pump is used for the improvement of air-fuel mixing and producing better liquid droplet are available. These cookers are larger in size than the traditional model. Since a larger cooking vessel was used for these cookers, a larger mass of water had to be used for the experiment. Thermal efficiency of the one with the pump outside is higher than the traditional model but the main reasons for its use are its other advantages which are, time to boil and soot production, both being low, and fire control which is very easy compared to the traditional model. IFRD in BCSIR has been working on the improvement of kerosene cookers. They expect that a new model might be available in the market within six months. The new model is stated to improve the performance of the pump-inside kerosene cooker by using a guard and a chimney.

4.1.3 Electric heater

Electricity is another energy carrier, which is a supplement to biomass fuel and kerosene, and is used in the semirural or urban areas where electricity is available. In Bangladesh different types of electric heaters of varying complexity are used but the most popular model is very simple. The thermal efficiency is 52%, which is low by international standards. Experimental results are given in Table 4.1.3(a). An interesting aspect of the electric heater is that the shape of the cooking vessel has no significant effect on the efficiency.

TABLE 4.1.3(a): Thermal efficiency of an electric heater available in Bangladesh

Type of cooking vessel	Weight of water + pot (kg)	Heat utilization efficiency (%)	Time to reach boiling point
Pot	4	52	52 min 16 sec
Pan	4	53	48 min 18 sec

Generation efficiency and system loss for the existing electricity system in Bangladesh is 27% and 33% respectively. The thermal efficiency of the electric cooker for these conditions is only 9.4% and 9.5% for the pot and the pan respectively. Table 4.1.3(b) shows the effect of generation efficiency plus system loss. As can be seen, even a very good performance of 10% system loss and 45% generation efficiency yields an efficiency of only 21.5% for the pan and 21% for the pot.

TABLE 4.1.3(b): Thermal efficiency (%) of an electric heater at various generation efficiency and system loss

Type of cooking vessel	33% system loss & 27% generation efficiency	20% system loss & 35% generation efficiency	10% system loss & 45% generation efficiency
Pot	9.4	14.6	21
Pan	9.5	14.8	21.5

4.1.4 Gas burners

Today natural gas is the most popular fuel in the urban centers of Bangladesh which have piped gas supply. Gaseous fuels have the advantage that complete combustion can be obtained with very little excess air in the mixtures, although gas mixtures containing large proportions of hydrocarbons require rather more excess air for combustion than do hydrogen or carbon monoxide. The rate of output of heat from a gas flame can be easily controlled by varying the flow rate of the gas within certain limits and the rate and mode of introducing the air for combustion. A number of gas burners are now available in Bangladesh. All of those have been studied and the results are given below.

4.1.4.1 Effect of gas flow rate on thermal efficiency

Figures 4.1.4.1(a), (b) and (c) show the variation in thermal efficiency with flow rates of natural gas for two types of cooking vessels. For nearly all the cases, when the gas flow rate is increased, the burner thermal efficiency first increases and then decreases. For the traditional burner the maximum efficiency is attained at 217 l/h and the values are 44% for the pot and 47% for the pan. For the improved burners the values of thermal efficiency, as may be expected, are higher. The maximum efficiency is attained at 147 l/h and the values in the improved burner-1 are 47% for the pot and 52% for the pan and in the improved burner-2 are 48% and 56% respectively. An explanation for the efficiency variation is as follows. At relatively low gas flow rates, the heat-transfer coefficient between the combustion gases and the bottom of the pan/pot is relatively small because of the low velocity of the gas flows past the pot/pan bottom. The process of heat transfer is enhanced when the gas flow rate is increased until optimum conditions are obtained. At this point, the thermal efficiency reaches its highest value. Beyond this point, any increase in the gas flow rate, will cause the thermal efficiency to decrease because the surface area available for heat transfer at the pot/pan bottom, for a given mass of water and a fixed temperature, becomes the controlling factor. In other words, the rates of heat loss with the flue gases to the environment grow faster than the heat absorption rate of the pot/pan.

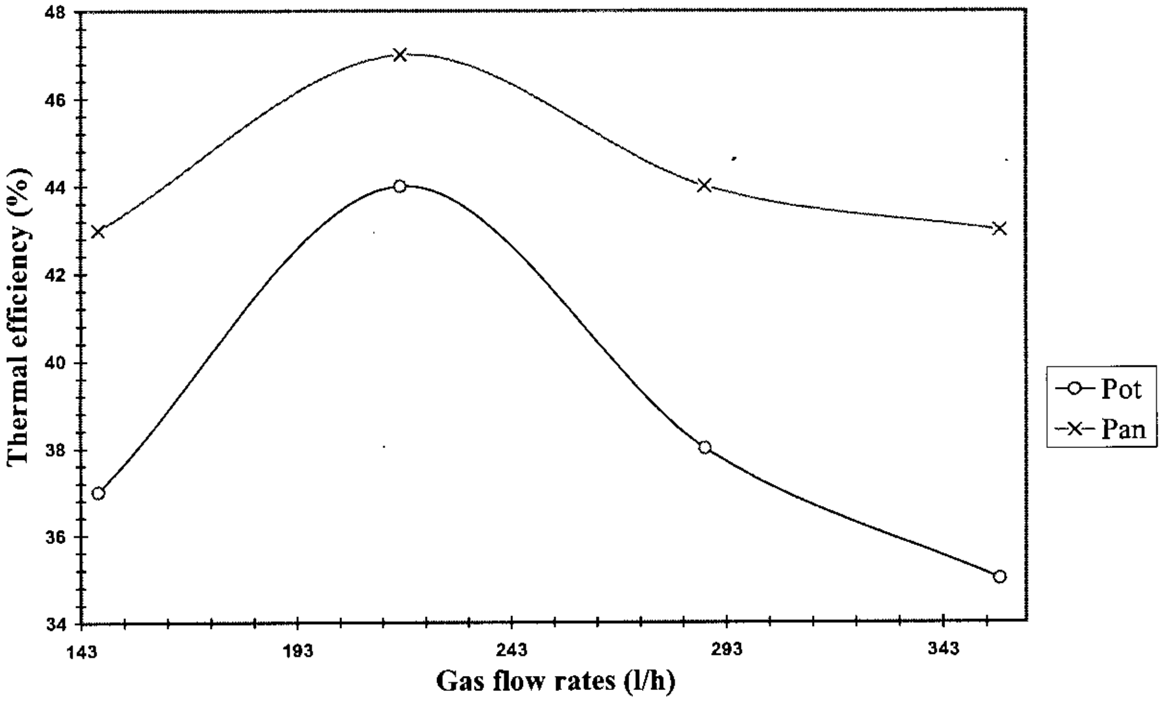

Fig. 4.1.4.1(a): Effect of gas flow rate on thermal efficiency for the traditional gas burner

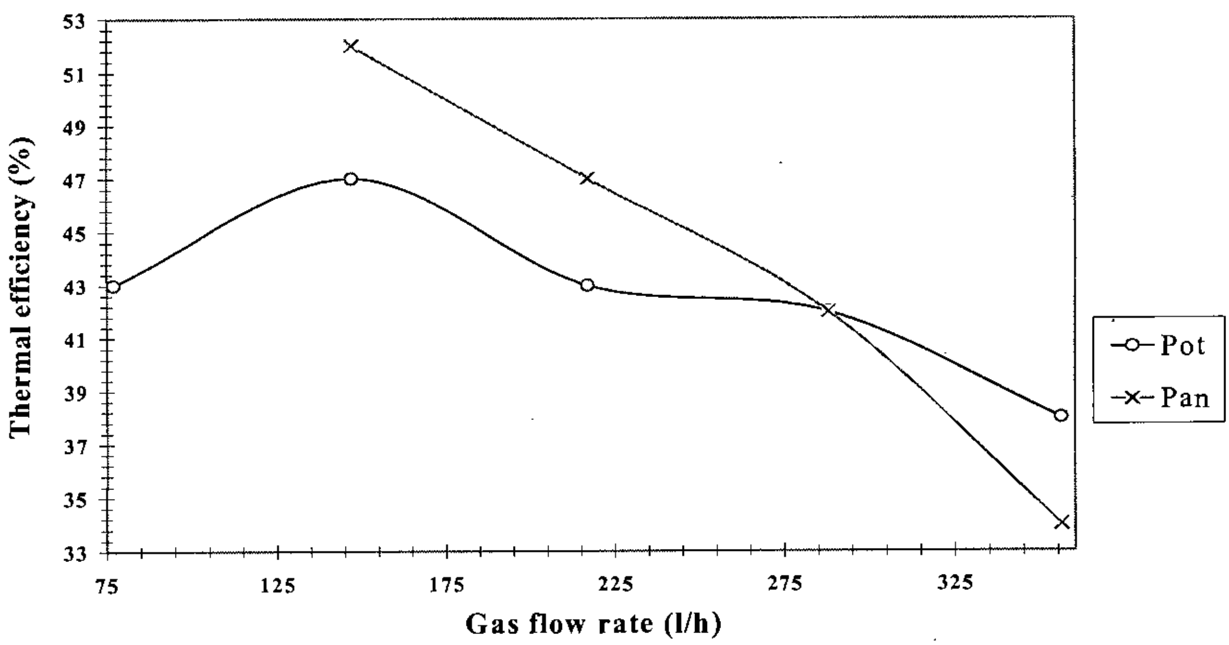

Fig. 4.1.4.1(b): Effect of gas flow rate on thermal efficiency for the improved burner-1

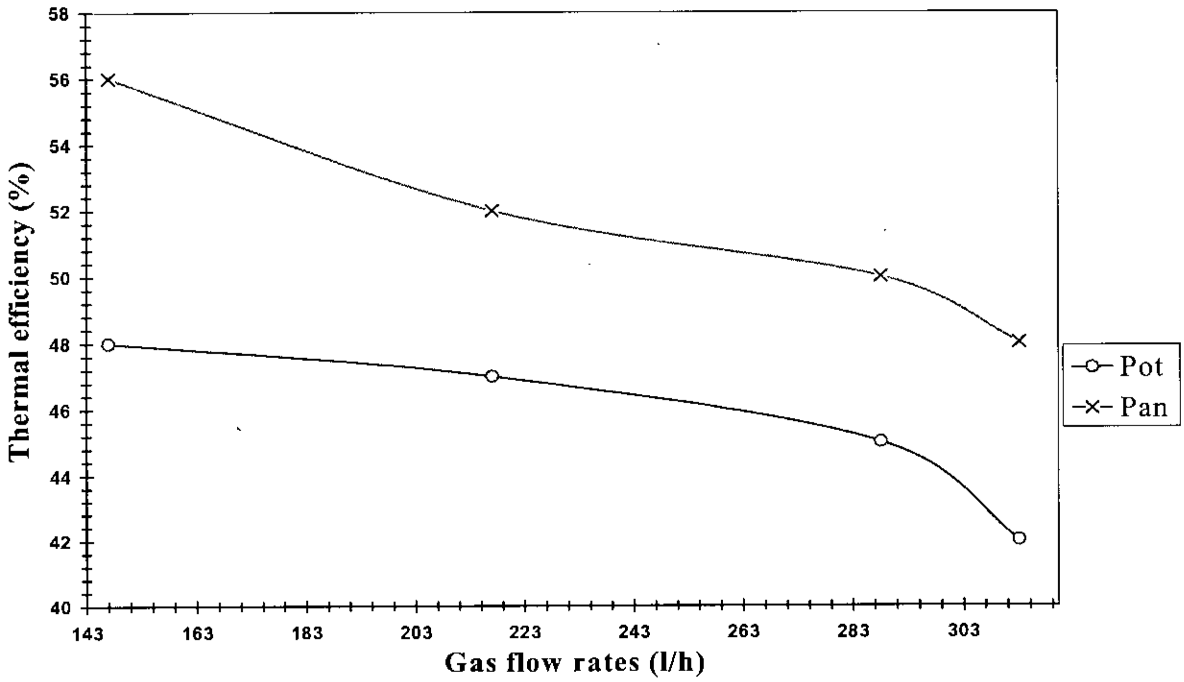

Fig. 4.1.4.1(c): Effect of gas flow rate on thermal efficiency for the improved gas burner-2

4.1.4.2 Effect of the shape of the pot

Two types of utensil, namely flat-bottomed saucepans and round-bottomed pitcher-shaped utensils were used. Fig. 4.1.4.1(a), (b) and (c) show that the thermal efficiency is higher for the flat-bottomed pan than for the round-bottomed pitcher shaped pot. Approximately 2-5% higher efficiency is obtained for the pan compared to the pot in all cases except for the improved burner-1 at gas flow rates 288 l/h and higher. Due to some experimental error this abnormal result was probably obtained. The experiment could not be repeated because the burner was dismantled to conduct the study described in Appendix E. However, the high flow rates at which the anomalous behavior is observed is outside the range of normal interest.

The higher thermal efficiency for the pan can be explained as follows. For the flat-bottomed pan, the flame covers a greater surface area of the base of the pan in comparison to the round-bottomed pitcher-shaped pot. So the heat transfer time before the hot gases get dispersed to the surrounding is higher for the pan. In the round-bottomed pot, the flame opens to the surrounding very quickly and the time for heat transfer is lessened. These factors lead to thermal efficiency for the pot being lower than the pan.

4.1.4.3 Effect of gas distribution

Three different types of burners as shown in section 3.5 were studied. These burners have different gas distribution systems. Effect of the gas distribution system on the thermal efficiency is presented in Fig. 4.1.4.3(a) and Fig. 4.1.4.3(b) for the pot and the pan respectively. Gas distribution and facility to mix air have significant effect on the thermal efficiency. Using the pot, the maximum efficiency attained by the improved gas burner-2, which occurs at 147 l/h, is 48%. For the improved gas burner-1 the maximum efficiency is 47% and occurs also at 147 l/h. For the traditional burner the maximum efficiency is 44% and occurs at 217 l/h. Using the pan, the maximum efficiency attained by the improved gas burner-1 and the improved gas burner-2, both of which occurs at 147 l/h, is 52% and 56% respectively. For the traditional burner the maximum efficiency is 47% and occurs at 217 l/h. In the traditional burner gas ejection holes are situated on the periphery (see Fig. 3.5.1). After the gas is ejected from the holes, combustion occurs at the boundary with the surrounding open air by diffusion. Combustion products produce

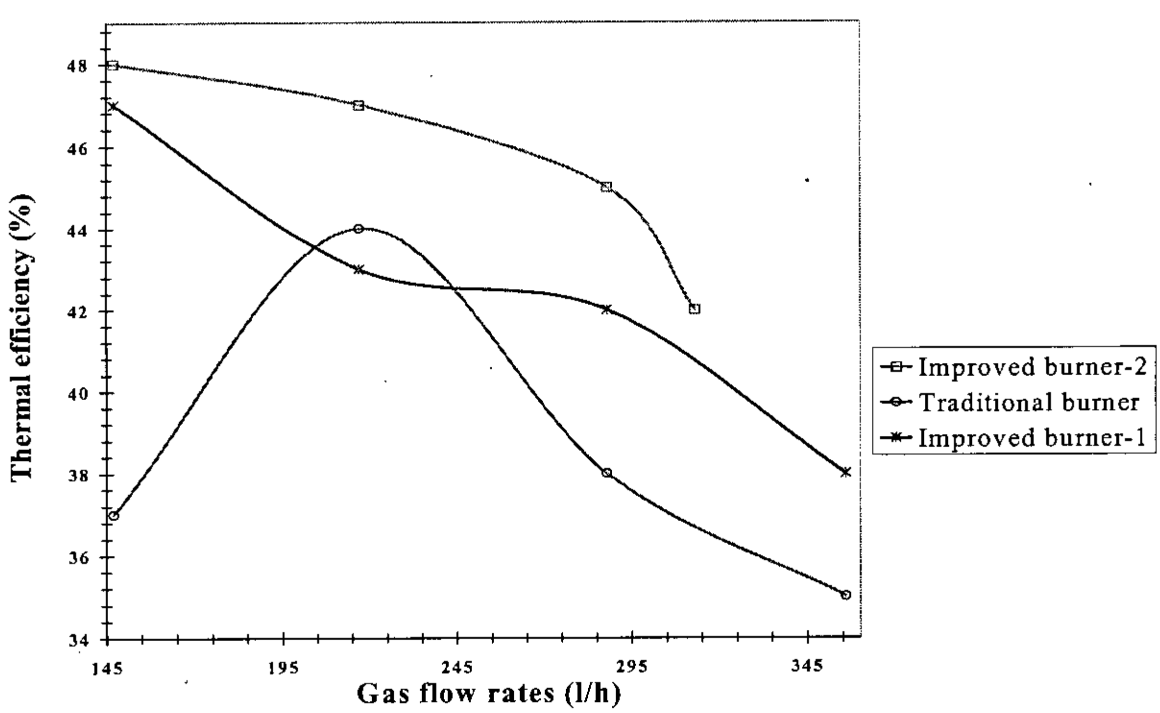

Fig. 4.1.4.3(a): Effect of gas distribution on thermal efficiency for the pot

flame on the rim of the burner head, and therefore, the contact area for heat transfer is small. But in the improved burners, a number of holes over the burner surface (burner head) is used to release gas, and combustion occurs all over the burner surface thus affording a large contact area for heat transfer.

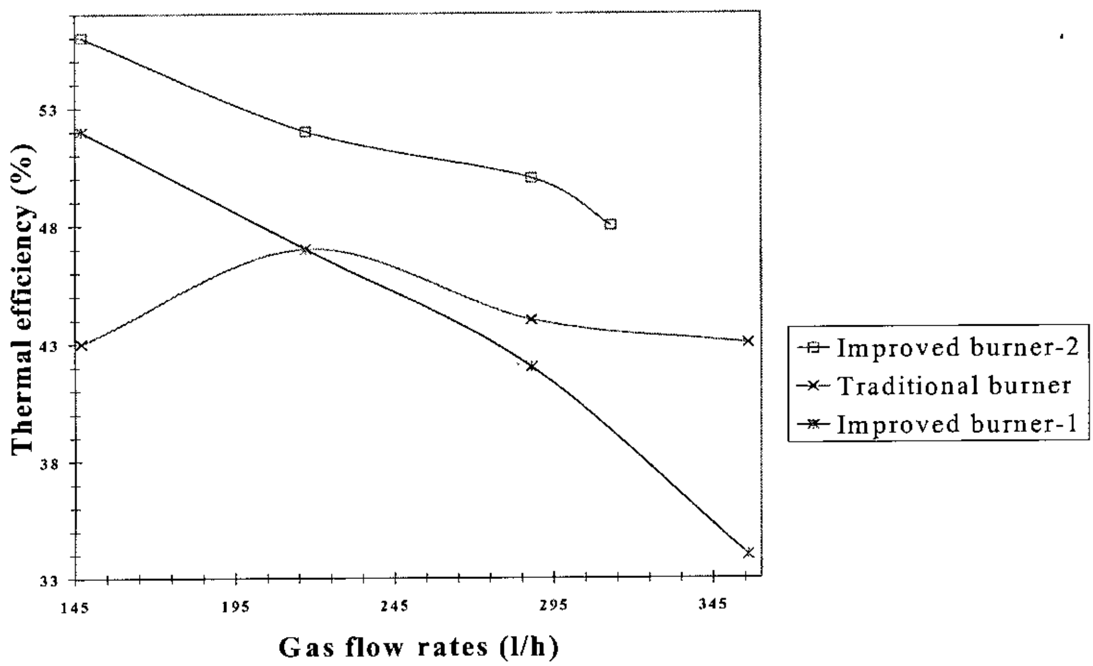

Fig. 4.1.4.3(b): Effect of gas distribution on efficiency for the pan

4.1.4.4 New gas burner developed by IFRD, BCSIR

A new gas burner has been developed by IFRD at BCSIR. But this model is not available in the market. As can be seen from Fig. 3.5.4, this new burner is essentially the improved burner-2 with a casing around it. Therefore, its efficiency was studied at the same flow rate which produces the maximum value for the improved burner-2. The maximum efficiency was 58% for this model. As a confirmation, the efficiency was studied at another higher flow rate. The efficiency was found to decrease.

4.2 Efficiency improvement of gas burner

The following section deals with the various efforts made in this study to improve the efficiency of the natural gas burner. The general requirement for any improved natural gas cooker can be stated as follows:

(1) That the improved burner shall be designed to accommodate as many different sizes and shapes of pots and pans as possible.

(2) That the improved burner shall consume less fuel or at least equal amounts to the existing good models.

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

(4) That the improved burner operation shall be conducted with ease and safety, including the burner's ignition, heat output control and fire extinguishing.

The above criteria indicate that the IFRD, BCSIR cooker, despite its high efficiency, is not a model which will be readily accepted by the existing users. The improved gas burners available in the market, whose result have been presented in section 4.1.4, are acceptable according to the above criteria, but scopes of efficiency improvement remain.

Efficiency of a cookstove can be improved by many techniques of which decreasing the heat loss is one. Heat loss can be decreased in the following ways.

1. Insulating the upper part of the cooking vessel--- when insulating material covers the upper part of the vessel, heat loss from the vessel to the surrounding is decreased.

2. Putting a guard around the zone where the flame comes into contact with the cooking vessel --- the guard restricts the flow of flue gas and increases contact time.

3. Using flue gas heat (configuration shown in Appendix E) --- If flue gas heat can be used, heat loss will be minimized.

All these methods including a combination of methods 1 and 2, were utilized in attempts to increase the efficiency of the existing natural gas burners. The experimental procedure was the same as that used for the gas burners, details of which is provided in chapter 3. A preliminary investigation (details given in appendix E) showed that only method 2, i.e., putting a guard around the flame, has any significant beneficial effect on the efficiency.

4.2.1 Efficiency improvement by putting an outer frame around the flame

Decreasing heat loss can increase thermal efficiency. Heat loss is high in existing burners because of the openness of the combustion zone. Results published in the literature for the development of biomass stoves indicate that putting an outer frame around the flame, which restricts the flow of flue gas and decreases heat loss, may be effective in increasing the efficiency of a natural gas cooker. A guard frame having a height of 10 cm and adjustable diameter, as shown in Fig. 4.2.1 and Plate 7, was constructed from GI sheet. For changing the diameter of the frame a nut and bolt arrangement was provided. The frame was placed on the cooker surrounding the bottom portion of the cooking vessel as shown in Plate 7.

In the first experiment, the guard frame had no holes. It was found that (results given in Fig. 4.2.2) the efficiency actually dropped. It was realized that the frame was preventing entry of secondary air and also causing backflow of the hot gases. Therefore, a number of holes were made in the bottom section of the frame, as can be seen in Fig. 4.2.1 & Plate 7.

The main factors that effect the efficiency and operability of gas burners are gas flow rate, gas distribution and air supply. To study the effect of the diameter of the frame on the thermal efficiency of a gas burner, the improved gas burner-2, which has the highest thermal efficiency compared to the other two models, was selected. The maximum efficiency for this burner was attained at 147 l/h, and therefore, all the tests were conducted at this flow rate. For the other two burners, the efficiency was measured only for the optimum frame diameter at flow rates which gave maximum efficiency without the frame. Durability and operability are important factors in burner construction and design. So the frame was made of GI sheet.

The effect of the guard frame on the thermal efficiency was examined and the results are shown in Fig. 4.2.2. Analyzing the results it is clear that putting an outer frame around the flame increases the efficiency, but the distance between the cooking vessel and the frame is an important parameter.

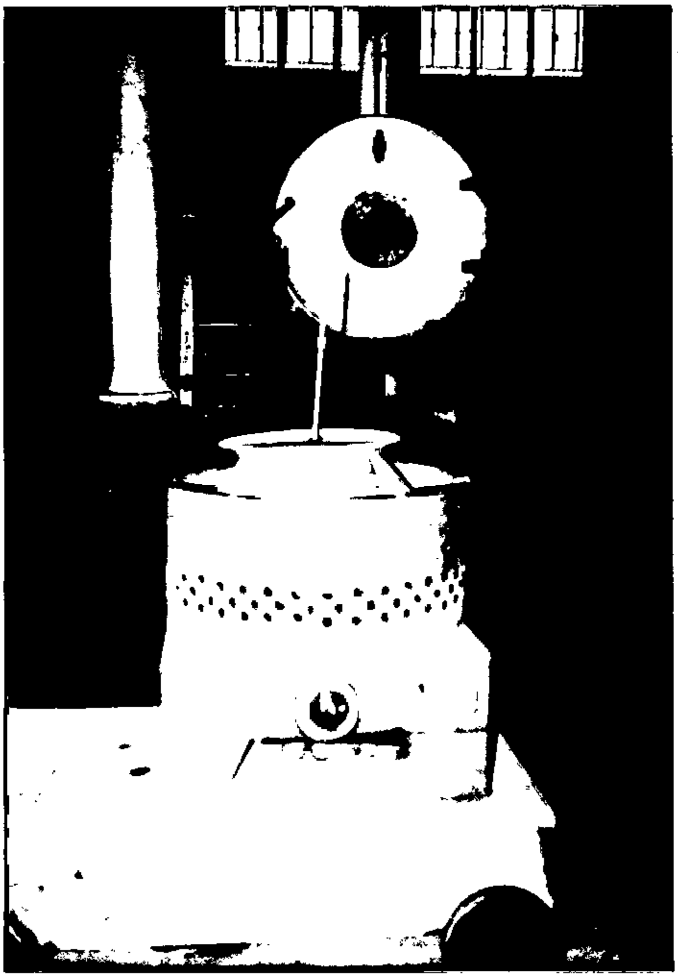

Plate 7: Arrangement of the guard

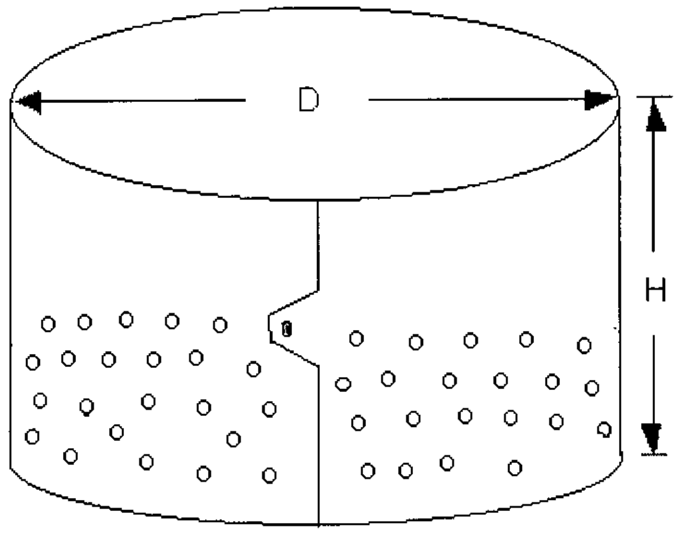

Fig. 4.2.1: Schematic diagram of the guard frame

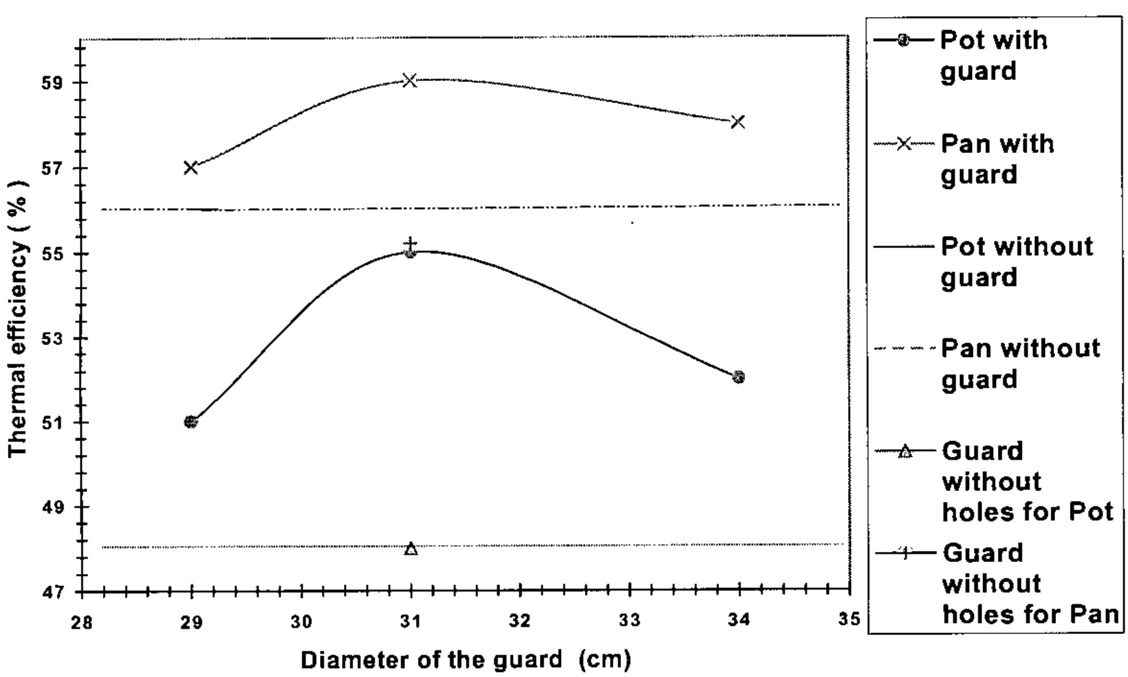

Fig. 4.2.2: Effect of diameter of the guard on the thermal efficiency

For the pot and the pan the maximum efficiency was obtained when the gap between the cooking vessel and the frame was 2.5 cm and 3 cm respectively. When the gap is very small, flue gas cannot flow freely and backflow occurs which restricts entry of air for combustion. When the gap is large, flue gas flows out freely thus lowering the residence time around the cooking vessel. Beyond a certain distance the effect of the frame is negligible. The frame has a significant effect on the thermal efficiency for the pot, but for the pan the effect is marginal.

The reason for this is connected with the flow pattern of the hot gas around the cooking vessel. As explained in section 4.1.4.2, the contact between the gases and the vessel bottom for the pan is good, and therefore, the frame has a small role to play. For the case of the pot, the contact between the hot gases and the vessel bottom is poor because of its shape. The frame is able to sufficiently restrict the hot gases causing greater contact. Thus the efficiency improvement obtained for the pot is higher.

The thermal efficiency for the pot using the traditional burner with the guard was found to be 48% (Appendix-D7). The thermal efficiency has been increased by 4% in the traditional burner when the guard is used. Similarly the thermal efficiency for the pot using the improved burner-1 with the guard was found to be 48% at 217 l/h. The thermal efficiency has been increased by 5% in the improved burner-1 when the guard is used. For the pot thermal efficiency has been increased by 5% in the improved burner-2 when the guard is used. Table 4.2 summarizes all the results using the guard.

TABLE 4.2: Efficiency of different types of burner with and without guard

Model	Gas flow rate (l/h)	Type of cooking vessel	Maximum efficiency attained (%)	
			With guard	Without guard
Traditional	217	Pot	48	44
Improved burner-1	217	Pot	48	43
		Pan	49	47
	288	Pot	49	42
		Pan	44	42
Improved burner-2	147	Pot	55	48
		Pan	59	56

Comparing the efficiency of the traditional burner with the improved burner-2 plus frame, it is clear that approximately 10% efficiency improvement can be achieved.

4.3 Efficiency of all types of cookstoves available in Bangladesh

Table 4.3 summarizes the thermal efficiency of all cookstoves available in Bangladesh.

TABLE 4.3: Thermal efficiency of all types of cookstoves available in Bangladesh

Fuel	Model	Type of cooking vessel	Heat utilization efficiency (%)
Biomass	Traditional	Pot	10
	Improved	Pot	24
Kerosene	Traditional	Pot	46
	Improved (inside pump)	Pot	42
	Improved (outside pump)	Pot	50
Electricity	Simplest	Pot	52
		Pan	53
Gas burner	Traditional	Pot	44
		Pan	47
	Improved gas burner-1	Pot	47
		Pan	52
	Improved gas burner-2	Pot	48
		Pan	56
	BCSIR	Pot	58
	New improved	Pot	55
		Pan	59

Chapter 5

COMPARATIVE STUDY OF COOKSTOVES

5.1 Economic analysis of different cookstoves

A comparative study has been performed to analyze the financial implications of the different cookstoves used in Bangladesh. Biomass, kerosene, electricity and natural gas cookstoves have been studied in this work. LPG is one other fuel used in the semiurban and urban areas where natural gas is not available. The LPG burner is similar to the natural gas burner and therefore the thermal efficiency of this burner was not studied in this work. However, since LPG is used in the country, in the comparative study along with other fuels, the financial implication of using LPG as a cooking fuel is also included.

For the comparative study, cost data have been assessed from prevailing international market prices. The average members of a family shown in Table 5.2 has been taken from the Statistical yearbook, 1995 and the average amount of energy required per family is taken from "Rural energy in Fiji: A survey of domestic rural energy use and potential" (Siwatibau, 1981) and "Bigganchareha", a science and technology journal.

TABLE 5.1: Economic cost of fuel

Cost of wood per kg	Tk 3
Cost of Kerosene per kg	Tk 10
Cost of electricity per kWh	Tk 2.5
Cost of LPG per kg	Tk 20
Cost of gas per m^3	Tk 8.5*

*Equivalent to \$5 /1000 ft^3 of natural gas

TABLE 5.2: Data used for the comparative study

Average number of members of a family	6
Average amount of energy required	600 MJ

Using the data presented in Tables 5.1 and 5.2 along with the efficiency values of chapter 4, the fuel cost per month for the various stoves used in Bangladesh is presented in Table 5.3.

TABLE 5.3: Monthly expense for fuel of different cookstoves

Fuel	Model	Price of cookstove (Taka)	Fuel used	Fuel cost per month (Taka)
Biomass	Traditional	50	330 kg	990
	Improved	150	140 kg	420
Kerosene	Traditional	180	29 kg	290
	Improved (inside pump)	250	31 kg	310
	Improved (outside pump)	300	26 kg	260
Electricity	Simplest	100	315 kWh	800
Gas	Traditional	250	35 m^3	300
	Improved burner-1	350	32.5 m^3	275
	Improved burner-2	400	30 m^3	255
	BCSIR model	Not available	28 m^3	238
	New improved model	Not available	27 m^3	230
LPG	Traditional	350	29 kg	580

5.2 Selecting suitable fuel for different areas

From Table 5.3 it is clear that a kerosene cookstove and natural gas burner are economical stoves. However, economy is not the only criteria for selecting a cookstove. A large number of factors affect the choice of a suitable fuel or cookstove. Among these, the most important factors are given below.

(1) Low cost

(2) Abundance and ready availability

(3) Efficiency of use

(4) Cleanliness in handling, storage and use

(5) Convenience for transport

(6) Family income

(7) Level of education of the head of the family

(8) Cooking habits

Bangladesh is an agricultural country and more than 80 percent of her population live in rural areas. The other 20 percent live in urban or semi-urban areas. The choice of a suitable fuel is strongly dependent on the geographical location. Therefore, a suitable fuel is different for different areas. The following sections present discussions on suitable fuels for rural, semiurban and urban areas.

5.2.1 Rural areas

Readily available fuel in the rural areas are firewood, cow-dung, straw, rice husk and other miscellaneous biomass materials. About 20 million tons of firewood and non-commercial fuels, which constitute 74 percent of the total energy consumption, are consumed annually, even though biomass fuels have several disadvantages, such as (1) thermal efficiency of fuel is low, (2) heating value of fuel is low, (3) collecting fuel is difficult, especially in bad weather, (4) gathering fuel and cooking over open fires are time consuming and (5) open fire smoke is detrimental to the eye.

Bangladesh is fortunate to have a good deposit of natural gas. Approximately 10.44 TCF of natural gas has been discovered, and it is already making an impact on our economy through the production of electricity and fertilizer. However, this gas will not provide much relief to rural areas in the near future because of the difficulty in laying pipelines in a riverine country like Bangladesh, and also, since this gas cannot be liquefied at room temperature, it will not be economic to supply this gas to rural areas in cylinders. If biomass fuels were to be replaced by commercial fuels such as kerosene or LPG, the national spending for the total import of these fuels would increase tremendously. Furthermore, many problems exist both with effectively distributing these forms of energy to rural areas, as well as with their prohibitive cost.

Table 5.3 shows that if a family uses a traditional cooker, it requires 330 kg of firewood or other non-commercial fuels. The annual cost for cooking fuel is Tk. 990. Using an improved biomass cooking stove, the fuel requirement is reduced to 140 kg, whose cost is Tk. 420. Thus, approximately Tk. 570 is saved, although for poor families, who use leaves, cow-dung, straw etc., this cost is not relevant. With the improvement in cooking facilities, time would be saved, and this would enable the women to do other household tasks like weaving mats, making handicrafts and fishing.

Recommendations for rural areas:

1. People in the rural areas should use the improved biomass cookstove.
2. Develop commercial bio-gas project and supply the gas as an alternative source of energy.
3. Firewood consumption is causing rapid deforestation leading to erosion and changes in the ecosystem and climate. Since firewood consumption is not likely to decrease in the near future, in order to combat the prevailing situation, the Bangladesh Government should undertake an elaborate program of large scale forestation.

5.2.2 Semiurban

In the semiurban areas where firewood supplies have dwindled and natural gas is not available, people use electricity or kerosene as fuel.

Table 5.3 shows that kerosene is the most suitable fuel because kerosene is easily transportable and inexpensive when compared with other commercial fuels and can be utilized by less expensive equipment. Three types of cookers are available. These cookers have different initial cost and thermal efficiency. Depending on the thermal efficiency, different amounts of kerosene are required. The improved model (pump outside) is the most efficient and requires less fuel but people still buy the less efficient 10-wicks kerosene cooker (which also present the greatest fire hazard), because these are the cheapest. People are generally unaware of the safety and efficiency features of the cookers on the market. So the government has to set minimum requirements for safety and efficiency to ensure that cookers on the market conserve fuel and are safe for people.

If the family uses an electric heater, it would require approximately 315 kWh of electricity per month, the total cost of which is Tk 800 (Table 5.3). In Bangladesh, the electricity generation efficiency is 27% and the system loss is approximately 33%. For this case, the efficiency for the system is very low at 9.5%. By increasing the generation efficiency and reducing the system loss, system efficiency can be improved, but at the present time, the efficiency of electric cookers are not satisfactory.

Recommendation for semiurban areas

(1) Economic analysis reveals that kerosene is the more suitable fuel for semiurban and urban areas.

(2) Tests indicate that the less efficient 10-wicks cooker needs improvement in design to increase its efficiency of fuel use and to raise its safety standards.

(3) A standards board should be set up to inspect and evaluate the cookers that are presently available or may be introduced in the market.

5.2.3 Urban areas

In the urban areas, where natural gas is available, people do not bother with any other fuel because natural gas is a very clean burning and convenient to use fuel. It is easy to control and combust without encountering any problems. Table 5.3 shows that the improved gas burner-2 will require an initial cost of approximately Tk. 400 and a per month gas cost of Tk. 255 while the corresponding costs for an improved gas burner-1 and traditional gas buner are Tk. 350 and Tk. 275, and Tk. 250 and Tk. 300 respectively. If the BCSIR model is used, the cost for fuel per month will be Tk. 238. However, this model is not available in the market and its initial cost may be high because of its design complexity. The new improved model developed in this study, i.e., the one incorporating a guard on the existing improved model will require Tk. 230 fuel cost per month. If this model is made available in the market its initial cost will be not so high because of its design simplicity. Approximately Tk. 70 per month can be saved by using this improved gas burner as opposed to the traditional model.

Chapter 6

CONCLUSIONS

Bangladesh is a developing country. Like other developing countries, the per capita energy consumption is very low in Bangladesh. Published data reveal that about 65% of the total energy are consumed for cooking purpose. It is essential to save energy used for cooking. Using efficient cookstoves energy can be saved. The main objectives of this work were to study the thermal efficiency of all types of cookstoves available in Bangladesh, develop a more efficient gas burner and present the financial implications of using a particular cookstove. Experiments to measure efficiencies were performed according to a set standard procedure. This study has analyzed the cookers used in this country on a common framework. Therefore, from the experimental results and the comparative study the following conclusions can be made.

1. Comparing the efficiency of the improved biomass cookstove with the traditional one, it is clear that the efficiency of the improved biomass cookstove is approximately 2.5 times higher than the traditional model.

2. Comparing the results for different kerosene cookers, it is clear that the improved (outside pump) cooker has higher thermal efficiency. The most commonly used kerosene cooker is the 10-wicks traditional cooker because people are generally unaware of the safety and efficiency features of the cookers in the market.

3. Among biomass, kerosene and electricity, kerosene is the most suitable fuel for semi-rural areas.

4. Experimental results show that the shape of the cooking vessel has significant effect on the thermal efficiency of gas burners. Pan type flat-bottomed vessels have been found to have the higher efficiencies and are therefore recommended.

5. The improved natural gas burner available in the market has an efficiency 5% higher than the commonly used model.

6. Using a guard around the flame can increase thermal efficiency by 3-10% depending on the shape of the cooking vessel and the model of the burner.

7. Different organizations and research institutions have developed a large number of different types of improved cookers. It is necessary to properly evaluate these and disseminate these to users.

NOMENCLATURE

BCSIR	Bangladesh Council of Scientific and Industrial Research
C_p	Specific heat of water, 4.18 J/gm
D	Diameter, cm
E	Heating value of fuel
E_{CO}	Heating value of charcoal, J/gm
E_f	Heating value of fire wood, J/gm
IFRD	Institute of Fuel Research and Development
H	Height, cm
HU	Heat utilization efficiency, %
LDC	Least Developed Country
NGO	Non-governmental Organization
P	Power, kW
T_f	Temperature of water at boiling, 100°C
T_c	Temperature of water at the start of test, °C
W	Amount of fuel used
W_e	Weight of water evaporated at the end of test, gm
W_f	Weight of firewood used, gm
W_m	Weight of water in pot at the start of test, gm
W_R	Weight of charcoal remaining at end of each test, gm
λ	Latent heat of water at 100°C, 2256 J/gm

REFERENCES

1. Abdullah, T. & Rahman, M.S., "Characterization of Reservoir Fluid of 'TITAS' Gas Field", B. Sc. Engg. Thesis, 1998.

2. A Science and Technology Monthly, "Biggancharcha", Special Edition on Improved Cooker, April-June, 1996.

3. Dryden, I.G.C. ed., "The Efficient Use of Energy", IPC Science and Technology Press, UK, 1975.

4. Eusuf et al. (1990), "Studies in Cooking Stove", Part-II Optimization of Parameter of an Efficient Stove, Bangladesh J. Science.

5. Eusuf, M., seminar on. "Alternative Energy resources and their potential in rural development" Ninth commonwealth science council meeting, Srilanka, 1976.

6. Eusuf et al., "Improved Model of Domestic Gas Cooling Stove, Patent and Design" (19890).

7. Harker, J.H. and Allen, D.A., "Fuel Science", Oliver and Boyd, Edinburgh, 1972.

8. Imam, B. "Mineral Resource of Bangladesh", Bangla Academy, December, 1996.

9. "Improved Biomass Cooking Stove for Household, USA, National Energy Administration with Funding from the U.S. Agency for International Development, Bangkok, Thailand, 1984.

10. Joseph, S., "Stove testing," ITDG, 1970.

11. Omar, K.J., "Chula-Need for Improvement", Dept. of Chemical Engineering, BUET, Dhaka, Bangladesh.

12. Prasad, K.K., "Some Studies on Open Fires, Shielded Fines and Heavy Stoves", Department of Applied Physics, Endhoven University of Technology Eindhoven, The Netherlands, 1981.

13. Prasad, K.K., "A study on the performance of two metal stoves", Department of Applied Physics, Endhoven University of Technology Eindhoven, The Netherlands, 1981.

14. Prasad, K.K., "Some performance tests on open fires and the family cooker ", Department of Applied Physics, Endhoven University of Technology Eindhoven, The Netherlands, 1980.

15. Reddy, A.K.N., Williams, R.H. & Johansson, T.B., "Energy After RIO: Prospects and Challenges", United Nation Development Program, New York, 1997.

16. Roy, K.C., "Biomass Energy for Less Environmental Pollution", Cover Story, Published in Observer Magazine, Dhaka, October 2, 1998.

17. Siwatibau, S. "Rural energy in Fiji: A survey of domestic rural energy use and potential," International development research center, Ottawa, Canada ,1981.

18. Speight, J. G., "Fuel Science and Technology Handbook," Marcel Dekker, New York, 1990.

19. Spiers, H.M. ed, "Technical data on fuel", The British national committee, London, 1962.

20. "Statistical yearbook of Bangladesh 1995", BBS, 1996.

21. Tamir, A., Elpepin, I. & Yotzer, S., "Performance characteristics of a gas burner with a swirling central flame," energy vol.14, Pergamon press, 1989.

Appendix-A

Accurate determination of volumetric flow rates of gas is an essential part to determine the efficiency of a gas burner. The rotameter was used in this project because flow rates can be determined accurately and easily from it's calibration curve. With the help of a wet-test meter the rotameter was calibrated. The calibration curve is given below.

TABLE 1: Calibration of rotameter

No. of obs.	Rotameter reading	Volumetric flow rate (l/h)
1	4	62
2	6	92
3	8	120
4	10	147
5	12	175
6	14	203
7	16	233
8	18	260
9	20	288
10	22	313
11	24	342
12	26	370

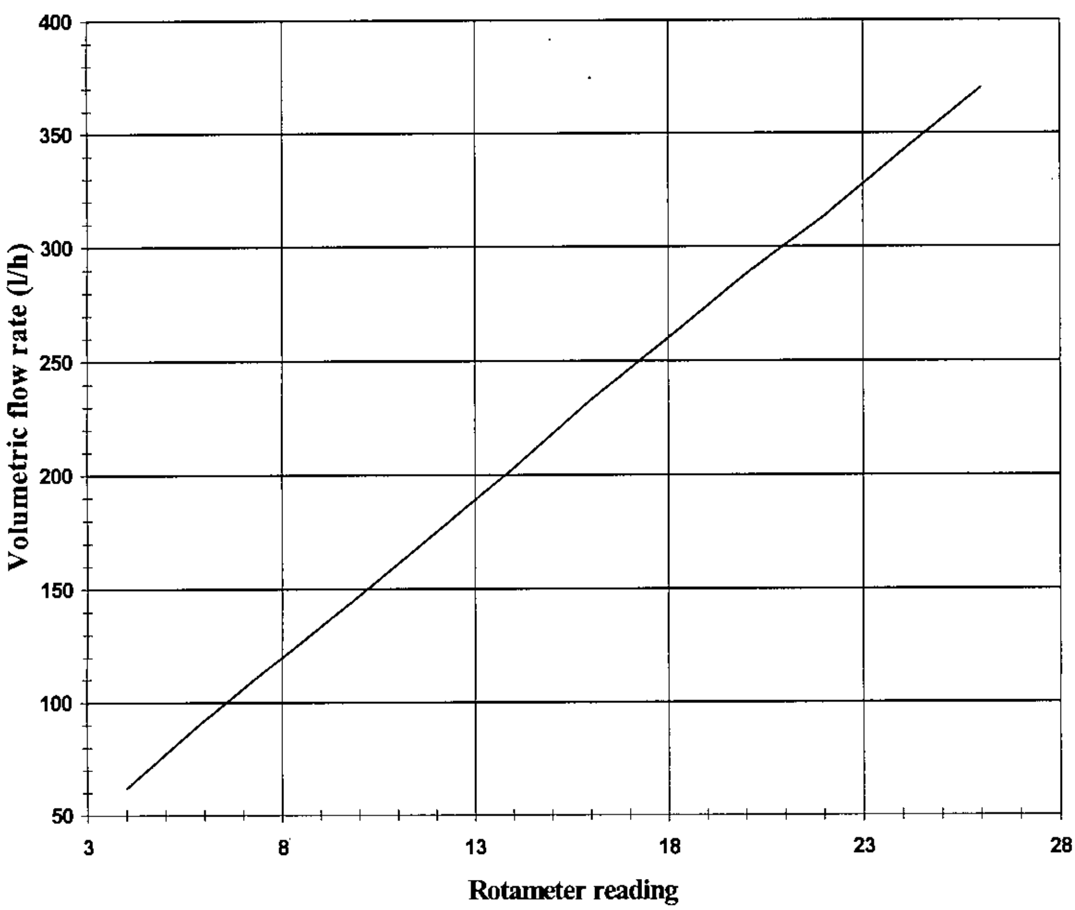

Fig. A1: Calibration of rotameter

Appendix–B

TABLE B1: Observed data for different types of biomass cookstoves

Model	Weight of pot + water (kg)		Weight of wood	Initial temp.	Time to reach boiling point
	Initial	Final	gm	°C	minute
Traditional	3.34	3.1	800	29	21.5
Improved	3.34	2.9	435	29	13.5

TABLE B2: Observed data for different types of kerosene cookers

Type of cooker	Weight of cooker + oil (kg)		Weight of pot + water (kg)		Time to reach boiling point
	Initial	Final	Initial	Final	Minute
Traditional	2.005	1.895	3.429	2.810	24
Improved (inside pump)	3.7	3.313	11.326	10.458	20
Improved (Pump outside)	4.525	4.294	11.332	10.332	31

- Pot-1 and Pan used for experiments listed in Table B3, B6, B9, B10, B11(A) & B11(B).
- Pot-2 and Pan used for experiments listed in Table B4, B5, B7, B8 & B12.

TABLE B3: Observed data for electric heater

Type of cooking vessel	Weight of water + pot (kg)		Initial temperature	Time to reach boiling point
	Initial wt.	Final wt. after 20 min boiling	°C	
Pan	4	3.77	21	48 min. 18 sec.
Pot	4	3.7	26	52 min 16 sec.

TABLE B4: Observed data for traditional gas burner

No. of obs.	Rotameter reading	Type of cooking vessel	Weight of water + pot (kg)		Initial temp	Time to reach boiling point
			Initial wt.	Final Wt. after 25 min boiling	°C	
1	10	Pot	4	3.63	27	32 min
2	10	Pan	4	3.60	27	30 min 20 sec
3	15	Pot	4	3.33	26	20 min 15 sec
4	15	Pan	4	3.32	26	19 min 20 sec
5	20	Pot	4	3.23	27.5	17 min 45 sec
6	20	Pan	4	3.16	27.5	16 min 05 sec

TABLE B5: Observed data for traditional gas burner with same amount of water

No. of obs.	Rotameter reading	Type of cooking vessel	Weight of water + pot (kg)		Initial temp. °C	Time to reach boiling point
			Initial wt.	Final wt after 10 min boiling		
1	10	Pot	3.9	3.78	29	30 min
2	10	Pan	4	3.85	29	26 min 20 sec
3	15	Pot	3.9	3.60	29	20 min
4	15	Pan	4	3.70	29	18 min
5	20	Pot	3.9	3.60	30	16 min 10 sec
6	20	Pan	4	3.60	30	14 min 53 sec
7	25	Pot	3.9	3.55	30	13 min 57 sec
8	25	Pan	4	3.55	30	11 min 50 sec

TABLE B6: Observed data for improve gas burner – 1

No. of obs.	Rotameter reading	Type of cooking vessel	Weight of water + pot (kg)		Initial temp	Time to reach boiling point
			Initial wt.	Final wt. after 25 min boiling	^{0}C	
1	5	Pot	4	3.75	30	55 min
2	10	Pot	4	3.50	30	26 min 15 sec
3	10	Pan	4	3.45	28	24 min 15 sec
4	15	Pot	4	3.35	29	19 min 20 sec
5	15	Pan	4	3.30	28	19 min
6	20	Pot	4	3.20	29	14 min 04 sec
7	20	Pan	4	3.15	28	15 min 27 sec
8	25	Pot	4	3.10	28.5	13 min
9	25	Pan	4	3.25	28	12 min 25 sec

TABLE B7: Observed data for improved gas burner-2 with same amount of water

No. of obs.	Rotameter reading	Type of cooking vessel	Wt. of water + Pot (kg)		Initial temp. °C	Time to reach boiling point
			Initial weight	Final weight after 10 min boiling		
1	10	Pot	3.9	3.70	29	24 min 45 sec
2	10	Pan	4	3.75	29	22 min 30 sec
3	15	Pot	3.9	3.65	29	16 min 10 sec
4	15	Pan	4	3.60	29	15 min
5	20	Pot	3.9	3.55	29	13 min 30 sec
6	20	Pan	4	3.70	29	12 min 40 sec
7	22	Pot	3.9	3.60	29	11 min 45 sec
8	22	Pan	4	3.60	29	11 min 15 sec

TABLE B8: Observed data for improved gas burner –2

No. of obs.	Rotameter reading	Type of cooking vessel	Weight of water + pot (kg)		Initial temp. °C	Time to reach boiling point
			Initial wt.	Final wt after 10 min boiling		
1						
1	10	Pot	4	3.80	30	25 min 25 sec
2	10	Pan	4	3.75	30	22 min 50 sec
3	15	Pot	4	3.75	31	16 min 20 sec
4	15	Pan	4	3.70	31	15 min
5	20	Pot	4	3.65	31	13 min 45 sec
6	20	Pan	4	3.60	31	12 min 26 sec
7	22	Pot	4	3.70	30	12 min 45 sec
8	22	Pan	4	3.60	30	11 min 15 sec

TABLE B9: Observed data for improved model developed by BCSIR

No. of obs.	Rota meter reading	Type of cooking vessel	Distance between pot & burner (cm)	Weight of water + pot (kg)		Initial temp. ^{0}C	Time to reach boiling point
				Initial wt.	Final wt after 15 min boiling		
1	15	Pan	16	4	3.78	26.5	25 min 30 sec
2	15	Pan	12	4	3.70	27	19 min
3	15	Pan	11	4	3.68	28	18 min 40 sec
4	15	Pot	9	4	3.68	26	18 min 03 sec
5	15	Pot	8	4	3.68	28	17 min
6	15	Pot	7	4	3.63	28.5	15 min 50 sec
7	15	Pot	6.5	4	3.63	28	15 min
8	17.5	Pan	6.5	4	3.65	28	15 min 50 sec
9	17.5	Pot	6.5	4	3.63	29	14 min 30 sec

TABLE B10: Observed data for improvement of traditional gas burner

No. of obs.	Rotameter reading	Type of arrangement	Weight of water + pot (kg)		Initial temp. ^{0}C	Time to reach boiling point
			Initial wt.	Final wt after 20 minute boiling		
1	15	Only pot insulated	4	3.45	28	21 min 30 sec
2	15	Guard with insulation	4	3.45	27	21 min
3	15	Pot + cover Insulated	4	3.50	26	20 min 40 sec
4	15	Guard with 31cm diameter (all insulated)	4	3.56	23.6	22 min 33 sec
5	15	Guard with 34 cm diameter	4	3.5	24	19 min 48 sec
6	15	Guard with 29 cm diameter	4	3.45	25	19 min
7	15	Guard with 31 cm diameter	4	3.45	32	15min 30 sec

TABLE B11 (A): Observed data for improvement of improved burner-1

No. of obs.	Rotameter reading	Type of cooking vessel	Types of arrangement	Weight of water + pot (kg)		Initial temp. °c	Time to reach boiling point
				Initial wt.	Final wt after 20 min boiling		
1	15	Pot	All insulation + guard	4	3.45	25.5	15 min 3 sec
2	15	Pot	Guard with 29 cm diameter	4	3.45	28.5	17 min 20 sec
3	15	Pot	Guardwith31 cm diameter	4	3.45	29	16 min 25 sec
4	15	Pot	Guard with31 cm diameter (with conical shape)	4	3.5	33.5	15 min 25 sec
5	15	Pot	Guard with31 cm diameter (without hole)	4	3.48	37	15 min 30 sec
6	15	Pot	(insulation)	4	3.45	28	17 min 14 sec

TABLE B11(B): Observed data for improvement of improved burner-1

No. of obs.	Rotameter reading	Type of cooking vessel	Types of arrangement	Weight of water + pot (kg)		Initial temp. (°C)	Time to reach boiling point
				Initial wt.	Final wt after 15 min boiling		
1	20	Pan	Guard with 31 cm diameter	4	3.48	28.5	14 min 11 sec
2	20	Pan	Guard with diameter 34 cm	4	3.55	29	15 min 30 sec
3	20	Pan	Guard without hole	4	3.48	29	13 min 15 sec
4	15	Pan	Guard with diameter 29 cm	4	3.55	28.5	18 min 20 sec
5	15	Pan	Guard 34 cm diameter	4	3.60	28	19 min 25 sec
6	15	Pan	Guard without hole	4	3.56	31.5	16 min 50 sec
7	20	Pot	Guard with 31 cm diameter	4	3.50	27.5	12 min 52 sec
8	20	Pot	Guard with 31 cm diameter	4	3.50	28.5	13 min
9	20	Pot	Guard with 31cm diameter (conical shape)	4	3.45	31	11 min 13 sec
10	20	Pot	Guard with 31 cm diameter (without hole)	4	3.48	29	14 min 50 sec
11	20	Pot	With insulation	4	3.52	29	13 min 45 sec

TABLE B12: Observed data for improvement of improve gas burner - 2 at rotameter reading 10

No. of obs.	Type of cooking vessel	Arrangement for improvement	Weight of water + pot (gm)		Initial temp. °c	Time to reach boiling point
			Initial wt.	Final wt. after 10 min boiling		
1	Pot	Guard with dia 29 cm	3.9	3.67	29	22 min 50 sec
2	Pot	Guard with dia. 29 cm	3.9	3.67	30	24 min 25 sec
3	Pan	Guard with dia 29 cm	4	3.75	30	21 min 45 sec
4	Pot	Guard with dia 31 cm	3.9	3.63	29	24 min 8 sec
5	Pan	Guard with dia. 31 cm	4	3.73	29	21 min 45 sec
6	Pot	Guard with diameter 34 cm	3.9	3.65	29	24 min 45 sec
7	Pan	Guard with dia. 34 cm	4	3.74	29	21 min 30 sec
8	Pot	Guard with dia. 31 cm (without hole)	3.9	3.70	29	25 min
9	Pan	Guard with dia. 31 cm (without hole)	4	3.78	29	22 min
10	Pot	Without guard	3.9	3.70	29	24 min 45 sec
11	Pan	Without guard	4	3.75	29	22 min 30 sec

TABLE B13: Observed data for new developed model

No. of obs.	Amount of water(kg)		Initial temp °C	Final temp of the second pot °C	Time to reach boiling point
	First pot	Second pot			
1	2.15	2.25	29	42	20min
2	2.15	2.25	30	44	19min
3	3.65	3:65	30	42	30min

TABLE B14: Observed data for new developed model

Cooking vessel	Initial wt of water (kg)	Final wt after 25 min boiling (kg)	Amount of water evaporate (kg)
First pot	2.5	2.0	0.5
Second pot	2.5	2.3	0.2

Appendix – C

Equation for calculating heat utilization efficiency

Heat utilization efficiency (HU): The heat utilization efficiency 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 is adapted from Toseph (Toseph, 1979)

$$HU\% = \frac{energy absorb}{energy given} \times 100 \tag{1}$$

$$= \frac{C_p \times W_m (T_f - T_e) + (\lambda \times W_e)}{(W_f \times E_f) - (E_{CO} \times W_R)} \times 100 \quad \text{(For biomass)} \tag{2}$$

$$= \frac{C_p \times W_m (T_f - T_e) + (\lambda \times W_e)}{W \times E} \times 100 \tag{3}$$

where, C_p = Specific heat of water, 4.18 J/gm

W_m = Weight of water in pot at start of test

T_f = Temperature of water at boiling, 100°C

T_e = Temperature of water at the start of test, °C

λ = Latent heat of water at 100°C, 2256 J/g

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

E_f = Heating value of fuel, J/gm

W_f = Weight of fuel used, gm

E_{CO} = Heating value of charcoal, J/gm

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

W = Amount of fuel used

Appendix-D

TABLE D1: Calculated data for traditional gas burner

No. of obs.	Gas flowrate (l/h)	Type of cooking vessel	Weight of water + pot (kg)	Heat utilization efficiency (%)	Time to reach boiling point
1	147	Pot	4	38	32 min
2	147	Pan	4	40	30 min 20 sec
3	217	Pot	4	44	20 min 15 sec
4	217	Pan	4	45	19 min 20 sec
5	288	Pot	4	38	17 min 45 sec
6	288	Pan	4	41	16 min 05 sec

TABLE D2: Calculated data for traditional gas burner with same amount of water

No. of obs.	Gas flowrate (l/h)	Type of cooking vessel	Weight of water (kg)	Heat utilization efficiency (%)	Time to reach boiling point
1	147	Pot	3.65	37	30 min
2	147	Pan	3.65	43	26 min 20 sec
3	217	Pot	3.65	44	20 min
4	217	Pan	3.65	47	18 min
5	288	Pot	3.65	38	16 min 10 sec
6	288	Pan	3.65	44	14 min 53 sec
7	356	Pot	3.65	35	13 min 57 sec
8	356	Pan	3.65	43	11 min 50 sec

TABLE D3: Calculated data for improved gas burner – 1

No. of obs.	Gas flowrate (l/h)	Type of cooking vessel	Weight of water + pot (kg)	Heat utilization efficiency (%)	Time to reach boiling point
1	77	Pot	4	43	55 min
2	147	Pot	4	47	26 min 15 sec
3	147	Pan	4	52	24 min 15 sec
4	217	Pot	4	43	19 min 20 sec
5	217	Pan	4	47	19 min
6	288	Pot	4	42	14 min 04 sec
7	288	Pan	4	42	15 min 27 sec
8	356	Pot	4	38	13 min
9	356	Pan	4	34	12 min 25 sec

TABLE D4: Calculated data for improved gas burner - 2 with same amount of water

No. of obs.	Gas flowrate (l/h)	Type of cooking vessel	Weight of water (kg)	Heat utilization efficiency (%)	Time to reach boiling point
1	147	Pot	3.65	48	24 min 45 sec
2	147	Pan	3.65	56	22 min 30 sec
3	217	Pot	3.65	47	16 min 10 sec
4	217	Pan	3.65	52	15 min
5	288	Pot	3.65	45	13 min 30 sec
6	288	Pan	3.65	50	12 min 40 sec
7	313	Pot	3.65	42	11 min 45 sec
8	313	Pan	3.65	48	11 min 15 sec

TABLE D5: Calculated data for improved gas burner – 2

No. of obs.	Gas flow rate (l/h)	Type of cooking vessel	Weight of water + pot (kg)	Heat utilization efficiency (%)	Time to reach boiling point
1	147	Pot	4	48	25 min 25 sec
2	147	Pan	4	55	22 min 50 sec
3	217	Pot	4	46	16 min 20 sec
4	217	Pan	4	52	15 min
5	288	Pot	4	44	13 min 45 sec
6	288	Pan	4	49	12 min 26 sec
7	313	Pot	4	41	12 min 45 sec
8	313	Pan	4	48	11 min 15 sec

TABLE D6: Calculated data for improved model developed by BCSIR

No. of obs.	Gas flow rate (l/h)	Type of cooking vessel	Distance between pot and burner	Wt of water + pot(kg)	Heat utilization efficiency (%)	Time to reach boiling point
1	217	Pan	16 cm	4	34	25 min 30 sec
2	217	Pan	12 cm	4	46	19 min
3	217	Pan	11 cm	4	47	18 min 40 sec
4	217	Pot	9 cm	4	49	18 min 03 sec
5	217	Pot	8 cm	4	50	17 min
6	217	Pot	7 cm	4	54	15 min 50 sec
7	217	Pot	6.5 cm	4	58	15 min
8	254	Pot	6.5 cm	4	55	14 min 30 sec
9	254	Pan	6.5 cm	4	51	15 min 50 sec

TABLE D7: Calculated data for improvement of traditional gas burner at gas flowrate 217 l/h

No. of o,bs.	Type of arrangement	Heat utilization efficiency (%)	Time to reach boiling point
1	Pot insulated	38	21 min 30 sec
2	Guard with insulation	39	21 min
3	Pot and cover insulated	37	22 min, 40 Sec
4	Guard with 31cm diameter with insulation	36	22 min 33 sec
5	Guard with 34 cm diameter (without insulation)	43	19 min 48 sec
6	Guard with 29 cm diameter (without insulation)	46	19 min
7	Guard with diameter 31 cm	48	15 min 30 sec

TABLE D8: Calculated data for improvement of improved gas burner – 1

No. of obs.	Gas flow rate (l/h)	Type of cooking vessel	Type of arrangement	Heat utilization efficiency (%)	Time to reach boiling point
1	217	Pot	All insulation + Guard	46	15 min 53 sec
2	217	Pot	Guard with diameter 29 cm	47	17 min 20 sec
3	217	Pot	Guard with diameter 31 cm	48	16 min 25 sec
4	217	Pot	Guard with diameter 31 cm with conical shape	45	15 min 25 sec
5	217	Pot	Guard with diameter 31 cm without hole	45	15 min 30 sec
6	217	Pot	insulation	42	17 min 14 sec
7	288	Pot	Guard with diameter 31 cm	45	12 min 52 sec
8	288	Pot	Guard with diameter 29 cm	44	13 min
9	288	Pot	Guard with diameter 31 cm with conical shape	49	11 min 13 sec
10	288	Pot	Guard with diameter 31 cm without hole	43	14 min 20 sec
11	288	Pot	With insulation	38	13 min 45 sec
12	217	Pan	Guard with diameter 31 cm	49	16 min 50 sec
13	217	Pan	Guard with diameter 29 cm	47	18 min 20 sec
14	217	Pan	Guard with diameter 34 cm	43	19 min 25sec
15	288	Pan	Guard with diameter 31 cm	44	14 min 11sec
16	288	Pan	Guard without hole	38	13 min 15sec
17	288	Pan	Guard with diameter 34 cm	41	15 min 30sec

TABLE D9: Calculated data for improvement of improved gas burner - 2 at gas flowrate 147 l/h

No. of Obs.	Type of cooking vessel	Type of arrangement	Heat utilization efficiency (%)	Time to reach boiling point
1	Pot	Guard with diameter 29 cm	51	24 min 25 sec
2	Pan	Guard with diameter 29 cm	57	21 min 45 sec
3	Pot	Guard with diameter 31 cm	55	24 min 08 sec
4	Pan	Guard with diameter 31 cm	59	21 min 45 sec
5	Pot	Guard with diameter 34 cm	52	24 min 45 sec
6	Pan	Guard with diameter 34 cm	58	21 min 30 sec
7	Pot	Guard with diameter 31 cm without hole	48	25 min
8	Pan	Guard with diameter 31 cm without whole	55	22 min
9	Pot	Without guard	48	24 min 45 sec
10	Pan	Without guard	56	22 min 30 sec

Appendix-E

Efficiency of a cookstove can be improved by many techniques of which decreasing the heat loss is one. Heat loss can be decreased in the following ways.

1. Insulating the upper part of the cooking vessel --- when insulating material covers the upper part of the vessel, heat loss from the vessel to the surrounding is decreased

2. Putting a guard around the zone where the flame comes into contact with the cooking vessel --- the guard restricts the flow of flue gas and increases contact time

3. Using flue gas heat (configuration shown in Fig.E1) --- If flue gas heat can be used, heat loss will be minimized

All these methods including a combination of methods 1 and 2, were utilized in attempts to increase the efficiency of the existing natural gas burners. The experimental procedure is the same as those used for the gas burners, details of which are provided in chapter 3. A preliminary investigation showed that only method 2, i.e., placing a guard around the flame, has any effect on the efficiency. Procedure and results for all methods except placing a guard around the flame (detail description is given in sec. 4.2) is given below.

1. **Insulating the upper part of the cooking vessel**

    Procedure: upper part of the cooking vessel is covered by insulating rope. Then experiments were performed according to the procedure given in chapter 3. Results are presented in Appendix D.

    Results show that insulation has no positive effect on the thermal efficiency. In some cases efficiencies are lower than without insulation.

2. **Simultaneously guard and insulation**

    To show simultaneous effect of the guard and insulation a few experiments were performed. Results are presented in App-D. It is not possible to conclude that guard and insulation increase the efficiency or not. Because results has no general trend.

3. Using flue gas heat

To use flue gas heat the following model was developed. Detail design is given below.

Design: The design of the burner is shown in Fig. E.1. This model consists of a steel box with a burner but using two potholes. Fuel burn in one burner and heat the first pot then the flue gas goes to the second pot hole to heat the second pot. A inclined surface is used to ease pass of the gas and a number of holes in the outer box require to supply the combustion air.

In this case first pot was placed on the burner and second pot was placed on the hole without burner. Three experiments were performed according to the procedure described in chapter 3. Results are given below.

Percentage of heat utilization efficiency shows that percentage of sensible heat used by the pot.

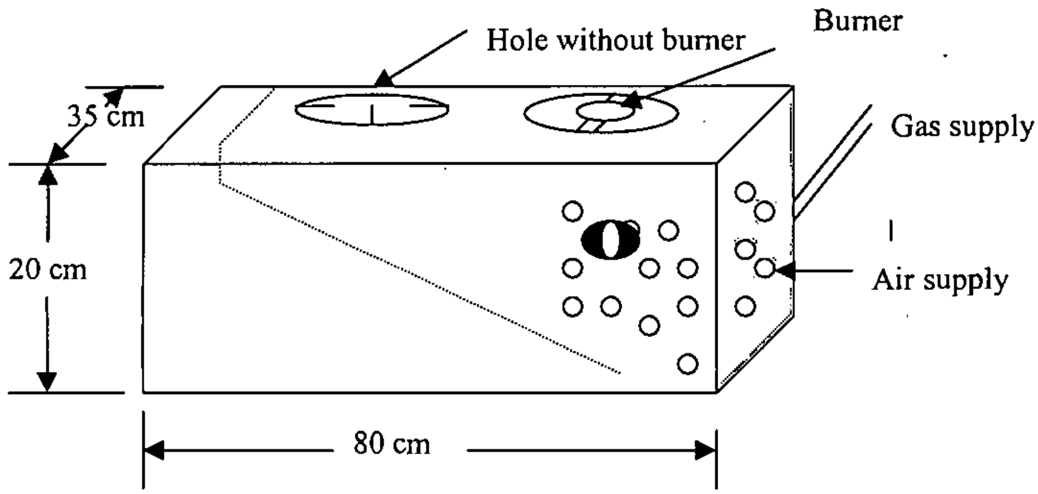

Fig. E1: Developed model for using flue gas heat

TABLE E.1: Percentage of heat used by the pot

No. of obs.	Percentage of sensible heat used (%)		
	First pot	Second pot	Total
1	35	7	42
2	36	7.6	44
3	39	6.7	46

The results show some interesting point, which are described below

1. The second pot used about 20% heat of the first pot

2. The second pot used about 7% of the total heat

3. To show the evaporation rate, second pot was heated to the boiling point and then placed on the hole. After fifteen minute heating, measured the amount of water evaporated. Observation shows that evaporation rate for the second pot is about half than the first pot

4. Water cannot be boiled by the second hole. Maximum attainable temperature by the second hole is 85 °C.

Though the second pot uses 7% of the total heat, the overall efficiency is not higher than the simple model. There may be some designing error. So further investigation is needed.

The model can be changed in the following way

1. The combustion chamber is built by clay or cement and covering the surfaces with an insulating material, which prevent heat loss.

2. Using a chimney for flow the flue gas. It helps to drag sufficient air in the combustion chamber.

3. Model can be redesigned in compact way. So length of the box will be small. The improved model is given here for further investigation.

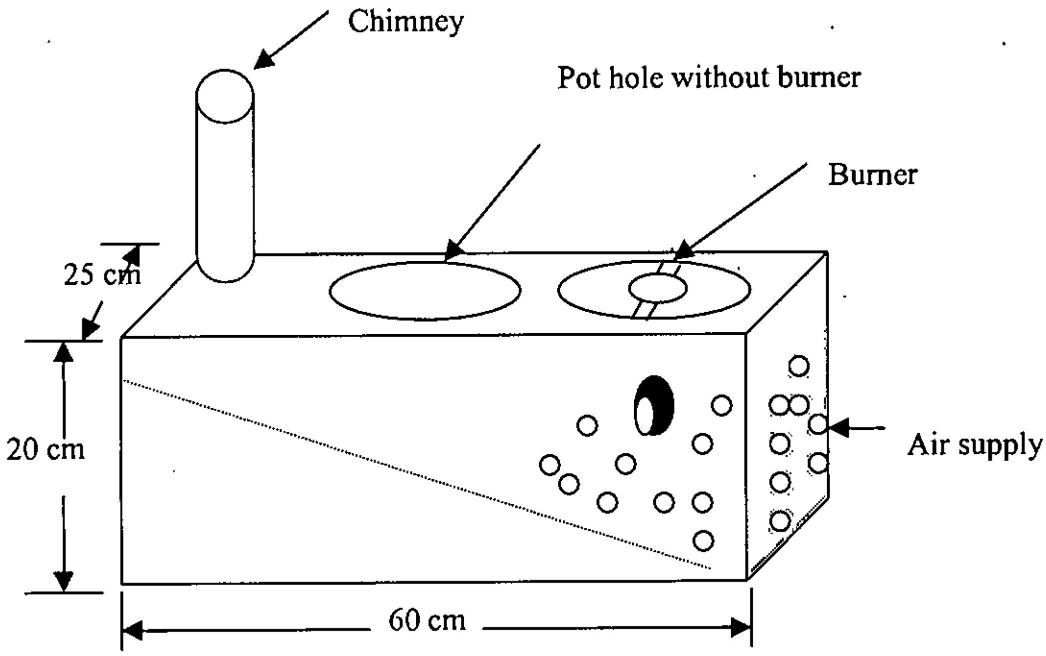

Fig. E2: New improved model