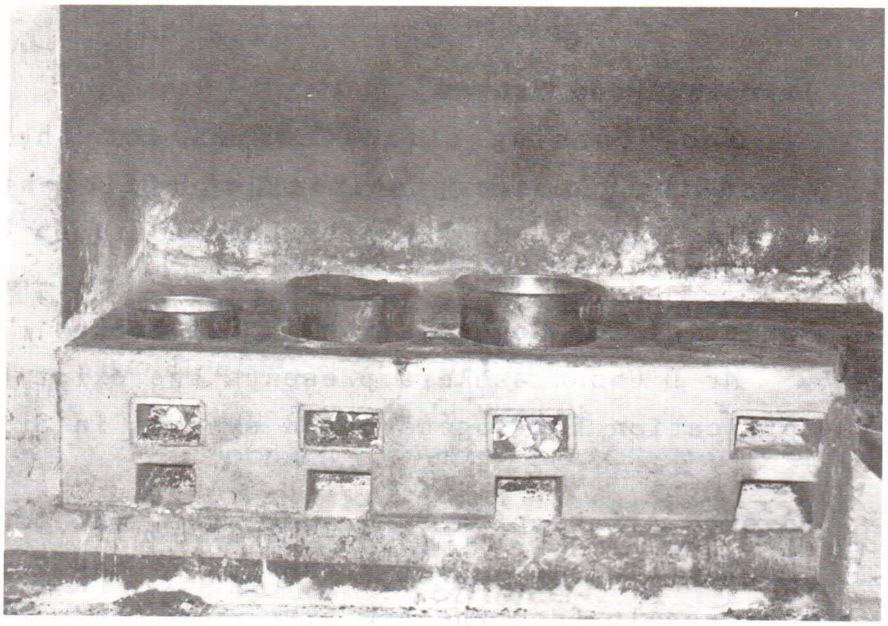
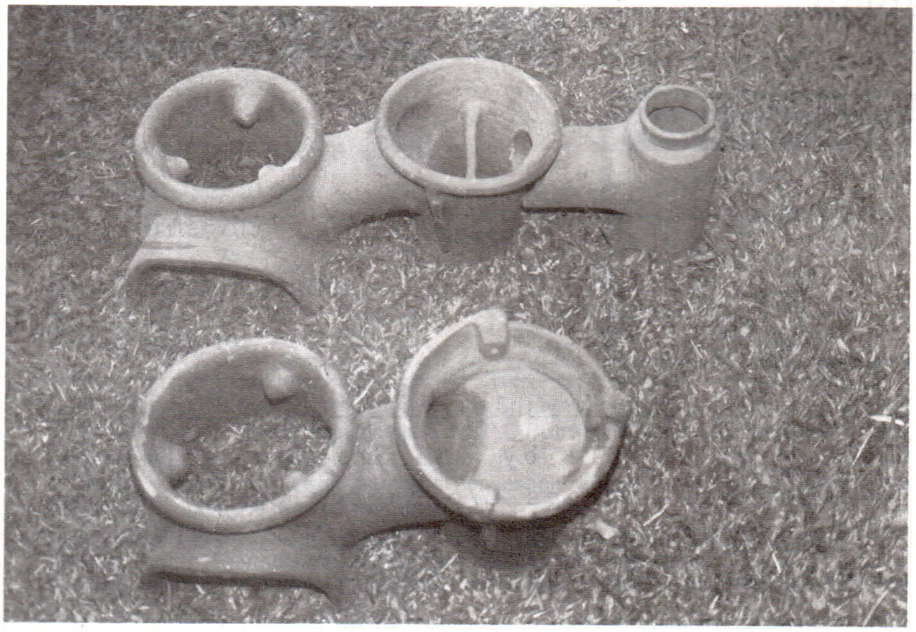
BEFORE IMPROVEMENT

AFTER IMPROVEMENT





NEW MODELS OF

EFFICIENT STOVE

IMPROVED WOOD STOVES

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Abstract-During the last two decades, a great deal of attention has been focused on stove development activities all over the world. This paper provides a brief outline of some of the technical and social issues involved in stove development, dissemination and utilisation.

INTRODUCTION

The initial efforts started in India in the late 1940s with the introduction of the smokeless chula. As the name implies, the initial concerns were related to health and convenience of the housewives, particularly focused on taking away smoke from the kitchen. Although this trend followed for some time, widespread adoption was not very evident. Interest was again raised in the late 1970s with realisation of the "poor man's" energy crisis due to large scale deforestation taking place throughout the world. With about 80% of the population of the 3rd world depending on biomass for their domestic energy needs, it was thought that there was an urgent need to conserve fuelwood, thereby reducing the rate of deforestation and reducing the pressure on available fuelwood resources. Thus, there was a shift of emphasis from socio economic concerns to energy saving, which brought-in technologists and energy planners to the forefront of stove development activities. This resulted in building up of a substantial body of theoretical knowledge following enormous amount of research and development work done to improve technical efficiency of stoves. These efforts threw a lot of light on the various parameters which influence performance of stoves which were very useful to the stove designers.

A wide variety of stove designs have since evolved throughout the world. Mud stoves, brick stoves, chimney or chimneyless stoves, pottery stoves, single pot or multi pot stoves, metal stoves, stoves with grates, portable stoves, non portable stoves, stoves with various controls etc. The common objective behind improvement of stoves was to improve the energy efficiency as it was thought that the three stone, open fire or traditional hearths were wasteful of energy.

TECHNICAL FACTORS

Stove Design -The combustion of wood is a complex phenomenon and therefore current scientific understanding is not mature enough to provide quantitative prediction. As a result, stove designs are mostly based on empirical studies. The basic theory given in this article is based on the research and development activities carried out by the Wood Stove Group in the Netherlands. However various other successful approaches have been made by other groups working in the field of stove development.

The main technical objectives of stove designs are to,

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(a) Maximise the efficiency of the combustion process.
(b) Maximise the efficiency of heat transfer from the heat source to the food.

In designing stoves, the laws of thermodynamics as well as empirical formulae derived from experiments are generally used. The design exercise consists of three steps.

(a) Determination of maximum power output needed depending on the user requirements.
(b) Calculation of the volume and dimensions of the combustion chamber including the distance between grate and pan bottom on the basis of the maximum power output and the size of the grate.
(c) Determination of the geometry of shield: Chimney, primary and secondary air holes and stove door.

The maximum power output required for a specific cooking task is calculated making use of the following formula,

$$P_{max} = \frac{M_w \, C_p \, d_T}{t_b}$$

where,

P_{max} - Maximum power output kW
M_w - Water equivalent of food kg
C_p - Specific heat of water kJ/kg
t_b - Boiling time
d_T - The difference between boiling temperature and ambient temperature

Determination of the dimensions of the combustion chamber which is a vital element of a stove is done using the following empirical relationships.

$$A = K_1 \; P_{max} \; cm^2$$

where,

A - Combustion chamber Fuel bed area cm^2
P_{max} - Maximum power kW
K_1 - Constant = 1/22

and the combustion chamber is scaled according to the formula:-

$$H = K_2 \; P^{0.4}$$

H - Chamber height (m)
P - Power output (kW)
K_2 - 0.053

Depending on the power output, the primary and secondary air required for complete combustion of charcoal and the volatiles produced can be calculated which gives the size and number of air holes in the grate. Experience suggests that the total area of air holes to be 30% of grate area. The total cross sectional area of the air holes is taken to be equal to the total area of fuel loading door, to ensure sufficient air passes through the grate.

In the case of chimney stoves, the height of the chimney is selected so as to balance the resistances to flow of the flue gases with the chimney draft. These formulae are used for this purpose.

$$dp_1 = (1/2).r_o.(T_o/T).V^2$$

$$dp_2 = (1 - T_o/T).r_o.gH_c$$

where,

dp_1 - Resistance (N/m^2)
r_o - flue gas density (1.25 kg/m^3)
TO - Reference temperature 273 K
T - flue gas temperature K
V - Velocity of flue gas (m/s)
g - acceleration of gravity (10 m/s^2)
dp_2 - Chimney draft (N/m^2)
H_c - Chimney height (m)

SOCIAL OBJECTIVES OF STOVE DESIGN AND ACCEPTABILITY

Past experience shows that a technically perfect stove is not always the most acceptable stove. There are other complex factors which are non technical which need to be considered when designing stoves. Unless these factors are addressed adequately, wide spread dissemination of stoves may not be achieved.

It has to be recognised that the open fire which the majority of the people use cater for many other needs other than cooking. It provides light, warmth, smoke for food preserva tion and allows for cultural and ritual practices.

Apart from the numerous disadvantages of the open fire, it is a very versatile piece of equipment in that it has a number of extremely important benefits. It costs nothing to make no skills or special equipment are needed. It can be located in whatever place suitable, can be moved anywhere, can be adjusted easily to accommodate any size of pot or pan, heat can be easily controlled and can accommodate any type and size of fuelwood or biomass.

There are also other factors that need to be taken into account which include the availability of skills and resources, cost to the consumer, desirability, ease of operation etc.

These considerations make the task of a designer a complex one which requires compromise, judgment and sensitivity to the needs and capabilities of the intended users. It is clear that the designer does not have a free hand and above all has no right to enforce what he thinks is the priority. Therefore the stove design, in addition to the technical objectives, should have the following social objectives as well:-

(a) Be socially acceptable.
(b) Provide recognisable benefits such as faster cooking, safety etc.
(c) Be easily produced locally.
(d) Be cost effective to the users.
(e) Be able to accommodate most of the user requirements.

It is therefore imperative that prior to stove design or dissemination efforts, a need assessment study to be conducted. This study should gather information on,

(a) physical environment and socio economic factors, land use and , demographic patterns, fuel supply etc.
(b) household structure such as types of kitchen, pots and pans used, fire place, type of food, kitchen economics etc.
(c) available infrastructure for new stoves such as availability of local skills, resources, organisations capable of participating in the development activities.
(d) user requirements such as fuel saving, faster cooking, safety, cost, removal of smoke etc.

PERFORMANCE AND TESTING OF STOVES.

Performance of stoves can be compared and evaluated only when they have been tested according to a standardised procedure. There had been considerable debate over the different procedures adopted. However, the performance of stoves are generally characterised by,

* Power output of the fire.
* Range of power output.
* Efficiency.
* The ease of starting.
* Tar and soot formation.
* Maintenance and durability.

Nevertheless the popular practice is to assess the performance by a single efficiency value derived by performing a water boiling test. This is a simulation test where water takes the place of a food mix and evaporation represents the storage or absorption of the heat in the mix. It is common to hear engineers or stove designers boasting of high efficiency figures with regard to the stoves they have developed. By giving a high efficiency the users are made to believe that the stoves save more firewood than a stove with a lower efficiency. But experience shows that it is not always true.

Efficiency is an engineering concept which denotes how much we get from the equipment we designed as a percentage of what we put in. In the case of stoves the efficiency is determined by water boiling tests performed under a well defined operational procedure. It is the ratio of energy transferred to the water divided by the energy liberated by burning fuel assuming complete combustion. It is calculated by the formula,

$$\text{Efficiency} = \frac{M_w C_p \ (T_b - T_o) \ fM_c \ L}{M_f E_f}$$

M_w - Mass of water in the pot (kg)
C_p - Specific heat of water (kJ/kgoC)
T_o - Starting temp. of water (oC)
T_b - Boiling temp. of water (oC)
M_c - Mass of water evaporated (kg)

L - Latent heat of evaporation (kJ/kg)
M_f - Weight of fuel used (kg)
E_f - Calorific value of fuel (kJ/kg)

However, the results of research work carried out by various organisations reveal that indication of a high efficiency alone does not guarantee that a certain amount of food can be cooked with a less amount of fuel. Therefore, higher efficiency alone does not make a stove fuelwood efficient. There are other factors, mainly,

(a) Maximum power output.
(b) Turn down ability ratio

which collectively contribute towards fuelwood saving capability of a stove.

The cooking phase involves three phases namely heating up, rapid boiling and simmering. In the simmering phase, the task of the stove is to provide only the minimum heat required to meet the radiative and connective losses and maintain simmering with minimum evaporative losses. If the stove cannot be turned down to this minimum power output without letting the fire to die, the stove would be giving out excess heat which would be wasted in steam generation. This makes the stove to consume firewood for a wasteful output which the user did not want and has no control of, thus making the stove consume more fire wood even though it has a high efficiency. It would also mean that the cooking should commence with more water than normally required to allow for undesirable evaporation to take place in the simmering phase which again results in more firewood being burnt.

This is similar to a situation where a car with poor control of speed requiring to be slowed down by applying brakes. The engine may be efficient but the car will consume more fuel.

Results of experiments carried out by the wood stove group (WSG) in The Netherlands throw some light on the firewood consumption pattern of stoves with various efficiencies which are given in the table below. The table also gives the relative technical performance.

Stove designs / Parameters	D_0	D_1	D_2	D_3	D_4	D_5
P_m, kW	12.5	12.5	6.25	12.5	6.25	12.5
r	1.5	1.5	1.5	3	1.5	3
Efficiency(η)%	8	16	8	8	16	16
M_f(kg)	5.75	5.16	3.47	3.47	2.87	1.74
t_c(minutes)	155	143	179	150	155	150

M_f - Fuel consumption. P_m = maximum power output.
t_c - Cooking time.

D_o represents a traditional fire with maximum power output P_m = 6.5 kW, efficiency (η)=8% and turn down ability ratio r = 1.5 where

$$r = \frac{\text{Minimum power output}}{\text{maximum power output}}$$

D_1, D_2, D_3, D_4, & D_5 represent improved stoves with different values of P_m, η, & r as indicated in the table.

It is observed that,

(a) With stove D_1, consumption drops by a marginal 10% although the efficiency has doubled with the other factors remaining the same.
(b) With D_2, consumption drops by 40% merely by reducing P_m by half with the other factors remaining the same.
(c) With D_3 consumption again drops by 40% without a change in η and p_m but by 100% increase in "r".
(d) With D_4 consumption drops by 50% by increase in "r" by 100% and halving the p_m, r remaining the same.
(e) With D_5 consumption drops by 69% by 100% increase in the η, r and halving P_m and doubling r.

The following conclusions can be arrived at from this experiment.

(a) Higher efficiency alone does not make a stove fuelwood efficient.
(b) Improving the efficiency does not make proportional increases in firewood savings.
(c) Increasing the turn down ability ratio or lowering the maximum power output alone could bring more substantial savings than by increasing the efficiency.
(d) Appropriate improvements in all three factors provide the highest savings.

There are several other reasons why emphasis on overall energy efficiency is not desirable. In the simmering phase, the concept of efficiency is irrelevant as it is always zero. A criteria which is not true for part of the process cannot be a suitable measurement to judge the whole process. This is similar to case of a car brake where the performance is judged by safety and not by efficiency.

A single overall efficiency figure can be meaningless since the stove has to work under varying conditions. An energy plot may be useful in such circumstances.

Efficiency of a stove is influenced by many factors other than the parameters of the stove itself (η, r, P_m). For example, moisture and density of fuel, the pan base are pan to fuel bed distance, air fuel ratio a some of them. Some of these variations a shown by means of graphs in figures 2,3 and 4.

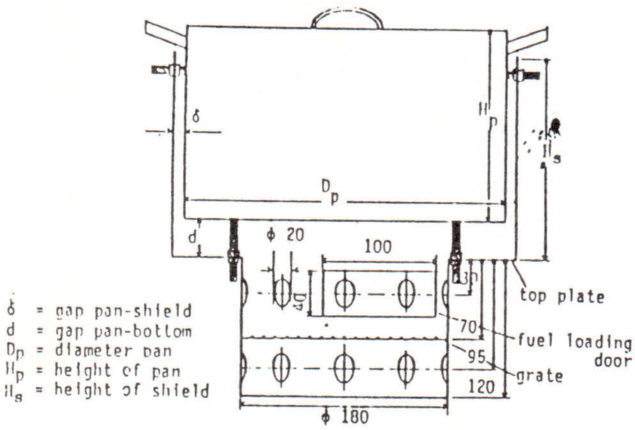


Figure 1- Prototype

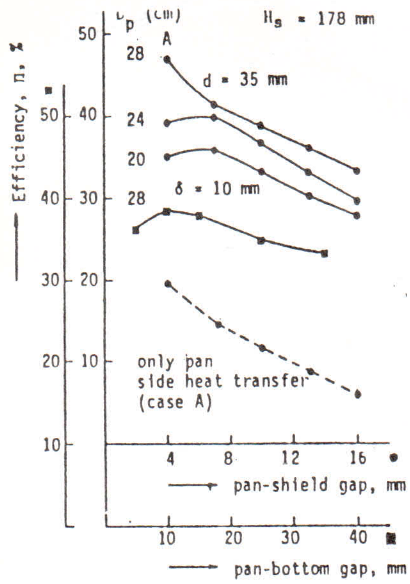


Figure 2- Efficiency of the prototype

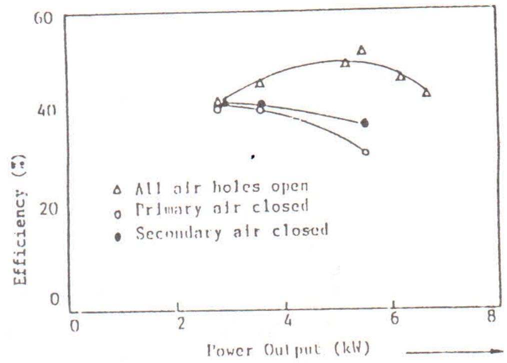


Figure 3- Efficiency as a function of the nominal power.

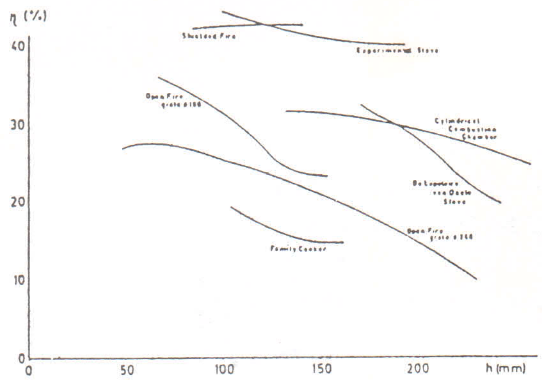


Figure 4- Influence of the distance between the pan and the grate on the efficiency.

COMBUSTION QUALITY

In testing stoves, this factor has often been neglected. Relatively little work has been done to determine how modifications in improved stoves influences smoke emission. In the eagerness to improve the overall efficiency of a stove, in many cases, there had been high emission factors which indicate a higher percentage of Carbon Monoxide (CO) in the flue gases. The overall energy efficiency is a combination of two internal efficiency namely combustion efficiency and heat transfer efficiency. This is illustrated in figure 5.

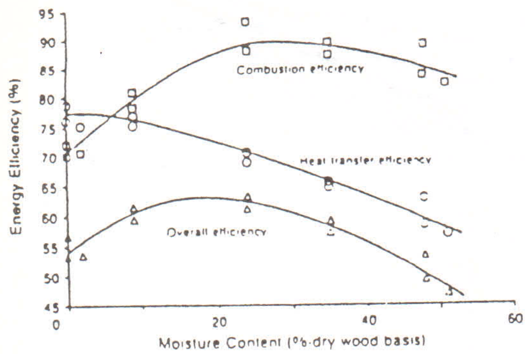
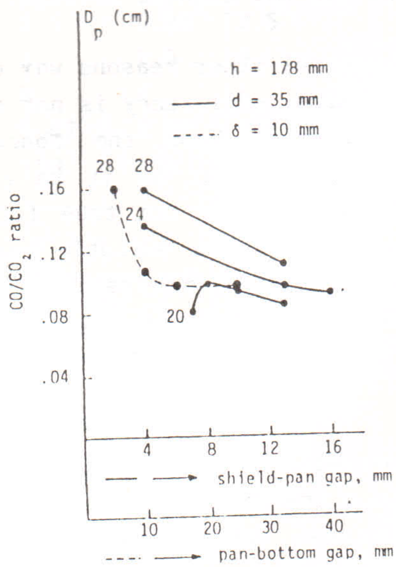


Figure 5- Efficiency variation against moisture in wood.

It is seen that combustion is not at optimum level when the overall efficiency the highest. Therefore, increasing the overall efficiency may cause poor combustion. There are also several other factors which influence combustion quality such as moisture content of wood, air-fuel ratio, pan to grid distance, excess air factor, to name a few.



Carbon monoxide to carbon dioxide ratio as a function of the shield-pan gap and the pan-bottom gap

Figure 6- CO to carbon dioxide ratio.

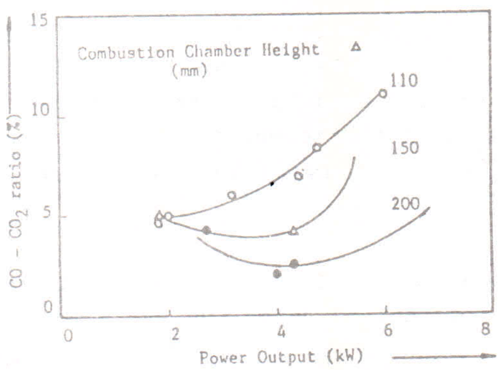


Figure 7- Carbon Monoxide-Carbon Dioxide ratio as a function of nominal power

A comparison of the performance of three types of wood stoves namely metal, brick and mud stoves carried out by Claus and Sulalithu give out some interesting observations. Under similar test conditions stove efficiencies appear to be 18-20% for the mud stove, 15-20% for the brick stove and 25-30% for the metal stove. The relationship between the carbon monoxide (CO) concentration and the efficiency for the brick stove is shown in figure 7. This figure indicates that higher efficiency is accompanied by a poorer combustion performance.

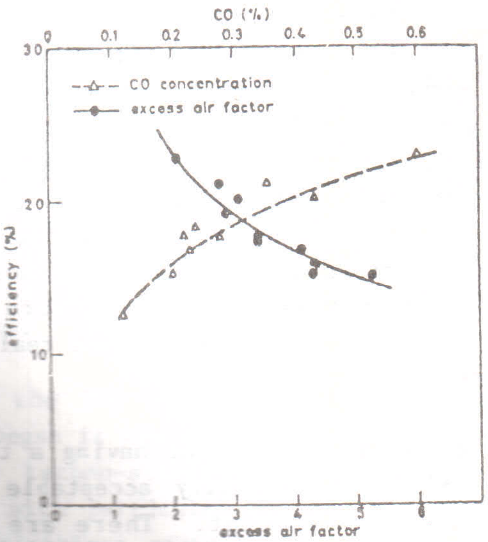


Figure 8- Efficiency of the brick stove as a function of the excess air factor and CO concentration.

The Carbon monoxide (CO) concentration as a function of the heat load of the three stoves is given in figure 8. It is observed that the combustion performance is the best in the brick stove. But still it is too high to be acceptable for health reasons (however it is indicated by the authors that including a baffle in the flue gas channel increases the efficiency of the stove without appreciably increasing the Carbon monoxide percentage.)

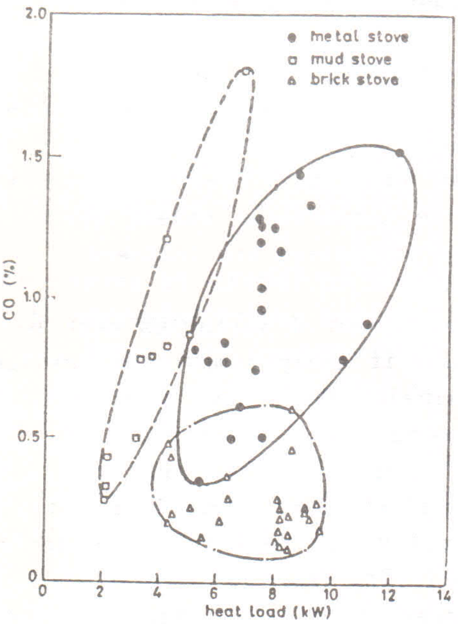


Figure 9- CO concentration as a function of the heat load.

The degree of toxicity of the CO is a function of the exposure time illustrated in figure 10.

Increase in CO quantity, particularly in a small kitchen with poor ventilation, can be dangerous to housewives.

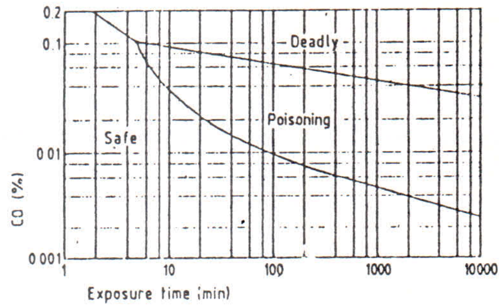


Figure 10- Toxicity of CO as a function of exposure time.

PROBLEMS OF MEASURING EFFICIENCY

The foregoing information reveal that efficiency figures can often be misleading when applied to judge the fuelwood economy and combustion quality. These figures do not provide true comparisons unless strict standardisation procedures are followed.

A large number of variables must be taken into account if truly comparable results are to be obtained. There have been considerable debates among stove experts on this issue. Given the limited applicability, a set of international standards have been established in 1982 called the Volunteers in Technical Assistance (VITA) tests. These include carrying out three basic tests with detailed instructions on how to do the tests and standard procedure for reporting the results. The tests are,

(1) Water boiling tests.
(2) Controlled cooking tests.
(3) Kitchen performance tests.

Although these tests throw a lot of light on performance of stoves and are extremely useful to the designers as a design tool, the users are still at a loss to understand or interpret these results in their choice of a suitable stove.

The kitchen performance tests mentioned above give a measure of the relative quantities of fuelwood consumed by two stoves when they are used under rural household conditions. This test will indicate whether an improved stove is capable of saving fuel. But it is not a simple test to carry out or to interpret the results. There must be at least 5 households participating in this test where the fuelwood consumption is measured for a period of one week.

To overcome this difficulty it has been suggested that to judge the performance of the stove, the concept of specific fuel consumption be used as done in the case of cars. The reasons given for this approach are,

(a) It gives an overall idea of the Energy performance.
(b) It is readily checked even by the user.
(c) It is perfectly understood by the user as it is related to the expenditure.

However in this case too, a range of specific consumption values related to the type of food cooked need to be given like in a car where the specific consumption is given related to a range of speeds.

STOVE DISSEMINATION

The development of stove activities can be divided into three phases. The early phase which started in the late 1940s concerned mostly the socio economic objectives where social workers were greatly involved. With the onset of the Energy crisis, the focus shifted to energy saving when technologists and the energy planners dominated the scene in the 2nd phase. Although a great deal about technical factors pertaining to stoves were known and some very good stoves were developed, large scale adoption did not realise as expected.

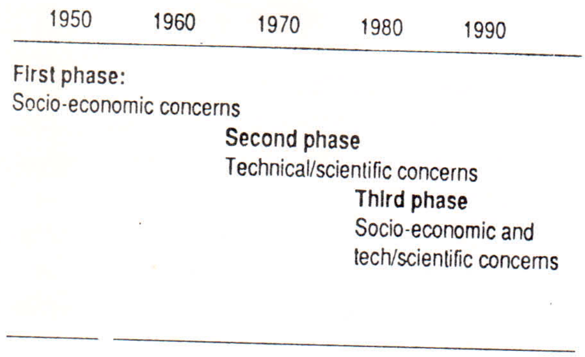
It was then evident that having a technically perfect and socially acceptable stove alone is not sufficient. There are other issues that need to be addressed if widespread extension is desired.

The fact that a stove is efficient and acceptable does not mean that it would disseminate on its own. For widespread adoption to take place, it is necessary to establish mechanisms that can reach a wide cross section of people. It requires a long term commitment, availability of manpower and financial resources, clear objectives, a proper plan and a dissemination strategy. There can be several strategies for large scale dissemination which depend, among many other things, on

(a) The objectives of the programme.
(b) Type of stove disseminated.
(c) Type of implementing organisation.
(d) Government policy.
  - Energy situation.
  - Local infrastructure.
  - Target group
(e) Availability of man power and financial resources. The basic activities in a stove programme are,
  - Sensitisation and creating awareness.
  - Training of project personnel: promoters, potters.
  - Developing a communication system.
  - Production.
  - Distribution and marketing.
  - Quality control
  - Financial Control.
  - Review and adjustments.

As in the case of developing a stove design, in the implementation and management of stove programmes too, a wide range of issues have to be addressed. Evidence from past experience indicate that users are interested in stoves for reasons other than fuel saving particularly in rural areas where fuelwood is not monetised. Gender issues, indoor air pollution, kitchen improvement, employment and income generation are a few among the many concerns.

In the 3rd phase of stove development which began in the early 1980's focus was both on the techno-scientific and socio-economic issues with particular concern on user needs and aspirations giving rise to a more integrated approach.



Three phases on stove development

Stove issues are generally approached from two perspectives: one at the macro level and the other at a micro level. The macro level encompasses global and national issues and the macro level emphasises issues at a household level.

This approach necessitated multi disciplinary inputs requiring the services of engineers, social scientists, managers, marketing experts, architects, environmentalists and above all the users.

The issues at global or national level cannot be addressed unless issues at household level are taken into consideration so as to influence the women's behaviour in a way she is motivated to save fuel. The experiences and knowledge gained during the last four decades it is clear that stove development efforts are considered to be not merely one energy intervention but as a component of a total package for integrated development.

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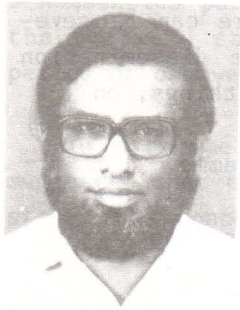

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