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Low-concentration ethanol stove for rural areas in India

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Only 17.5 % of all Indian homes use LPG as their primary cooking fuel, with 90 % of rural households dependent on some form of biomass. To improve the quality of life of such a large number of people, it is imperative that clean and renewable alternatives are provided for cooking. This paper presents one such. An ethanol stove running on 50 % ethanol-water mixture has been developed at Nimbkar Agricultural Research Institute (NARI). The stove allows easy flame regulation and gives an output similar to the conventionally-used LPG and kerosene stoves. Field tests conducted on the stove show that it is safe to use and very suitable for a typical rural household. In addition, the cost of using the ethanol stove is comparable to those of the conventional liquid fuel alternatives. However, for this stove to be a viable alternative certain policy issues have to be tackled. These have been suggested at the end of this paper.

1. Introduction

Cooking and lighting constitute 75 % of the total energy utilized in India's rural areas, where more than 65 % of the country's population resides [Rajvanshi, 2003]. Nearly 90 % of this population depends on some form or other of biomass fuels (firewood, agricultural wastes and cowdung) to fulfil its energy requirements [D'Sa and Murthy, 2004]. Smoke resulting from the combustion of these solid fuels contains complex pollutants. These are especially harmful when burnt in poorly-designed stoves in unventilated rooms. According to World Health Organisation (WHO) estimates, over 1.6 million deaths worldwide are attributable to indoor air pollution resulting from the use of biomass fuels [ITDG, 2004]. Hence, to improve the living conditions of such a large number of people it is imperative to develop clean and sustainable alternatives to fulfil their energy requirements.

The availability and cost of cleaner cooking fuels such as liquified petroleum gas (LPG) and natural gas keep them out of the reach of the rural poor. Besides, these fuels are non-renewable and hence present only a short-term solution. To solve the cooking fuel crisis clean and renewable alternatives have to be promoted. Ethanol is one such.

Nimbkar Agricultural Research Institute (NARI) was the first to propose and develop a stove running on 50 % ethanol-water mixture to solve the cooking fuel crisis. The output of the stove closely resembles that of the present kerosene and LPG stoves and has easy flame control.

2. Ethanol as a cooking fuel

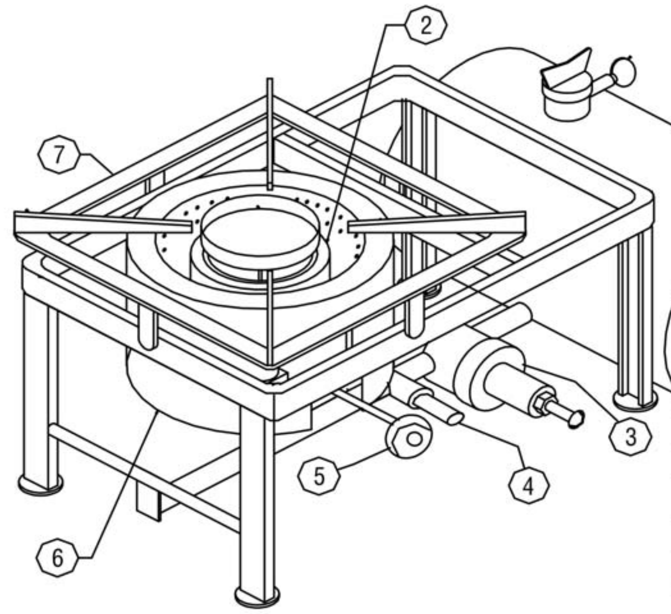
Some of the clean and renewable fuels for cooking are gaseous fuels like biogas, solid fuels like charcoal and liquid fuels like biodiesel and ethanol. However, due to their high energy density, easy transportability, easy storage and local availability, the liquid fuels are superior to other renewable alternatives.

High viscosity, tendency of gumming and formation of soot are the reasons why biodiesel has not been extensively explored as a cooking fuel option. The absence of these drawbacks in ethanol makes it a more attractive possibility.

Ethanol can be produced locally from a variety of materials that can be classified as sugar-containing (e.g., sugar cane and sweet sorghum), starch-containing (e.g., maize and grain sorghum), and cellulose-containing (e.g., wood and crop residues) [Mathur, 1988]. In India ethanol can be produced inexpensively from sugar cane and distributed at retail prices of Rs. 16 to 18 per litre (l) (1 US$ = Rs. 45) if the government removes excise duty for its use in rural areas [Rajvanshi, 2003]. Thus, the low cost and abundant availability of raw materials for the production of ethanol will make it very competitive with the other fuels used for cooking, as shown later in the paper.

Ethanol has roughly similar limits of inflammability (limits of fuel-to-air ratio in which combustion will proceed) to those of the component gases of LPG. Due to the extremely low value (4.3 %) of the lower limit of inflammability, the use of pure ethanol for household purposes is dangerous. This problem can be overcome by the use of ethanol mixtures in a suitably designed stove. Tests done at NARI showed that 50 % (w/w) ethanol-water mixture was a good cooking fuel [NARI, 2006]. The main reasons for the choice of this mixture were the following.

1. The 50 % ethanol-water mixture is less flammable than pure ethanol, making it safe to handle and hence ideal for household cooking purposes.
2. The 50 % ethanol-water mixture is easy to distil and can be produced in a one-step distillation process (even using solar energy as the driving force [Rajvan-



Part no.	Component
1	Fuel tank
2	Burner
3	Pressure-regulating valve
4	Filter
5	Flame-regulating valve
6	Jacket
7	Utensil support

Figure 1. Layout of NARI ethanol stove (patent applied for)

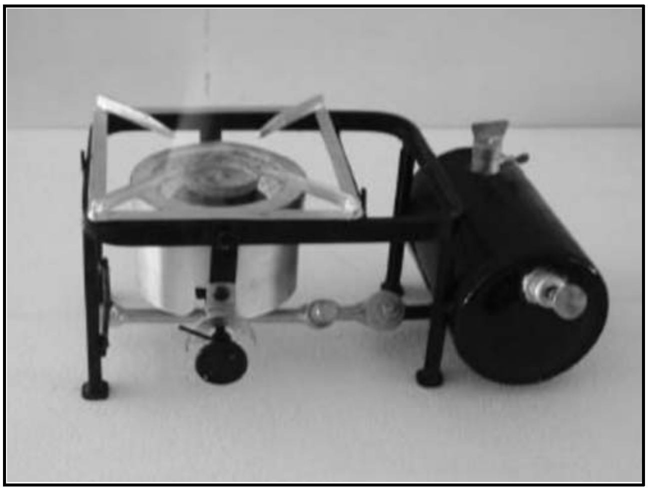


Figure 2. Flame of the NARI ethanol stove burning 50 % ethanol-water mixture

shi, 1984]), thus reducing the energy utilized in its production and hence the overall cost of fuel.

3. In rural areas of developing countries, a substantial amount of illicit liquor production takes place in make-shift backyard and rudimentary distillation units, which produce alcohol with 45-60 % (w/w) ethanol-water concentration. This alcohol is mainly used for drinking. The use of this as fuel in the ethanol stove can hopefully help solve both the problems of drinking and cooking.

3. Ethanol stove

3.1. Basic features

Commercially there are many stoves (available in Europe and the US for camping and recreational purposes) running on 85 % ethanol mixtures and above, but to the best of our knowledge no stove running on 50 % ethanol-water mixture has been developed. Hence, many of the concepts used in this stove are very novel. The basic layout of the ethanol stove is shown in Figure 1.

The burner (Part no. 2) is the heart of the stove. It vaporizes the ethanol-water mixture just before combustion. A preheating step is required to cold-start the stove (as is required by the presently-used kerosene stoves). The resultant clean flame burns with a yellowish-orange colour and has a temperature of around 850º to 900º C. This low temperature and colour is due to the presence of water vapour in the combustion zone. Figure 2 shows the flame of the stove.

The jacket (Part no. 6) provides the turbulence required for complete combustion of the ethanol vapour. The flame can be regulated easily by the flame-regulating valve (FRV, Part no. 5). The extent of flame regulation it provides is roughly comparable to that of the conventionally-used LPG stoves.

In order to get a precise range of stove capacity a pressure-regulating valve (PRV, Part no. 3) has been introduced in the stove design. The PRV is of a diaphragm type and regulates the flow rate of fuel over a large range of tank pressures. If the fuel tank (Part no. 1) is filled with 1.8-2 l of fuel and is pressurized up to 150 kPa by the hand-pump attached to the fuel tank, the stove can be operated for a continuous period of two hours without further pumping (enough time to cook a meal for 4 to 5 people).

3.2. Specifications

Table 1 shows the specification details of the ethanol stove.

Table 1. Specifications of the ethanol stove

Item	Specification
Design stove capacity	0.9 to 2.45 kW (or turn-down ratio of 1:2.7)
Efficiency	44 to 46 %
Design fuel composition	50 % (w/w) ethanol-water mixture
Tested fuel composition	38 to 95 % (w/w) ethanol in the mixture
Minimum fuel composition that can be used in the stove	45 % (w/w) ethanol in the mixture
Fuel tank capacity	2.6 l
Fuel tank operating pressure	50-150 kPa
Overall dimensions	42 × 19 × 21 cm
Weight	4.6 kg (empty) and 6.9 kg (full with fuel)
Construction materials	Mainly stainless steel (around 70 %) and mild steel
Estimated mass production cost	Rs. 1500 per stove

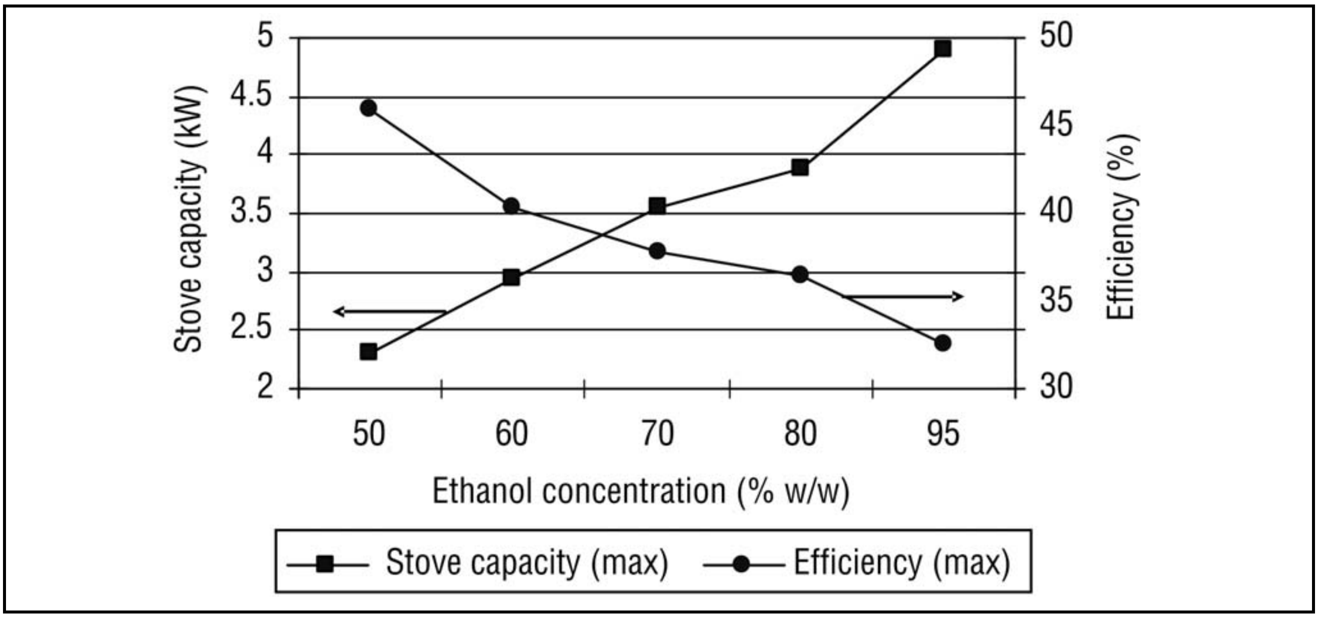


Figure 3. Stove performance with increasing ethanol concentrations (max. capacity)

The low efficiency (44 to 46 %) of the ethanol stove is because a part of the energy of ethanol is used to evaporate water, which does not take part in the combustion process. This reduces the flame temperature and consequently the efficiency. Similar capacity LPG stoves have efficiencies of nearly 60 % [D'Sa and Murthy, 2004]. All the efficiency measurements were based on water-boiling tests.

4. Stove characteristics

The stove was tested for varying ethanol percentages. Figures 3 and 4 show the effect of increasing ethanol concentrations on the performance of the stove at maximum and minimum capacity respectively.

The stove capacity increases with increasing ethanol concentrations since the fuel-flow rate is maintained constant. As the ethanol concentrations increase, the efficiency of the stove drops at maximum capacity (from 46 to 32 %) and increases at minimum capacity (from 44 to 61 %). The drop in efficiency observed at maximum capacity tests is attributed to higher radiation losses and carbon monoxide emissions. This offsets the gain resulting from the reduced water content in the fuel mixture. No such loss occurs at minimum capacity.

A minimum of 45 % w/w ethanol in the solution can be utilized in the stove. However, the stove gives best results in terms of ease of use and performance with ethanol concentrations ranging from 50 to 55 %.

5. Field testing

Field tests (FTs) were conducted on the ethanol stove to demonstrate suitability to the target market and to validate the design. The stove's performance was compared with those of conventionally-used LPG and kerosene stoves. All FTs were conducted in a room (4.5 m × 3.1 m and 3 m ceiling) that resembled a typical size room in rural

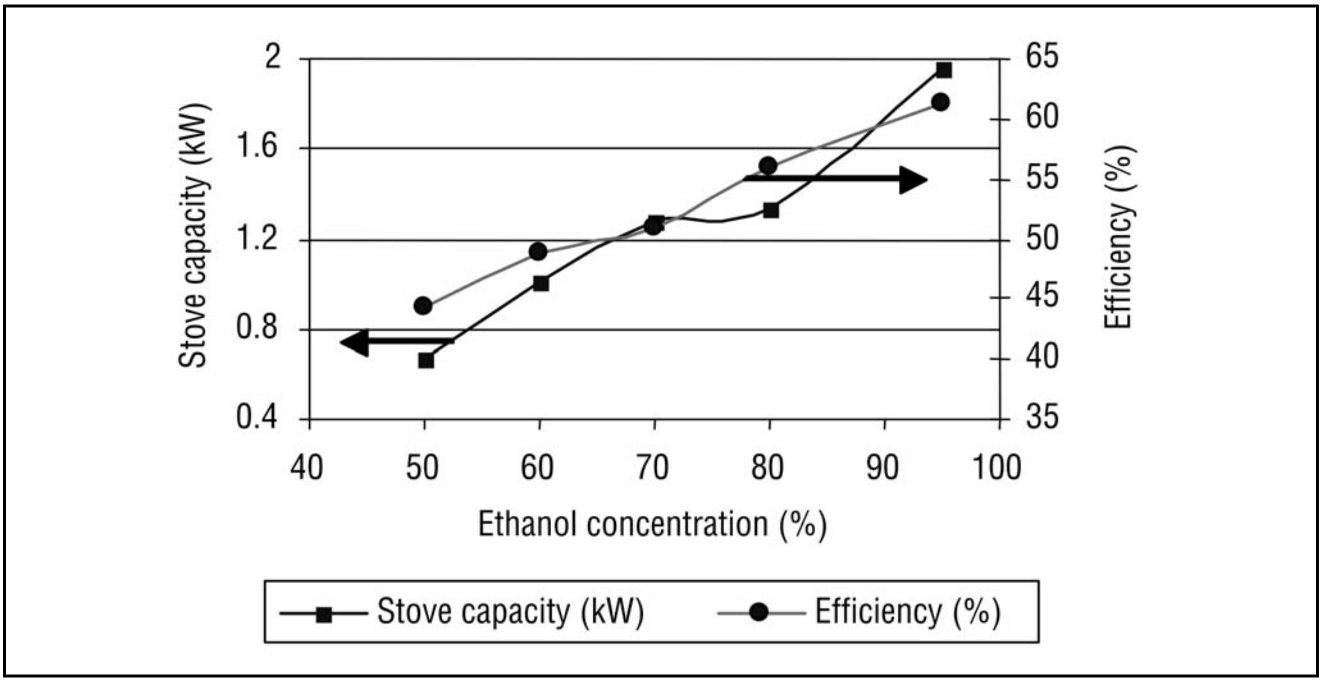


Figure 4. Stove performance with increasing ethanol concentrations (min. capacity)

households. The room had one door and one window on the same wall, which were left open during the test. The details of the FTs are given in Table 2.

The FTs showed that the specific energy required for the ethanol stove is more than that required for the LPG stove and less than that for the kerosene stove. These values are indicative of the efficiencies of the three stoves. The time required to cook is similar for the three stoves, indicating that the useful output energy provided by the ethanol stove is comparable to those of the two conventionally-used stoves. The CO emissions recorded during the tests (around 10 ppm near the cook) were found to be acceptable, indicating that it is a clean and safe fuel.

Further comparison of cooking costs, including stove capital costs and fuel costs, with and without subsidies, is shown in Section 6, "Economic analysis", below.

5.1. User comments

Detailed interviews were conducted during the field-testing of the ethanol stove. The general responses of the women are given below.

- It is very easy to light and run.
- It has no smell and does not give out any smoke; hence, it is much better than the woodstove. Additionally, the eyes do not burn and it does not cause headaches.
- Women who cook on kerosene stoves said that this is much better than the kerosene stove because it is completely silent and does not emit any smell after being extinguished. Some of them also felt that it is simpler and safer to use than the kerosene stove since it requires much less pumping.
- Some women thought that it is just like the LPG stove since it has easy flame control.
- The general acceptable cost for the ethanol stove as stated by the women was Rs. 400 to 500 with the cost of ethanol at Rs. 10 to 12/l.

6. Economic analysis

To compare the cost of using the ethanol stove with other stoves in India, the annualized life-cycle cost (ALCC) method was used.

In the case of kerosene and LPG, there are differences between the administered (subsidized) and open market prices. Hence, two options for fuel costs have been considered. A similar situation is assumed for ethanol. Table 3 summarizes the findings of the economic analysis.

The analysis shows that the cheapest option for cooking is the wood-burning *chulhas* (stoves). However, this analysis does not consider the environmental problems associated with woodstoves and the time spent gathering fuel. Using market fuel prices, the LPG stove works out to be around 23 % and the kerosene stove 8 % cheaper than the ethanol stove. A higher initial cost and higher fuel costs are the main reasons for the ethanol stove's higher comparatively annual expense.

Even though the ethanol stove works out to be slightly more expensive than both LPG and kerosene stoves, with the rising crude oil prices and the search for alternatives to contemporary cooking fuels, it can still be seen as a viable alternative in the near future.

7. Policy issues

For ethanol to be used as a cooking fuel in rural households the following policy issues need to be addressed.

1. The government of India should allow ethanol to be used as a cooking and lighting fuel for rural areas. Besides solving the energy crisis, the production and use of ethanol in rural areas will provide major stimulus to the rural economy. It is estimated that the ethanol economy for rural areas could be worth Rs. 2 trillion (~US$ 45 billion) annually [Rajvanshi, 2006a].
2. Presently the production and sale of ethanol is con-

Table 2. Summary of the field tests conducted for the three stoves

No.	Item	LPG	Kerosene	Ethanol stove
1	Total number of FTs	2	6	59
2	Total number of women	2	4	16
4	Average amount of fuel used per meal (kg)	0.212	0.266	0.479
5	Average mass of food and water cooked per meal (kg)	5.23	5.12	5.98
6	Average time required per meal (min)	126	125	137
7	Average specific energy required (kWh/kg)	0.52	0.63	0.60
8	CO values near the cook (ppm)	0 to 2	6 to 8	8 to 10
9	Cooking fuel cost per kg of food cooked (Rs./kg)	0.88	1.60	1.62

Notes

1. Meals were cooked for 4 to 5 people.
2. The above data is for meals cooked without the use of a pressure cooker. There is 20 to 30 % saving in the specific energy required per meal if a pressure cooker is used.
3. Cost of cooking is estimated taking ethanol cost at Rs. 16/l, kerosene (market price) at Rs. 25/l and subsidized LPG at Rs 310 per cylinder of 14.2 kg (1 US$ = Rs. 45). It should be noted that the subsidized price of kerosene is Rs. 10/l and the unsubsidized price for LPG is ~Rs. 500/cylinder.

Table 3. Summary of the ALCC conducted for different stoves

Item	Wood or crop waste[1]		Kerosene[1]		LPG[1]		Ethanol[2]	
	Standard stove	Improved stove	PDS[4] fuel	Market fuel	Subsidized fuel	Market fuel	Subsidized fuel	Market fuel
Stove price (Rs.)	10	150	200	200	1250	1250	1500	
Life of stove (yr.)	3	3	5	5	15	15	15	
Capital recovery factor[3]	0.402		0.264		0.131		0.131	
Annualized capital cost (Rs.)	4.02	60.32	52.8		164.3		196.5	
Annual fuel usage (l/yr or kg/yr)[5]	1395	698	199		115		260	
Fuel price (Rs./l or Rs./kg)[5]	2	2	10	25	21.83	34.7	10	16
Annual fuel cost (Rs.)	2790	1396	1990	4975	2507	3991	3300	5272
Maintenance cost (Rs.)	3	20	25		75		50	
Annualized costs per stove (Rs.)	**2797**	**1476**	**2068**	**5053**	**2746**	**4230**	**3547**	**5518**

Notes

1. Data for wood, LPG and kerosene stoves is taken from [D'Sa and Murthy, 2004]
2. Data for the ethanol stove is from [NARI, 2006]. Subsidized ethanol price is taken arbitrarily.
3. All analysis done at 10 % discount rate.
4. PDS = public distribution system (rationing by the government).
5. The units are kg for solid and gaseous fuels and l for liquid fuels.

trolled by a very rigid excise regime primarily because of issues regarding the drinking of this ethanol. However, there is enough chemistry known to mankind to make ethanol non-potable and unpalatable. Use of such chemicals will completely prevent drinking ethanol meant for use as fuel. If the government does decide on making such ethanol available as a cooking and lighting fuel in rural areas then it should exempt this ethanol from all excise duties. This will reduce its cost and make it a viable alternative to LPG and kerosene. Besides its use for cooking and lighting[1], it can also be used in internal combustion engines for producing decentralized electricity [Rajvanshi, 2006a]. Thus, all the present subsidies given in rural areas for cooking fuels (kerosene and LPG) and electricity should be lumped together and made available for ethanol use in rural areas.

8. Conclusions

1. An efficient stove running on 50 % w/w ethanol-water mixture has been successfully developed at NARI. To the best of our knowledge this is the first stove of its kind developed anywhere in the world.
2. 67 field tests involving 16 women were conducted at NARI during the course of this study. These tests demonstrated the suitability of the stove to the target market.
3. Economic analysis showed the cost of using the ethanol stove was comparable to those of both LPG and

kerosene stoves at the prevailing fuel prices in India. ■

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Note

1. Electric lighting using fluorescent lamps or LEDs is much more energy-efficient compared to lamps using kerosene. This is because the luminous efficacy of kerosene lamps is very low, generally about 1 lm/W [Dutt, 1994]. Nevertheless, our research has shown that lamps using kerosene and alcohol can be made substantially more efficient, with efficacies approaching 3 lm/W [Rajvanshi, 2005; 2006b]. These lamps could be an effective substitute for existing kerosene lamps used for lighting for households that remain without electricity. Moreover, the lighting efficacy of electric lamps is substantially lower if one considers the energy losses in converting fuel into electricity as well as transmission and distribution losses. Much additional improvement is possible in liquid-fuel lamps through the use of nanotechnology so that such lamps could become more competitive in the future.

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