MINIMIZING ENERGY USAGE IN COOKING TO PROTECT ENVIRONMENTS AND HEALTH

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ABSTRACT: *This paper describes the environmental and health impacts of toxic emissions from the energy uses for cooking along with application of simple physics with detailed experimental studies on procedures of reducing "On-stove time" and cooking with minimum Energy (Heat) using a new innovative energy efficient cooking techniques with a simple inexpensive insulation box. The total minimum amount of heat, Q_m, and on-stove time t_1 required to cook 1 kg of dry rice, 1 kg of dry beans, 1 kg of raw potato and 1 kg of goat meat using the new technique of cooking with a stove of power 626 + 10 W are found as: 562$\pm$ 3 kJ, 708 $\pm$ 4 kJ, 278 $\pm$ 2 kJ, 716 $\pm$ 4 kJ. The barest minimum (sensible) heat, h_t required to transform 1 kg of raw food into cooked food of these items are: 440 $\pm$ 3 kJ, 609 $\pm$ 4 kJ, 212 $\pm$ 2 kJ and 626 $\pm$ 4 kJ. With computations of the Global CDM potential of our new cooking method we have discussed the possible contributions of the energy and economically efficient cooking method towards significant reduction of emissions of CO_2 and other toxic gases and protection of environment and health.*

KEYWORDS: Sensible Heat Of Transformation, Energy Efficient Cooking, CDM Potential, Heat Insulation Box, Environment and Health Protection, Toxic Emissions.

INTRODUCTION

Rice, meat, beans and potato are among the most common food items cooked and consumed globally. Rice is a staple food for over half of the world's population (FAO, 2004). It accounts for over 20 percent of global calorie intake. Even with decreasing trend in per capita rice consumption (with increasing consumptions of other food items of more nutritional values), the global rice consumption is expected to be around 500 million tons annually[1] by 2050. The total global consumption of dry beans and baked beans is roughly around $3.5x10^{10}$ kg annually[2a, b, and c].The total consumption of meat stands at $2.5x10^{11}$ kg annually[2d]. Meat and beans require on the average much more energy for cooking than rice and potato. The recent experiments (see discussion) show that approximately 3 MJ of energy is spent to cook 1 kg of dry rice on the average in controlled cooking (without firewood). Thus the energy used in cooking globally is enormous. Food related energy uses stood at 340 million BTU per person in 2002[2e]. With the current population of 7 billion, at that rate the current annual global energy uses for cooking can be estimated 2.380×10^{18} BTU = 2.519×10^{21} J. Except for the energy generation by solar, nuclear and hydropower, all processes of energy generation from wood and other biomasses, kerosene, coal, natural gas etc. give rise to emission of CO_2 and toxic gasses leading to environmental pollution and health effects. In many countries and villages rice is cooked with heat obtained from wood, coal and kerosene, wasting a lot of energy with emissions of toxic gasses resulting in environmental pollution. With ever increasing demand on available energy sources (petroleum products, firewood, coal, etc.), eventually these energy resources will be depleted in the near future. It will then result in scarcity of energy availability[2f] .Since most of these energy sources are non-renewable, there is a need therefore, to explore new ideas on how to save both time and energy in the process of utilization of energy –in other words to make the energy utilization processes more efficient in terms of time and energy savings. Excessive usages of energy sources have dual effects on our income and environment[3-5]. At most governmental levels energy issues are addressed at producing more energy and making more energy sources available[6] rather than making energy utilization processes more efficient.

Concerted world-wide efforts are needed through application of Physics to push the boundary of science & technology to improve energy efficiencies of all processes that are of importance to human civilization and development of a country. Wastage of energy more than necessary as per thermodynamic principles gives rise to environmental pollution due to excess greenhouse gas emissions. Such excessive wastages are mostly preventable by making the energy utilization processes energy efficient. Life cycle analysis of building energy helps to design buildings with efficient energy uses[7]. In African and part of Asian Countries with growing population, the increasing use of wood fuels (firewood and charcoals) mainly for cooking is giving rise to increased rate of deforestation [8].

This is mainly due to inefficient methods of cooking used and consequently the demand on firewood is ever increasing. The increasing deforestation in turn can lead to severe environmental pollution, expansion of deserts and global warming. Increasing depletion of locally available wood supply can lead to reductions in available energy for cooking and heating. This will increase diversion of agricultural residues to fuel use, causing further deterioration of physical environments dependent on tree cover. In developing countries, specially, in remote areas 2.5 billion people rely on biomass, such as fuel wood, charcoal, agricultural wastes and animal dung to meet their energy needs for cooking. In many countries these resources account for 90% of household energy consumption (OECDEMA 2006)[9]. Below we give a brief account of environmental pollution and health affects arising out of cooking

ENVIRONMENTAL POLLUTION AND HEALTH AFFECTS FROM COOKING IN 3RD WORLD (DEVELOPING) COUNTRIES

In many countries 90% of household energy consumption (OECDEMA 2006)[9] depend on biomass, coal, kerosene and natural gas. Below we give a brief account of environmental pollution and health affects arising out of cooking as described below. The emissions from different energy sources have been quantified in Appendix [9j]. The acute respiratory infection (ARI) is one of the leading causes of child mortality in the world, accounting for up to 20% of fatalities among children under five, almost all of them in developing countries which is caused by pollution from cooking[9a] This makes solid fuels the second most important environmental cause of disease after contaminated waterborne diseases[9b] and the fourth most important cause of overall excess mortality in developing countries after malnutrition, unsafe sex, and waterborne diseases[9b] The environmental insults at early ages can have long lasting influences on human health and productivity[9c]

The higher concentrations of total suspended particulates (TSPs) are strongly associated with higher rates of infant mortality; it has been found that a 1% increase in ambient TSPs results in a 0.35% decrease in the fraction of infants surviving to 1 year of age[9d].

KEROSINE STOVE

Long-term exposures to “low” concentrations of kerosene have been reported to produce non-specific CNS effects such as nervousness, loss of appetite and nausea that are not related to hypoxia[9k]. The most common health effect associated with chronic / repeated kerosene exposure is Dermatitis[9e]. Thus exposure within a confined space at elevated temperature may induce narcotic effects such as narcolepsy, cataplexy and confusion 10[a, b]

WOOD STOVE

In India, biomass cooking fuels (wood or dung) have been strongly linked to tuberculosis (even after correcting for a range of socioeconomic factors) leading to conclusion that in subjects over 20 years of age 51% of the prevalence of active tuberculosis is attributable to cooking smoke[9f].

Exposure of preschool children living in homes heated with wood burning stoves or in houses with open fireplaces yielded these effects: decreased pulmonary lung function in young asthmatics[10c]; increased incidence of acute bronchitis and severity/frequency of wheezing and coughing10d; and increased incidence, duration, and possibly severity of acute respiratory infections10e-

COAL STOVE

In China, where coal is used widely at homes, case-control studies have strongly implicated indoor cooking smoke in the development of lung cancer among women9h, I who are mostly exposed to the smoke.

Dr. Kirk Smith has pointed out the importance of products of incomplete combustions (PICs) of energy sources. “Simple stoves using solid fuels do not merely convert fuel carbon into carbon dioxide (C). Because of poor combustion conditions, such stoves actually divert a significant portion of the fuel carbon into PICs, which in general have greater impacts on climate than C . Eventually most PICs, are oxidized to C , but in the meantime they have greater global

warming potentials than C by itself. Indeed, if one is going to put carbon gases into the atmosphere, the least damaging from a global warming standpoint is C , most PICs have a higher impact per carbon atom.” 9k.The global warming effects of other emissions are summarized below.

Carbon Monoxide (CO) is one of the primary products of incomplete combustion. Emissions of carbon monoxide from unimproved wood-burning stoves are frequently as much as 10-15% of the C emissions, and this figure is even higher for charcoal. Carbon monoxide has a global-warming potential of 3 times that of carbon dioxide[9m].

Methane (CH_4) is a relatively potent greenhouse gas. Averaged over 100 years, each kg of CH_4 warms the Earth 21 times as much as the same mass of CO_2. Methane has an atmospheric lifetime of about 12 years. Methane is a part of the Kyoto Accords and is considered one of the most important greenhouse gases resulting from biomass burning[9l].

Nitrous Oxide (O) – A powerful greenhouse gas, nitrous oxide has an atmospheric lifetime of 120 years and a GWP (global warming potential) of 296 over 100 years[9m]. **(O)** Is also a part of the Primary Kyoto Accords and one of the primary gases considered in inventories of biomass burning[9n].

Non-Methane Hydrocarbons (NMHC) – Hydrocarbons are gases consisting primarily of hydrogen, carbon and oxygen. Emissions of unburned hydrocarbons indicate incomplete combustion and the vapours can be harmful if inhaled. Overall, the 100-year GWP of the non-methane hydrocarbons is approximately 12 times that of C , with climate change occurring because of their contribution to ozone formation[9o].

Oxides of Nitrogen (N) Is a broad term for the various nitrogen oxides produced during combustion when combustion temperatures reach a high enough level to burn some of the nitrogen in the air. N is an ozone precursor and when dissolved in atmospheric moisture can result in acid rain. Oxides of nitrogen affect atmospheric chemistry in complex ways, including interactions with •OH radicals and contributing to ozone chemistry. They are presently thought to be greenhouse neutral9p.

Black, Elemental Carbon (EC) is carbon that will not volatilize at a temperature of ~600 (in an inert environment). It is produced in flaming fires and is also called soot. EC is one of the most important absorbing aerosol species in the atmosphere. Elemental carbon from combustion has a global warming potential 680 times that of each equivalent mass of C 9p.

If the cooking methods can be made highly energy efficient, then demand on wood and other forms of biomass, coal, kerosene etc. energy sources can be reduced. Based on above discussion about the highly deleterious effects of the emissions arising out of the burning of these energy sources while cooking, minimization of energy uses for cooking can significantly add to the protection of our environment and health.

The primary objective of this study is to apply Physics to explore the possibility of finding out a new cooking technique to cook food with the lowest amount of energy so as to lead to considerable savings of energy (fuel) and on-stove-time over the conventional methods used in domestic cooking. Another objective is to find out the on-stove time, t_i, the actual amount of heat, Q_N, minimum heat, Q_m, and sensible heat (the barest minimum heat), h_t required to cook 1 kg of dry beans, 1kg of dry rice, 1 kg of raw meat and 1 kg of raw Irish potato using both the new technique and the conventional method of cooking by pressure cooker. At the same instant, on-stove time, t_i was also noted in each case. This depends on the power of stove used and is not constant. Scientifically, this is the minimum time at which the food (containing 1 kg of the raw food item along with other ingredients) inside the pot will attain the maximum temperature after being put on stove. For the pressure cooker used in this study, this temperature is calculated to be 114 C. The on-stove-time here is defined as the minimum time the cooking pot needs to be put on stove before being transferred to an insulating box detailed construction of which has been discussed in our earlier work. The data for beans and rice have been published earlier[10a,b] (Ref 10 &11. In this paper we publish the experimental data on meat and potato quoting the earlier data[10] for comparison and discussion. Another objective is to estimate the efficiencies of the cooking method based on the concept of h_t[10a-b](REF 10,11), and possible Clean Development Mechanism(CDM) Potential of the new method of cooking each of the food item and when applied globally for cooking.

MATERIALS AND METHODS

In our earlier published works[10a,b] we have discussed at length the methodology. It involves the pressure cooker containing the food items, required amount of water and ingredients to be kept on the stove of constant power (626 W) till the time(t_i) when the first whistle is heard in the new technique and for the time(t_i) until a specified number of whistles are heard in the conventional method of using pressure cooker as per Table in Appendix B. For each experiment on cooking, temperature (T) of the external surface of the pot is noted at given interval of time(t) until ti. In the new cooking method the pressure cooker pot is removed immediately after ti from the stove and kept in a closed insulation box (Fig.1) for 30 minutes for the cooking to be done by the heat already stored in the food items

The data collected are shown in Tables 1-8 for rice[10b], beans[10a], potato[10a] and goat meat. However, in the earlier published work[10a] the power of the stove was determined to be 650 W assuming the emissivity of the aluminum pressure cooker pot to be 1. Upon research of published emissivity data[12] of various types of aluminum, we have taken an average value (0.22) of the emissivity of aluminum for recalculation of the power of stove (626 W) and the various parameters mentioned in this work. This power of stove is the effective power of delivering energy to the cooking pot on top of the kerosene wick stove that is used in all experiments. It allows us to estimate the actual minimum energy required in cooking each item(excluding all energy wastages). It is not the burning power of the stove. However, in all our experiments we have recorded also the volume of kerosene used to determine the net energy used(including all energy wastages) in cooking each item. The data of the ref. 10a & 10b are also shown `here in order for the comparison to be made and for the recalculations of the heat parameters (Q_N, Q_m, h_t) of potato and beans. Q_N is the actual amount of heat delivered to the pressure cooker pot by the stove. It is different from the net fuel energy, $E_N = V_k d H_c$ used in cooking. V_k is the volume of fuel consumed during cooking in a specific technique. d is the density of fuel. H_c is the lower heat content of the fuel(kerosene). h_t is the sensible heat (the barest minimum heat) that can cook 1 kg of dry rice. The cooking efficiencies for the items rice, beans, potato and goat meat have been calculated in this work. The cooked food items based on new method of cooking are shown in Fig.2-5. For ensuring same stove power, P_s each time of cooking, same level of kerosene and the wicks are maintained in the stove.

Data Analysis

III.1. *Data Collection:* The main data in this work is the temperature, T_p of the outside Pot‟s wall and the time t which are shown in Tables 1-8. Values of all other required parameters are given in Appendix C

For computations of (Q_N, Q_m, h_t) of and the cooking efficiencies for the items rice, beans, potato and goat meat the data on T_p vs. t_i are needed and shown in Tables 1-8.

Table 1: On-stove time and pot's external temperature T_P during on-stove time of cooking 1 kg of dry rice[10b] using the present method.

Room tempt.: 30 ^{0}C; water added: 1.6 litres; vol. of Of kerosene used: 31ml

On-stove time, t_1(min)± 2 s	0	2	4	6	8	10	12	14	15.11
Pot‟s external tempt. T_p (K)± 1	303	317	328	352	354	359	363	367	370

Mass of final cooked rice product = 2.55 kg.

Table 2: On-stove time and pot's external temperature, T_p at complete cooking of 1kg of dry rice[10b] using conventional method of pressure cooker; Room tempt: 34^0c; vol. of water used 1.6 liters; t_i =1357 seconds; vol. of kerosene used: 47 ml; m_f = 2.55 kg

On-stove time(min)$\pm$ 2 s t_1	0	4	8	12	16	20	22.37
Pot"s external tempt. T_p (^{0}C)$\pm$ 1	305	325	343	359	360	365	369

Table 3: On-stove time and pot's external temperature T_P during on-stove time of cooking 1 kg of goat"s meat using new cooking method vol. of kerosene used: 89 ml; m_f = 1.3 kg. Room temp=32 ^{o}C. Water used = 0.3 liter. t_i = 19.25 Time = 1165 s. Vol. of kerosene used = 43 ml.

On-stove time(min)	0	2	4	6	8	10	12	14	16	18	19.3
Pot"s external tempt. T_p (^{0}c)	32	43	53	64	72	78	85	92	93	94	95

Room tempt.: 34^0C; water added: 0.3 litres; t_i =1165 seconds;
vol. of kerosene used: 43 ml; m_f = 1.3 kg

Table 4. On-stove time and pot's external tempt. T_p at complete cooking of 1kg of meat using conventional method of using pressure cooker.

Room tempt.: 34 C; vol. of water used 300 ml; t_i =2451 seconds; vol. of kerosene used: 89 ml; m_f = 1.3 kg

On-stove time(min)	0	4	8	12	16	20	24	28	32	36	40	40.51
Pot"s external tempt. T_p (^{0}c)	32	51	70	83	91	93	95	96	97	98	99	99

Table 5. On-stove time and pot's external temperature T_P during on-stove time of cooking 1 kg of beans

Room tempt.: 32 ^{0}C; water added: 1.2 litres; t_i = 1144 seconds; vol. of kerosene used: 42 ml; m_f = 2.2 kg

On-stove time(min), $t_i \pm$ 2 s	0	2	4	6	8	10	12	14	16	18	19.04
Pot's external tempt. T_p (^{0}C) $\pm$ 1	31	44	49	55	60	65	70	75	83	93	95

Table 6. On-stove time and pot's external tempt. T_P at complete cooking of 1kg of beans using conventional method of using pressure cooker.

Room tempt.: 31^{0}c; vol. of water used 1.2 liters; t_i = 2943 seconds; vol. of kerosene used: 112 ml; m_f = 2.25 kg

On-stove time(min) $\pm$ 2s	0	4	8	12	16	20	24	28	32	36	40	44	48	49.03
Pot's external tempt. T_p (^{0}C) $\pm$ 1	29	48	60	69	82	95	96	97	98	99	99	99	99	99

Table 7. On-stove time and pot's external temperature T_P during on-stove time of cooking 1 kg of Irish potatoes

Room tempt.: 35^{0}c; water added: 150 ml; t_i = 466 seconds;
vol. of kerosene used: 15 ml; m_f = 1.038 kg

On-stove time(min) $\pm$ 2 s	0	2	4	6	7.46
Pot's external tempt. T_p (K) $\pm$ 1	33	48	68	84	96

8. On-stove time and pot's external tempt. T_P at complete cooking of 1 kg of Irish potatoes in Conventional Method of Cooking

Room tempt. 33.3 ^{0}C; vol. of water used 150 ml; t_i = 1041 seconds; vol. of kerosene used: 39 ml;

On- stove time (min) $t_i \pm 2$ s	0	2	4	6	8	10	12	14	16	17.51
Pot's external tempt. T_p (^{0} C) $\pm$ 1	31	47	66	80	94	96	97	98	99	99

III.2. Computations of Q_N, Q_m, h_t, and the cooking efficiencies of the new and conventional methods.

Q_N is calculated using the simple formula **$Q_N = P_s t_i$. Q_m** is related to **$Q_m = Q_N - Q_{rh}$. Q_{rh}** is calculated from each table by the method described below:

From Table 1 it is seen that from t = 0 min to t = 6 min the temperature rise of the pot (containing food) is quite fast compared to the interval from t = 6 min to t = 15.11 min. We calculate the radiation losses Q_{rh1} and Q_{rh2} separately for these two intervals of time, using the following method:

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$$Q_{rh} = \int \varepsilon_{AL} \sigma A (T_p^4 - T_a^4) dt$$

$$Q_{rh} = \int \varepsilon_{AL} \sigma A (T_p^4 - T_a^4) \frac{dt}{dT_p} dT_p$$

$$Q_{rh} = \int \varepsilon_{AL} \sigma A (T_p^4 - T_a^4) \left| \frac{dt}{dT_p} \right|_{av} dT_p$$

$$Q_{rh} = \varepsilon_{AL} \sigma A \left| \frac{dt}{dT_p} \right|_{av} \int_{T_1}^{T_2} (T_p^4 - T_a^4) dT_p$$

For each table the data is divided in a 2-4 regions where each successive $\frac{dt}{dT_p}$ value is quite close to each other and does not differ much.

For example, Table 1:

(1) For the time interval of 0 to 6min, $\left| \frac{dt}{dT_p} \right|_{av}$ = 7.33 s/^{0}C

And $T_1 = 30 + 273 = 303K$

$T_2 = 79 + 273 = 352K$

Taking $\varepsilon_{AL} = 0.22$, $Q_{rh1} = 1.17kJ$

(2) For the time interval 6 min. to 15.11 min., $\left| \frac{dt}{dT_p} \right|_{av}$ = 30.37 s/^{0}C

And $T_1 = 79 + 273 = 352K$

$T_2 = 97 + 273 = 370K$

$Q_{rh2} = 4.79kJ$

Thus total radiation loss $Q_{rh} = Q_{rh1} + Q_{rh2} = 5.96kJ$ for the new method (technique I).

Method 2:
It involves the plotting of T_p (K) vs t(s) curve and find a polynomial up to 3rd degree in time(t) (for $0< t \leq t_i$) for the best fit of the T_p vs t curve. Then we have an equation $T_p = T_p(t)$. Use the expression $T_p(t)$ of T_p in terms of t in the equation:

$$Q_{rh} = \int \varepsilon_{AL} \sigma A(T_p^4 - T_a^4)dt$$

To obtain Q_{rh}. As for example the equation representing Table 1 data is found to be:
$T_p(t)= (-0.8*10^{-5}t^2+ 0.1472t + 303.16)$ for $0 < t \leq 907$s. Here T_p is in Kelvin and t is in second.
Then the above equation yields Q_{rh} = 6.12 kJ. The average of the two methods is then taken as $\overline{Q_{rh}} = 6.0 \pm 0.1 kJ$

Following the methods 1 & 2 we can thus find the radiation heat losses from the data of each Table (1-8). The two methods if applied
correctly should yield the two values in close agreement. The Q_{rh} thus determined for beans, potato and meat for both the new and conventional method are given in the Table 9.

Table 9: The on-stove time t_i and the radiation losses for the new and conventional cooking technique for different food items:

Parameter	New Method of Cooking				Conventional Method of Cooking			
	Rice Meat	Beans	Potato	Goat	Rice Meat	Beans	Potato	Goat
Q_{rh}(kJ)± 0.1	6.0	7.1	2.2	7.2	8.6	25.3	6.5	17.8
t_i(Min)± 2s	15.11	19.04	7.46	19.25	22.37	49.03	17.51	40.51

Calculation of the sensible heat h_t:

We have shown earlier[11] that when the pot's outer wall temperature (T_p) does not change with time, then, it is nearly equal to the temperature (T_i) of the inner wall. This is also true when the temperature of the water is
rising at a low rate ~ 0.1^0C/s which is usually the case for the temperature rise in all the Tables presented below. This idea is used in estimating the total radiation heat loss during the rise of temperature of the pot and Q_m. We had also shown[11a] how to non-invasively(even 10 without using thermometry of any kind) estimate the temperature of the food inside. Temperature of the steam, T_s was determined from steam temperature pressure relation[13] to be 114°C.
h_t = Absolute minimum required heat to transform 1 kg uncooked dry rice to well cooked rice product.

It is calculated using the formula below:

$$h_t = \{Q_m - m_p c_p (T_p' - T_a) - \Delta m (L_v - + c_w (T_i' - T_a))\} \quad \text{(i)}$$

Δm = mass of water lost by evaporation.

P_{in} =inner pressure of the pot: $P_{in} = P_o + \frac{w_h}{A_v}$ = 163992Pa (ii)

T_i is taken as equal to T_p (see above)

T_s = Mean steam temperature

T_i' = the mean internal temperature, which is equal to average sum of T_i' and steam temperature, T_s which is using the value of P_{in}

$$T_p' = \frac{T_i + T_s}{2} \quad \text{(iii)}$$

T_p' = Temperature of Pot's external wall (measured)

T_p' = the mean wall (Aluminum pot) temperature: $T_p' = \frac{T_i' + T_p}{2}$ (iv)

The pressure P_{in} of equation (ii) correspond to the steam tempt, T_s, 114 ^{0}C(387 K)(Keenan, Keyes, Hill and Moore, 1969)[13]. It is assumed $T_i = T_p$ from heat balance equations[11a]. By measuring loss of weight , *h_t can then* be calculated from Eq. x above if Q_m is known. To calculate Q_m from Equation $\mathbf{Q_m = Q_N - Q_{rh}}$, Q_{rh} is evaluated shown above. This same method is used to compute Q_m and h_t for beans, potato and goat meat.

Table 10: Comparison of on-stove time and energies involved in the new and the conventional methods of cooking. Thermal rating power of the stove, Q_r = 626 J/s

Parameters determined	New innovative method of using Pressure Cooker(Technique I)				Conventional method of using Pressure Cooker (Technique II)			
	Rice*	Potato	Beans	Goat Meat	Rice	Potato	Beans	Goat Meat
Time,t_i Min	15.11	7.46	19.04 ± 0.2	19.25±0.2	22.37±0.2	17.51±0.2	49.03±1	40.51± 0.7
Q_N±kJ	568± 3	280± 2	715± 4	723± 4	840± 5	658±4	1.84± 0.01MJ	1.52MJ ± 0.01MJ
Q_m±kJ	560± 3	278±2	708±4	716± 4	831± 5	641 ±3	1.81± 0.01MJ	1.48 MJ±0.01
h_t± kJ	465± 3	212± 2	609.0 ± 4	626± 4	**	**	**	**
V_k±1 ml	31±1 ml	15±1 ml	42±1 ml	43±1 ml	45	36	100	82

normal rating power of the stove, P_s = 626 W $\pm$ 3. V_k = Volume of kerosene used.
*The data on rice is communicated to Journal of Renewable and Sustainable Energy(AIP)(2013) under

** During conventional method of cooking with pressure cooker, the definition of h_t does not apply since it is the absolute minimum amount heat that can cook food item well (quite soft to eat)

Table 11: Thermal efficiency of the new and conventional method of cooking with pressure cooker with a stove of power W= 626 J/s.

Items	New method of Cooking with pressure Cooker Efficiency	Conventional method of Cooking with Pressure Cooker Efficiency
Rice Min	78%	53%
Potato	76%	32%
Beans	85%	33%
Goat Meat	87%	41%

Normal rating power of the stove, P_s = 626 W $\pm$ 3. V_k = Volume of kerosene used.

DISCUSSION

The experiments above determined the minimum heat Q_m = 562 KJ[10b] required in cooking 1 kg of dry rice using the new method(Table 10) of cooking and the sensible heat h_t = 465 KJ. It appears that these quantities (i.e.,Q_m, h_t) also depends on quantity of water used. In the determination of these quantities we have used 1.6 liter of water to ensure that the cooked rice is quite soft. When 1.2 is of water is used (As per Appendix 1) with 1 kg of dry rice, the cooked rice is hard. Thus amount of water can be adjusted between 1.2 liters to 1.6 liters per kg of rice, depending on the taste of the consumer. If the amount of water used is less than 1.6 liter the values of Q_m and h_t will be still further lower following the new method of cooking. For example, if 1.2 liter is used, the values of Q_m and h_t are expected to be around 455 kJ and 360 kJ respectively. The time t_1 for which the pot has to be on the stove (i.e., on-stove-time) before being transferred to the box depends on stove power will also be reduced. In our experiments the stove power was quite low 626 W and with that power it only took only 15.11mins on-stove-time to cook the rice. There have been only a few experiments on determination of minimum energy needed for cooking food items. From the Table 1 we see that the volume of kerosene consumed in technique I to cook 1 kg of dry rice is 31 ml. Using lower heat content of kerosene(43.1 MJ/kg) and density of kerosene 0.8 kg per liter, we see that the net energy used is 1.067 MJ. The detailed experiments carried out by Carlsson- Kanynma and Bostrom Carlsson[14] showed that the minimum heat r e q u i r e d to cook 0.045 kg of dry rice is 0.12 MJ with electric stove. This translates to 2.67 MJ required to cook 1 kg of dry rice using their methods. Anoopa et al[15] carried out detailed studies on the energy uses in cooking rice using different fuels and stoves. Their studies showed that the energy uses depend on the quality of rice also. They concluded that parboiled rice requires more energy than raw rice. Their detailed experiments gave a value of minimum energy required for cooking rice was 1.97 MJ(equivalent to 45 ml kerosene) per 0.5 kg of raw rice. These latter figures are however expected to be lower than 3.94 MJ per kg of rice when 1 kg of dry rice is cooked at one time using their method. Using our method the minimum heat required is 0.562 MJ per 1 kg of dry rice and it can be further reduced if the amount of water used is less than what we used. To date this (0.562 MJ per kg of dry rice(this excludes all energy wastages)) is the reported lowest amount of heat required so far in cooking 1 kg of dry rice when the net energy used (1.067 MJ) is also the lowest of all reported energy used to cook 1 kg of dry rice. Here a question may arise why the net energy(kerosene used) is 1.067 MJ while the Q_N, the heat delivered to the pot is 568 kJ? It is because of the heat transfer ratio, H_r of the stove. $H_r = E_N/Q_N$ which is usually about 50%. From the data on V_k The conventional method of using pressure cooker(as per Appendix 1) required 872 KJ of minimum energy(Q_m) and 22.37 mins of on-stove-time and 45 ml of kerosene, corresponding to E_N = 1.56 MJ. Our experiments (data not reported here) shows that the conventional method of cooking rice without pressure cooker (as done by most of the households in African countries with fire wood) requires(Q_N) roughly 3 times the energy required in conventional method of using pressure cooker, i.e., about 2.7 MJ of energy per kilogram of raw rice. The last figure compares favorably well with 2.67 MJ for 1 kg rice used by Kanynma and Carlsson to cook 1 kg of rice on electric stove. Thus when rice is cooked with the new method presented here a saving of 80% of energy used in conventional method of cooking without pressure cooker can then be achieved. With electrical stove the heat transfer ratio is expected to be close to unity and therefore, Q_N would not be far less than E_N. The term conventional method as used in this paper referred to the use of pressure cooker with the lid closed and counting the time from the first whistling of steam from the pressure cooker as given in the reference time table of cooking (Appendix 1). In our case (Technique I) the on-stove-time is counted from the time the cold pot is put on the stove. We have seen that the on-stove-time for rice is 15 min 11 s right from the moment the pot was put on the stove. Now according to the manufacturer of the pressure cooker the accounting time for rice is 5 minutes as indicated in appendix 1 with stove of power 1 KW. Thus our new technique of cooking is superior in terms of energy and time saving to the conventional method of cooking with pressure cooker. Thus saving energy and on-stove time in domestic cooking using our method is expected to reach the level unattained by any other means of cooking so far. *This method is primarily is to raise the* temperature of the food inside a pressure cooker to the pressurized steam point (to about 115 ^oC) and as soon as the whistling of the cooker starts, remove the pressure cooker pot and enclose it in an well-insulated box(Fig.1)(volume about two to three times the pot) and leave it there for about 30 minutes. The food will be well-cooked if the initial water is just sufficient.

It has been reported that energy used in cooking 1 pound of beans is equivalent to $0.08 dollar[16] of electrical energy. With this rate the energy used in cooking 1 kg beans is equivalent to $0.18 of electrical energy. At the rate of $0.12 per KWH this translates to 1.3 KWH of electricity. In terms of joules, it is 4.5 MJ of energy. Our new method of cooking beans (see Table 6) requires only 710 kJ of energy, saving nearly 84% of the reported energy usage. To date we have not seen reported energy quantification for cooking meat. So we could not compare our results with that of others. Carlsson-Kanyama reported in their investigation that minimum 0.23 MJ of energy is required to cook one portion of potato which weighs 200 g. This translates to use of 1.15 MJ of energy in cooking (boiling) 1 kg of potato. From Table 6 we see that our new method of boiling potato requires only 220 kJ of energy thus saving nearly 80% of the energy used in the energy saving method A Carlsson-Kanyama[14].

We have defined h_t as the absolute minimum amount of heat(the sensible heat) that is solely required for cooking 1 kg of raw food item. So, far our knowledge goes such determination has not been done in literature before. Determination of h_t requires elimination of all other heat losses (such radiation, convection, energy used in cooking pot and in the evaporation of water) from the total heat input for cooking. If h_t is determined for different food items, then it can be of help in making a new electric pressure cooker with the design as was shown in our earlier work[10a] to cook food items with lowest amount of energy. Here the heating current in the coil could be adjusted so that the total energy delivered inside the pot is just 5-8% more than the heat of transformation, h_t. It may also be switched off when the temperature inside the pot reaches the maximum value ~ 116^{0}C. The cooking pot (Fig. 4 in ref. 11a) will be highly energy efficient if the space in between the two metal walls could be made vacuum and highly reflecting instead of putting the metal foil and white paper sandwiches as done in the cooking box (Fig.1a). This however would make the pressure cooker pot costly.

In this paper we have also described method 1 & 2 of determining the methods of radiation losses from measured time-temperature data. The two methods are found to yield fairly agreeable evaluations of the radiation losses. We have not estimated convective heat losses which we expect to be quite small since the flame area is much smaller than the bottom area of the pot. The estimated amount of fuel used in the conventional method of using pressure cooker was about 81 ml of kerosene while in new technique(technique I) only about 31 ml of kerosene was needed (Table 10) to cook 1 kg of rice. Only 15 ml of kerosene was needed to cook(boil) 1 kg of potato with technique I. It should be noted that there is further room for research. Based on the above findings one can still design a cooking vessels that can cook rice with lesser energy (heat) and shorter on-stove time or with electric timer. For example, if a new designed pressure cooker (see Fig 4 in ref. 11a) has a heating coil of 1 kW, then the net heating time for cooking 1 kg of rice using the above calculated heat of transformation h_t, will just be around 520 seconds, with 10% excess heat supply. In our experiments the box was made of card board inside walls of which were lined with layers of aluminum foil and white paper sheet (Fig 1a). The highly reflecting internal surfaces (which were made fabry-perot type) of the cooking box conserved the radiant heat of the pot to continue rest of the cooking. The white paper in between the shining aluminum foils has two fold actions: It partially absorbs the heat and also separates the two reflecting surfaces from where multiple reflection of the same heat ray takes place. It has been analyzed that with four or more smooth reflecting surfaces(with white paper underneath each reflecting surface) most of the heat remains as stationary waves within the region preventing further heat from the pot pass through the box wall, allowing heat conservation inside the box. It has been observed that the pot"s external wall temperature when kept inside the box after a period of an hour was recorded to be 79C, while the temperature of the center of the cooked food was 90C.

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This is an indication that the box maintained temperature of the food close to boiling point. It thus enables the partially cooked food to be completely done inside the box. Without the box, the corresponding readings under the same conditions have been determined to be 41C and 52C respectively.

Based on experimental investigation carried out on the box, the heat retaining capacity of the box is about 11 to 13 hours. The box design (i.e., insulation) can be improved further to cook the food (once hot pot is kept inside) in about 15 minutes and to keep the food sufficiently warm for more than 12 hrs. Note that the box has no source of heat supply. The heat insulation property of the reflecting surface has been found to be ineffective if the foil surface is not smooth and shiny. Such materials can find applications in between sheet rocks in buildings as insulating materials to conserve energy and thus reduce energy bills of buildings in cold countries. The insulation property of the box can be further improved by using Styrofoam materials on the outside walls of the box. The higher the insulation of the box the better the food can be cooked once it is transferred to the box after raising the temperature of the food to around 115 ^{o}C.

The results of this investigation can find many applications in restaurants and kitchen, especially, for saving energy and on-stove cooking time. If the findings of this research are utilized in developing countries for cooking along with highly energy efficient wood stove[17]rapid deforestation due to fire-wood collection can be prevented and this can help protection of our environment.

Energy Efficiency of the present method of cooking and comparison with conventional methods of cooking.

Ideally the efficiency, η of a cooking method should be defined by the equation: $\eta_{cm} = 100xh_t/Q_N$. Where as defined earlier, h_t = sensible heat required to cook 1 kg of a food material i.e., to transform 1 kg of raw food with required ingredients into a completely cooked food product and Q_N = Total amount heat supplied by the stove for the cooking process. While values of Q_N have been determined by several workers, knowledge of h_t is not available for all types of food materials. The energy efficiency of cooking rice with the present method(Technique I) is calculated to be 79%(0.79) while with the conventional method of using pressure cooker it is found to be 54%(0.54). Actual energy efficiencies of all cooking methods should be calculated using the values of heat of transformation, h_t, of the food item. We recommend some further works on determinations of energy efficiencies of cooking methods using the idea mentioned above. It is an important parameter found in this work. Normal cooking so far used heat energy far in excess of h_t. Overall energy savings now depends on the product of η_{cm} and η_{stove}. For total minimization of emission (hence environmental protection) due to cooking we need to have this product as close to unity as possible.

Table 10: Energy Efficiencies of different types of cooking methods

Food Items	Energy efficiency of cooking with present method(%)	Energy efficiency of cooking with conventional method ofusing pressure cooker	Energy efficiency of cooking With conventional method of cooking without pressure cooker.
Rice	78*	54*	22*
Beans	85	33	13
Goat Meat	87	41	16
Potato	76	32	13

*Ref.10b

CONTRIBUTIONS OF THE PRESENT RESEARCH TO THE CLEAN DEVELOPMENT MANAGEMENT POTENTIAL (CDM POTENTIALS)

Obviously, if the results of the present research are applied world-wide to cooking, it will give rise to a significant savings of energy and thus carbon emission. It thus will reduce environmental pollution significantly. In other words, it has clean development management (CDM) potential. To quantify precisely the CDM potential of the present research when applied to cooking world-wide is beyond the scope of the work. However, we have approximately estimated the minimum and the maximum CDM potential as follows:

Minimum CDM potential: In India[22] approximately 2.5 liters of kerosene is used per person per month. Emissions from kerosene stove (with blue flame) is lower by a factor of 3 when compared to biomass[23]. To estimate the minimum CDM potential we assume that globally everybody is using kerosene for cooking at the rate of 3.0 liters per person per month (assuming six persons per family). The total annual usage of kerosene for cooking = $7x10^9$(global population) x 3.0 x12 = $4.3x10^{11}$ liters. The carbon factor[24] for 1 liter of kerosene is 2.331 kg of CO_2 emission. Thus the total minimum annual global carbon emission from cooking (if kerosene is used) = $2.331x4.3x10^{11}$ = $1.0x10^{12}$ kg. If our method is used for cooking globally, at least 75% of the energy will be saved. Thus the total minimum CDM potential = $0.75x1.0x10^{12}$ = 7.510^{11} **kg.** Thus globally minimum $7.5x10^{11}$ kg CO_2 emissions could be saved if our method is used in cooking**.**

Maximum CDM potential of our cooking method: The global energy usage in 2010 stands at 510 quadrillion BTU[25]. One BTU is 1055 Joules of energy. We assume that 10% of this energy is used for cooking globally. Thus the total global energy use for cooking = $510x10^{15}$ x 1055x0.10 Joules = $5.4x10^{19}$ Joules .One kwh has a carbon factor of 0.2. One kwh = 1000x3600 = $3.6x10^6$ Joules.

Thus the total Maximum annual CDM potential = 5.4×10^{19} J$\times0.75\times$ 0.2 kg/(3.6×10^{6} J) = 2.2×10^{12} = 2.2×10^{12} kg.

Contributions of improved cooking methods to the CDM potential and the total energy savings from cooking depend on the product of stove efficiency (η_{stove}) and the efficiency of the cooking methods (η_{cm}). A lot of research works have been carried out on improving efficiency of stoves using renewable energy sources[26-31]. Thus if our energy efficient cooking methods are applied along with efficient stoves as mentioned above, the emissions of carbon dioxide and toxic gases from cooking would become minimum globally and cooking can be done with minimum use of energy. Thus a huge amount of energy can be saved globally in cooking which can be diverted to other useful works apart from cooking. This will contribute significantly not only to reduction of environmental pollution but also to the reduction of global warming[32], saving thus our environments and atmosphere. This will reduce health hazards (as mentioned earlier in Introduction) arising from cooking.

Estimation for CDM potential of the present method for rice cooking: Assuming global consumption of rice stands around 400 million tons annually, then minimum total energy savings in cooking rice with our methods is (using data presented above)
– 400×10^{9} kg rice x (2.6 – 0.56) x 10^{6}/kgx 0.2kg/3.6×10^{6} J = 45.3×10^{9} kg = 4.5×10^{10} kg of CO_2.
Similarly CDM potential of our present method for cooking beans, potato and meat can be found.

The results obtained so far can help designing a new pressure cooker, which can be self-timed to cook with the heat of transformation, h_t.. In addition to saving on-stove time, the new technique could yield a highly improved method of saving food nutrients[33] which are destroyed when food is subjected to excessive heat and cooked for long time. All the symbols used in this work are defined in Appendix B.

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Appendix A: Mean, minimum and maximum emission factors of each fuel type (gram of compound per kg of fuel)9j

Fuel type		CO	C		TSP		
Wood Min. (Instant Emission)	9.87E +02	1.97E+ 01	3.80E – 01	2.57E-02	1.17E+ 00	1.23E- 01	Nd
Mean	1.45E+ 03	5.87E+ 01	2.70E+ 00	2.27E+ 00	3.05E+ 00	1.16E+ 00	2.77E +00
Max.	1.41E +03	1.11E+ 02	7.40E+ 00	9.68E+00	5.87E+ 00	2.77E+ 00	6.08E-02
Wood Min. (Ultimate Emission)	1.41E+ 03	2.41E+ 01	5.37E+ 01	2.94E- 01	1.51E+ 00	1.24E- 01	Nd
Mean	1.52E+ 03	6.92E+ 01	5.06E+ 00	4.34E+ 00	3.82E+ 00	1.19E+ 00	8.21E-03
Max.	1.63E+ 03	1.23E+ 02	1.99E+ 01	1.77E+ 01	8.73E+ 00	2.78E+ 00	6.24E-02
Crop (Residues) Min.	8.34E+ 02	2.36E+ 01	4.00E- 02	4.64E- 02	1.12E+ 00	3.93E- 02	nd
Mean	1.13E+ 03	8.63E+ 01	4.56E+ 00	4.35E+ 00	8.05E+ 00	7.00E- 01	2.16E-01
Max.	1.37E+ 03	2.23E+ 02	1.59E+ 01	1.97E+ 01	2.90E+ 01	2.21E+ 00	2.64E+00
Coal Min.	1.07E+ 03	1.10E+ 01	nd	nd	2.60E-02	8.28E-02	nd
Mean	2.28E+ 03	7.13E+ 01	2.92E+ 00	6.64E-01	1.30E+ 00	9.14E-01	2.67E+ 00
Max.	2.91E+ 03	2.10E+ 02	1.69E+ 01	6.90E+ 00	1.00E+ 01	3.86E+ 00	2.05E+ 01
Kerosene Min.	3.12E+ 03	2.37E+ 00	nd	9.18E- 02	4.61E- 02	2.18E- 01	nd
Mean	3.13E+ 03	7.39E+ 00	2.48E-02	3.92E- 01	1.34E- 01	1.10E+ 00	2.49E- 02
Max.	3.13E+ 03	1.09E+ 01	6.24E-02	9.21E- 01	2.83E- 01	1.69E+ 00	6.31E- 02
Gases Min.	1.85E+ 03	nd	nd	Nd	nd	7.23E-02	nd
Mean	2.98E+ 03	3.72E+ 00	1.37E- 01	1.60E- 00	2.61E- 01	1.76E+ 00	4.51E+ 00
Max.	3.44E+ 03	3.13E+ 01	1.62E+ 00	8.79E+ 00	1.62E+ 00	4.51E+ 00	2.54E+ 00

Appendix B

Reference Cooking Time Table

Note: *Time counted from first exhausting gas of cooking (i.e first whistling). Stove power 1 kW.

Food name	**Food (kg)**	**Water(kg)**	**Cooking time (min)***	**Cooking situation**	**Remark**
Rice	1.5	1.2	5	Done	
Porridge	0.2	2	10	Done	Natural cool
Spareribs	1	0.6	15-18	Done meat	Natural cool
Pig leg	1	0.8	20-25	Done meat	Slice
Old chicken	1.5	1	25	Cut meat off bones	Slice
Young chicken	1	0.6	20	Cut meat off bones	Whole chicken
Pork	1	0.5	15	Done meat	Slice
Beef	1	0.6	15	Done meat	Slice
Lamb/Goat	1	0.8	15	Cut meat off bones	Slice
Fish	1	0.45	10		Cutting piece steam

Multi-Insurance Safe Type Aluminum Alloy Pressure Cooker Company Ltd., (SHUNJIN).

The counting time of cooking for this research work was compared with the cooking time table of the conventional method of cooking employed by "Multi-Insurance Safe Type Aluminum Alloy Pressure Cooker Company Ltd" -Shunjin, China, 2003.

Appendix C

Variables constants that were used where necessary σ = Stefan-Boltzmann constant (5.67×10^{-8} W/m^{2}K)
L_v = latent heat of vaporization (2.26×10^6 J/kg or 540 cal/kg) c_w = specific heat capacity of water (4200 J/kgK)
c_p = specific heat capacity of the pot (896 J/kgK); E.R.G., Ekert and R.M. Drake, 1972 P_o = atmospheric pressure (101325 Pa)
ε = emissivity of the pot (assumed to be 1)
g= acceleration due to gravity (10 m/s^2)
Variables that are directly measured
m_p = mass of the pot with cover (1.45 kg) and without cover (0.85 kg)
h= height of the pot (14 cm)
r = radius of the pot (10 cm)
d = thickness of the pot (3 mm)
r_n = nozzle's valve radius (0.19 cm)
m_h = mass of the head of pressure limit valve (71.1 g) T_p = pot's external tempt. (^{0}C)
T_a = initial tempt. of the pot (^{0}C)
T_i =pot's internal wall tempt. after on-stove time (^{0}C) t_i = total on-stove time
m_w = mass of water used
m_f = mass of rice plus water after time t_i of cooking
Δm = amount of water lost ($\approx 10^{-3}$ kg) Variables that are calculated
A_v = area of the nozzle's valve: $\pi r^2 = 1.135 \times 10^{-5}$ m^2 (i) A_p = area of the pot = $2\pi rh = 0.088$ m^2
W_h = weight of the head of pressure limit valve: mg = 0.711 N (ii)

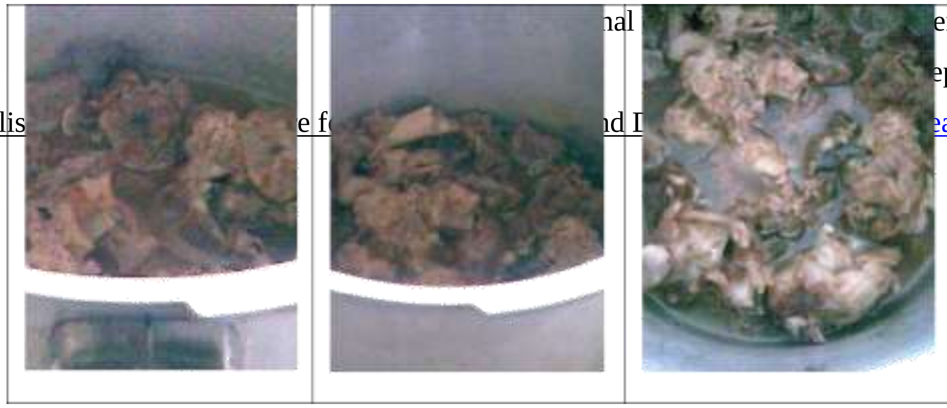

Fig.1a

Fig.1b

Fig.1c

Fig. 1a: Insulation box made of card board and aluminum foil/white paper sandwiches. Highly reflecting internal surface of new Innovative Box. Fig.1b: shows pressure cooker on stove. Fig.1c: Hot pressure cooker(after time t_i) inside the insulation box (which is closed later).

(a) (b) (c)

Fig. 2***Cooked 1 kg of Irish potatoes. The pictures are three different views.***

(a) (b) (c)

Fig.3 Cooked 1 kg of Meat with three different views

(a) (b) (c)

Fig 4. Cooked 1 kg of Beans with three different views