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Cooking with Minimum Energy and Protection of Environments and Health

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Abstract

This paper describes the environmental and health impacts of toxic emissions from the energy usage 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, 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 respectively. The energy savings with the new cooking method is unprecedented. The barest minimum (sensible) heat, h_s 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 respectively. Our new cooking method have provided minimum energy for cooking, reduction of emissions of CO_2 and other toxic gases for protection of environment and health.

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Keywords: Sensible heat of transformation; energy efficient cooking; CDM potential, heat insulation box; environment ;health protection and toxic emissions

1. 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, accounting for over 20 percent of global calorie intake with the global rice consumption being expected to be around 500 million tons annually [1] by 2050. The total global consumption of dry beans and baked beans is roughly around 3.5×10^{10} kg annually [2-4]. The total consumption of meat stands at 2.5×10^{11} kg annually [5].

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 [6]. 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 these items are 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,

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firewood, coal, etc.), eventually these energy resources will be depleted in the near future. It will then result in scarcity of energy availability [7]. Excessive usages of energy sources have dual effects on our income and environment [8-10]. At most governmental levels energy issues are addressed at producing more energy and making more energy sources available [11], rather than making energy utilization processes more efficient. 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 [12].

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 [13] and environmental pollution due to the toxic emissions. This is mainly due to inefficient methods of cooking used and consequently the demand on firewood is ever increasing. In developing countries, specially, in rural 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 [14]. Below we give a brief account of environmental pollution and health affects arising out of cooking.

1.1 Environmental pollution and health effects from cooking in third world (developing) countries

The emissions from different energy sources have been quantified [22]. 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 [15]. This makes solid fuels the second most important environmental cause of disease after contaminated waterborne diseases and the fourth most important cause of overall excess mortality in developing countries after malnutrition, unsafe sex, and waterborne diseases [16]. The environmental insults at early ages can have long lasting influences on human health and productivity [17]. 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 [18].

1.1.1 Wood stove

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 [20-21].

1.1.2 Black, Elemental Carbon (EC)

Exposure to emissions from kerosene stoves within a confined space at elevated temperature may induce narcotic effects such as narcolepsy, cataplexy and confusion [23-24]. 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 reduction of exposures to toxic emissions from cooking stoves and thus lead to increased protection of our environment and health. The aim 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. With this aim, using an energy efficient cooking method, we 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_S 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. 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 [25-26]. In this paper we published the experimental data on meat and potato quoting the earlier data [25,26] for comparison and discussion. In line with our main aim we also estimate the efficiencies of the cooking method based on the concept of the sensible heat, h_S [25], and possible Clean Development Mechanism (CDM). Potential of the new method of cooking each of the food item and when applied globally for cooking.

2. Materials and Methods

We have described the materials and methods at length in our earlier published works [25,26]. 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 Figs.1-3. For ensuring same stove power, P_S each time of cooking, same level of kerosene and the wicks are maintained in the stove.

3. Data Analysis

The main data in this work is the temperature, T_p of the Pot's outside wall and the time t which are shown in Tables 1-8. For computations of (Q_N, Q_m, h_s) 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[26] using the new innovative method (Technique 1); Room tempt.: 30 C; water added: 1.6 litres; vol. of kerosene used: 31 ml Mass of final cooked rice product = 2.55 kg.

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

Table 2 On-stove time and pot's external temperature, T_p at complete cooking of 1kg of dry rice[26] using conventional method of pressure cooker (Technique 2); Room tempt: 34 C; 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 external tempt. T_p (K) $\pm$1	305	325	343	359	360	365	369

Table 3 On-stove time and pots external temperature T_p during on-stove time of cooking 1 kg of goat's meat using Technique 1 cooking method. Vol. of kerosene used = 43 ml. Water added = 0.3 liter. m_f = 1.3 kg.

On-stove time(min)	0	2	4	6	8	10	12	14	16	18	19.25
Pot external tempt. T_p (K)	305	316	326	337	345	351	358	365	365	367	368

Table 4 On-stove time and pot external tempt. T_p at complete cooking of 1 kg of meat using Technique 2 cooking method. Room tempt.: 34 C; vol. of water used 300 ml; t_i =2451 seconds;vol. of kerosene used: 89 ml; m_f = 1.2 kg

On-stove time(min)	0	4	8	12	16	20	24	28	32	36	40	40.51
Pot external tempt. T_p (^{0}c)	305	324	343	356	364	366	368	369	370	371	372	373

Table 5 On-stove time and pot's external temperature T_P during on-stove time of cooking 1 kg of beans using Technique 1 method of cooking room tempt.: 32 C; water added: 1.2 liters; t_i = 1144 seconds; vol. of kerosene used: 42 ml; mf = 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 external tempt. T_p (K) $\pm$ 1	304	317	322	328	333	338	343	348	356	366	368

Table 6: On-stove time and pot's external tempt. T_p at complete cooking of 1 kg of beans using Technique 2 method of cooking. Room tempt.: 31 C ; vol. of water used 1.3 liters; t_i = 2943 seconds; vol. of kerosene used: 112 ml; m_f = 2.1 kg

On-stove time(min) ± 2s	0	4	8	12	16	20	24	28	32	36	40	44	48	49.03
Pot's external tempt.T_p (K) ± 1	302	321	333	342	355	368	369	370	371	372	372	372	372	372

Table 7 On-stove time and pots external temperature T_p during on-stove time of cooking 1 kg of Irish potatoes using technique 1 method of cooking.

Room tempt.: 35 C =308 K; water added: 150 ml; t_i = 466 seconds; vol. of kerosene used: 15 ml; m_f = 1.038 kg

On-stove time(min) ± 2 s	0	2	4	6	7.46
Potexternal tempt. T_p (K) ± 1	306	321	341	357	369

Table 8 On-stove time and pot's external tempt. T_p at complete cooking of 1 kg of Irish potatoes in technique 2 method of cooking. Room tempt. 33.3 C = 306 K; vol. of water used 150 ml; t_i = 1041 seconds; vol. of kerosene used: 39 ml;

On-stove time(min), t_i ± 2 s	0	2	4	6	8	10	12	14	16	17.51
Pot's external tempt. T_p (K) +1	304	320	339	353	367	369	370	371	372	372

3.1 Computations of Q_N, Q_m, h_s, and the cooking efficiencies of the new and conventional Methods of cooking.

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 heat losses Q_{rh1} and Q_{rh2} separately for these two intervals of time, using the following method.

$$Q_{rh} = \varepsilon_{AL}\sigma A \left|\frac{dt}{dT_p}\right|_{av} \int_{T_1}^{T_2} \left(T_p{}^4 - T_a{}^4\right) dT_p \tag{1}$$

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.

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:

$$Q_{rh} = \varepsilon_{AL}\sigma A \int_0^{t_i} \left(T_p(t)^4 - T_a{}^4\right) dt \tag{2}$$

To obtain Q_{rh}. As for example the equation $T_p(t)$ 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 The on-stove time t_i and the radiation losses for the new and conventional cooking technique for different food items:

Table 9a New Method of Cooking

Parameter	Rice	Beans	Potato	Goat Meat
Q_{rh}(kJ)± 0.1	6.0	7.1	2.2	7.2
t_i(Min)± 2s	15.11	19.04	7.46	19.25

Table 9b: Convection Method of Cooking

Parameter	Rice	Beans	Potato	Goat Meat
Q_{rh}(kJ)±0.1	6.0	7.1	2.2	7.2
t_i(Min)± 2s	15.11	19.04	7.46	19.25

Calculation of the sensible heat, h_s We have shown earlier [26], 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^{0}C/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 [25], how to non-invasively (even 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 [28] to be 114°C. h_s the sensible heat is calculated as:

$$h_s = \left\{Q_m - m_p c_p\left(T_p^{/} - T_a\right) - \Delta m\left(L_v + c_w\left(T_i^{/} - T_a\right)\right)\right\}. \quad (3)$$

Δm = mass of water lost by evaporation. P_{in}=inner pressure of the pot:

$$P_{in} = P_o + \frac{W_h}{A_v} \quad (4)$$

= 163992Pa T_i = Temperature of the pot's wall inside. T_i is taken as equal to T_p (see above); T_s = Mean steam temperature; $T_i^{/}$= the mean internal tempt, which is equal to average sum of T_i, and steam tempt, T_s which is estimated using the value of P_{in}.

$$T_i^{/} = \frac{(T_i + T_s)}{2} \quad \textbf{(5)}$$

T_p = Temperature of Pot's external wall (measured); $T_p^{/}$= the mean wall (Aluminum pot) tempt.:

$$T_p^{/} = \frac{\left(T_i^{/} + T_p\right)}{2} \quad (6)$$

The pressure P_{in} of eqn. (4) corresponds to the steam tempt, T_s, 114 ^{0}C (387 K) Keenan et al [28]. It is assumed $T_i = T_p$ from heat balance eqn. (11a). By measuring loss of weight Δm, h_t can then be calculated from Eqn. (3), if Q_m is known. To calculate Q_m from Equation $Q_m = Q_N - Q_{rh}$, Q_{rh} is evaluated shown above. This same method is used to compute Q_m and h_s for beans, potato and goat meat.

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

Table 10a New innovative method of using Pressure Cooker (Technique I)

Parameters Determined	Rice	Potato	Beans	Goat
Time, t_i(min)±	15.11	7.46	19.04 ± 0.1	19.25 ± 0.1

$Q_N \pm$ Kj	568 ± 3	280 ± 2	715 ± 4	723 ± 4
$Q_m \pm$ Kj	560 ± 3	278 ± 2	708 ± 4	716 ± 4
$h_s \pm$ Kj	465 ± 3	212 ± 2	609.0 ± 4	626 ± 4
$V_k \pm 1$ ml	31 ± 1 ml	15 ± 1 ml	42 ± 1	43 ± 1 ml
$E_N = \rho H_{kr} V_k$(MJ)	1.069	0.52	1.45	1.48

Table 10b Convection method of using Pressure Cooker (Technique II)

Parameters determined	Rice	Potato	Beans	Goat
Time, t_l(min) ±	22.37 ± 0.2	17.51 ± 0.2	49.03 ± 1	40.51 ± 0.7
$Q_N \pm$ kJ	840 ± 5	658 ± 4	1.84 ± 0.01	1.52 ± 0.01MJ
$Q_m \pm$ kJ	831 ± 5	641 ± 3	1.81 ± 0.01	1.48MJ ± 0.01
$h_s \pm$ Kj	**	**	**	**
$V_k \pm 1$ ml	46 ± 1 ml	39 ml	163 ± 3 ml	136 ± 3 ml
$E_N = \rho H_{kr} V_k$(MJ)	1.59	1.34	5.62	4.68

Power of the stove, P_S = 626 W ± 3. V_k = Volume of kerosene used.

The errors are given for each item and method. ** 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 the 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	78%	53%
Potato	76%	32%
Beans	85%	33%
Goat Meat	87%	41%

Normal rating power of the stove, P_S = 626 W ± 3. V_k = Volume of kerosene used.

4. Results and Discussion

The aim of this research work has been to emphasize that energy usage for cooking is always associated (directly or indirectly) with emissions that affect both environment and health and to explore energy efficient cooking method to conserve maximum energy during cooking and thus reduce emissions to a minimum in order to protect health and environment. The toxic emissions are very pronounced in developing countries where most of the people use biomass, kerosene, coal etc. for cooking. It has been reported that energy used in cooking 1 pound of beans is equivalent to $0.08 dollar of electrical energy [29]. 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 4.7 MJ of energy. Our new method of cooking beans (see Table 10) requires only 710 kJ of energy, saving nearly 85% of the reported energy usage. The sensible heat, h_s value of dry beans has been found to be 609 kJ and is comparable to that of goat meat. Our determination shows that Q_N values for goat meat and beans are quite close while the values are quite different from that of rice and potato. Potato has the lowest Q_N and h_s values. It is different from the amount of energy E_N burnt, by the stove as given in [Table 10a, 10b] because of heat transfer ratio, h_{tr} of the stove. h_{tr} depends on the kerosene content in the stove. 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 I in ref.11b] taking into account the power of stove, 626 W instead of 650 W as in ref11a. 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 with a stove of power 626 W, the on-stove-time for rice is 15 min 11 s (the time of first whistle) right from the moment the pot was put on the stove. Now according to the manufacturer of the pressure cooker the accounting time (counting from the first whistle) for rice with 1.2 Kg of water is 5 minutes as indicated in Appendix I with stove of power 1 KW. With 1.6 Kg of water the accounting time will be 6.67 minutes. Thus our method saves at least 400 kJ of energy in cooking 1 Kg of rice compared to the conventional method using pressure cooker as proposed by Multi-Insurance Safe Type Aluminum Alloy Pressure Cooker Company Ltd.,

Shunjin and China [Appendix in Ref. 25]. In cooking goat meat the accounting time is 15 minutes, thus using 900 kJ of more energy than required in our new method in cooking goat meat. Since beans also require nearly the same amount of energy as goat meat for cooking the energy saving is nearly 900 kJ per kg of beans compared to the company's proposed method of cooking. We have also determined in this work that the conventional method of cooking without pressure cooker requires at least 76 minutes and 69 minutes of on-stove time (with stove of power 626 W) corresponding to 2.85 MJ and 2.59 MJ of energy. Thus our new technique of cooking (Technique I) is superior in terms of energy and time saving to the conventional method of cooking with or without 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 C) and as soon as the whistling of the cooker starts, remove the pressure cooker pot and enclose it in an well-insulated box (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. We believe that if our method is used for cooking the popularity of pressure cooker usage will increase and save energy tremendously. This would automatically reduce emissions and thus protect health and environment globally. In our earlier work[26] we discussed the tremendous energy savings of our new method of cooking rice in comparison to the published works [30,31], on energy usage in cooking rice. 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.

We have defined h_S 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_S 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_S 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 [25] 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 ~ 116^0C. The cooking pot 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 [25]. This however would make the pressure cooker pot costly. If it is difficult to create the second metal wall of [25], then the pressure cooker with the automatic time & energy control can be kept inside a food warmer, so that the heat delivered to the food items by the heating coil, is not lost to the surroundings. This will make the cooker cost effective. Such a cooker as shown in Fig.4 of ref[25], that cooks food with input energy equal to the sensible heat h_s can be said to be the world's most energy efficient cooker. The heat retaining capacity of the simple and inexpensive, light insulation box was discussed in our earlier works [25,26]. The results of our energy efficient and pollution reducing cooking method 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 [32] rapid deforestation due to fire-wood collection can be prevented and this can help protection of our environment.

5. 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: $\eta_{cm} = 100 x h_S/Q_N$. While values of Q_N have been determined by several workers, knowledge of h_S is not available for all types of food materials except for the foods determined in this work. 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 53%(0.53) (Table 11) . 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_S. Overall energy savings now depends on the product of η_{cm} and η_{stove}. For total minimization of emission (hence environmental and health protection) due to cooking we need to have this product as close to unity as possible. Thus if our energy efficient cooking methods are applied along with energy efficient stoves, the emissions of toxic gases from cooking would become minimum globally and cooking can be done with minimum use of energy.

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