An Indoor Experimental Determination of Thermal Efficiency of a Cooking Stove

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Abstract: ***Certain mil of water were heated to complete evaporationindoor inside an opening 4 liters cooking pot using a three (3) liters kerosene stove whose wicks were adjusted to a fixed level. On complete evaporation of 50 mL, 75 mL and 100 mL, the internal and external temperature of the pot and time taken were recorded and the measured parameter were used to calculate the quantity and the rate of heat energy supplied by the stove. The quantities of heat calculated for each mil of water evaporated are: 177394 J, 237300 J and 296596 J respectively, while the thermal power supplied by the stove is 664 J/s.***

Keywords: water, complete evaporation, liter, stove, temperature, thermal power, parameter and fixed level

1. Introduction

Energy has always been an essential input to all aspects of the modern age. It is indeed the life-wire in industrial productions and modern living.

Over the centuries, man has used various sources of energy in order to meet his basic life essentials such as food, water, and shelter. Starting with using his own physical body energy and sunlight, he progressed to using fuel wood; employing animals to using water and wind power, and then developed engine power fueled by wood, coal, petroleum, and nuclear energy. Man have utilized energy in modifying and manipulating land, water, plants and animals to obtain food, clothing, shelter and pleasure.

Presently, fossil fuels provide the bulk of the world's primary energy source. Hydroelectricity provides about 2% and nuclear power, wood and other sources accounting for less than 1% of the primary industrial energy used in the world, (CIA World Fact Book USA, 2004). Since fossil fuels are non-renewable natural resources, their reserve especially oil and natural gas, may soon be completely depleted because the rate of formation is not relatively the same with the rate of consumption, (WEC, 2003). It implies that, there is the need to develop the means of economizing the available energy resources as an alternative to the fast depleting fossil fuel and the accompany constantly rising energy cost which lowers the standard of living of the common man. Over use of energy sources has dual effect on income and the environment as a whole. To this effect, the efficiency of the stove plays a significant roles in conserving energy resources as well as minimizing environmental pollution. Stoves with low thermal efficiency will result in delay of cooking and release of high soot into the atmosphere and this will leads to environmental pollution and global warming.

2. Theory of Burning

The energy used in heating water in a container (pot) of known thermal capacity per unit of fuel consumed (or the energy utilized) E_u for a given type of fuel can be deduced using a simple thermodynamic relation adopted by Groves *etal*. (1989), which is given as

$$E_u = \{(100 - t)M_1\,\alpha + M_2 L_v\}(\text{J/kg}) \quad (1)$$

where: t =initial temperature of water (°C)
α =specific heat capacity of water (4200 J/kg K)
L_v = latent heat of vaporization of water (2,257,000 J/kg) or (539 cal/s)
M_1 = initial mass of water (kg)
M_2 = mass of water lost (kg)

The efficiency, η, for such a thermodynamic system is the ratio of the useful energy to energy supplied to it, (Porteous, 1980; Foley and Moss, 1985; Groves and Chivuya 1989).

$$\eta = \frac{measure\ \ of\ energy\ \ output\ ,E_u}{measure\ \ of\ energy\ \ input\ ,E_i} \quad (2)$$

Therefore thermal efficiency, η_T

$$\eta_T\,(\%) = \left(\frac{E_u}{E_i}\right) \times 100\% \quad (3)$$

where:
E_u = energy used in heating the water to boiling point, (100 °C) at 760 mmHg.
E_i = amount of heat energy released by certain amount of fuel when combustion is complete.

Similarly, the performance of the stove, can also be analyzed. Two methods were employed to measure the stoves performance using known procedures employed in the provisional standard for comparison of the stoves performance.

The methods are:

(a) Water Boiling Test (WBT)
This method is useful in determining the magnitude of heat utilized by a stove, and can be expressed, as percentage heat of utilization (PHU). It is, also used to compare the performance of different stoves or the same stove under different operating conditions.

$$PHU = \frac{[(Total\ \ heat\ utilized\ )\times 100]}{Net\ heat\ supplied} = \frac{[\alpha(M_3 - M_1)(100 - t) + M_2 L_v][100]}{MC_v} \quad (4)$$

where:

M_3	=	mass of water plus the pot
M_1	=	mass of aluminum pot
C_v	=	Calorific value of fuel

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M, M_2, L, α and t hold to their previous meanings, (Akinbode, 1991; Danshu *et al.*, 1992). According to Meethan *et al.*, (1981), the C_v for firewood is 16.0 M J/kg. Though this value is not constant/standard for all wood, because the C_v of wood depends on the softness or hardness and the moisture content (MC) of the wood.

(b) Control Cooking Test

The objective of this method is to compare the energy consumed and the time spent in cooking a given mass of food on different stoves. It can effectively determine whether the stove can cook the varieties of food normally prepared in a particular locality. Equally, it is accepted as a provisional standard in comparing different stoves performances. In this case, the specific consumption, which expresses the amount of fuel required to boil off certain amount of water is given by

$$S_c = \frac{M_{fc}}{M_{wc}} \quad (5)$$

where

M_{fc} = mass of fuel consumed

M_{wc} = mass of water consumed

In view of these and in order to minimize crises (source of energy scarcity) as experienced in ancient Greece and Rome, (Botkin and Keller, 1998), there is need for energy saving of the world, nations, states and local Government area. In this research, the rate of heat (energy) given out by the stove for the period of on-stove time was determined using equations 6 – 11 stated below.

3. Methodology

The Boiling Procedure

Evaporation of: 50 ml, 75 ml and 100 ml of water

A new set of wicks was inserted into a ten wicks of three (3) liters kerosene stove. The wicks of the stove were adjusted to a fixed uniform level that will produce a blue flame. Error in setting of wicks and kerosene levels were assumed not too large enough to invalidate the rate of heat supplied by the burning flame. The base of the stove was filled with a kerosene to a fixed point (reference mark).

A measured 50 ml of water was poured into a dried pressure cooker of capacity four (4) liters and its room temperature was recorded as 35^0C.

The lighted stove was allowed to burn for 3 minutes to enable stability of the flame. The uncovered pressure cooker contained 50 ml of water was gently mounted on top of the blue flame and the on-stove time and the inner temperature (T_i) of the pot in which evaporation is taking place were measured and recorded at an interval of one minute until complete evaporation. The reading (T_p) of the external thermometer firmly fixed to the rim of the pot was taken at the end of complete evaporation of water. On the completion of the boiling, the pot was quickly removed from the stove simultaneously with stopping of watch and the fire was immediately quenched off.

The stove, was allowed to cool down after which a 100 ml measuring cylinder was filled to a level marked V_1 with kerosene, then gently poured into the base of the stove to be refilled back to its reference mark. The level of kerosene remained after refilling the stove was noted as V_2. The quantity of kerosene used up in boiling off 50 ml of water was deduced as ($V_1 - V_2$) ml.

The same experiment was repeated with 75 ml and 100 ml of water, with the wicks and kerosene levels kept constant at the beginning of each experiment. The results of the readings, were tabulated as shown below in tables' 1-3. Error in timing was on the average of ±5 seconds

(a) T_p (b) T_i

Plate 1: Measurement of T_p and T_i of the boiling water

4. Calculation/Data Analysis

Calculation of Rate of heat supply by the stove

The rate of heat supplied by the stove was calculated using the equations below

$$Q_r = \left(\frac{Q_{50}}{t_{50}} + \frac{Q_{75}}{t_{75}} + \frac{Q_{100}}{t_{100}}\right)/3 \quad (6)$$

$$Q_{50} = m_{50}(100 - T_{50})c_w + m_{50}L_v + \delta A_p \in (T_p^4 - T_a^4)t_{50} + M_p C_p (T_p' - T_a) \quad (7)$$

$$Q_{75} = m_{75}(100 - T_{75})c_w + m_{75}L_v + \delta A_p \in (T_p^4 - T_a^4)t_{75} + M_p C_p (T_p' - T_a) \quad (8)$$

$$Q_{100} = m_{100}(100 - T_{100})c_w + m_{100}L_v + \delta A_p \in (T_p^4 - T_a^4)t_{100} + M_p C_p (T_p' - T_a) \quad (9)$$

$$T_p' = (T_i' + T_p)/2 \quad (10)$$

$$P_i' = (T_i + T_s)/2 \quad (11)$$

(Dilip, Kumar De *et al*, 2014)

During each experiment, the wick and kerosene level were maintained constant.

Where:

Q_{50} = quantity of heat required to evaporate 50 ml of water.

Q_{75} = quantity of heat required to evaporate 75 ml of water.

Q_{100} = quantity of heat required to evaporate 100 ml of water

M_p = mass of the pot

δ = Stefan Boltzmann constant

ε = Emissivity of the pot surface area. In absence of proper knowledge of ε, ε = 1. This will give us slight upper value of Q_r.

C_p = specific heat capacity of the pot materials.

L_v = Latent heat of vaporization of water.

A_p = Surface area of the pot from which radiation takes place.

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T_p = temperature of the outside surface of the pot.
T_a = room temperature
T_i = inner temperature of the pot
T_s = steam temperature
1/3 = mean factor

5. Discussions

Introduction

This section of the study aimed to show the procedure and analysis of the data/results obtained from the series of experiments conducted on boiling using a kerosene stove and a cooking pot. The ON-STOVE timing and the corresponding internal and external temperature of the pot were taken at the end of each experiment. The results of the findings, were presented in tables showing ON-STOVE TIME and TEMPERATURE.

Determination of the Rate of Heat Supply from the Stove (Thermal Power of the Stove)

Table 1: On-stove time and pot's internal temperature on complete evaporation of 50 ml of water with lid opened Room Temperature: 35^0 C; t_{50} = 278 seconds; Volume of kerosene used: 9 ml

On-stove Time (min)	Pot's Internal Temperature T_i (^{0} C)
0	33
1	56
2	92
3	96
4	98
4.38	97

Table 2: On-stove time and pot's internal temperature on complete evaporation of 75 ml of water with lid opened Room Temperature: 35^o C; t_{75} = 354 seconds; Volume of kerosene used: 12 ml

On-stove Time (min)	Pot's Internal Temperature T_i (^{0}C)
0	33
1	54
2	89
3	95
4	98
5	97
5.54.	96

Table 3: On-stove time and pot's internal temperature on complete evaporation of 100 ml of water with lid opened Room Temperature 35 ^{o}C; t_{100} = 435 seconds; Volume of kerosene used: 15 ml

On-stove Time (min)	Pot's Internal Temperature T_i (^{0}C)
0	32
1	62
2	82
3	94
4	96
5	96
6	98
7	97
7.16	96

Quantity of Heat (Energy) Required, to Boil Off 50, 75, and 100 ml of Water.

$$Q_{50} = m_{50}(100 - T_{50})c_w + m_{50}L_v + \delta A_p \in \left(T_p^4 - T_a^4\right)t_{50} + M_p C_p\left(T_p' - T_a\right)$$

$$T_i' = (T_i + T_s)/2$$

$$T_p' = \left(T_i' + T_p\right)/2$$

T_s is the steam temperature which was obtained from the pressure chart of Engineering Thermodynamics by Wiley, 1989. The values of the following K_p, C_p σ, A_p, and L_v were obtained from E. R. G. Eckert and R. M. Drake, Analysis of Heat and Mass Transfer, 3d Ed, M_cGraw-Hill Book Company, New York, 1972 and appendix 1.

$$\begin{aligned} Q_{50} &= 0.05(100 - 97)\ x\ 4200 + 0.05\ x\ 2.26\ x\ 10^6 \\ &\quad + 5.67\ x\ 10^{-8}\ x\ 0.0879(370^4 \\ &\quad - 308^4)278\ + 0.85\ x\ 896(101.08 - 35) \\ &= 177394\ J \end{aligned}$$

$$\begin{aligned} Q_{75} &= 0.075(100 - 96)\ x\ 4200 + 0.075\ x\ 2.26\ x\ 10^6 \\ &\quad + 5.67\ x\ 10^{-8}\ x\ 0.0879(369^4 \\ &\quad - 308^4)353 + 0.85\ x\ 896(100.33 - 35) \\ &= 237300\ J \end{aligned}$$

$$\begin{aligned} Q_{100} &= 0.1(100 - 96)\ x\ 4200 + 0.1\ x\ 2.26\ x\ 10^6 \\ &\quad + 5.67\ x\ 10^{-8}\ x\ 0.0879(369^4 \\ &\quad - 308^4)435 + 0.85\ x\ 896(98.33 - 35) \\ &= 296596\ J \end{aligned}$$

The Rate of Heat Q_r (Energy) Supplied by Stove is

$$Q_r = \left(\frac{Q_{50}}{t_{50}} + \frac{Q_{75}}{t_{75}} + \frac{Q_{100}}{t_{100}}\right)/3,$$

$$Q_r = \left(\frac{17744.056}{278} + \frac{237300.445}{353} + \frac{296596.325}{435}\right)/3 = 664.1\ J/s$$

This is the power of the kerosene stove. The low power is because of the adjusted low flame of the stove. From the experiment, it, was observed that the internal temperature of the pot was almost the same with the external temperature due to good thermal conductivity of the pot.

Table 4: Summary to Tables 1 - 3
Q_i= Q_{50}, Q_{75} and Q_{100}.

Volume of water evaporated (ml)	Initial temperature of water T_a (^{o}C)	Time t_v to complete evaporation (seconds)	Pot's internal tempt. T_i (^{o}C)	Pot's external tempt. T_p (^{o}C)	Volume of kerosene used (ml)	Quantity of heat, Q_i for complete evaporation using eqns 7-9 (J)
50	35	278	97	96.5	9	177394
75	35	353	96	96	12	237300
100	35	435	96	96	15	296596

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6. Summary, Conclusion and Recommendation

6.1 Summary

The primary objective of this work is to focus on thermal efficiency of cooking stove and on-stove time saving in our domestic cooking. Efficient of cooking stove save energy and time and these factors affect the dynamics of human life. Man depends on energy for his successful conduct of life. Scarcity of such means only gives rise to problems which may result in termination of his activities. Many nations of the world experience energy crisis. Non-renewable energy resources are gradually depleting from their reservoirs. This is because of over utilization of energy which has become a problem coupling with increase in population of the world. Energy is needed in all areas of life. Stove with high efficiency help in minimizing energy usage, for a given work output, and this isone of the main goals and objective of current scientific research.

6.2 Conclusion

From the result of this experimental research, it can be concluded that thermal efficiency of cooking stove in evaluating the performance of stove will now warrant the patronage of the products by the customers. As such the economy of the producer and national economy can be boosted. The thermal power of the stove used was calculated to be 664 watt and this value is closed to world standard solar radiation of 700 W/m^2. All experiments were conducted indoor so as to avoid wind interference with the reading of thermometer.

6.3 Recommendations

Appendix 1
Pots' Data and Constants Used in Calculations
Mass of the Pot without cover: 0.85 kg
Height of the Pot: 14 cm
Diametre of the Pot: 19.8 cm
Radius of the Pot: 10 cm
Area of the Pot: 2¶rh = A_p = 0.0879 m^2
Thickness of the Pot, d =0.245 cm
L_v = 2.26×10^6 J/kg or 540 cal/g
δ = 5.67×10^{-8} W/m^2 K^4
ε = 1 (assumed)
C_w = 4200 J/kg K
C_p = 896 J/kg K
K_p=200 – 240 W/m K At temperature 77 ^{0}C to 127 ^{0}C, (E. R. G. Eckert and R. M. Drake, 1972).

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