Experimental Investigation of Eco-Friendly and Energy Efficient Auto and Allo Thermal Charcoal Kiln

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Abstract: Like many countries in India, Charcoal production is the primary employment for rural masses in most of South Tamilnadu. It is a foremost source of income and environmental degradation in rural regions. The yield and transport of charcoal are a precarious process with energy and economic cycle. This process emits greenhouse gases to the atmosphere. It frequently made in traditional charcoal method that are harmful to the environment. It requires efficient manpower for completing the process. The quality and yield for the conventional method is very low because of prolonged time. This method is mostly practised in rural areas. People over there will be more concern about quantity not the quality. So this reduces the yield of the charcoal. In this eco-friendly concept time consumption is reduced and hence yield will be more than the conventional method. In this paper, the indirect heating kiln has been tested with prosopis juliflora wood and the results were the lowest ash content of less than 2% and fixed carbon content of greater than 75%. The temperature was in range of 400-600º C inside the kiln which helps to understand the process of pyrolysis reactions.

Keywords: Charcoal, Emissions, Proximate analysis, Ultimate analysis, Thermogravimetric analysis, Biomass

Nomenclature:
T_f – Average flue gas temperature (°C)
T_a – Ambient temperature (°C)
M – kg of moisture in 100kg of fuel
H_2 – kg of hydrogen present in fuel on 100 kg basis
C_p – Specific heat in kCal/kgC
V.M – kg of volatile matter present in fuel on 100 kg basis
V_m – Wind velocity in m/s
T_s – Surface temperature (K)
T_a – Ambient temperature (K)

1. Introduction
Due to increasing concerns about global warming, the development of accessible, clean and sustainable resources has arrived much attention. Effectiveness of forest management can be enhanced via energy utilization from biomass when obtaining bioelectricity and biofuels throughout direct combustion, thermochemical or bio-chemical processes, respectively. One of the appropriate biofuels is charcoal. Wood feedstocks which possess energy value of around 3EJ are transformed to
charcoal which holds an energy value of 0.7-1 EJ (even in the cases of minimal efficiency). Its energy density is such that it can be transported long distances and, with many reduced emissions in cookstoves, it is a fuel that is better suited to urban use in developing countries than fuel-wood [10]. One of the oldest technology existing from the medieval times is the production of charcoal by using earth-mound kiln and its production involves the burning of raw material without the presence of air (oxygen). Using this ancient technology, charcoal production was probably with a pit kiln, positioned in the forest, close to the point of wood collection. This involves stacking the wood to be used inside a shallow level pit and its tightly sealed by surrounding the pit by straw, vegetation and earth. This wood was lit and the burning allowed to progress from one end of the pit to the other end, a process taking around 10-15 days [1]. Unpredictable fires and heat loss through radiation occurs during the above-mentioned time period required for charcoal production using an earth-mound kiln. As a consequence, the efficiency rating is lowered. An experimental method is illustrated in this paper for producing charcoal of high quality from long stick woody biomass. Within 3 to 5 hours of time taken for reaction, with respect to the moisture content of the woody biomass, the outcome is a yield of 38% experimentally.

For this study, to address the above-mentioned points, we have designed and constructed a kiln to determine the production and yield of charcoal and to obtain the temperature profiles inside the kiln [10]. During the carbonisation process, smoke is partly burned off, resulting in reduced air pollution of 75% [7]. The CO released due to burning of wood will be reused by circulating them back inside the walls of the kiln and it will be made to burn by supplying a fire inlet (Fire + Oxygen). By this method of re-circulating, the CO the amount of wood to be burned at the inlet can be reduced. Quality of charcoal depends on the factors such as the size of the material, type of kiln, and the carbonization process [6]. The amount of charcoal is only 8%-25% at a temperature of 500℃. The usual cycle will be like 7 days of heating and 5-7 days of cooling, ash content will be 4%-6% and the other tarry residues will constitute 30% of weight [5]. This method of charcoal production using kiln is expected to give an overall yield of 35%-40% and decreased ash content.

2. Allo Thermal Retort
The Allo Thermal Retort was designed and fabricated which as shown. The Allo Thermal Retort is positioned in the horizontal and hot gases is used for the carbonisation process. The four experiments were conducted and results are shown below. All heat required for pyrolysis is transferred through the walls of the reactor. The transfer of heat is relatively slow inside the biomass bed but large reactors cannot depend only on this heating method. For large reactors, heating through the external walls should be accompanied by the use of internal direct heating.

![Fig. 1. Heating Through Reactor Wall](image)

3. Modelling of Kiln
- In this the hot gas which is obtained by burning wastes in the fire chamber is allowed to pass inside the furnace through the inlet valve V1.
- Then the hot gas flows through the wood logs and goes out through the outlet chimney through valve V2.
- During this first phase of the process the valve V3 will be closed.
- In the second process the valve V1 and V2 are closed, now due to high pressure and temperature inside the furnace all the CO gas will be passed through the hollow space of the kiln.
The CO gas will be re-circulated through the hollow space and a fire inlet will be given from the bottom side.

So the outer surface of the furnace will be heated through burning of CO gas around it.

4. Energy Balance

Quality of charcoal depends largely on its end-use. There are various opinions on how much-fixed carbon content charcoal must possess and the minimum amount of volatile matter that should be present. These opinions have to be taken into account before being regarded as good quality charcoal. Good commercial charcoal must have a volatile matter content(moisture-free)of less than 30%, the higher the volatile content, the lower will be the calorific value of charcoal and the optimum value of the volatile content depends on the end use. For example, charcoal for domestic use can have a minimum volatile matter of 20%-30% while charcoal for metallurgy must have a fixed volatile content of 85%-90%. Ash content of good quality charcoal must lie in between 0.5%-5% and it should have a heat value of about 28-33MJ/kg.

4.1 Heat loss due to evaporation of moisture present in fuel

\[ Q_m = M \times \{ 584 + C_p \times (T_f - T_a) \} \]

\[ = 11.6 \times \{ 584 + 1 \times (100-30) \} \]

\[ = 7645 \text{ kcal} / 100\text{kg of wood} \]

Latent heat corresponding to the partial pressure of water vapour is 584
4.2 Heat loss due to formation of water from $H_2$ in fuel
\[ Q_H = 9 \times H_2 \times \{ 584 + C_p \times (T_f - T_a) \} \]
\[ = 9 \times 0.0529 \times \{ 584 + 1 \times (100-30) \} \]
\[ = 314 \text{ kcal} / 100 \text{ kg of wood} \]

4.3 Heat loss due to volatile matter in fuel
\[ Q_{VM} = V.M \times C_p \times (T_f - T_a) \]
\[ = 55.4 \times 0.45 \times (350 - 30) \]
\[ = 7977.6 \text{ kcal} / 100 \text{ kg of wood} \]

4.4 Heat loss due to radiation and convection
\[ Q_{RC} = 0.548 \times \left[ (T_s / 55.55)^4 - (T_a / 55.55)^4 \right] + 1.957 \times (T_s - T_a)^{1.25} \times \text{sqrt} \left[ (196.85 Vm + 68.9) / 68.9 \right] \]
\[ = 0.548 \times \left[ (50 / 55.55)^4 - (30 / 55.55)^4 \right] + 1.957 \times (50 - 30)^{1.25} \times \text{sqrt} \left[ (196.85 \times 5 + 68.9) / 68.9 \right] \]
\[ = 399.9 \text{ kcal} / \text{m}^2 \]
\[ = 1199.7 \text{ kcal} / 100 \text{ kg of wood} \]

4.5 Heat required to heat wood
\[ Q_R = M_s \times C_p \times (T_f - T_a) \]
\[ = 33 \times 0.45 \times (400 - 30) \]
\[ = 5494.5 \text{ kcal} / 100 \text{ kg of wood} \]

4.6 Heat loss in flue gas
\[ Q_f = M_s \times C_p \times (T_f - T_a) \]
\[ = 3542 \text{ kcal} / 100 \text{ kg of wood} \]

4.7 Total heat loss
Total Heat Loss
\[ Q_T = Q_m + Q_h + Q_{VM} + Q_{RC} + Q_f \]
\[ = 26173 \text{ kcal} / 100 \text{ kg of wood} \]
\[ CV = 3000 \text{ kcal} / \text{kg of wood} \]
Efficiency of HAG = 60%
Wood required = 26173 / (3000 X 0.6)
\[ = 14.55 \text{ kg} / 100 \text{ kg of wood} \]

4.8 Auto thermal method (Direct heating)
Moisture = 11.6 kg
Volatile matter = 55.4 kg
Wood required for heating = 14.55 kg
Yield of Charcoal = 100 - 11.6 - 55.4 - 14.55 = 18.5 %
4.9 Allo thermal process (Indirect heating)

- Moisture = 11.6 kg
- Volatile matter = 55.4 kg
- Wood required for heating = Nil (Burning waste only)
- Yield of Charcoal = 100 - 11.6 - 55.4 = 33%

5. Results and Discussion

5.1 Charcoal Yield

As we observed in the trial 1, the temperature of the kiln was exceeds above 500 °C and the maximum volatile were released which results as low yield charcoal and the un-burnt quantity also minimum. In the trail 2, the maximum wood was loaded which results much un-burnt and lower yield.

Even the temperature of the trial 2 was attain 520 °C but in the trial 2 & 3 was well controlled inside kiln temperature by the heating rate.
The temperature of the kiln monitored every 15mins as well as both wood chamber and chimney flue gas temperature. Even though trial 2 & 3 was used high moisture content, its only given high yield when compared to other trials.

5.2 Temperature distribution in the wood chamber

The peak temperature is reached during the carbonization process. This temperature largely has an impact on the quality (i.e., the volatile matter content) and other properties of the charcoal product.
Loosely bound water is evaporated from the wood within the temperature range of 100 to 180° Celsius, Pyrolysis oil releases gases in the temperature range 180-270°C containing CO, CO2 and condensable vapours. An Exothermic reaction starts above 270° and 288° C and it can be detected by the increasing temperature of CO and CO2 gases along with a spontaneous generation of heat. The mass of condensable vapours will intensify. Cellulose loses weight below 220° C via formation of water. But at a slightly elevated temperature than that of the former (i.e) at 250°C, CO2 and CO are also produced.

5.3 Temperature distribution in the chimney flue gas
The carbonization process upon entering the exothermic phase requires no more external heating and this condition is sufficient to reach a temperature of 500° C. By the above continuous process, the gas-vapour mixture which is consistent, is let out. The charring unit is kept in the high temperature mentioned in the former for a fairly short time and the ceaseless operation rely on the residence time of the charring unit. A Time Vs Temperature graph is drawn for the wood charring process. The maximum pyrolysis temperature in the bottom, middle and top zone are found to be 450 °C,420 °C,430 °C respectively. Thus the pyrolysis temperature is not uniform in all zones due to unsteady state of burning of wood in these zones in the kiln. This method resulted in the highest yield of charcoal(30%) when compared to the methods used in other trials

5.4 Influence of carbonization temperature on yield and composition of charcoal

| Trials | Temperature °C | % of Fixed Carbon | % Volatile | Yield (%) |
|--------|----------------|-------------------|------------|-----------|
| 2      | 520            | 72                | 26         | 23        |
| 1      | 500            | 70                | 27         | 24.7      |
| 4      | 450            | 66                | 29.5       | 26.8      |
| 3      | 400            | 64                | 32         | 29.5      |

![Fig. 9. Temperature Distribution in the Chimney flue gas](image)
Higher yield of charcoal is observed in low carbonization temperatures, but low-grade charcoal is obtained. Acidic tars are present in low-grade charcoal and its corrosive which leads to burning with smoke production. A relatively high temperature of 500°C is the carbonizing temperature of good commercial charcoal which possess a standard carbon content of about 75%.

5.5 Proximate analysis of charcoal sample

| Table 2. Proximate Analysis of Charcoal Samples in ATR |
|------------------------------------------------------|
| **Composition** | **Trial 1** | **Trial 2** | **Trial 3** | **Trial 4** |
| Moisture (%)    | 0.99       | 0.5        | 1.5         | 1.5         |
| Volatile Matter (%) | 27       | 26        | 32          | 29.5        |
| Ash (%)         | 2.01           | 1.5        | 2.5         | 3           |
| Fixed Carbon (%) | 70         | 72        | 64          | 66          |
| CV Kcal/kg      | 8160       | 8354      | 7856        | 7873        |

5.6 Ultimate analysis of charcoal sample

| Table 3. Ultimate Analysis of Charcoal Samples in ATR |
|-----------------------------------------------------|
| **Composition** | **Trial 1** | **Trial 2** | **Trial 3** | **Trial 4** |
| C (%)           | 86.1        | 87.6       | 83.4        | 83.6        |
| H (%)           | 4.8         | 4.8        | 5.0         | 4.9         |
| N2 (%)          | 1.6         | 1.6        | 1.5         | 1.5         |
| Mineral Matter (%) | 2.21    | 1.65       | 2.75        | 3.3         |
| Moisture (%)    | 0.99        | 0.5        | 1.5         | 1.5         |
| Oxygen (%)      | 4.3         | 3.8        | 5.8         | 5.2         |

6. Comparison of charcoal sample analysis with conventional kilns

6.1. Comparision proximate analysis of charcoal samples

| Table 4. Comparison Proximate Analysis of Charcoal |
|--------------------------------------------------|
| **Composition** | **Conventional** | **Igloo** | **Allothermal Retort** |
| Moisture (%)    | 5.07            | 2.8       | 0.5                   |
| Volatile Matter (%) | 30.56       | 22.8      | 26                    |
| Ash (%)         | 4.9            | 3.2       | 1.5                   |
| Fixed Carbon (%) | 59.47          | 71.2      | 72                    |
| CV(Kcal/kg)     | 6810            | 7725      | 8354                  |

6.2. Comparision ultimate analysis of charcoal samples

| Table 5. Comparison of Ultimate Analysis of Charcoal Samples |
|------------------------------------------------------------|
| **Composition** | **Conventional** | **Igloo** | **Allothermal Retort** |
| C (%)           | 75.9            | 83.2      | 87.6                   |
| H (%)           | 4.6             | 4.5       | 4.8                    |
| N2 (%)          | 1.5             | 1.6       | 1.6                    |
| Mineral Matter (%) | 5.39          | 3.52      | 1.65                   |
| Moisture (%)    | 5.07            | 2.80      | 0.5                    |
| Oxygen (%)      | 7.46            | 4.37      | 3.8                    |
7. Advantages of allo thermal retort

![Advantages of Allo Thermal Retort](image)

**Fig. 10. Advantages of Allo Thermal Retort**

**CONCLUSION**

The traditional earth mound kiln is used to make charcoal and this technique persists in Southern Province of Tamilnadu mainly because it is flexible to use and cheap. However, this traditional method results in a meagre yield (typically 15-20%). Inconsistency in the quality of charcoal is observed because it is unfeasible to maintain uniform carbonization. Environment pollution is also on the rise due to the emission of tar and poisonous gases.

- The processing time is quick. Duration of the cycle is about 5 hours along with an additional duration of 5-6 hours for cooling. The overall time consumption is less when compared to the other kilns.
- Allo thermal Retort imparts flexible design due to the absence of mechanical or electrical components. Therefore, customised kilns can be locally manufactured in mass production which is not possible with the other kilns.
- Allo Thermal Retort requires minimal supervisions of its working conditions since flame avoids contact with the chamber and it avoids the burning of wood (Heat rate 14000 - 15000 kcal/hours)
- Allo Thermal Retort has a high charcoal yield efficiency (30-35%) depending upon the moisture of wood whereas the efficiency of other kilns is (20-25%)

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