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Comparative Study of Gaseous and Particulate Emissions from Traditional and Modified Charcoal Production Kilns

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Abstract
Charcoal, a carbonaceous solid fuel, is prepared by two technologies; traditional pit system and bio-energy kiln, which use forest invasive biomass,otherwise treated as waste, as a feedstock especially in community forest of Nepal. This study aims to compare the emission impact of these two charcoal producing technologies in terms of emission factors of CO_2, CO, $PM_{2.5}$ and Black Carbon (BC). Emission factors for these types of technologies are helpful in assessing their impact on immediate environment and air pollution. An emission measurement system was designed that continuously monitor the emission concentration of CO_2, CO, $PM_{2.5}$ and BC from two charcoal technologies throughout the combustion of invasive species feedstock. The emission measurements were performed at Nawajagriti Community Forest, Chitwan. E-sampler, Microaethlometer, IAQ Probe, Licor Gas Analyzer were used to measure $PM_{2.5}$, BC , CO and CO_2 respectively. One complete batch of biomass was burned and the emission was measured continuously for the batch. The emission factor was calculated by Carbon Balance Method. The average emission factors for BC, $PM_{2.5}$, CO_2 and CO of Bio-energy Kiln were found to be $0.85 \pm 0.78 gm/kg$, $10.78 \pm 16.56 gm/kg$, $184.01 \pm 60.0 gm/kg$ and $42.5 \pm 37.92 gm/kg$ of fuel burnt respectively. Similarly, the average emission factor of for BC, $PM_{2.5}$, CO_2 and CO of Traditional Pit System were found to be $1.39 \pm 1.08 gm/kg$, $31.73 \pm 29.06 gm/kg$, $275.4 \pm 97.45 gm/kg$ and $51.31 \pm 39.28 gm/kg$ of fuel burned respectively. It is observed that average emission factor of Traditional Pit System was found 63.5%, 194.3%, 49.6% and 20.7% higher than that of Bio-energy Kiln for BC, $PM_{2.5}$, CO_2 and CO respectively.

Keywords
Bioenergy Kiln, Tradition Pit System, Carbon Balance Method, Emission Factor, Charcoal

1. Introduction

Major part of primary energy consumption is supplied by biomass sources in Nepal[1]. Forest occupies 40.36% while shrubs cover 4.38% of the Nepal's total land mass. Total bio-mass remains at 1159.7 million tons, average stem volume stands at $165m^3$ and average number of trees stands at 408 per hectare [2]. Forest fires and invasive species are having threatening impact to different species of forest in Nepal [3]. Removal of invasive species, weeds, shrubs and twigs form the forest helps to conserve forest diversity and reduce fire hazards on one hand [4]. On the other hand, such unwanted biomass can be taken business opportunity through the promotion of charcoal based enterprises. Production of charcoal from invasive species, weeds, shrubs and twigs can provide a good alternative energy mix for the crisis prone energy scenario of country.

Currently, Traditional Pit System(TPS) and modified Bio-energy Kiln(BEK) system are used to produce charcoal from community forest biomass resources [5]. TPS works on long carbonization time that takes about 5-14 days [6]. In the case of shrubs and weeds the process can be completed in 24 hours. The capacity of TPS can range from $2.5-6m^3$ [7]. The system is inefficient regarding environmental concerns as it emits excessive amount of pollutants(Tars, GHG, obnoxious gases), the technology is not much desirable even though large quantities of the charcoal can be produced per batch, the contribution of pollutants from the system into the atmosphere is also very high. BEK is the charring technology developed by Bio-energy Project. These technologies are claimed to be efficient in emission reduction and producing quality charcoal production [5].

Several researchers had discussed the efficiency, mechanisms, quality and financial analysis of contemporary charcoal technologies but very few papers have actually measured the gaseous and particulate emission of these technologies. The emission factors most likely depend on physical properties of the fuel such as fixed carbon, moisture content, fuel size and packing content [8]. The emission factor for CO and CO_2 was measured for different cookstoves using wood as a feedstock and was found 19–136gm/kg and 1560–1620gm/kg respectively [9]. In another research, using time series of trace gas concentrations from different fire cases, trace gas emission factors (EFs) for wheat, rice and rapeseed residue burns was measured to be $1739 \pm 19 gm/kg$,$1761 \pm 30 gm/kg$ and $1704 \pm 27 gm/kg$ respectively for CO2 and $60 \pm 12 gm/kg$, $47 \pm 19 gm/kg$ and $82 \pm 17 gm/kg$ respectively for CO [10]. The emission factor, calculated using carbon balance method, for CO_2 of retort kiln was measured to be $195 \pm 209 gm/kg$ and of non-retort kiln was found to be $2380 \pm 973 gm/kg$ of charcoal. For CO, emission factor of Retort kiln was found to be $157 \pm 64 gm/kg$ and of the non retort kiln was found to be $480 \pm 141 gm/kg$ of charcoal [11]. In another research for emission of flame curtain kiln, mean emission factors for the flame curtain kilns were also measured $4300 \pm 1700 gm/kg$ for CO_2 and $54 \pm 35 gm/kg$ of bio-char [12].

Excessive invasive species coverage in the forest sanctuary which has to be cleared as per the forestry regulations can be used to charcoal making. The practice of converting such resources for producing charcoal is being done in traditional pit system which is very time consuming, emissive and causes discomfort to the associated workers while burning and retrieving charcoal[13]. Thus a Bio-energy Kiln system, envisaging better working comfort and reducing emission was developed by Bio-energy Project Nepal [5]. With an objective of comparing the emission pattern of two charcoal kiln technologies in terms of emission factor, this research will contribute to a number of air-pollutant emission inventories from a unique source-charcoal production.

2. Methods and Material

For the emission analysis the charcoal was produced in two technologies and real time emission data was monitored throughout the charcoal feedstock burning period. The test was conducted at Nawajagriti Community Forest, Chitwan, Nepal. The feedstock used for charcoal production was invasive alien species generated from the forest cleaning practices which mainly contain *mikania micrantha*,*eupatorium adenophorum* and *lantena camera*. Continuous monitoring method was adopted to measure emission concentration of BC, $PM_{2.5}$, CO_2 and CO [14]. The Met One Instruments, Inc. model E-Sampler 9800 was used to measure $PM_{2.5}$, meanwhile Microaethlometer of model microAeth AE51 was used to measure BC found in the smoke exhausted to ambient air. For CO measurement IAQ Probe was used while for CO_2 measurement Licor Gas Analyzer LI-820 was used.

Figure 1 shows the experimental setup that was used to measure the emission concentration. The emission sample was captured via $PM_{2.5}$ cyclone and then the sample was passed towards microaeth and sampler for BC and $PM_{2.5}$ measurement respectively. The smoke sample was then passed towards Licor LI-820 for CO_2 concentration measurement and then finally ending up to IAQ Probe measuring CO. The concentration reading of background was taken for 20 minutes for background correction and then background corrected data was used to calculate the emission factors of the two technologies.The concentration of pollutant was measured real time using suitable time frame and one minute average basis was used to plot and calculate concentration and emission factors. For calculation and analysis of emission factor via generating different plots, MATLAB R2013 was used.

The mass balance of carbon in feedstock combustion process was used to calculate the emission factor which states as follows;

$$C_{total} = C_{CO_2} + C_{CO} + C_{PM_{2.5}} + C_{C_xH_y} + C_{BC} \quad (1)$$

where, C_{total} is total carbon content in the emission and on the right side is the sum of carbon content of all combustion gases containing carbon and can be

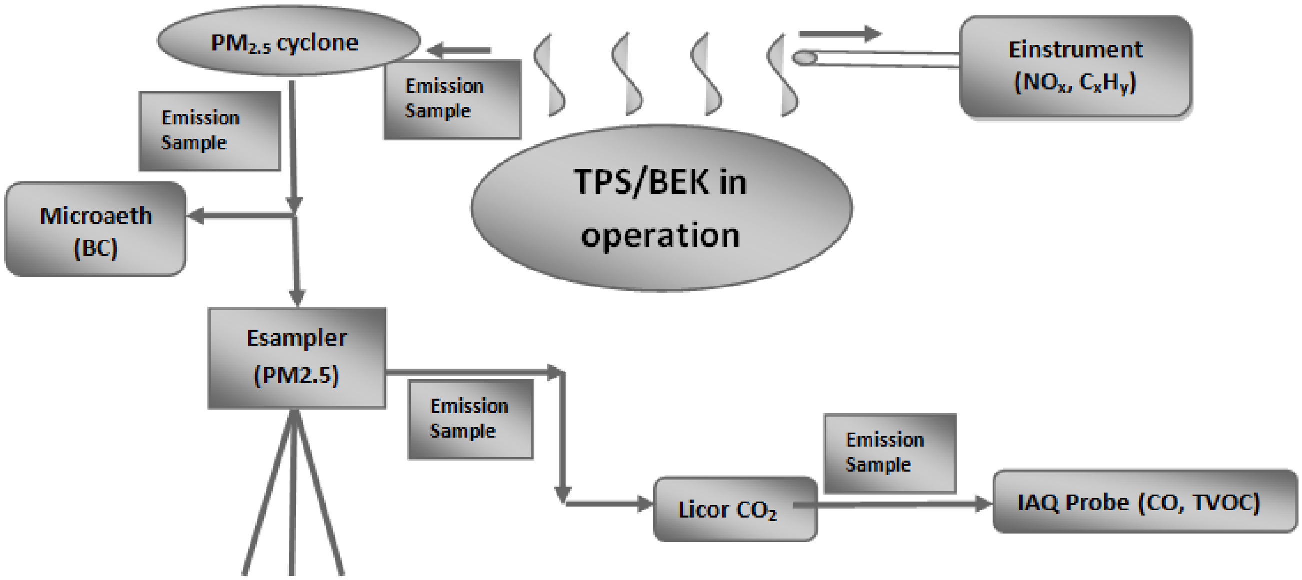

Figure 1: Experimental Setup for Emission Concentration Measurement

calculated as equation 2[15].

$$C_{CO_2} = \frac{CO_2(ppm) \times P \times 12}{T \times R \times 1000} \quad (2)$$

The emission factor of CO_2 on a carbon basis is defined as total emission concentration per kg of fuel burnt which can be stated as;

$$EmissionFactor(EF_{CO_2}) = \frac{\frac{TCC}{100} \times C_{CO_2} \times \frac{44}{12}}{C_{total}} \quad (3)$$

where, TCC= Total carbon fraction contributing emission on fuel and C_{CO_2}= Total carbon concentration of CO_2 on emission

3. Result and Analysis

3.1 Emission Concentration

Figure 2 depicts the in-situ measurement of the concentration reading of the black carbon while burning feedstock in TPS and BEK system. It was observed that the average concentration of the BC throughout the charcoal production of TPS was to be around $1264 \pm 1510\mu g/m^3$ and for BEK it was around

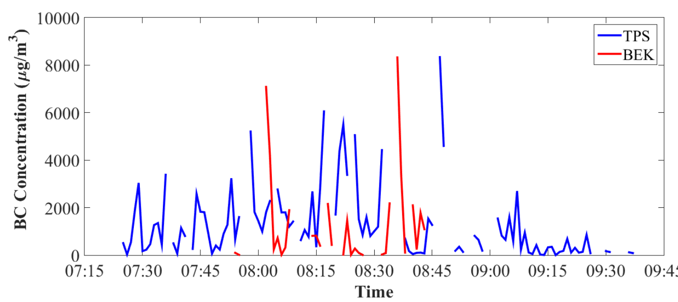

Figure 2: BC Concentration Plot of TPS vs BEK

$1278 \pm 1989\mu g/m^3$. One minute average plot of BC of two systems suggest that the average value of black carbon concentration emitted while producing charcoal in both TPS and BEK system does not varies much. The average concentration reading of the $PM_{2.5}$ while burning micania micranta in TPS was observed to be around $20685 \pm 16486\mu g/m^3$ while burning the same in BEK the concentration was measured to be $7631 \pm 11134\mu g/m^3$ as shown in Figure 3. The average value of $PM_{2.5}$ concentration emitted while producing charcoal in BEK system is generally found low and the higher deviation on the reading may be due to the variation in the sample emission during the flaming phase and smoldering phase. As plotted on Figure 4, the average concentration reading of the CO_2 while burning biomass in TPS system it was observed to be around

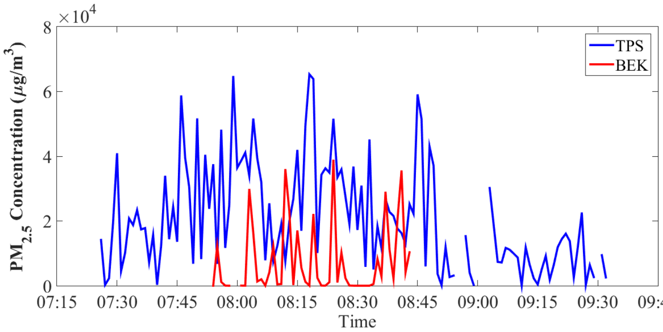

Figure 3: $PM_{2.5}$ Concentration Plot of TPS vs BEK

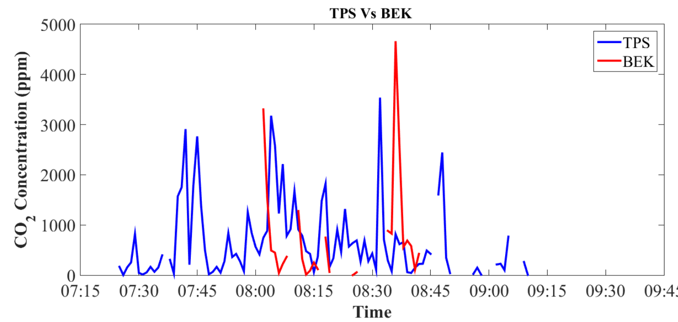

Figure 5: CO_2 Concentration Plot of TPS vs BEK

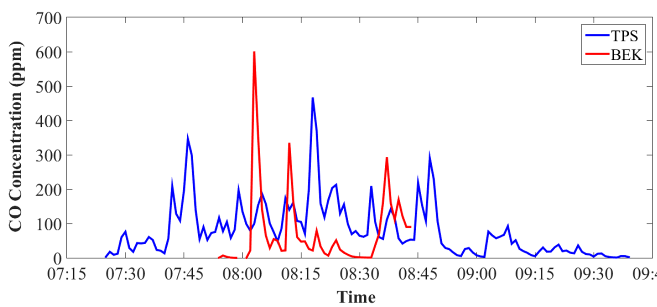

Figure 4: CO Concentration Plot of TPS vs BEK

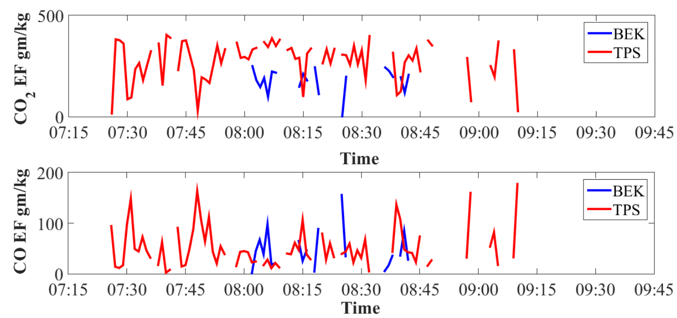

Figure 6: TPS vs BEK Comparative plot of EF of CO and CO_2

$656.04 \pm 765.96 ppm$ while burning the same in BEK it was observed to be around $747.6 \pm 1084.8 ppm$. The average concentration of CO2 emitted in BEK is found to be greater than in TPS. Figure 5 shows the real time plot of the concentration reading of CO while burning invasive feedstock on TPS system and BEK system. The average concentration of CO in TPS was measured to be around $80.55 \pm 80.67 ppm$ while burning the same in BEK it was measured to be around $77.6 \pm 115.32 ppm$. The average reading of concentration of CO emitted throughout the production of charcoal from TPS system and BEK system seems not to defer that much.

3.2 Emission Factors

The real time emission factor plot of CO_2 and CO for BEK is shown on the Figure 6. The average emission factor of the Bio-energy Kiln for CO2 was $184.01 \pm 60.0 gm/kg$ while emission factor for CO for the same technology was measured to be $42.5 \pm 37.92 gm/kg$ of fuel burnt which are found to be lower than the emission factor of CO_2 ($440 gm/kg$) and CO ($70 gm/kg$) while charcoal making reported by previous researcher [8]. The emission factor of CO and CO_2 are found to be inversely correlated with a correlation coefficient of -0.999 which validate the fact that if combustion is complete the concentration of CO_2 increasing meanwhile decreasing the concentration of CO. The mean emission factor for CO_2 is $275.4 \pm 97.45 gm/kg$ of fuel burnt while average emission factor for CO is measured to be $51.31 \pm 39.28 gm/kg$ of fuel burnt while burning feedstock on TPS. The correlation coefficient between emission factor of CO and CO_2 for TPS is calculated to be -0.932. As shown in Figure 7, the average emission factor for $PM_{2.5}$ of BEK is $10.78 \pm 16.56 gm/kg$ while emission factor for BC for the same technology is measured to be $0.85 \pm 0.78 gm/kg$ of fuel burnt however the average emission factor for BC of TPS is measured to be $1.39 \pm 1.08 gm/kg$ of fuel burnt while the average emission factor of $PM_{2.5}$ for the same technology is measured to be $31.73 \pm 29.06 gm/kg$ of fuel burnt. As compared in the Figure 6 and Figure 7, the average emission factor for CO, CO_2, $PM_{2.5}$ and BC of Traditional Pit System is measured significantly higher

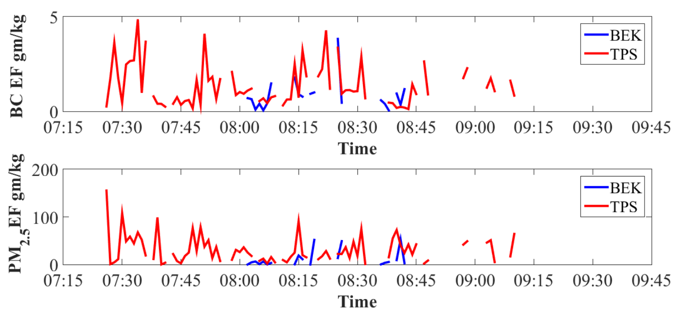

Figure 7: TPS vs BEK Comparative plot of EF of $PM_{2.5}$ and BC

than that of Bio-energy Kiln. The smaller plot of BEK is due to the lower charcoal burning period per batch of BEK being 1 hrs as compared to be 2 hours of TPS. The emission factors calculated in this research are comparable to the previous researches[8], [9],[10].

Table 1: Emission factors in gm/kg of fuel burnt of TPS and BEK

SN	Particulate	TPS	BEK	Difference (%)
1	CO	51.31	42.5	20.7
2	CO_2	275.4	184.01	49.6
3	$PM_{2.5}$	31.73	10.78	194.34
4	BC	1.39	0.85	63.5

Table 1 shows the comparison of the emission factor of TPS and BEK. The emission factor of TPS for $PM_{2.5}$ and BC was found to be higher than of BEK by greater margin. This may be due to smouldering phase being prevalent than flaming phases on TPS while the same being less prevalent on BEK. The emission factor of TPS for CO_2 and CO was found marginally higher than that of BEK.

4. Conclusion

The average emission factors for BC, $PM_{2.5}$, CO_2 and CO of Bio-energy Kiln were found to be $0.85 \pm 0.78 gm/kg$, $10.78 \pm 16.56 gm/kg$, $184.01 \pm 60.0 gm/kg$ and $42.5 \pm 37.92 gm/kg$ of fuel burnt respectively. Similarly, the average emission factor of for BC, $PM_{2.5}$, CO_2 and CO of Traditional Pit System were found to be $1.39 \pm 1.08 gm/kg$, $31.73 \pm 29.06 gm/kg$, $275.4 \pm 97.45 gm/kg$ and $51.31 \pm 39.28 gm/kg$ of fuel burned respectively. The average emission factor of Traditional Pit System was found 63.5%,194.3%,49.6% and 20.7% higher than that of Bio-energy Kiln for BC, $PM_{2.5}$, CO_2 and CO respectively during the charcoal production using the forest invasive species as the feedstock.

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