



Indicative simplified baseline and monitoring methodologies
for selected small-scale CDM project activity categories

TYPE III - OTHER PROJECT ACTIVITIES

Project participants shall take into account the general guidance to the methodologies, information on additionality, abbreviations and general guidance on leakage provided at <http://cdm.unfccc.int/methodologies/SSCmethodologies/approved.html>.

III.K. Avoidance of methane release from charcoal production by shifting from traditional open-ended methods ~~pit method~~ to mechanized charcoaling process

Technology/measure

1. This category is applicable to project activities that avoid release of methane from traditional open-ended charcoal ~~pit charcoal~~ production methods by producing charcoal in new facility(ies) equipped with recovery and flaring/combustion of methane generated in the production process. Traditional open-ended charcoaling methods are defined as non-industrial production processes where the gases produced by the wood pyrolysis are not destroyed or used for other (industrial) purposes, therefore being released directly to the atmosphere. Traditional open-ended production units include, but are not limited to, open pits, hot-tail kilns and brick-based Missouri kilns.
2. The category is applicable under one of the following conditions;
 - (a) Local regulations do not require controlling methane emissions in charcoal production;
 - (b) There is a widespread non compliance¹ of the local regulation evidenced by:
 - (i) Annually collected data from control groups set up by the project activity, or
 - (ii) Annually collected data on legal action and enforcement mechanisms implemented under the prevailing regulation, or
 - (iii) Official reports (e.g. annual reports of regulatory bodies for pollution control).
3. No relevant changes in greenhouse gas emissions other than methane occur as a consequence of the project activity and/or need to be accounted, except for the possibilities of leakage.
4. The implementation of the project activity shall not result in changes in the type and source of biomass raw material used for production of charcoal (e.g. if in the baseline charcoal was produced from coconut shells, the project activity will only produce charcoal from coconut shells).
5. Measures are limited to those that result in emission reductions of less than or equal to 60 kt CO₂ equivalent annually.
6. If the combustion facility is used for heat and electricity generation that component of the project activity shall use a relevant category under type I.

¹ Less than 50% of charcoal production activities comply in the country



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Boundary

7. The project boundary is the physical, geographical sites:
- (a) Where the charcoal is manufactured in ~~traditional open-ended production units~~ ~~open pits~~ and the avoided methane emission occurs in absence of the proposed project activity;
 - (b) Where the charcoal manufacturing with recovery and flaring/combustion of methane takes place;
 - (c) And in the itineraries between them, where the transportation of raw material for charcoal manufacturing occurs.

Project Activity Emissions

8. Project activity emissions consist of:
- (a) Incremental CO₂ emissions due to incremental distances between the charcoal manufacturing facility(ies) to the consumption points in comparison to the baseline case;
 - (b) Incremental CO₂ emissions due to incremental distances between the raw material collection points to the new charcoal manufacturing facility(ies) in comparison to the baseline case;
 - (c) CO₂ emissions related to the power used by the project activity facilities, including the equipments for air pollution control required by regulations. If the project activity consumes grid electricity, the corresponding emissions are calculated as described in category I.D;
 - (d) Fugitive emissions of methane due to capture and flare inefficiencies;
 - (e) Emissions from the auxiliary fossil fuels for supporting the flaring facility.

$$PE_y = PE_{y,transp1} + PE_{y,transp2} + PE_{y,power} + PE_{y,fugitive} + PE_{y,support} \quad (1)$$

Where:

PE_y	Project activity direct emissions in the year “y” (tCO ₂ e)
$PE_{y,transp1}$	Emissions from incremental transportation from raw material collection points in the year “y” (tCO ₂ e)
$PE_{y,transp2}$	Emissions from incremental transportation to consumption points in the year “y” (tCO ₂ e)
$PE_{y,power}$	Emissions from electricity or diesel consumption in the year “y”(tCO ₂ e)
$PE_{y,fugitive}$	Fugitive emissions from capture and flare inefficiencies in the project charcoal manufacturing plant in the year “y” (t CO ₂ e)



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PE_{support} Emissions from the auxiliary fossil fuels used to maintain the incineration of the carbonization gas calculated as per the tool for “Estimation of project or leakage emissions from fossil fuel combustion” (t CO₂e)

When trucks are used for transportation, emissions from incremental distances for transportations shall be estimated as follows.

$$PE_{y,transp1} = (Q_{y,raw}/CT_{y1}) * DAF_{w1} * EFCO_2 \quad (2)$$

Where:

$Q_{y,raw}$ Quantity of raw material used in the year “y” (tonnes)
 CT_{y1} Average truck capacity for raw material transportation (tonnes/truck)
 DAF_{w1} Average incremental distance for raw material transportation (km/truck)
 $EFCO_2$ CO₂ emission factor for the fuel used (tCO₂/km) Local values or IPCC default values can be used.

$$PE_{y,transp2} = (Q_{y,prod}/CT_{y2}) * DAF_{w2} * EFCO_2 \quad (3)$$

Where:

$Q_{y,prod}$ Quantity of charcoal produced in the year “y” (tonnes)
 CT_{y2} Average truck capacity for charcoal transportation (tonnes/truck)
 DAF_{w2} Average incremental distance for charcoal transportation (km/truck)

Fugitive emissions due to capture and flare inefficiencies shall be estimated as follows:

$$PE_{y,fugitive} = (1 - CFE_{project}) * ME_{y,project} * GWP_{CH4} \quad (4)$$

Where:

$CFE_{project}$ Capture and flare efficiency of the methane recovery and combustion equipment in the project charcoal manufacturing plant (a default value of 0.9 shall be used, given no other appropriate value)
 $ME_{y,project}$ Methane emission potential of the project charcoal manufacturing process in the year “y” (tonnes)

$ME_{y,project}$ shall be estimated ex-ante and reported in the project design document. Amount of methane generated by the project activity in each year will be assessed ex-post through direct measurement.

Baseline

9. The baseline scenario is the situation where, in the absence of the project activity, charcoal is produced through traditional open-ended methods open pits within the project boundary and methane is emitted to the atmosphere. The baseline emissions are the amount of methane that would have been

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produced from traditional open-ended methods open pits to process the equivalent quantity of raw material used in the project activity to produce charcoal. Only dry weights of the biomass raw material shall be considered for the calculations.

The baseline emissions shall be estimated using the relation below:

$$BE_y = Q_{y,raw} * (M_{y,b} - M_{y,d}) * GWP_{CH4} \quad (5)$$

Where:

BE_y	Baseline emissions (tCO ₂ e)
$Q_{y,raw}$	Quantity of raw material used in the new facility in the year “y” on a dry basis (tonnes)
$M_{y,b}$	Methane emission factor for the traditional open-ended open pits charcoal manufacturing process considered (tonnes of CH ₄ /tonne raw material used)
$M_{y,d}$	Factor to account for any legal requirement for capture and flare of methane in the traditional open-ended open pits charcoal production installation considered (tonnes of CH ₄ /tonne of raw material)
GWP_{CH4}	GWP of CH ₄ (a value of 21)

$M_{y,b}$ shall be determined from experiments using relevant statistical methods. Examples of generic procedures are provided in annex 1 and 2.

Leakage

10. If the charcoal manufacturing technology is equipment transferred from another activity or if the existing pit charcoaling equipment is transferred to another activity, leakage effects are to be considered.

11. If the implementation of the project activity occurs in conjunction with other project activities directly related to the inputs and outputs associated with the carbonization process (e.g. coconut shell, eucalyptus or charcoal), the overall supply chain relationship of the respective baseline and project emissions of the individual project activities must be taken into account. In such cases, provisions to avoid double counting may be included in the CDM-PDD as per the EB guidance on double counting of emission reductions as outlined in the paragraph 38 of the EB26 Meeting Report.

Monitoring

12. The emission reduction achieved by the project activity will be measured as the difference between the baseline emission and the sum of the project emission and leakage.

$$ER_y = BE_y - (PE_y + Leakage_y) \quad (6)$$

Where:

ER_y Emission reduction in the year “y” (tCO₂e)

13. The following parameters shall be monitored and recorded under the project activity:



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- (a) Quantity of raw material ($Q_{y,raw}$) used each year and its moisture content through representative sampling;
- (b) Quantity of charcoal produced ($Q_{y,prod}$) and its moisture content in each year;
- (c) The average truck capacity (CT_{y1} and CT_{y2}) and the distances over which the raw materials and charcoal are transported in the baseline and the project situation (to determine the component of project activity emission on account of transportation);
- (d) The power consumption and/or generation of the production facility including auxiliary fossil fuels used for supporting the flaring facility.

14. To estimate the fugitive emissions through capture and flare inefficiencies in the project charcoal manufacturing plant, the amount of methane generated, fuelled or flared shall be monitored ex-post, using continuous flow meters. The fraction of methane in the gas should be measured with a continuous analyser or, alternatively, with periodical measurements at a 95% confidence level. Temperature and pressure of the gas are required to determine the density of methane combusted.

15. Regular maintenance should ensure optimal operation of flares. The flare efficiency, defined as the fraction of time in which the gas is combusted in the flare, multiplied by the efficiency of the flaring process, shall be monitored.

16. The project participants will demonstrate annually that the amount of charcoal raw material used in the project activity facilities would have been used in charcoal ~~open pits~~ manufacturing sites using traditional open-ended methods with out methane recovery in the absence of the project activity.

Project activity under a programme of activities

17. The following conditions apply for use of this methodology in a project activity under a programme of activities:

18. In case the project activity involves the replacement of equipment, and the leakage effect of the use of the replaced equipment in another activity is neglected, because the replaced equipment is scrapped, an independent monitoring of scrapping of replaced equipment needs to be implemented. The monitoring should include a check if the number of project activity equipment distributed by the project and the number of scrapped equipment correspond with each other. For this purpose scrapped equipment should be stored until such correspondence has been checked. The scrapping of replaced equipment should be documented and independently verified.



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Annex 1

**GENERIC PROCEDURE FOR ESTIMATING METHANE EMISSION FACTOR FOR OPEN
PIT CHARCOAL MANUFACTURING PROCESS**

($M_{y,b}$ in the equation for estimating baseline emissions)

1. The procedures described here are based on the principles that charcoaling yield is inversely proportional to the temperature of carbonization, and the release of methane is directly proportional to the charcoaling temperature. Laboratory and field experiments are to be carried out to establish the relationship between the release of methane and charcoaling temperature. Experimental steps described below need to be repeated several times for data consistency purposes.

Procedure for laboratory trials

Step 1. Laboratory Rotary type kiln is used for the generation of lab-scale data. Crushed and dried samples of raw material are subjected to charcoaling at different temperatures ranging from 400 °C to 700 °C at different time intervals, varying from 1 to 10 hours of carbonization.

Step 2. The resulting solid masses are weighed and analyzed for their properties. The volatiles released are collected into gas sample bags and their volumes are measured.

Step 3. Using a calibrated gas chromatograph in a certified laboratory, the percentage composition of methane (volume basis) in the collected volatile gas samples is determined.

Step 4. Compute the total weight of methane released when processing 1 tonne of raw material.

Step 5. Conduct a regression analysis and establish a linear or non-linear regression equation that best demonstrates the relationship between the methane emissions and temperature of the carbonisation, consistent with the statistical procedures, the EB guidance on the use of regression in methodologies;

$$\text{CH}_4 \text{ (kg/tonne of raw Material)} = A \times \text{Temperature (}^\circ\text{C)} - B$$

Procedure for field trials

2. The Pit charcoaling cycle consists of four stages

- (a) Pyrolysis phase of over 12 hours when gases are released;
- (b) Pacification phase of 12 hours when the pit is closed and hence no gases are released;
- (c) Cooling phase of 12 hours;
- (d) Unloading of the charcoal and loading of the fresh raw material for the next cycle.

Step 1. Charcoaling temperature and gravimetric charcoal yield (mass of charcoal over mass of biomass raw material) are measured in selected pits. Temperature measurements are done throughout the pyrolysis phase at one-hour intervals in the selected pits.



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Step 2. The projected methane release from the pits is calculated based on the temperature of the charcoaling zone using the co-relation derived using the laboratory testing. Temperature measured at pit locations is recorded in following format:

Location	Temperature (⁰ C)
	Charcoaling zone
1	
2	
3	
4	
Mean charcoaling Temperature (⁰ C)	xx
Standard deviation	x

If the laboratory charcoaling temperatures and the gravimetric charcoal yield are falling in the same range as the pit charcoaling, the correlation between temperature and methane emissions established is valid.

The selected pits should be representative of the industry by way of geographical location, raw material, and size of pits and duration of charcoaling. The measured temperature values are the average of a minimum five measurements covering the cross section of the pit.



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Annex 2

PROCEDURES FOR ESTIMATING METHANE EMISSION FACTOR FOR BRICK-BASED CHARCOAL MAKING PROCESS

(Based on Sampaio, et al, 2006, Appendix I of the CDM Approved Methodology AM0041)

The objective of this annex is to provide a step-wise approach for establishing a fixed methane emission factor in charcoal production for a given set of brick-based kilns functioning under the same relevant operational parameters. This experimental protocol is based upon the experimental protocol supporting the baseline determination in the approved methodology AM0041 which in turn is drawn upon the most up-to-date published literature on the carbonization process and on a pioneer research conducted in Brazil, triggered by the CDM incentive.

Contrary to the AM0041 methodology, in the present case, no study of the correlation between gravimetric yield and methane emissions will be conducted. This is justified by the fact that, this small-scale methodology only targets projects, which incinerate the methane produced during carbonization process. Moreover, the adoption of a fixed emission factor finds justification in the nature of the improvement brought on by the proposed project activity, which is the substitution of a precisely defined production unit (set of brick-based kilns) that has historically operated under fairly constant conditions.

The experimental procedures described below (such as carbonization tests and gas sampling) must be conducted on a representative sample of kilns to be replaced by the kilns equipped with flaring facility to ensure that the results obtained are statistically representative of the overall production process. These tests must also be in accordance with physical and operational features currently adopted by the project entity.



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III.K. *Avoidance of methane release from charcoal production by shifting from ~~traditional open-ended open pits~~ methods to mechanized charcoaling process (cont)*

Abstract

The aim of this annex is to establish a fixed and representative ratio of methane emissions (kg CH₄) per tonne of raw material (Dry basis) processed ($M_{y,b}$) in the production of charcoal .

For this, it is necessary to perform a mass balance analysis on a representative sample of the existing kilns to assess the quantity of methane emitted during the carbonization process.

Basically, the operation performed for each run on each selected kiln consists of the following:

1. Measurement of the raw material mass (Dry basis) loaded into the kiln (Q_{RAW})
2. Ignition of the carbonization process
3. Mass balance and determination of the total amount of methane emitted in the atmosphere during the total process (Q_{CH_4})
4. Statistical treatment of the measured value of $M_{y,b} = Q_{CH_4} / Q_{RAW}$

Choice of the sample

Basically one unit of carbonization (e.g.: array of brick kilns) is linked to a given plantation. Because of transportation cost, catchment area for raw material procurement is limited. Thus, in situations where the implementation of the project activity implies on the deactivation of the pre-existing units, it is reasonable to consider the new kilns as a replacement of these units for the considered catchment area.

The baseline determination will focus on the kilns, which have a common catchment area with the project activity.

Once kilns of the baseline are identified, the project developer should take great care in selecting a representative sample among these kilns.

The selected kilns should be representative of actual practices by way of geographical location, raw material, size, operating conditions and operation protocol.

Once selected kilns are divided into homogeneous families with similar characteristics (same location, same operation and same design), then the project proponent select one kiln in each family and perform minimum 8 carbonization cycles on this selected kiln.

Operative protocol

Third party measurements

The mass balance on the kilns of the baseline shall be performed by an **independent party** which has the ability and the required certification to handle such operations.



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Weighing of raw material

The project developer should use an industrial calibrated scale to measure the wood to be loaded into the kiln. Precision to be reached is +/- 2 %.

The measure of the wet material weight is recorded as Q_{wRAW}

Raw material moisture content

In order to allow the calculation of a total mass balance, it is important to determine the moisture content of the wood logs, in addition to the wood weight. Preliminary research has demonstrated the existence of some variance in moisture, as a function of the wood log diameter, i.e. high moisture levels for pieces of greater diameter and low levels for pieces of shorter diameter. Therefore, this protocol adopts rigorous provisions to reduce the influence of uncertainties associated to the wood moisture measurement, by determining the sampling and stratification of wood into diameter classes, as per the procedure below:

1. Put the wood logs to be carbonized in a stack. The wood must come from the same sources currently used by the project entity.
2. Measure the diameter of all the pieces of wood log in the “stack” (a log pile whose width and volume of wood are approximately equivalent to the carbonization kiln (dimensions) with a pachymeter. The diameter shall be calculated as the mean of two perpendicular and center-crossing measurements of the log transversal section, taken at the middle-length of the log.
3. Determine the distribution histogram of the diameters of the entire population of wood logs in the “stack”. The interval size of each diameter class shall not exceed 6.0 centimeters.
4. Choose 60 to 70 samples from the lot of wood logs. The pieces shall follow the proportions of diameter classes of wood logs as shown in the histogram. The samples shall be taken in 3 different vertical areas, covering at least the width equivalent to four average diameters (as measured in step 2).
5. Cut a 5 to 7 cm thick transversal slice (wood disks), removed from the point that represents 1/3 of total length of each wood log sample, starting from the extremity.

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Figure 1 provides an example of the sampling collection:

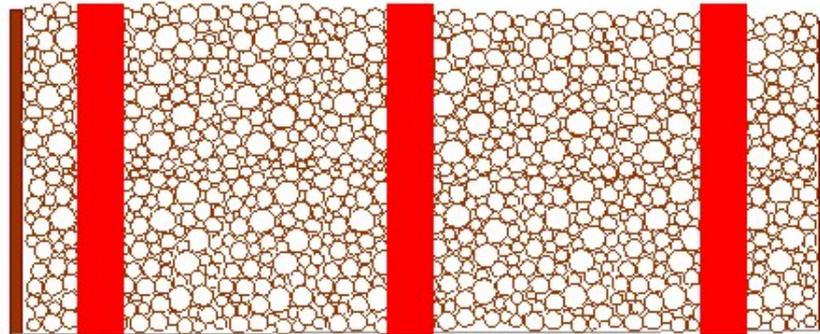


Figure 1: Example of sampling collection in a stack.

6. Weigh each disk immediately on the laboratory scale and note the mass.
7. Note the sample number on the wooden disk itself.
8. Place the wooden disks in the oven to dry.
9. Set the oven to $103 \pm 2^\circ\text{C}$.
10. Dry until they reach constant weight, after three consecutive weighing processes indicate constant weight.
11. Weight the wooden disks and note the weights.
12. Calculate the dry basis moisture content (W_{db}) of each disk:

$$W_{db} = \frac{\text{Wet Mass} - \text{Dry Mass}}{\text{Dry Mass}} (\text{kg/kg})$$

13. Calculate the mean moisture content of each diameter class.
14. The mean moisture content of the logs in the entire “stack” shall be calculated by the mean moisture content of each diameter class multiplied by its frequency in the diameter distribution histogram

Q_{RAW} the quantity of raw material on dry basis is given by:

$$Q_{\text{RAW}} = \frac{Q_{\text{wRAW}}}{(1 + W_{db})}$$

Experimental Apparatus for mass balance during the carbonization process

Weighing and Temperature Measurement Apparatus



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- Two (2) industrial thermometers with range 0-1100°C, and precision of +/- 2.0°C for the temperature measurement on the top and chimneys.

Gas Sampling

- One (1) constant volume peristaltic pump
- One (1) water cooled gas condenser
- One (1) oil filter
- One (1) 100-liter-gasometer
- Glass bottles or Tedlar bags

Gas Analysis

- Calibrated Gas Chromatography apparatus for CH₄, CO₂, CO, O₂, and N₂
- Wood and Charcoal Elementary Analysis
- Elementary analysis of wood (C, H, O, N, S, Ash and Moisture).
- Elementary analysis of charcoal produced (C, H, O, N, Ash and moisture).

Technical Staff

- One (1) carbonization expert (to conduct the carbonization tests)
- One (1) chemistry technician (to make the measurements)
- One (1) team assistant
- One (1) carbonization operator for each carbonization test

Carbonization procedures

The carbonization procedures conducted under this protocol, also referred as “carbonization tests”, shall accurately reflect the physical and operational features of the charcoal manufacturing process currently adopted by the project entity, allowing the assessment the actual carbonization emissions observed in the absence of the cleaner mechanized process. The following procedures shall be followed for the carbonization tests:

1. Carefully load the kiln with the wood.
2. Close and seal the kiln's door.
3. Ignite the kiln.
4. Keep track of temperature measurements, off gas removals, measurement and sampling of the condensable gases, and gaseous fractions generated in each hour.
5. Seal the kiln at the end of carbonization process.
6. Stop the gas sampling procedure.



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7. Wait for natural cooling.
8. Open the kiln.
9. Take off the charcoal.
10. Set up the scale for zero weight for taring purposes.
11. Measure the weight of the charcoal immediately after unloading the kiln (M_{charcoal}).
12. Remove all brands (large partly charred pieces of wood, not usable as fuel).
13. Measure the weight of all brands removed (M_{brands}).

Gas sampling procedures

High variations in temperature, composition and density of the volatile materials released make the determination of the flow of non-condensable gases, where methane is present, a relatively complex task. Nevertheless, it is possible to get representative samples of these volatiles during the carbonization process to measure the mass proportions of condensable and non-condensable materials produced. The non-condensable gas fraction shall also be analyzed by chromatography, so as to determine its methane content. Therefore, in order to evaluate the specific methane emissions (in kg CH₄/kg charcoal produced), this protocol is based on the measurement of the volatile mass released (condensable and non-condensable), resulting in the measurement of the amounts of methane released with the non-condensable gases.

In light of the above, the implementation of the following operational procedure, illustrated by scheme below, is required for measuring methane emissions:

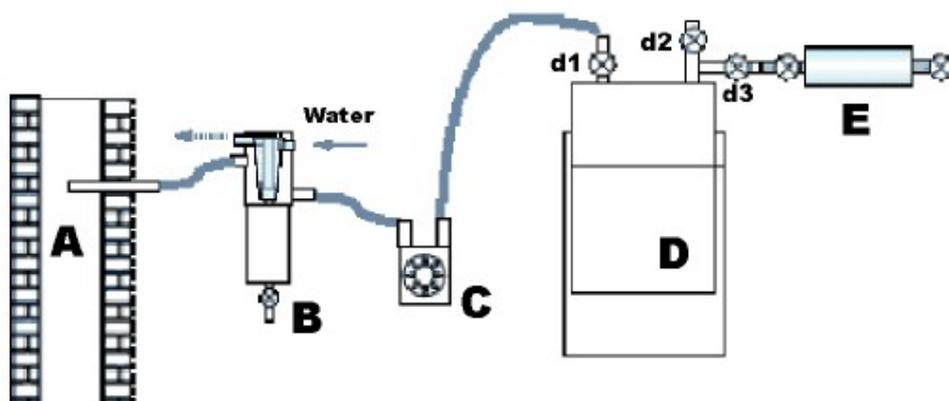
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Figure 2: A schematic view of the assembly for collecting gas samples. An intake with a stainless steel tip (A) is installed in the central point of the chimney's transversal section. The suctioned gas passes through the condenser and oil filter (B), through the pump (C), and is released by the gasometer (D). The pump shall be turned on every hour for 10 minutes, suctioning in the gas. After 6 intake periods, covering an operating period of 6 hours, a gas sample shall be collected in a (E) glass cylinder with a double valve, or a Tedlar bag.

A. Set up

1. Connect the stainless steel tip in the central point of the chimney's transversal section before the beginning of the carbonization procedure.
2. Connect all collecting gas sample system.
3. Close the gasometer valves d1 and d3 open the valves d2 to purge the gasometer.
4. Close all gasometer valves.
5. Set the peristaltic pump to 1.3 to 1.5 liters per minute.

B. Purge the gas after one hour from the beginning of carbonization

1. Open the gasometer valves d1 and d2.
2. Turn on the pump for 1.0 minute to purge the gas system.
3. Close all gasometer valves.
4. Purge and close the condenser.

C. Gas sampling

1. Turn on the constant volume peristaltic pump for 10 minutes at every hour.



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2. Take off a gas sample for analysis within each six-hour time interval (after six gas samples):
 - i. Drain the condenser.
 - ii. Measure the mass of condensed liquid (wood tar and pyroligneous water) M_{cond} .
 - iii. Measure carefully the volume and temperature of the gasometer ($V_{\text{gasometer}}$, $T_{\text{gasometer}}$).
 - iv. Connect the glass bottle or Tedlar bag to valve d3.
 - v. Open the valve d3 to fill the glass bottle or Tedlar bag.
 - vi. Close the valve d3.
 - vii. Connect a second glass bottle or Tedlar bag to valve d3.
 - viii. Open the valve d3 to fill the glass bottle or Tedlar bag.
 - ix. Close the valve d3.
 - x. Take note of date and time on glass bottle or Tedlar bag.
 - xi. The glass bottles or Tedlar bags must be send to a laboratory to gas chromatography analysis of CH_4 , CO_2 , CO , O_2 , and N_2 .
 - xii. Open the gasometer valve d2 to drain all gas.
 - xiii. Close the gasometer valve d2.
 - xiv. This gas sampling procedure shall be repeated during the entire carbonization process.
 - xv. The glass bottles or Tedlar bags must be expeditiously send to an laboratory for chromatographic analysis of CH_4 , CO_2 , CO , O_2 , and N_2 . The recipients must be carefully packed and transported in order to ensure that the samples be adequately preserved.

Note 1: It is necessary to fill and purge the glass bottle or Tedlar bag 2 times to ensure that all remaining air inside be removed.

Note 2: Researchers may connect a gas chromatography apparatus directly to valve d2 to make the chromatography analysis.

Note 3: Researchers may also connect an Orsat apparatus directly to valve d2 to make the CO_2 , and O_2 analysis.

Mass balance analysis

Based on the experimental results, the mass balance to obtain the mass of methane released for each dry ton of processed raw material shall be calculated. Figure 3 illustrates the mass inputs and outputs within the experimental apparatus:

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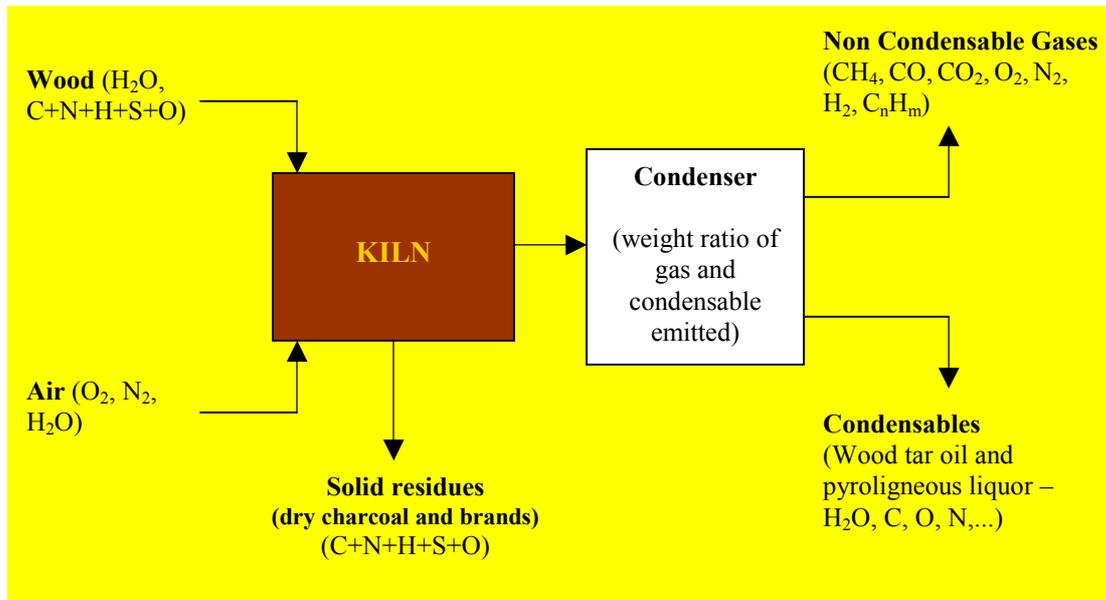


Figure 3 – Major inputs and outputs of the mass balance

The measurement technician shall start the peristaltic pump every hour, read the temperatures, and wait ten minutes to stop the pump until the following hour. After a six-hour-period, the gasometer volume shall be measured and the gas samples shall be taken for analysis purposes (by chromatography and Orsat, if applicable).

$$\text{INPUT} = [\text{mass of wood}] + [\text{mass of air}]$$

The mass of wood is a measured value and the mass of air is determined from other measured data and the mass balance:

$$[\text{mass of wood}] = [\text{mass of dry wood}] + [\text{mass of water from moisture in wood}]$$

$$[\text{mass of air}] = [\text{mass of O}_2 \text{ from air}] + [\text{mass of N}_2 \text{ from air}] + [\text{mass of H}_2\text{O from air}]$$

$$\text{OUTPUT} = [\text{mass of solid residue}] + [\text{mass of non-condensable gases}] + [\text{mass of condensable volatile}]$$

[mass of solid residues] = weight of the materials left inside the kiln at the moment of measurement, e.g., the carbonizing biomass. When the entire carbonization procedure is finished, it results in the weight of dry charcoal produced.

The volatile material mass leaving the kiln cannot be directly measured, since it contains part of the air that was introduced into the kiln during the carbonization process. The mass of air is an indirectly measured value of the input equation. Nevertheless, the ratio of condensed and non-condensed materials (K_{fi}) can be obtained, as follows:



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K_{fu} = the weight ratio between the collected samples of condensed material (water, wood tar, and pyroligneous liquor) and the gases in the gasometer. It is one of the critical measured values of the experiment because it permits one to calculate, for every time interval, the real total amounts of condensable and non-condensable materials. Therefore,

$K_{fu,t} = [\text{mass of condensable volatile sampled at time interval } t] / [\text{mass of non-condensable gases sampled at time interval } t]$.

When the entire carbonization process is over, the value of K_{fu} is a mass proportional value of all the K_{fu} measured at each six-hour-time-interval.

$[\text{mass of condensable volatile sampled at time interval } t] = \text{a measured value at each time interval when the volatiles sample is taken from the kiln chimney.}$

The volume in milliliters shall be recorded during the experiments for each timed interval and its density shall be measured to calculate the weight.

$[\text{mass of non-condensable gases sampled at time interval } t] = \text{the measured and analyzed gas sample volume accumulated in the gasometer at each time interval. The mass value is determined by assuming ideal gas under the experimental conditions (Temperature and Pressure) and using the chromatographic gas analysis to convert the gas analysis from molar base to weight fraction. This procedure also provides the amount of } CH_4 \text{ released in each time interval } t. \text{ Some minor components of the gas are not analyzed and shall be referred as others.}$

The values for each six-hour time interval are assumed to be proportional to the whole mass lost at that time interval. Therefore, for the ten-minute samples taken every hour when the six hours are reached, the samples are collected and analyzed for CH_4 , CO , CO_2 , N_2 and O_2 . In that time interval, the precise weight of the material released to the volatile phase is measured and is separated into two phases: non-condensable gases and condensable liquids have their mass ratios measured.

To calculate the mass of air introduced in the kiln at time interval t (six hours), a nitrogen balance shall be conducted:

$[\text{mass of nitrogen in output volatile gas}] = [\text{mass of nitrogen from air}] + [\text{mass of nitrogen in the dry wood}] - [\text{mass of nitrogen in solid residues}]$

The wood nitrogen is either retained in the solid residues or released in the form of non-condensable gases. Thus, by knowing the nitrogen content of the non-condensable gases and the nitrogen from the dry wood and the charcoal, the balance can be calculated based on the infiltrated air. The values of nitrogen present in the wood and in the residue product can be obtained for the initial (dry wood = $M_{DryWood}$) and the final product (charcoal = $M_{charcoal}$).

As above, the following data and calculations are required to perform the mass balance:

Initial Data

Wood Mass $M_{Wood} =$ [kg]



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$$\text{Dry basis moisture content of Wood } W_{db} = \quad \quad \quad [\text{kg/kg}]$$

$$\text{Dry Wood Mass } M_{\text{DryWood}} = M_{\text{Wood}} / (1 + W_{db}) = \quad \quad \quad [\text{kg}]$$

$$\text{Mass of Charcoal Produced } M_{\text{Charcoal}} = \quad \quad \quad [\text{kg}]$$

$$\text{Mass of Brands Produced } M_{\text{Brand}} = \quad \quad \quad [\text{kg}]$$

$$\text{Nitrogen Content in Wood } N_{\text{Wood}} = \quad \quad \quad [\text{kg/kg}]$$

$$\text{Nitrogen Content in Charcoal } N_{\text{Charcoal}} = \quad \quad \quad [\text{kg/kg}]$$

For each 6 hours interval, the following measurements and calculations shall be conducted:

Measured Data

Six-hour-interval-data:

- Mass of condensed liquid in condenser $M_{\text{cond}\Delta t} = \quad \quad \quad [\text{kg}]$

- Gasometer volume (dry non-condensable gases) $V_{\text{gasometer}\Delta t} = [\text{m}^3]$

- Gasometer temperature $T_{\text{gasometer}} = \quad \quad \quad [^{\circ}\text{C}]$

- Gasometer pressure $P_{\text{gasometer}} = \quad \quad \quad [\text{atm}]$

- Gas analysis (% molar basis):

- $X_{\text{CO}_2} =$

- $X_{\text{CO}} =$

- $X_{\text{O}_2} =$

- $X_{\text{H}_2} =$

- $X_{\text{N}_2} =$

- $X_{\text{CH}_4} =$

Six-hour-interval-calculations:

Specific mass of gasometer dry non-condensable gases

$$(\text{NTP}) = \rho_{\text{gas}} = (44/0.224) \cdot X_{\text{CO}_2} + (28/0.224) \cdot X_{\text{CO}} + (32/0.224) \cdot X_{\text{O}_2} + 2/0.224 \cdot X_{\text{H}_2} + (22/0.224) + (28/0.224) \cdot X_{\text{N}_2} + (16/0.224) \cdot X_{\text{CH}_4} \quad [\text{kg gas/m}^3 \text{ gas}]$$

Gasometer mass of dry non-condensable gases

$$M_{\text{gas}\Delta t} = [273/(T_{\text{gasometer}} + 273)] \cdot P_{\text{gasometer}} \cdot V_{\text{gasometer}} \cdot \rho_{\text{gas}} \quad \quad \quad [\text{kg}]$$

Mean 6 hours Methane mass fraction gas content:

$$P_{\text{CH}_4\Delta t} = (16/0.224) \cdot X_{\text{CH}_4} / \rho_{\text{gas}} \quad \quad \quad [\text{kg CH}_4/\text{kg gas}]$$



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Mean 6 hours Nitrogen mass fraction gas content:

$$P_{N2\Delta t} = (28/0.224) \cdot X_{N2} / \rho_{\text{gas}} \quad [\text{kg N}_2/\text{kg gas}]$$

Final Mass Balance

Total gasometer mass of dry non-condensable gases

$$M_{\text{gas}} = \Sigma M_{\text{cond}\Delta t} \quad [\text{kg}]$$

Total Mass of condensed liquid in condenser

$$M_{\text{cond}} = \Sigma M_{\text{gas}\Delta t} \quad [\text{kg}]$$

Ratio of condensed and non-condensed effluents

$$K_{\text{FU}} = M_{\text{cond}} / M_{\text{gas}} \quad [\text{kg/kg}]$$

Mean Methane mass fraction content of carbonization run

$$P_{\text{CH}_4} = \Sigma P_{\text{CH}_4\Delta t} / \text{NumberAnalysis} \quad [\text{kg CH}_4/\text{kg gas}]$$

Mean Nitrogen mass fraction content of carbonization run

$$P_{\text{N}_2} = \Sigma P_{\text{N}_2\Delta t} / \text{NumberAnalysis} \quad [\text{kg N}_2/\text{kg gas}]$$

Mass of dry non-condensed effluents of carbonization run

$$\text{MNC} = \{M_{\text{DryWood}} (1+W_{\text{db}}) - M_{\text{Charcoal}} - [N_{\text{Wood}} \cdot M_{\text{DryWood}} + N_{\text{Charcoal}} \cdot M_{\text{Charcoal}}] / 0.769\} / [K_{\text{FU}} + 1 + P_{\text{N}_2} / 0.769] \quad [\text{kg non-Cond Gas/run}]$$

Methane emission of carbonization run

$$M_{\text{CH}_4} = P_{\text{CH}_4} \cdot \text{MNC} \quad [\text{kg CH}_4 / \text{run}]$$

Specific emission factor determination

Specific emission factor will be calculated for each run (i) as:

$$SE_i = M_{\text{CH}_4} / Q_{\text{RAW}} \quad [\text{kg CH}_4 / \text{kg of raw material}]$$

A Final Report on the implementation of each step of this protocol shall be presented and attached to the Project Design Document of the respective project activity. The report must contain all data, calculations and conclusions reached as a result of the proposed procedures.

Statistical Treatment

After conducting minimum 8 cycles on each homogeneous family of kilns to be replaced, a conservative statistical treatment of the result is performed in order to calculate the fix emission factor of each family.



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This approach is based on the standard deviation of the sample.

Hypothesis:

- EF_i the Emission factors (kg CH₄ / Kg raw material) obtained for the family k
- SD the standard deviation of the sample of EF_i
- $CV = SD / \text{Average}(EF_i)$

Then EF_k , emission factor of the given family k of kilns, is equal to:

- **Case 1** - If $CV(EF_i) \leq 10\% \rightarrow$ take average of EF_i
- **Case 2** - If $10\% < CV(EF_i) \leq 20\% \rightarrow$ take average of $EF_i \leq Q3$

Where:

Q3 is the third quartile of the distribution of EF_i . The average is over all the values of EF_i that are lower than the third quartile.

- **Case 3** - If $20\% < CV(EF_i) \leq 30\% \rightarrow$ take average of $EF_i \leq Q2$

Where:

Q2 is the second quartile of the distribution of EF_i . The average is for all the values of EF_i that are lower than the second quartile value.

- **Case 4** - If $30\% < CV(EF_i) \leq 40\% \rightarrow$ take average of $EF_i \leq Q1$

Where:

Q1 is the first quartile of the distribution of EF_i . The average is for all the values of EF_i that are lower than the first quartile value.

- **Case 5** - If $CV(EF_i) > 40\% \rightarrow$ take 0 as Emission factor

Once emission factor of each family is calculated, the fixed emission factor $M_{y,b}$ of the baseline is obtained by calculating the weighted average of the various EF of each family (weighted according to the annual production of each family before project implementation).

$$M_{y,b} = \frac{\sum_{\text{family}_k} EF_k \times P_k}{P}$$

Where:

$M_{y,b}$ is the emission factor to be used in the baseline scenario



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EF_k is the emission factor calculated for the family k

P_k is the annual production of the family k.

P is the total production of the kilns to be replaced
