

Roland V. Siemons*, Loek Baaijens

Clean Fuels b. v., Oldenzaal, The Netherlands

An Innovative Carbonisation Retort: Technology and Environmental Impact

Technical paper

South-Eastern Europe is a very large producer of charcoal (200,000-300,000 tonnes/yr). The major part of this amount is produced in traditional ways using kilns. With large emissions to air of unburnt methane and volatile organic compound this technology is very polluting. The first of these is a well known greenhouse gas. This paper introduces a new technology that fully eliminates such emissions. The development of the technology is based on an existing concept of batch retorts that are operated in counter-phase. A heat storage is used to bridge periods of heat shortage, so that large production capacities can be achieved without using support fuels such as diesel oil. The technology is protected by a new patent (2011). The environmental impact of introducing the technology on a large scale is estimated.

Key words: charcoal, carbonisation, emissions, environmental impact, retorting

Introduction: Emissions from charcoal making

In principle, the gaseous products from charcoal making include: non-condensable gases (CO, CO₂, CH₄, and C₂H₆), acids (mainly acetic acid), methanol, ethanol, tars including polycyclic organic matter (POM), and water vapour. The distribution of these constituents varies, depending on the wood types used as feed material, and on process parameters. If combustion would be complete (which it is not), the said products (except CO₂ and H₂O) would be formed into CO₂ and water vapour before leaving the reactor. Because the extent of this combustion varies from plant to plant, emission levels are quite variable. If left uncombusted, tars may solidify to form particulate emissions, acids may form aerosol emissions, and methane is emitted as a severe green house gas.

As part of an air quality programme, the U. S. Environmental Protection Agency (EPA) prepared an number of sets of air pollutant emission factors** for the industry, and this includes the charcoal manufacturing industry [1]. Approximately seven studies were

* Corresponding author; e-mail: siemons@cleanfuels.nl

** An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as in making source-specific emission estimates for areawide inventories for dispersion modelling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations [1]. For each individual emission type averages were prepared over a range of individual processes. Therefore, the EPA data are not suitable to construct a mass balance for a single specific process.

used to form a basis for a set of standard emissions for the charcoal industry. The emission types include: methane, ethane, methanol, CO, non-methane organic compounds (VOC), polycyclic organic matter (POM), N₂O, NO_x, and particulate matter (dust). Whereas the American dataset, which is based on sources dating back to as early as 1967, was focussed on emissions to air of matter that is potentially harmful for human health and nature, a new series of emission studies was carried out a couple of years later, with a primary focus on the global warming potential. Here, methane emissions got the major attention. Some of these studies were carried out for EPA [2] other studies were scientific [3] and again other studies were prepared for projects that were funded through the clean development mechanism (CDM) which is one of the flexibility mechanisms defined in the Kyoto Protocol. The latter studies have ultimately resulted in a baseline methodology concerning the mitigation of methane emissions in the wood carbonization activity for charcoal production [4]. An important justification as to the methodology was given by the CDM financed Plantar project in Brazil [5]. Another relevant source of emission factors are the IPCC guidelines for national greenhouse gas inventories [6]. Table 1 reviews typical emission factors that emerge from the cited literature. The data concern charcoal making by means of batch-operated kilns.

Table 1. Reported emission factors for charcoal making using batch-operated kilns (kg emission/tonne of charcoal)

Emission type	EPA documentation for AP-42 (1995)	IPCC guidelines (1996)*	Pennise, <i>et al.</i> [3], Kenya and Brazil (2001)		CDM Plantar project (data 2003)	
			From	To	Baseline	Project
Methane	54	30	32	62	47.5	34.7
Ethane	26	–	–	–	–	–
Methanol	76	–	–	–	–	–
CO ₂ **	560	–	543	3027	–	–
CO	140	210	143	373	–	–
Non-CH ₄ organic compounds	140	51	24	124	–	–
POM	0.0047	–	–	–	–	–
Particulate matter (dust)	160	–	13	41	–	–

* Recalculated from the cited data, using a calorific value of 30 GJ/t charcoal (this was also assumed by the quoted source)

** This is not the net CO₂ emission from charcoal production, since CO₂ may be captured by biomass growth

The accuracy of these emission factors is much smaller than suggested by the number of digits, the most precise data being provided by Pennise, *et al.* [3], since those data concern an actually measured range. The uncertainty in the emission factors of the Plantar project deserve a special study (which is actually provided in the project docu-

mentation, and is not further analyzed here). The reasons why the data are merely indicative are:

- The processes concerned are manually controlled batch processes, the emissions of which are strongly dependent upon the habits and skills of individual operators.
- The mass unit of charcoal (here tonne), which forms the basis to express the emission factors, is intrinsically vague, since the quality of charcoal varies strongly from one producer to another, or even from one batch to another. A major undefined parameter is the volatile matter content. Antal *et al.* [7] report that charcoal intended for domestic cooking typically contains 20-30% volatile matter (with a value of 40% being marginally acceptable). It is obvious that considerably more emission precursors (vapours) are formed when charcoal is made that contains less volatile matter.

However, one would tend to accept the order of magnitude for the individual compounds as indicative values.

CO₂ is considered to be a major global warming agent. Nevertheless, emissions of CO₂ of charcoal manufacture, although measured in some cases, are not considered very relevant for global warming by the data sources quoted. This is because the assumption made by the researchers cited is that the biomass used for charcoal manufacture is grown sustainably. All CO₂ emitted would be captured again by the returned growth of the biomass involved. The question into what would happen to the carbon already captured, if less wood would be needed for charcoal manufacture as a result of efficiency improvement, is apparently not analyzed. It could be argued, though, that efficiency improvement is a form of carbon capture. We leave this issue aside here, but the potential impact is quite relevant, traditional carbonisation technologies yielding 5-20% charcoal and industrial techniques being capable of producing at least 30% of charcoal out of wood (an improvement of 50-500%).

Carbonisation technologies used

The most wide-spread method of charcoal making, for which the emission factors of tab. 1 apply, is by way of mound or pit kiln (fig. 1). The carbonisation process involves a chemical decomposition of wood at elevated temperatures in the absence of oxygen. Thereby, a high-temperature gas (resulting from combustion) is used to transfer heat to the respective pieces of wood processed one after another from one end of the stacked batch to another. And since inside the kiln,

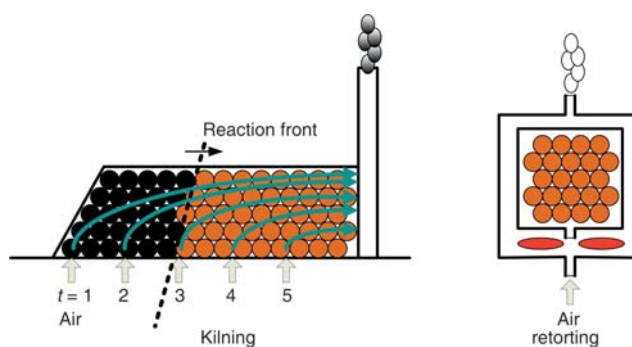


Figure 1. Kilning: Air valves are controlled to provide combustion air at the required periods ($t = 1-5$). Uncombusted vapour cools down on the heating load. The cooled vapour cannot ignite and gives dirty emissions. Retorting: Released vapour is combusted to (1) indirectly provide heat to the load, and (2) to prevent dirty emissions

contact with air is avoided, the gas ultimately emits from the kiln as unburnt smoke. At that point, the temperature of the smoke has decreased to such an extent that it does not ignite anymore. Hence the considerable emissions of a common kilning process (fig. 2).



Figure 2. Smoke emissions from kilning in Madagascar (1992) and Germany (2011)

To raise gas temperatures to the desired level in charcoal kilning, part of the feedstock is offered as a fuel. This is not the case with retorting, which is the usual alternative to kilning. By means of a retort, the process vapours are separated from the raw material, before being combusted to generate process heat (see fig. 1). Here, only the vapours are used to provide the energy sustaining the process. In this manner it is ensured that the entire raw material is available for conversion into charcoal. Therefore, the yields of charcoal from retort processes are the highest technically achievable.

Kilning is the mostly wide-spread technology to manufacture charcoal, all over the world, across all continents. Clean Fuels estimate that 85% of the charcoal manufacturing capacity throughout Europe consists of kilning processes. For SE Europe we estimate this level at 95%. Virtually nothing changed in the carbonisation technologies employed since centuries.

Emissions from charcoal making in Europe

Whereas the 2009 worldwide production of charcoal is estimated at 49 million t/a (FAOStat), the 2009 European production is estimated at 530,000 t/a. The production in SE Europe varies between 210,000-310,000 t/a. In these statistics for SE Europe, the following countries are included: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Greece, Hungary, Montenegro, Romania, Serbia, Slovakia, and Slovenia. The end-user value of the sector is more than € 500 million/a in the EU27, and more than € 215 million/a in SE Europe. We use the EPA emission factors to estimate emissions from this production, see tab. 2.

Emission caps made possible by a heat-buffered batch retort

A relevant technology improvement was developed by Reumerman *et al.* [8] in The Netherlands. The process involves two retorts in which two separate batch-wise

Table 2. Estimated of regional emissions, based on 2009 charcoal production data and EPA emission factors

	EU27	SE Europe
Charcoal production [t per year]*	500,000	214,000
Of which kilning (estimate)	85%	95%
= (t charcoal)*	425,000	203,000
Emission (t*), kilning only:		
Methane (only)	23,000	11,000
Global warming potential (on CH ₄)**	483,000	231,000
Methane, ethane + methanol	66,000	32,000
CO	60,000	28,000
Non-CH ₄ OC	60,000	28,000
POM	2	1
Particulate matter (dust)	68,000	32,000

* Source: FAOStat

** The equivalence of 1 t of CH₄ is 21 t of CO₂

carbonisation cycles are executed. Each cycle consists of an endothermic phase during which the retort needs to be heated from outside, and an exothermic phase during which the retort releases energy in the form of a combustible gas and vapour mixture. This mixture is combusted in a central furnace. The cyclic process of two retorts should be operated in counter-phase, whereby the exothermic phase of one retort provides the heat needed by the other retort which is in an endothermic phase (fig. 3).

A major step forward was that a retorting process was implemented as a batch process. Batch processes are known to be considerable simpler than continuous processes: less vulnerable, less difficult to control, and ultimately less expensive. This is relevant, because retorting is intrinsically more efficient than kilning, and, unlike kilning, retorting enables the controlled combustion of all volatile and gaseous matter yielded by the carbonisation process.

A difficulty that remained to be solved was that the exothermic phase and the endothermic phase of the retorting cycles are not usually in balance. The overall energy balance is not a problem (over the entire production cycle, the total heat released from combusting the process gases and vapours is more than enough), but rather the instantaneous energy balance: During a large proportion of the heating phase of a retort, the instantaneous heat demand is larger

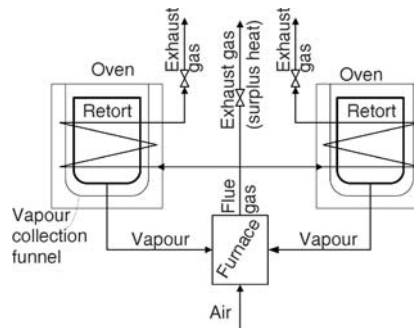


Figure 3. Flow sheet of a counter-phase batch retorting system

than the instantaneous heat provision based on the gases and vapours released by the other retort. An imbalanced heating phase and processing phase with the design reported in [8] mainly occurs when moisture contents of the feed material varies or is generally high. Users of the reported system [8] solve this problem by providing additional support fuel (diesel oil), so as to meet the rated capacity of their equipment.

Clean Fuels solved this problem by incorporating a heat storage buffer in the carbonisation system. At periods during which the exothermal processing phase of one retort generates more heat than required by another retort, the heat is stored in a heat buffer. When there is an instantaneous requirement for process heat which cannot be supplied by any retort, the stored heat is used. Worldwide a patent is applied for under the PCT treaty to protect this idea of energy provision to a retorting process.

The emissions resulting from a central furnace combusting the gases and vapours were measured. In tab. 3 they are compared with those that are reported by EPA.

Table 3. Emission factors for charcoal making (kg emission/tonne of charcoal)

	EPA Documentation for AP-42	Clean Fuels Carboniser*
Methane (only)	54	n. a.
Methane, ethane + methanol	156	0.03
CO ₂	560	5860
	Neutral re. global warming in case of sustainably grown wood	
Global warming potential (on CH ₄ only)**	1134	<0.68
CO	140	0.19
Non-CH ₄ OC	140	0.03
POM	0.0047	0.00032
Particulate matter (dust)	160	0.029

* Calculated from Promonitoring [9], which provides emission flows [g/h]. Parameters used for expressing the data as kg/t of charcoal: wood load [kg/cycle], charcoal yield [kg charcoal/kg of wood], cycle duration

** Assuming sustainably grown wood. The equivalence of 1 t of CH₄ is 21 t of CO₂

With regard to all emission factors considered (but irrespective of CO₂)¹, the reductions are phenomenal (15 times for POM, 750 times for CO and in the order of 5000 times for other emissions). For the Clean Fuels Carboniser, methane is not reported as a single emission. Rather, it is reported together with other alkanes (C_xH_y). Therefore, the methane emission reduction is larger than 53.97 (54-0.03) kg/tonne of charcoal if kilns are replaced by the proposed retorting process. (We calculate conservatively by deducting from the standard methane emission reported. The total emission of methane, ethane+methanol for the Clean Fuels Carboniser are calculated by EPA.

The emission reduction is found for the case of full replacement of all kilning processes through Europe (tab. 4).

¹ Formation of CO₂ is the unavoidable by-product of complete combustion of carbon compounds. The emission of CO₂ from the Clean Fuels Carboniser is in accordance of complete combustion of all carbon released as vapour from the carbonisation process. In other words, the mass balance is largely closed

Table 4. European emission reduction potential by employing charcoal retorting technology

Current technology	Current technology		If kilning replaced by heat-buffered batch carboniser			
	EU27	SE Europe	EU27	SE Europe	Saving EU27	Saving SE Europe
Charcoal production [t per year]*	500,000	214,000	–	–	–	–
Of which kilning = (t charcoal)*	85% 425,000	95% 203,000	–	–	–	–
Emission (t*)						
Methane (only)	23,000	11,000	14	7	23,000	11,000
Global warming potential (CO ₂ eq.) of methane only*	483,000	231,000	289	138	483,000	231,000
Methane, ethane + methanol	66,000	32,000	14	7	66,000	32,000
CO	60,000	28,000	80	38	60,000	28,000
Non-CH ₄ OC	60,000	28,000	14	7	60,000	28,000
POM	2	1	0.14	0.07	1.9	0.9
Particulate matter (dust)	68,000	32,000	12	6	68,000	32,000

* The equivalence of 1 t of CH₄ is 21 t of CO₂

Conclusions

At a unit value of € 15 /t CO₂, the value of emission reduction (if considering curbing of methane emissions only) amounts to approximately € 7.2 million and € 3.5 million annually for the EU27 and SE Europe. Under a discount rate of 10% and assuming a project duration of 15 years, these values represent a net present value (or an investment) of € 55 million and € 26 million respectively. On the basis of a single production unit with a capacity of 1000 t of charcoal per year, the NPV (net present value) represents € 130,000 (under the same economic assumptions). This is quite a relevant amount in view of the investments of such a system.

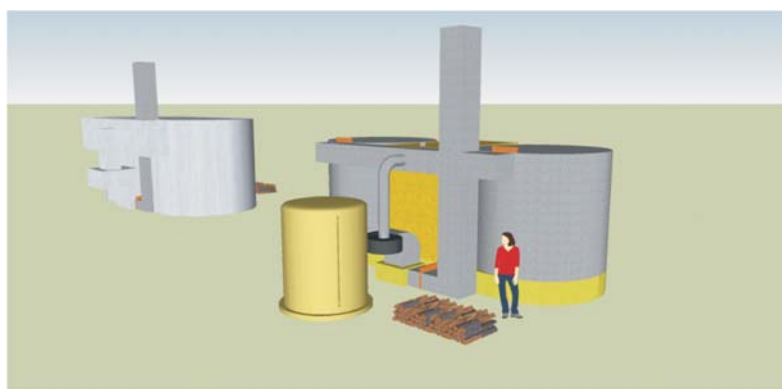


Figure 4. Two heat-buffered batch retorts. Capacity >1000 t charcoal* each

* The equivalence of 1 t of CH₄ is 21 t of CO₂

References

- [1] ***, EPA, Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Office of Air Quality Planning and Standards, 1995, www.epa.gov/ttn/chief
- [2] Smith, K. R., *et al.*, Greenhouse Gases from Small-Scale Combustion Devices in Developing Countries: Charcoal-Making Kilns in Thailand, for EPA, Washington DC, 1999
- [3] Pennise, D. M., *et al.*, Emissions of Greenhouse Gases and other Airborne Pollutants from Charcoal Making in Kenya and Brazil, *J. Geophysical Research*, 106 (2001), 24, 143-155
- [4] ***, IPCC, Approved Baseline and Monitoring Methodology AM0041, Mitigation of Methane Emissions in the Wood Carbonization Activity for Charcoal Production, AM0041/ Version 01
- [5] ***, RS Consultants, Plantar Project: Emissions at the Carbonization Stage, Final Report, 2003
- [6] ***, IPCC, Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual (Volume 3)
- [7] Antal, M. J. Jr., Gronli, M., The Art, Science, and Technology of Charcoal Production, *Ind. Eng. Chem. Res.*, 42 (2003), 8, 1619-1640
- [8] Reumerman, P. J., Frederiks, B., Charcoal Production with Reduced Emissions, 12th European Conference on Biomass for Energy, Industry and Climate Protection, Amsterdam, 2002, [www.cleanfuels.nl/Projects & Publications/Charcoal Production with Reduced Emissions \(paper\).pdf](http://www.cleanfuels.nl/Projects & Publications/Charcoal Production with Reduced Emissions (paper).pdf)
- [9] ***, Promonitoring, Emission Research on an Installation for the Preparation of Charcoal, Available at Clean Fuels, 2000

Апстракт

Роланд В. СИМОНС*, Лук БАЈЈЕНС

Иновативне посуде за карбонизацију: Технологија и утицај на околину

Регион југоисточне Европе је велики произвођач ђумура (200.000–300.000 тона годишње). Највећи део ове производње се одвија у пећима на традиционалан начин. У току овог процеса се ослобађа велика количина несагорелог метана, једног од главних гасова стаклене баште, и других испарљивих компонената што ову технологију сврстава у велике загађиваче.

У овом раду је представљена технологија која потпуно елиминише ове емисије. Развој ове технологије је заснован на постојећем концепту напуњених посуда које раде у контра фази. Складиште топлоте се користи да премости периоде у којима нема довољно енергије за процес, тако да велике количине могу бити произведене без коришћења додатног горива као што је то мазут или дизел гориво. Технологија је заштићена патентном документацијом 2011. године. Утицај ове технологије на околину је процењен у овом раду.

Кључне речи: ђумур, карбонизација, емисија, утицај на околину, реторте

* Одговорни аутор: електронска адреса: siemons@cleanfuels.nl

Paper submitted: May 3, 2012

Paper revised: August 03, 2012

Paper accepted: November 21, 2012