Pedosphere **25**(5): 696–702, 2015
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Production of Biochar for Soil Application: A Comparative Study of Three Kiln Models

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(Received March 2, 2015; revised July 22, 2015)

ABSTRACT

Biochar has potentials for soil fertility improvement, climate change mitigation and environmental reclamation, and charred biomass can be deliberately incorporated into soil for long-term carbon stabilization and soil amendment. Many different methods have been used for biochar production ranging from laboratory to industrial scales. However, in countryside of developing countries, biomass is generally used for cooking but not charred. Biochar production techniques at farmer scale have remained poorly developed. We developed and tested biochar production kilns for farmers with a dimension of 50.8 cm × 38.1 cm (height × diameter), using three different setups for optimizing oxygen (O_2) limitation and syngas circulation: airtight with no syngas circulation (Model I), semi-airtight with external syngas circulation (Model II) and semi-airtight with internal syngas circulation (Model III). A comparative assessment of these biochar production kiln models was made considering biochar pyrolysis time, fuel to biomass ratio, biochar to feedstock ratio and thermogravimetric index (TGI). Among the models, the best quality biochar (TGI = 0.15) was obtained from Model I kiln taking the longest time for pyrolysis (12.5 h) and the highest amount of fuel wood (1.22 kg kg^{-1} biomass). Model III kiln produced comparatively good quality biochar (TGI = 0.11), but with less fuel wood requirement (0.33 kg kg^{-1} biomass) and shorter pyrolysis time (8.5 h). We also tested Model III kiln in a three times larger size under two situations (steel kiln and pit kiln). The biochar to feedstock ratio (0.38) and quality (TGI = 0.14) increased slightly for the larger kilns. Quality of biochar was found to be mainly related to pyrolysis time. The costs for the biochar stove and pit kiln were US$ 65–77, while it was US$ 154 for the large size steel kiln. Model III kiln can potentially be used for both cooking and biochar production at farmer scale.

Key Words: biomass, farmer scale, feedstock, fuel wood requirement, O_2 limitation, pyrolysis time, syngas circulation, thermogravimetric index

Citation: Mia S, Uddin N, Mamun Hossain S A A, Amin R, Mete F Z, Hiemstra T. 2015. Production of biochar for soil application: A comparative study of three kiln models. *Pedosphere*. **25**(5): 696–702.

INTRODUCTION

Biochar is pyrolyzed biomass and meant for soil application and environmental gain (Lehmann and Joseph, 2009; Sohi *et al.*, 2010; Ippolito *et al.*, 2012). Biochar technology is considered to be a sustainable technology as it has several potential benefits. After soil application, it mitigates climate change effects by sequestering carbon to soil ranging from decades to thousands of years (Budai *et al.*, 2013). It increases soil fertility and crop yield (Major *et al.*, 2010; Jeffery *et al.*, 2011; Peng *et al.*, 2011). It has a high surface area and thus traps environmental pollutants (Beesley *et al.*, 2011; Kookana *et al.*, 2011; Jiang *et al.*, 2012). Bioenergy is also generated during pyrolysis. Furthermore, biochar technology contributes to a sustainable use of waste if it is used as feedstock. However, there is a tradeoff among the potential benefits (Jeffery *et al.*, 2015). Low-temperature biochar with a considerable labile part (Spokas, 2010; Mukherjee and Lal, 2013) may contribute to short- to medium-term agricultural benefits. In addition, in developing countries as in the case of Bangladesh where farm families almost completely rely on biomass for cooking, biochar technology can be utilized for harvesting heat energy for cooking while getting biochar for agricultural application (Mia *et al.*, 2014). For this purpose, a suitable biochar kiln design is needed.

Considering the positive effects of biochar, biochar research and extension initiatives have been launched

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all over the world: for example, the US Biochar Initiative (http://biochar-us.org/biochar-research), the UK Biochar Research Center (www.biochar.ac.uk/list_of_projects.php), the Australia New Zealand Biochar Research Network (www.anzbiochar.org/project.html), the European Biochar Research Network (cost.european-biochar.org/en/members), the China Biochar Network (http://www.biochar-international.org/chinanetwork), the Japan Biochar Association (http://www.geocities.jp/yasizato/JBA.htm) and the Biochar India (www.biocharindia.com). Simultaneously, high-tech biochar production plants have been developed in many countries, for example, the Pacific Pyrolysis Pty. Ltd. (Somersby, Australia), the Pyreg GmbH (Dörth, Germany) and the Biomass Technology Group BV (Enschede, Netherlands). Most of the research and extension of biochar was based on either laboratory- or industry-produced biochar (Duku *et al.*, 2011).

Biochar production at farmer scale is claimed to be more profitable than industrial production (Clare *et al.*, 2014). Recently, biochar production at farmer scale has also been started: for instance, the Biochar Project in Australia (http://biocharproject.org) and the Maya Mountain Research Farm Update: Pig and Biochar (http://permaculturenews.org/2012/06/06/maya-mountain-research-farm-update-pigs-and-biochar). Small-scale biochar production techniques have been widely described in various YouTube videos as well as in biochar blogs such as www.biochar.info and international biochar initiatives. Description of this technology with pictures can be found in the literature (Anderson, 2010; Duku *et al.*, 2011). Although charcoal has been produced traditionally for a long time (FAO, 1983) and recent efforts for promotion of biochar in different countries have been made, the traditional biochar production techniques at farmer scale have not been updated as they have been for industrial production. In fact, there is hardly any study giving description of design of the kiln along with information about productivity and quality of biochar.

While biomass is pyrolyzed at farmer scale, restriction of biomass exposure to oxygen (O_2) but generation of sufficient heat for pyrolysis is a big challenge. The quality of biochar depends on how efficiently these factors are optimized. Here, we tested three biochar production kiln models in respect of productivity and quality under variable O_2 limitations and effectiveness of syngas utilization for further heat generation during pyrolysis. For reference, we also compared the quality of kiln-produced biochar with that of laboratory-produced biochar.

PRINCIPLES OF BIOCHAR PRODUCTION

Pyrolysis differs from burning of biomass to ash in respect of production conditions. One of the predominant factors for the differences is the presence or absence of O_2. When biomass is heated in the presence of O_2, most of carbon is released as carbon dioxide (CO_2) and part of the minerals of the biomass are left as ash. In contrast, when the biomass is heated in the absence of O_2, molecular condensation occurs within the hydrocarbon material, leading to graphitization and carbonization (Sevilla and Fuertes, 2009; Manara and Zabaniotou, 2012). A considerable part of the initial carbon (around 50% depending on pyrolysis conditions) remains in the carbonized materials (Lehmann *et al.*, 2006). During this process, heat is generated and the feedstock releases syngas, a mixture of carbon monoxide (CO) and hydrogen (H_2) (Maag and Steinfeld, 2010). This heat and syngas might be reused for pyrolysis or other purposes, for example, cooking if it is a small kiln or electricity generation if it is a big kiln. During pyrolysis, the chemical structure of the feedstock changes, yielding char rich in aromatic carbon (Laine, 2012). The degree of aromaticity predominantly depends on heating temperature and heating rate (Mašek *et al.*, 2013). Therefore, production of biochar requires a heat source for converting biomass into biochar while limiting biomass access to O_2. Considering this basic principle, biochar is usually produced for research in a furnace oven under controlled conditions. For the laboratory production of biochar, the feedstock is wrapped with aluminum foil and placed in a furnace oven which is continuously flashed with N_2 gas to limit O_2 supply (Fig. 1). In practical production processes, the challenge is extracting heat while sufficiently producing biochar of high quality.

KILN DESIGN AND BIOCHAR QUALITY ASSESSMENT

Kiln design

A two-barrel biochar kiln of 50.8 cm × 38.1 cm (height × diameter) was developed using a metal steel (MS) sheet. The kiln consisted of five parts: i) inner chamber, ii) outer chamber, iii) cover, iv) kiln stand and v) cooking stand (Fig. 2). The inner chamber with a diameter of 12.7 cm was designed for generation of heat to pyrolyse the biomass placed in the outer chamber. The inner chamber was made with a thicker MS sheet (5 mm) as it would melt by heat generated from both of the chambers. It was permanently fixed to the