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Holistic approach to improve the energy utilization of *Jatropha curcas* L

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Abstract

Novel holistic approach to the energy utilization of *Jatropha curcas* L. is easily adaptable to other similar oil crops is presented. The novelty of the approach consists from deshelling, mechanical grinding and especially hot maceration followed by pressure shockwaves. The pressure shockwaves (50 up to 60MPa) were generated by the underwater high voltage discharges (3.5kV, 4W) which caused the rapid expansion of water plasma bubble. The subsequent deep intracellular disintegration increased the oil yield by 11.6% and methane yield from the seedcake by 27.4%. In addition it is proposed to utilize the hot flue gases of 490°C from the combustion engine at the cogeneration unit linked to the biogas station to charcoal the fermentation residue. This way was succesfully obtained biochar for soil enrichment, heating or other purposes.

Keywords: *Jatropha curcas* L., oil, biogas, charcoal, shockwaves.

Enfoque holístico para mejorar la utilización de la energía de *Jatropha curcas* L

Resumen

Se presenta enfoque holítico de la utilización de la energía de *Jatropha curcas* L., fácilmente adaptable a cultivos similares. El enfoque consiste de molimiento y maceración caliente, seguida por ondas de choque de presión generadas con altas descargas de tensión, en condiciones de agua. Así la desintegración intracelular aumenta el rendimiento de aceite en un 11,6% y el rendimiento de metano a partir de la torta de prensa en un 27,4%. Además, se propone utilizar los gases calientes de combustión de 490°C del motor de combustión a la cogeneración y el residuo de la fermentación para la producción de carbón vegetal.

Palabras clave: *Jatropha curcas* L., aceite vegetal, biogás, carbón, ondas de choque.

Introduction

Pressure shockwaves generated by the underwater high voltage discharges presents a new promising method of *Jatropha curcas* L. seeds disintegration to enhance oil extraction for biodiesel production [1, 2]. However, the electricity demands may hamper the use of this technique especially in developing countries, where the crop is mostly grown [3]. Also the seed cakes soaked with methanol are problematically utilizable [4-6]. Replacement of solvents by enzymes failed to establish [7-9]. Holistic approach of energy utilization, may provide additional energy [10-18], however, multiple pretreatment [19] or sophisticated techniques of anaerobic fermentation [20] can be hardly applied because of excessively high costs or high energy demands.

It was hypothesized that it would be more sustainable to replace the methanol (liquid carrier of the pressure shockwaves, solvent for oil extraction, alcohol for esterification) by water. This would limit the advantage of multiple use of methanol, however it will unblock further utilization of the seed cakes (methane and charcoal). In addition it was hypothesized that the hot flue gases from the combustion engine (490°C) used for electricity production from the biogas may be utilized for carbonization of the digested seed cakes as a substrate for improving soil of attributes (biochar) or spare energy resource (charcoal).

Material and methods

Substrate properties

The *Jatropha curcas* L. seeds were obtained from central Thailand, province of Nakorn Patom. After the harvest in 2010, the seeds were dried and stored in an opened perforated plastic bag in a dry and a shady place. Weight per 1,000 seeds: 622,3 g; bulk laid: 355 g L^{-1}; total solids (TS): 92,3%, 21,193 MJ kg^{-1}, labile pool 1 of carbon 16,1%, labile pool 2 of carbon 24,9%, recalcitrance pool of carbon 59%. The husks represented 44,3% of the TS (15.207 MJ kg^{-1}), while the kernels with vacuoles rich in oil represented the main proportion of the heating value (25,954 MJ kg^{-1}). Fresh manure (pH: 6,83, bulk laid: 1,26 kg L^{-1}, TS: 24,5%) from stabled cows on a grass and hay diet was used as inoculate for anaerobic fermentation of the seedcake.

Chemicals

A 90% sulfur acid (Wako, Japan) was used for determining the pools of carbon. 99,7% hexane and 99,7% 2-propanol were used as solvents in analysis by Soxhlet extractor (Wako, Japan).

Seeds pretreatment

The dried seeds of *Jatropha* were grounded by 20 g for 20 s in 80 mL of 70°C water using the crusher (IFM-800, Osaka Chemical) and strained into the 200 mL plastic bottles. The grounded seeds were macerated in the bottles for 48 hours in 70°C using the temperature control unit (CU-120, Sibata) and covered 200 L water bath (BZ-200, Yamato). Subsequently the bottles with the content (Fig. 1) were one by one exposed to a series of 5 pressure shockwaves (50 to 60MPa) caused by underwater high voltage discharges

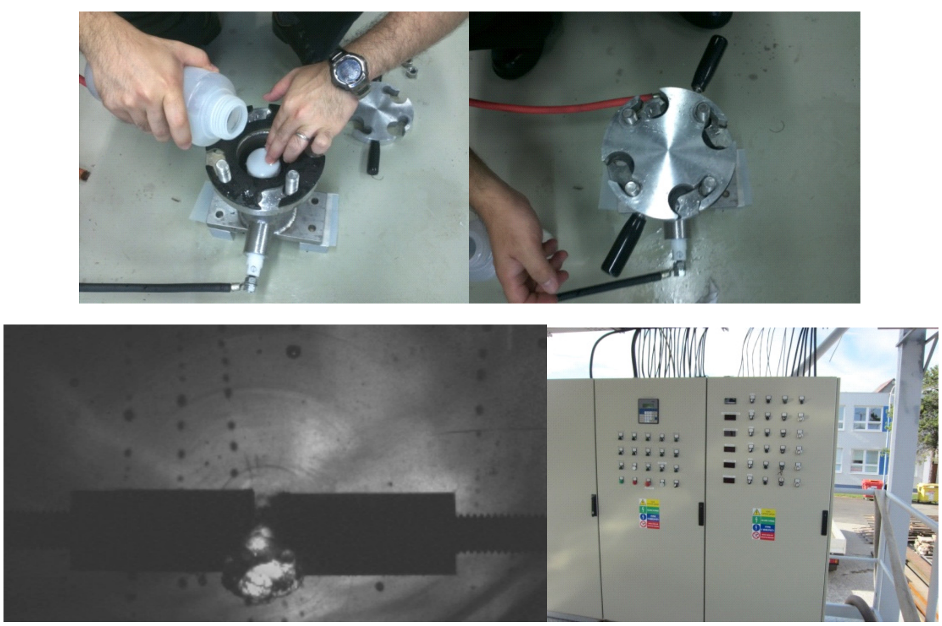

Figure 1. The used equipment. 1: filling of the pressure shockwave apparatus, 2: locking of the pressure shockwave apparatus, 3: the high-voltage generator, 4: slow motion of the underwater high-voltage discharge followed by the pressure shockwaves.

(3.5 kV) in lockable strengthened metallic vessel [1] according to developed method [2].

Oil expression

Oil expression was performed by a computer-controlled molding machine (D02, Marutani) with a 19.6 cm^2 free piston as described in [2].

Anaerobic fermentation

The 50 g seed cake residues were subjected to 5 s of grinding in a Labo Milser IFM-800 crusher to loosen the pellet from the molding machine. The grounded seedcakes were inoculated 4:1, (seedcake to cow manure by TS) and diluted to 10% of TS to respect common biogas power plant operating conditions. Obtained mush was sealed in FV801 (Hakko, Japan) 1,000 mL plastic bags with already sealed plastic outlet leading to inverted measuring cylinders (submerged in diluted H2SO4, pH = 2), which allowed observation of the quantity of the biogas. The quality was analyzed by 350-XL gas measuring system (Testo, Japan), while only methane and carbon dioxide were taken into account after conversion to 0°C and 101,325 Pa. The anaerobic fermentation was carried out for 30 days in 200L water bath (BZ-200, Yamato), while the temperature control unit (CU-120, Sibata) slightly shacked the plastic bags by stream of 35, 40 or 45°C water.

Charcoal

The fermented residue was drained to approximately 60% of TS using the constant temperature oven (FSS-S, Hirasawa) and charcoaled (total carbonization time 5, 4, 3, 2 and 1 hours, while initial 30 minutes from 20°C to 65°C, rest in 490°C, to respect the flue gases characteristics, 4L N2 per minute), in a prototype kiln (Meiwa Co., Kanazawa, Japan). The energy density of the charcoal was calculated using computer-controlled molding machine (D02, Marutani) with a 19.6 cm^2 free piston as described in [2] and auto-calculating bomb calorimeter (CA-4AJ, Shimadzu).

Analytical methods

TS were determinated according to method developed by the USEPA (2001) using constant temperature oven (FSS-S, Hirasawa) and electronic weighing scales (AUX 320, Shimadzu). The heat values were determinate using auto-calculating bomb calorimeter (CA-4AJ, Shimadzu). The proportions of the pools of carbon were determined by the acid hydrolysis (H2SO4) approach according to [21] modified by [22] using the automatic high sensitive N/C analyzer (NC-90A, Shimadzu). The oil residue in the seedcake was determined by 24 hours Soxhlet extraction in 65°C using 50 mL of hexane and 50 mL of 2-propanol per extraction.

Results and discussion

Reviewed papers [12, 23] state in agreement that the oil yields of mechanical extraction methods are in the range of 62.5 to 80%. According to the Soxhlet extraction molding released from our sample 75.6 ± 5.5% oil. Maceration and pretreatment (pretreatment by grinding in hot water at 70°C followed by 48 hours of hot maceration at 70°C and 5 pressure shockwaves of 50-60MPa) resulted in increase of the yield to 87.2 ± 1.2% (Fig. 2, both n = 6, α = 0,05). We assume that this mechanism can be explained as follows: 1) underwater grinding allows deeper penetration of the water into the seeds allowing the pressure shockwaves to be transmitted more effectively, 2) warm maceration coagulates the protein and weaken the cell walls, 3) the pressure shockwaves ruptures the vacuoles rich in oil, 4) the leaking oil is not soaked back into the husk capillaries while they are already supersaturated by water.

Beyond that, anaerobic fermentation of the pretreated seed cakes (pretreatment by grinding in hot water 70°C followed by 48 hours of hot at 70°C maceration and 5 pressure shockwaves of 50-60MPa) resulted in 107.7 ± 15.0 m^3 CH_4 t^{-1} TS at 40°C and 124.6 ± 12.7 m^3 CH_4 t^{-1} TS at 50°C in comparison to 84.5 ± 13.5 m^3 CH_4 t^{-1} TS at 40°C and 102.3 ± 10.0 at 50°C from seed cakes without pretreatment (Fig. 3, all n = 6, α = 0.05).

Some autors [14] achieved 358 and 309L of biogas kg^{-1} TS with 66% of CH_4, other autors [24] achieved 220 up to 250L of biogas with CH_4 content from 65 to 70% kg^{-1} and other autors [20] state 355L of biogas containing 70% kg^{-1} chemical oxygen demand, while running the anaerobic fermentation by the technology of upflow anaerobic sludge blanket. Results achieved by our trial are not surprising because the effect of reduced parti-

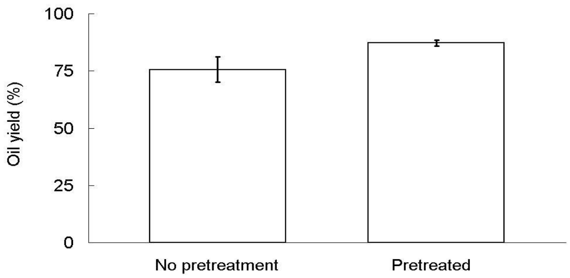

Figure 2. Oil yield.

cles size on biogas yield was many times observed [25, 26]. Also higher level of labile carbon 2 pool degradation (64.2 ± 7.5 for 40°C, 73.1 ± 4.7% for 50°C of pretreatment by grinding in hot water followed by 48 hours of hot maceration and 5 pressure shockwaves of 50-60MPa in comparison to 49.7 ± 9.9% and 55.4 ± 13.9% for 40°C without pretreatment (Fig. 4., both n = 6, α = 0.05), supports the hypothesis that the pretreatment including the pressure shockwave has also potential to intensify the process of anaerobic fermentation.

The energy value of the seedcake charcoal was detected 22.3 ± 0.0 $MJ.kg^{-1}$ (Fig. 5, n = 6, α = 0.05), for all variants (pretreated, without pretreatment, regardless the temperature of anaerobic fermentation) which is in close agreement to review done [10]. However, the energy density of the charcoal increased with pretreatment (6.4 ± 0.1 $MJ.L^{-1}$ for anaerobic fermentation in 40°C, 6.7 ± 0.1 $MJ.L^{-1}$ for anaerobic fermentation in 50°C, both n = 6, α = 0.05) in comparison to no pretreatment (5.9 ± 0.3 $MJ.L^{-1}$ for anaerobic fermentation in 40°C, 5.9 ± 0.1 $MJ.L^{-1}$ for anaerobic fermentation in 50°C, both n = 6, α = 0.05). We assume this is due higher proportions of energy-valuable lignin and crystalic cellulose (recalcitrance pool of carbon) grown up over less energy-valuable components like amorphous cellulose or hemicellulose (labile pools of carbon).

The charcoal yield is in the range of 2-42% [27]. Other autors [12] state that 70-80% of wood energy is lost with yield of only 30% in an industrial process, while *Jatropha* wood is a very light wood and it burns too rapidly. Using external heat did not result in any notable material loss (Fig. 6).

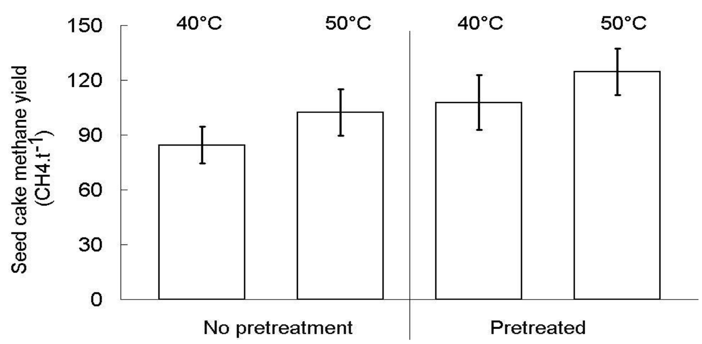

Figure 3. Seed cake methane yield.

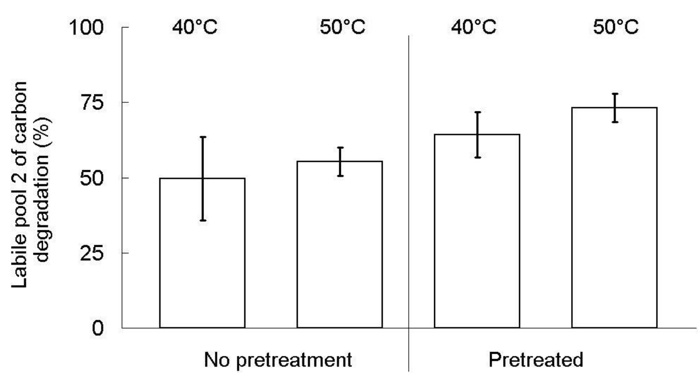

Figure 4. Labille pool 2 of carbon degradation.

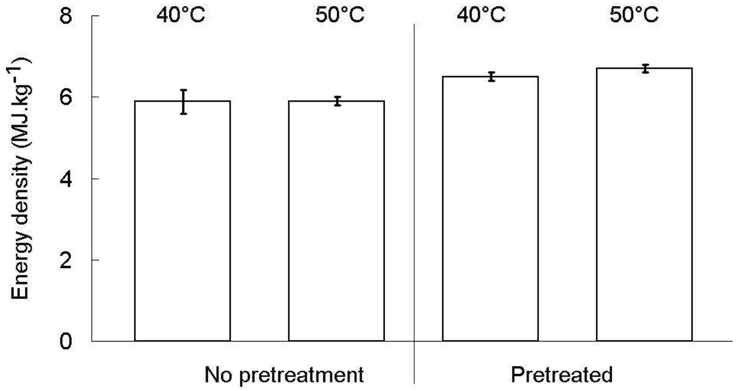

Figure 5. Energy density.

Figure 6. The used equipment and biochar. 1: the commercial scale charcoal kiln, 2: the charcoaled substrate.

Conclusion

The presented holistic approach of *Jatropha curcas* L. energy utilization manifested in several impacts. The intensive pretreatment enabled higher oil yield, higher methane yields from the seedcake and higher energy density of the charcoal. It was also proved that the temperature (490°C) from the hot flue gases of the combustion engine is high enough for charcoal production from the fermentation residue.

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