Industrial Crops and Products 53 (2014) 1–5

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Novel technique to enhance the disintegration effect of the pressure waves on oilseeds

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ARTICLE INFO

Article history:
Received 11 September 2013
Received in revised form
22 November 2013
Accepted 26 November 2013

Keywords:
Oilseeds
Oil extraction
Water plasma
Pressure wave transmission

ABSTRACT

A novel technique for continuous disintegration of oilseeds was designed. The operating principle consists of gasification of deshelled oilseeds mash using small amounts of gas. These were subsequently subjected to the pressure waves generated externally by underwater high-voltage discharges, which are then followed by expansion of the water plasma. It was observed that gasification using small amounts of gas may enhance the destruction effects of the edges of the pressure waves, resulting in deeper lignocellulose disintegration. Breakage of the cell walls increased the level of oil extraction from oil-rich vacuoles up to 93% and also accelerated the subsequent anaerobic fermentation of the presscake residue.

1. Introduction

The phenomena of the underwater high-voltage discharges have been already mentioned in the literature (Ammar et al., 2010; Grémy-Gros et al., 2009). The mechanism of the discharge, more specifically the subsequent formation of the water plasma, is not fully understood yet (Lee et al., 2003). It was observed that the expansion of water plasma bubbles is accompanied by ultrasound, heat and radical species, ultraviolet radiation and most importantly by countless pressure waves (Higa et al., 2012). There are known proposals on how to use these phenomena in rock, especially mineral disintegration applications (Money, 2011). Admittedly, the structure of phytomass is diametrically different. Moreover, hundreds of kV needed for rock excavation would undermine the economy of phytomass utilization. Anyway, tens of kV needed for sewage water treatment are not practical (Lee et al., 2003). Notwithstanding high energy demands, its commercial use in wastewater treatment is so far hindered by many design constraints. For example, the electrodes embedded in the process liquid release metallic nanoparticles from its surface during the high-voltage discharge and these act as inhibitors in the pretreated liquid. In addition, the conductivity, as well as other physical parameters of the wastewater, is variable. Therefore, the dynamics of the plasma formation, especially the following pressure waves, differs. Also, placing the electrodes into the pretreated substrate makes them susceptible to coating and eventually less effective, which brings difficulties linked with their replacement.

The first low-energy-consuming (3.5 kV, 2.2 W per discharge) prototype for phytomass disintegration overcoming most of the above mentioned shortcomings has been described recently (Higa et al., 2012). Admittedly, repeated discharge (up to 10 times) was needed to achieve significant effect on the level of phytomass disintegration. It is desirable to improve the performance of the apparatus. This could be easily achieved by increasing the voltage, repetition rate of the discharge or other electrochemical engineering work. Unfortunately, such procedures increase the energy demands. The hypothesis questioned whether gentle gasification (forming of multi-stage process fluid) of the pretreated substrate may enhance the effect of disintegration by intensifying the disintegration impact of the pressure waves without substantially increasing energy demands.

2. Materials and methods

Oilseeds of *Jatropha curcas* L. (cultivar Jmax 100) were obtained from Bamako (Mali), harvest of 2012 (fresh seeds: 608.3 ± 17.5 g per 1000 seeds, 355.6 ± 10.9 g L^{-1} volatile solids (VS) 90%, heating value 15.408 ± 0.07 MJ kg^{-1}, where $n = 20$, P^*). The seeds were cleaned using the JSE7 desheller (HDEM Ltd., China). The deshelled seeds were diluted into pumpable mash (10% VS) and gently gasified with different doses of carbon dioxide using a couple of PCFT-33 microporous ceramic filter tubes (XINTAO Ltd., China). Subsequently, the gasified mash was subjected to the continuous pressure wave apparatus (Fig. 1). The mechanism of the apparatus is as follows: 3.5 kV discharges are brought into strengthened metallic vessel filled

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0926-6690/$ – see front matter
http://dx.doi.org/10.1016/j.indcrop.2013.11.048

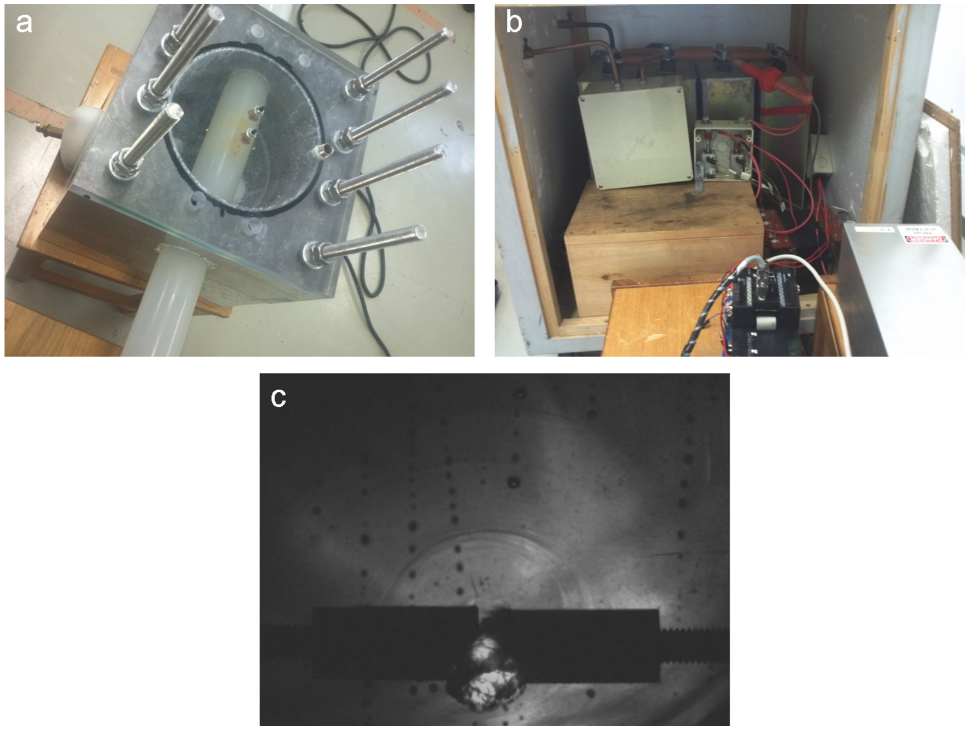

Fig. 1. Apparatus for continuous pretreatment by pressure waves (A) consists from a tube for the flow of the pretreated mash and surrounding metallic vessel where the underwater high-voltage discharges are performed. Capacitors for generating the high-voltage discharge (B). Expansion of the water plasma is followed by formations of pressure waves (C).

with water; these discharges form bubbles of water plasma; rapid expansions of the water plasma cause 50–60 MPa pressure waves which collide in the aquatic environment; biomass is exposed to these pressures shock disintegration 7 L min^{-1}, 3 discharges L^{-1}. The mash was decanted into approximately 40% VS and expelled using the UNO single screw press (Farmet, a.s., Czech Republic) operating at its maximum performance. The level of disintegration was measured by TriStar3000 surface area analyzer (Micromeritics Ltd., Japan) using the helium gas adsorption technique (after 24 h of degassing at 200 °C and 1 h of degassing at 300 °C). The oil yields were calculated from the presscake residue using Soxhlet extractor (Wako, Japan, 50 mL of hexane and 50 mL of 2-propanol were used every day at 65 °C extraction). The presscakes were subsequently inoculated (1:20, inoculate to substrate in VS) with fresh manure (cows on maize silage diet), which was diluted to 5% VS. The mixture was anaerobically fermented in S2 automatically monitored semi-continuous batch reactors (Stix s.r.o., Czech Republic) as described in Maroušek et al. (2012).

3. Results and discussion

Inexpensive increase in the oil yield is one of key prerequisites for the increased profitability of biodiesel production from all oily crops (Lim and Teong, 2011; Achten et al., 2008). Regarding jatropha, reviewers state that common mechanical expellers allow oil yields between 62.5 and 80% (Achten et al., 2008; Koh and Ghazi, 2011; Kumar and Sharma, 2008; Gübitz et al., 1999). If followed by cooking, these yields may increase up to 89% and 91% respectively after the first and second pass through the expeller. The single screw expeller used in this research confirmed these data provide good 77% oil yield on a blank sample. Manifestations of the single point surface area, Brunauer–Emmett–Teller surface area, Langmuir surface area, micropore area, external surface area, total pore volume, micropore volume, average pore diameter, cumulative surface area and cumulative pore volume on the pressure wave pretreatment with gasification were approximated by polynomial functions (Fig. 2), where the lowest sum of squared absolute error was the fitting criteria. The plots show in agreement that the increased flow of microscopically dispersed carbon dioxide acts on the level of disintegration. The effect of increased disintegration levels manifested itself into the subsequent oil expelling and anaerobic fermentation can be seen in Fig. 3. All aforementioned indicators of disintegration provided some correlations. But, only Langmuir surface area (R^2 = 0.9507) correlated significantly to the oil yield and cumulative surface area (R^2 = 0.9731) correlated significantly to the day with maximum production of methane (Fig. 4). Based on these data it is assumed that the micro-bubbles of carbon dioxide which passed through the microporous ceramic filters enhanced the destructive effect of the edges of the pressure waves transmitted through the pretreated substrate. Based on the reduced level of the oil residue in the presscake (up under 7%), it is derived that the vacuoles rich in oil were more disrupted. A prerequisite for the disruption of the vacuoles is the breakdown of the cell walls, which is associated with the disintegration of its lignocellulose structure (Khan and Hanna, 1983). This is also confirmed by the subsequent acceleration on the anaerobic fermentation (up to 10 days) of the presscake once the kinetics of methane production is strongly connected with the availability of the easily fermentable compounds. These are being hydrolyzed by cellulases from the cellulose crystals liberated by disintegration (Himmel, 2008). The data on the level of disintegration also shows that with the increased level of gasification, the level of disintegration firstly increases and then gradually decreases. To explain the initial increase in the level of disintegration a hypothesis was raised. The hypothesis lies in an assumption that the micro-bubbles covered the cell walls. The hypothesis continues that the cell walls are more readily breakable in the moment when the edge of the pressure waves is leaving the cell wall and meeting the bubble on its surface. This allows