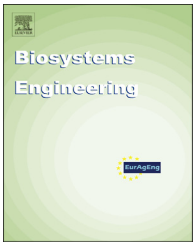
BIOSYSTEMS ENGINEERING 121 (2014) 46–55

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110



Research Paper

Development and testing of a Jatropha fruit shelling process for shell-free kernel recovery in biodiesel production

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ARTICLE INFO

Article history:
Received 19 September 2013
Received in revised form
15 January 2014
Accepted 14 February 2014
Published online 13 March 2014

Achieving shell-free kernel recovery from Jatropha fruits is important to improve oil yield and oil quality during oil extraction in biodiesel production. A shelling process with two stages of cracking and separation to remove the shells completely and husks partially was designed. Both stages used double-level cracking rollers and a blower with ducting as a separation unit. For the first, the performance was evaluated using five different roller clearances (9.5 mm, 10.0 mm, 10.5 mm, 11.0 mm and 11.5 mm) with a combination of five blower air speeds (8.5 ± 0.5 m s^{-1}, 9.0 ± 0.6 m s^{-1}, 9.5 ± 0.5 m s^{-1}, 10.0 ± 0.4 m s^{-1} and 10.5 ± 0.5 m s^{-1}). A roller clearance of 10.5 mm and air speed of 10.0 ± 0.4 m s^{-1} were selected as the optimal conditions with the highest separation efficiency between kernels and shells at 94.59%. The shells and husks achieved 95.88% and 12.20% removal respectively while kernel recovery achieved 98.65%. For the second stage, the performance was evaluated using five different roller clearances (5.0 mm, 5.5 mm, 6.0 mm, 6.5 mm and 7.0 mm) with a combination of five blower air speeds (6.5 ± 0.4 m s^{-1}, 7.0 ± 0.2 m s^{-1}, 7.5 ± 0.4 m s^{-1}, 8.0 ± 0.2 m s^{-1} and 8.5 ± 0.5 m s^{-1}). At the optimal conditions, with a roller clearance of 6.0 mm and air speed of 7.5 ± 0.4 m s^{-1}, the maximum separation efficiency was 97.69%. Total shell and husk removal achieved for the stages were 100.00% and 45.46% respectively. A total of 2.40% kernels were lost.

1. Introduction

Biodiesel has been recognised as a promising substitute for conventional diesel (Atadashi, Aroua, & Abdul Aziz, 2010). Among the feedstocks for biodiesel, *Jatropha curcas* L. which is non-edible and unlikely to compromise the future need for food supplies, has been reported as one of the most suitable feedstocks (Achten et al., 2010; Kalam, Ahamed, & Masjuki, 2012). *J. curcas* L. has been widely distributed throughout South East Asia, China, India, Africa and other tropical or sub-

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http://dx.doi.org/10.1016/j.biosystemseng.2014.02.004

Nomenclature

Abbreviation

A_1	total mass of loaded fruits in first stage, kg
A_2	total mass of input collected from first stage, kg
A_e	exposure of surface area to the wind, m^2
A_h	amount of husk content, kg
A_{hr1}	amount of husks removed in first stage, kg
A_{hr2}	amount of husks removed in second stage, kg
A_k	amount of kernel content, kg
A_{k1}	amount of kernels recovered in first stage, kg
A_{k2}	amount of kernels recovered in second stage, kg
A_{p1}	partially shelled and unshelled seeds in first stage, kg
A_{p2}	partially shelled seeds in second stage, kg
A_s	amount of seeds, kg
A_{sh}	amount of shells, kg
A_{sr1}	amount of shells removed in first stage, kg
A_{sr2}	amount of shells removed in second stage, kg
C_d	drag coefficient
F	net force by horizontal and vertical force components, N
F_w	wind load, N
g	gravitational acceleration, m s^{-2}
m	mass of fruit components, kg
MC_i	initial moisture content in wet basis, % w.b.
P_{hr1}	percentage of husks removed in first stage, %
P_{hr2}	percentage of husks removed in second stage, %
P_{sr1}	percentage of shells removed in first stage, %
P_{sr2}	percentage of shells removed in second stage, %
T_{kr1}	kernel recovery in first stage, %
T_{kr2}	kernel recovery in second stage, %
v	generated air speed, m s^{-1}
W	weight of fruit components, N
W_f	final mass of sample, kg
W_i	initial mass of sample, kg
η_{ce1}	cracking efficiency in first stage, %
η_{ce2}	cracking efficiency in second stage, %
η_{se1}	separation efficiency between shells and kernels in first stage, %
η_{se2}	separation efficiency between shells and kernels in second stage, %
θ	angle of displacement in the direction of net force, °
ρ	air density, kg m^{-3}

tropical regions (Pandey et al., 2012; Wang, Calderon, & Lu, 2011; Yang, Fang, Li, & Long, 2012). The characteristics of Jatropha include drought resistance, able to grow on marginal land and it easily adapts itself to arid and semi-arid conditions (Kalam et al., 2012; Koh & Ghazi, 2011; Kumar & Sharma, 2011; Leduc, Natarajan, Dotzauer, McCallum, & Obersteiner, 2009). The Jatropha tree begins produce fruits after six months and the yield becomes stable when the plants are 1–3 years old (Pradhan, Naik, Bhatnagar, & Vijay, 2010). The fruits are considered mature when the colour changes from green to yellow brown (Achten et al., 2008). The mature fruits, which remain on the branches, dry further until the shells become brittle and dark brown (Pradhan et al., 2010). A fruit is composed of shell, seed husk and kernel. The weight of the seeds and shells are 60–65% and 35–40% of the fruits respectively while the seeds consist of 40–42% husks and 58–60% of kernels by weight (Pandey et al., 2012). The seed yield has been reported to be around 4 tonnes [seed] ha^{-1} $year^{-1}$ while it is possible to achieve a higher yield with higher moisture and nutrient content in the soil (Ong, Mahlia, Masjuki, & Norhasyima, 2011; Pradhan et al., 2010).

The oil yield from Jatropha is around 1590 kg ha^{-1} but can be higher with decorticated seeds when compared to whole fruits (Kumar & Sharma, 2011). This is due to the fact that the outer shells, which do not contain any oil, prevent oil from leaving the kernels and also tend to absorb the oil during the extraction process. In addition, shell content can lead to high pressing pressures and energy loss in the oil expeller (Zheng, Wiesenborn, Tostenson, & Kangas, 2005). Therefore, as part of the shelling process it is important to remove and separate the shells to recover the pure seeds in Jatropha biodiesel production. This can be achieved manually or mechanically (Achten et al., 2008). The usual manual method uses a hard material to break the fruits and the shells are removed directly by using a finger (Achten et al., 2008). The process is labour intensive with low output rates. A manual process worker can only remove shells from 50 kg of dried fruits per day which is a relatively low rate compared to the 100 kg h^{-1} as achieved easily by a motorised machine (FACT, 2010; Wang et al., 2011). Further, labour shortages and costs are of major concern as labour is required at all stages during seed production stage, including fruit collection, drying and shelling (Wang et al., 2011). The replacement of labour by machine can ensure low production costs and improve the sustainability of biodiesel feedstock in the industry.

A shelling machine normally consists of a shelling or dehulling unit and a separation unit. The principle of shelling is to break, loosen and open the shells by applying adequate impulsive, compression or shearing force in order to detach the shells from the seeds. According to research literature, Jatropha shells can be detached by using compression rollers, rotating shearing blades or a horizontal rotating cylinder (FACT, 2010; Pradhan et al., 2010; Shamsudin, Yunus, Chong, & Azhari, 2010). The detached shells can be separated and discharged prior to the oil extraction process. The separation process can be easily completed by using a sieve or mesh that matches the size of the seed. However, zero shell content cannot be achieved because some shells are similar in size to the seeds and thus can pass through the mesh along with the seeds. Shell content in the feedstock during oil extraction can affect the crude oil quality in terms of purity. The cleanness of the extracted crude oil also decides the efficiency of the subsequent cleaning process in biodiesel production. Therefore, research is needed to enhance the separation process.

Currently, all of the commercially available machines recover whole seeds from the fruits without removing the husks (FACT, 2010; Pradhan et al., 2010; Shamsudin et al., 2010). As with the outer shells, the husks do not contain any