Journal of Cleaner Production xxx (2014) 1–8

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

# Pilot scale soda-anthraquinone pulping of palm oil empty fruit bunches and elemental chlorine free bleaching of resulting pulp

Arvind Kumar Sharma, Kumar Anupam*, Vinay Swaroop, Priti Shivhare Lal, Vimlesh Bist

*Physical Chemistry, Pulping & Bleaching Division, Central Pulp & Paper Research Institute, Himmat Nagar, Saharanpur 247001, Uttarpradesh, India*

A R T I C L E I N F O

*Article history:*
Received 29 September 2013
Received in revised form
19 December 2013
Accepted 31 March 2014
Available online xxx

*Keywords:*
Cellulose
Scale-up
Waste treatment
Environmental preservation
DEpD bleaching
Papermaking properties

A B S T R A C T

Development of large scale commercial pulping and papermaking processes using agricultural solid residues as raw materials is ecologically and environmentally important. This paper reports pilot scale soda-anthraquinone pulping of palm oil empty fruit bunches and elemental chlorine free bleaching of resulting pulp using DEpD sequence. The physical and morphological properties of resulting bleached and unbleached pulp fibres along with yield have been determined. The pilot scale unbleached pulp exhibited brightness 31.4%, kappa number 18, viscosity 845 mL/g, tensile index 59 Nm/g, burst index 5 kN/g and tear index 7.8 mNm$^2$/g with a yield of 48% and bleached pulp resulted in brightness 85%, viscosity 650 mL/g, tensile index 48 Nm/g, burst index 4.70 kN/g and tear index 9.1 mNm$^2$/g. Comparison of these values with those obtained at lab scale by various researchers through different processes revealed that the operating conditions adopted in this study can be successfully implemented at a paper mill for commercial production of pulp and paper from palm oil empty fruit bunches.



## 1. Introduction

Elevated demand of paper against scarcity of wood as raw material places a major challenge before pulp and paper industries. It is being estimated, on the one hand, that the demand of paper would be over 14 million tons in 2020 (Tewari et al., 2009) but, on the other hand, many industries that produce wood-based products is being shut down (Khalil et al., 2010). Further, the extensive utilization of wood in the past for pulp and papermaking has led to massive deforestation and replantation resulting in altered ecological balance and climatic conditions (Rodriguez et al., 2008a). These concerns have taken one research community in pulp and paper sector towards exploration of agricultural residues such as rice straw, wheat straw, bagasse, grasses etc. for evaluation and development of their pulp and papermaking potentiality. Palm oil empty fruit bunches (POEFB) is another such agricultural residue. POEFB is the solid biomass waste generated from the palm oil industry after the fresh palm fruit is processed to obtain oil. It is estimated that for each ton of palm oil produced, approximately 4 tons of empty palm fruit bunch is generated and about 15 million tonnes of POEFB is produced per annum (Tessarolo et al., 2013; Chong et al., 2013). Oil palm is produced in 42 countries worldwide on about 27 million acres of land with Malaysia, Indonesia, Thailand, West Africa and Colombia being the major producers (Khalil et al., 2010; FAO, 2011). With the expected expansion of palm oil industry to reach 80 million tons by 2020, the POEFB which is generated at palm oil mills can be considered as extremely abundant, renewable, and readily available lignocellulosic materials (Tessarolo et al., 2013; Baharuddin et al., 2013).

Many authors have advocated the utilization of POEFB for pulp and papermaking on the basis of numerous pulping and bleaching studies. Wanrosli et al. (2004) studied alkaline pulping of POEFB under experimental design conditions to investigate the influence of pulping conditions viz. cooking temperature, time–at–temperature and alkali charge on some properties of the pulp and paper obtained such as screened yield, kappa number, tensile and tear indices. Alriols et al. (2009) carried out ethylene glycol pulping of POEFB with special emphasis on by-products recovery, solvents recycling and determination of optimal conditions using computer simulation. Rodriguez et al. (2008b) investigated pulping of POEFB using high–boiling point organic solvents for example, ethylene glycol, diethyleneglycol, ethanolamine and diethanolamine under different sets of operating conditions and evaluated different properties of pulp and paper like yield, kappa index, viscosity, drainage index, breaking length, stretch, burst index, tear index and brightness. Ferrer et al. (2013) examined acetosolv pulping of POEFB under factorial design conditions to discover the influence

* Corresponding author. Tel.: +91 132 2714054; fax: +91 132 2714052.
*E-mail address:* kumaranupam@live.com (K. Anupam).

http://dx.doi.org/10.1016/j.jclepro.2014.03.095
0959-6526/

of operating parameters for instance, acetic acid concentration, hydrochloric acid concentration and time on the yield, drainability, kappa number, lignin and viscosity. Gonzalez et al. (2008) probed the effect of different pulping processes (ethyleneglycol, diethyleneglycol, ethanolamine and soda) on the ash, silicates and metals (Fe, Zn, Cu, Pb, Mn, Ni, and Cd) content of the pulps obtained from POEFB. Ghazali et al. (2006) considered alkaline peroxide mechanical pulping of POEFB and tried to unearth the responses towards washing, soaking, mechanical and chemical pretreatment techniques. Khoo and Lee (1991) looked into sulphate, neutral sulphite semichemical and thermo mechanical pulping of POEFB. They also performed bleaching of resulting sulphate pulps using three stage CEH (C is chlorine, E an alkaline extraction and H a hypochlorite stage) sequence. Jiménez et al. (2009a) applied the total chlorine free (TCF) bleaching sequence AOpAZRP(A is an acid treatment, Op an oxygen and peroxide stage, Z an ozone stage, R a reductive treatment and P a peroxide stage) to soda-anthraquinone and diethanolamine pulp acquired from POEFB. Leh et al. (2008) statistically investigated the effects of oxygen delignification on prehydrolysed-soda pulps of POEFB as the first stage towards TCF bleaching. Law and Jiang (2001) explored peroxide bleaching of POEFB pulp chemically cooked in caustic soda.

However, these investigations on pulping were conducted at laboratory scale and may or may not be appropriate for large-scale applications. Moreover, there is no study, to the best of our knowledge, available in the literature which describes DEpD (D is chlorine dioxide in acidic medium and Ep alkaline extraction with addition of hydrogen peroxide) elemental chlorine free (ECF) bleaching sequence for any type of pulp obtained from POEFB although DEpD bleaching sequence is at the present time common environment friendly bleaching process for production of bleached pulp (Lal et al., 2013). Hence, in the present study, a pilot scale soda-anthraquinone pulping of POEFB and lab scale DEpD bleaching of resulting pulp has been carried out. Selection of soda-anthraquinone pulping of POEFB was done due to its effectiveness, first, to produce good quality pulp, second, to generate less toxic pollutants, and third, to consume less amount of raw materials for high yield (Jiménez et al., 2009b). This paper also describes proximate chemical composition and fibre morphology of POEFB in conjunction with their comparisons to various contemporary raw materials studied for pulp and papermaking. Since the commercial development of pulping and papermaking processes using POEFB is presently in its early stage and the available public information in this regard is very limited especially concerning the possibilities and the technologies used, this research may provide quantitative proof that the pulping and papermaking using POEFB has potential to succeed on a full-scale basis with industrial utility.

## 2. Materials and methods

### 2.1. Raw material

POEFB (*Elaeis guineensis*) used in this study was procured from an oil palm mill based in Malaysia. POEFB was mechanically defibrated and dedusted before cooking. Dedusting became essential as POEFB contained lot of dust and it does not consist of any papermaking properties while serves as a dead load during cooking. Dust was removed by washing with the hot water. For this purpose, POEFB was soaked in hot water at 90 °C maintaining 1: 10 bath ratio for 30 min. The washed raw material was then cleaned, sorted, air-dried and then taken for pulping. Fig. 1a and b shows the photographs of POEFB and its fibrous strands respectively.

### 2.2. Raw material characterization

POEFB characterization involved determination of its proximate chemical composition. Proximate chemical composition of virgin and washed POEFB included the evaluation of following parameters: ash (TAPPI T 244 cm-99); cold and hot water solubility (TAPPI T 207 cm-99); 0.1 N NaOH solubility (TAPPI T 212 om-02); alcohol-benzene solubility (TAPPI T 204 cm-97); holocellulose (TAPPI T 249 cm-00); and acid insoluble lignin (TAPPI T 222 om-02). For this purpose, POEFB was chopped using laboratory chopper and a certain quantity of it was converted into 100 g of dust having mesh size 40 using the laboratory dust making machine. Samples for proximate chemical analysis were taken in a way that they represented the whole of the material and were in a suitable form to react with the reagents employed. All the parameters in this analysis were evaluated in a completely randomized design with duplicates.

### 2.3. Pulping experiments

Laboratory as well as pilot scale soda-anthraquinone pulping of POEFB was carried out. Laboratory scale pulping experiments were performed in a series digester consisting of six bombs of 2.5 l capacity each, rotating in an electrically heated polyethylene glycol bath. Different conditions maintained for laboratory scale pulping were: soda concentrations 16%, 18%, 20%; cooking temperatures 162 °C, 165 °C; and time to reach cooking temperature 90 min. The anthraquinone concentration, cooking time and liquid to solid ratio, however, in each case were fixed at 0.1%, 90 min and 1:5 respectively. At the end of the cooking, the bombs were removed and quenched in the water tank to depressurize. The cooked mass from each bomb was taken for washing on a laboratory flat stationary screen with a 300-mesh wire bottom. First, the washing was carried out with hot water till the cooked mass was free from

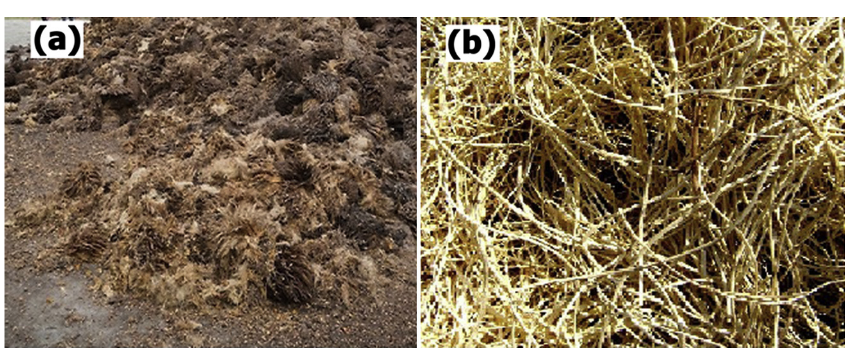


**Fig. 1.** Photographs of (a) POEFB generated at a palm oil mill, (b) Fibrous strand of POEFB.