The Empty Palm Oil Fruit Bunch as the Potential Source of Biomass in Furfural Production in Indonesia: Preliminary Process Design and Environmental Perspective

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Abstract. Empty Palm Oil Fruit Bunches (EPOFB) is a residual biomass from Palm Oil Industry (POI), which known to be produced in large quantity in Indonesia every year. EPOFB is now regarded as a potential feedstock to produce a variety of renewable and valuable biofuel and bio-based chemicals that can be derived from sugar, cellulose, and lignocelluloses, including furfural. Furfural is a bio-based chemical that can be obtained from cellulose that is contained within empty palm oil fruit bunches (EPOFB). Furfural can be used as a platform chemical for the production of a wide range of value-added products, such as the fuel additive methyltetrahydrofuran (MTHF), which is a more environmentally friendly alternative anti-knocking agent compared to lead. However, furfural has never reached commercial use in any significant volume because its industrial development was relatively slow due to the low yield obtained in the process. This study will explain the potential of waste biomass as EPOFB that can be obtained from palm oil industry in Indonesia. This study will also decide the biorefinery technology design that is applicable in Indonesia to process to be used to convert cellulose and lignocelluloses from EPOFB to furfural; which contains three main stages: separation of the biomass, hydrolysis, and purification process. The process simulation results in 26.58% of distilled furfural from 50 ton/day EPOFB as the basis.

1. Introduction
Fossil-based fuel is one of the most common energy source used in our world. Human have been using fossil-based energy since 150 years ago, which began with the development of mining technology and the discovery of coal; which leads to the discovery of world’s primary energy source, petrochemical-based energy; crude oil. As the human population grows, the demand of petrochemicals continues to increase along with the growth of energy demand, and also with the demand of the wide range of its derivative products like polymers, resins, textiles, lubricants, and fertilizers. In 2015, the consumption rate of crude oil in Indonesia had reached up to 504.88 million barrel per year, which consisted of 248.80 million barrel of fuel oil products, 80.68 million barrel of non-fuel oil products, and imported 175.4 million barrel of crude oil [1], [2].

Due to the high demand, a dramatic increase in the oil price was observed in the last decade. Furthermore, the Greenhouse Gasses (GHG) emissions from fossil fuel combustion have resulted in a major increase in the GHG concentration in the earth atmosphere. There is more and more evidences states that the problem will have a major impact on our global climate [3], [4]. The high consumption rate and the increase of demand of crude oil decrease the amount of reserved oil resource; which is
estimated to deplete in 2050 [5]. Considering these facts, the research of new and renewable, sustainable, low cost, and ergonomical energy sources is continuously attempted. One of the solutions to meet the needs of other energy source is using alternative energy from various biomass sources, which are available in large mass and low price. Biomass is a carbon neutral resource in its life cycle, which is a potential substrate of valuable chemicals if processed with biorefinery technology. Biorefinery technology integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass, which expected to have various advantages, which includes finding the environmental-friendly energy source and processing methods.

As one of solid waste from palm oil industry, which always produced in large mass after harvest season, Empty Palm Oil Fruit Bunches (EPOFB) is one of the most potential source of cellulose, hemicellulose and lignin [6]. Based on the material HSE, EPOFB complies with the heuristic 1 of process synthesis that states the raw material chosen must not be toxic and dangerous for people and environment [7]. Previous EPOFB researches and waste management implementation in Indonesia are mostly focused on conversing the EPOFB into composts, charcoals, fibrous material, composites, and bioethanol [8]–[10] but rarely on green chemicals. Carbohydrates derivated from lignocelluloses used for the synthesis of large number of substances via established chemical method such as, butanol, ethanol, furfural, lactic acid itaconic acid, and other derivatives. Lignocelluloses materials consist of three primary chemical fractions namely: hemicelluloses/sugar-polymer, cellulose/glucose polymer, and lignin/ phenols-polymer. With biorefinery technology, biomass to biofuels conversion processes can be conducted [11]. The lignocellulosic biorefinery process extract valuable green chemicals namely levulinic acid, formic acid, and furfural [12]–[14]. The preliminary process design can be obtained from process simulation, of which the kinetic equation and material composition can be derived from previous researches.

2. Materials and Method
2.1. Literature Review
Literature studies is done to address the approximate amount of EPOFB and its availability from the Directorate General of Plantation, Ministry of Agriculture Republic of Indonesia (MoA-RI) database from 2007 to 2017 [15]. Preliminary studies through literature are done to find the potential chemical substance that can be processed from EPOFB and the way to extract the substance from EPOFB. Study of furfural as a chemical substance is done through literature review [16]–[21].

Based on the literature review, two technologies used to produce large amount of furfural in continuous process, Reactive Extrusion Technology and Biofine Technology are compared and scored to find the best method for furfural extraction. Both technologies have been proved to produce levulinic acid in a large scale, which then possible for producing furfural through addition of distillation column. The process technology selection is done through scoring of parameters namely technical factors, waste obtained, material loss, process equipments and developments, which will be based on literature review.

2.2. Process Technology Selection and Process Simulation
After literature review is done, then the availability of process technology will be selected. There are 2 technologies that can be used to produce furfural: Reactive Extrusion Technology and Biofine Technology. Both technologies have been proved to produce furfural in a large scale. Continuous processing for furfural production is more advantageous because it can reduce the number of energy used from the process. Afterwards, the research will be continued with the making of Process Flow Diagram and Block Flow Diagram. The process flow design simulation will be done with SuperPro Designer software. Kinetic equations and conversion rate used within the simulation are based on the previous process patent, average EPOFB content, and chemical reaction researches [5], [12]–[14], [16], [22]–[25].

Reactive Extrusion Technology (RET) technology is considered to be advantageous in the way it is continuous, requires fewer steps, and reduces reaction time compared with other processes. However, the extrusion process is limited due to the loss of Hydroxymethylfurfural (HMF), which is formed from glucose and then converted to furfural and formic acid by heating in the presence of an acid. In
addition, there are limited studies done to assess the effectivity of RET and the waste produced from RET are hard to be re-processed. Meanwhile, the waste from Biofine Technology can be processed to produce another valuable products, such as levulinic and formic acid. The total yields obtained are also higher. Therefore, Biofine Technology is recommended to implement in the mass production of furfural.

3. Results and Discussion

3.1 Literature Review

Furfural has been identified as a promising green, biomass derived platform chemical, which has large application in plastics, biofuel, pharmaceutical, and agrochemical industries: as chemical solvent for lubricating oil, fungicides, nematicides, insecticides, gasoline and jet fuel additives, lubricants, resins, decolorizing agents, bio-plastics, cosmetics and food additives [5], [20], [21], [25]. Previous studies also use this chemical substance as a precursor to specialty chemicals including fuel additives such as Methyltetrahydrofuran (MTHF), pesticides such as D-amino furfural (DALA), Formic Acid (FA), and Diphenolic Acid (DPA).

Figure 1. Potentially interesting derivatives of furfural

Based from the data obtained from the Directorate General of Plantation, Ministry of Agriculture Republic of Indonesia (MoA-RI), it is shown that the areas of oil palm plantation in Indonesia in 2013 reached up to 10,010,835 ha, and were predicted to increase in 2020, up to 20 million ha. According to the estimated yearly increase of palm oil production data from MoA-RI (2013), the production of palm oil or crude palm oil in Indonesia in 2013 reached up to 27.75 ton per year. In 2017, the total plantation area reached 12,307,677 ha and produced up to 35,359,384 ton of Crude Palm Oil (CPO) [15].

High production of palm oil in Indonesia caused high volume of EPOFB obtained from palm oil industry. Based on the mass balance, each ton of fresh fruit bunches processed will result in 22-23% EPOFB waste (approx. 230 kg), which then will be combusted to be commercial bricket in usual practice. To each ton CPO produce, palm oil industry will receive up to 1.1 ton EPOFB as biomass. From this calculation, it could be predicted that the amount of EPOFB in 2017 reaches up to 35,695,000 ton, and will increase yearly. This large amount has potential value to be the source of biomass, since crude EPOFB contains 41.3 – 46.5% of cellulose, 25.3 – 33.8% of hemicellulose, and 27.6 – 32.5% of lignin. The remaining percentages are mineral and dirt, which is around 5%.

3.2 Process Technology Selection

Biofine technology aims for a complete valorisation of the biomass source by performing the overall processes with a minimum loss of energy and mass and to maximize the overall value of the production chain. It consists of an efficient fractionation of the biomass into various value-added
products and energy using physical separation processes in combination with bio-chemical and thermochemical conversion steps. In that sense, the biofine process concept has similar objectives as today’s petroleum refineries. Typically, there are three stages defined in biofine process:

3.2.1. Separation of the biomass into its components (cellulose, hemicellulose, lignin, proteins, amino acids, pure plant oil, minerals, fine chemicals, and pharmaceutical compounds) in a primary fractionation unit. Typical technologies applied in this stage are traditional separation processes, such as filtration, solvent extraction, and distillation. This stage is called pretreatment unit [18]. The pretreatment unit to produce furfural in biofine process can be divided in physical and chemical pretreatment.

3.2.2. Conversion of the intermediate fractions to valuable end products (furfural). This stage is called secondary refinery process. Hydrolysis is the secondary refinery process to produce furfural. This process is simulated with kinetic equation from lignocellulose to furfural.

3.2.3. Further processing of the chemical intermediates to high added value end-products. This stage called purification/distillation process and aimed to obtain higher yields of furfural production.

![Figure 2](image)

**Figure 2.** Possible pathways and products of the acid-catalysed hydrolysis of a typical lignocellulosic material

3.3 Process Simulation

The process simulation is done with SuperPro Designer. The basis of the simulation is continuous process in a Continuous Stirred Tank Reactor (CSTR), from which the product output will be distilled in distillation column (Figure 4). The continuous process is selected to optimize the total amount of furfural compared to the batch process, since the product reflux will continuously happened in the continuous process. The process will be calculated with the basis input of 50.0 ton of EPOFB daily (in 24 hours). The input is estimated with the average percentage of EPOFB content and the chemicals added (hexane, ethanol, NaOH, and HCl solution) are counted with kinetic reaction equation. The overall mass balance is described in Table 1.

![Figure 3](image)

**Figure 3.** Possible pathways and products of the acid-catalysed hydrolysis of a typical lignocellulosic material, numbers are green chemicals, of which 1: furfural; 2: levulinic acid, and 3: formic acid [5]
There are three valuable products that can be obtained from this process pathways: furfural, levulinic acid (LA), and formic acid (FA).

**Table 1. Overall Mass Balance Process**

| Materials         | Input Material (ton/day) | Product (ton/day) |
|-------------------|--------------------------|-------------------|
| **EPOFB**         |                          |                   |
| Cellulose         | 25.61                    | Furfural          | 13.29 |
| Hemicellulose     | 14.12                    |                   |
| Lignin            | 7.59                     |                   |
| Mineral & Dirt    | 2.68                     |                   |
| **Hexane & Ethanol** |                        |                   |
| Ethyl Alcohol     | 69.64                    |                   |
| Hexane            | 139.28                   |                   |
| **NaOH Solution** | NaOH                     | 7.90              |
| **Sulphuric Acid 1% Solution** | HCl                     | 0.97              |
|                   | Water                    | 333.51            |
| **Total Input**   | 601.3                    | 13.29             |

The overall process of furfural production’s efficiency is 26.59% and can be categorized as efficient. Most of the time, the factory will obtain the yield and efficiency of 29-35%. Moreover, other valuable chemicals namely levulinic acid and formic acid can also be obtained from further distillation process.

**4. Conclusions**

Based from the simulation, EPOFB is potential as the source of biomass to produce furfural in Indonesia when it is processed with biofine technology. From the process simulation, it is predicted that 13.29 ton/day distilled furfural can be obtained from 50.0 ton/day of EPOFB.

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