Production of Tannin-based Natural Dye from Mangrove (Rhizophora mangle) Tree Bark Waste from Wood Chips Industry: A Feasibility Study

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Abstract. The potential effect of synthetic textile dyes towards human health and environment is much severe. Currently available dye in national and global market is dominated by synthetic commercial dye from various producers. Meanwhile, Indonesia demand for textile dye is increasing, but is not followed by production rate of textile dye. Producing environmentally friendly natural dye, which can compete in the global market, may solve those problems. A potential natural dye may be produced from tannin which is extracted from Mangrove bark. It has high yield with purity of 95% tannin (w/w) with solvent extraction method under moderate temperature condition. Mangrove tree bark is obtained from the side product of wood chips production. There are four species of Mangrove available for wood logging and chips producing activities namely Rhizophora Apiculata, Bruguiera Gymnorhiza, B., Bruguiera Parviflora, and Ceriops Tagal. Mangrove can spread out the seed through the sea water naturally, making this wood reproduces widely and quickly. With proper treatment and logging management, considering the growth rate of mangrove, the sustainability of raw material is assured. The production of tannin will take place nearby the wood chips production. From 540 tonnes/month of mangrove bark as raw material, a 67 tonnes/month product could be extracted. The process will be carried out in small scale plant on empty land with area of 3.6 Ha. This plant has three units: raw material preparation, synthesis, and product purification. The product has desired purity and specification, and can be sold commercially. It also has expected cash flow, and the profitability analysis result is also stunning. With Capital Expenditure (CAPEX) of Rp 141,896,000,000,- and operational Expenditure (OPEX) of Rp 28,842,000,000,-, the plant has Return on Investment of 27%. It has pay out time of 2.77 year, 19.08% DCFRR, Break Even Point at 40.85%, Shutdown Point at 10.25 %, IRR of 9.90%, and Net Present Value at Rp7,601,000,000,-. This investment also proves that at 5% change of raw material and products cost, the plant still overcomes the change and defend its profit state, making this investment feasible.

Keywords: extraction, mangrove, tannin, profitability, wood chips
1. Introduction
Fashion is one of the important life aspects of the world. As the fashion industry growing, the demands for the textile unit as raw material also develops rapidly. The growth stated in percent growth towards market value is 4.3% in 2019 and 4.0% in the following years (Lu, 2019). The textile also needs a high demand for textile dyes, approximately 1.3 million tonnes around the world (Mansour, 2018). On June, 13th 1996, CBI cef CBI/HB-3032 announced the danger of synthetic dye for fabric and yarn on textile products. A synthetic dye is the aromatic hydrocarbon derivatives such as benzene, toluene, naphthalene, and anthracene obtained from coal tar and consists of carbon dispersed in oil. Synthetic dye has various types. Naphthol, acid, basic, direct, reactive, azo, and amino aromatic are the dyes which are carcinogenic towards the human body. The danger makes these types of dyes are restricted in Germany and the Netherlands since April, 1996. As a matter of facts, more than 80% of total craftsmen in Indonesia are still using synthetic dye. Its large usage, emits a large amount of toxic amine waste (Fröse et al., 2018). The negative effects of the use of the dyes are 1) the decrease of health quality of labor who work in coloring unit at batik industries. 2) the increase of children with down syndrome and cancer 3) the increase of children with chronic disease, obesity, autism and food poisoning 4) the increase of improperly growth of fish (Samchetshabam, Hussan and Choudhury, 2017), 5) The synthetic dye waste will cut off the oxygen supply and sunlight exposure preventing water biomass from photosynthesis. According to BPPS data from March, 13th 2019, the import of textile synthetic dye in 2018 as much as US$ 300 million or 47 million kg. Indonesia is the target market of foreign synthetic dye. The Dystar product, for example, has 64% of the market share in the textile dye market (Naibaho, 2014). Nowadays, Indonesia also produces various types of dye, including natural dye. Several industries which produced synthetic dyes and natural dyes in Indonesia can be shown in Table 1.

### Table 1. Various Producer of Textile Dye in Indonesia

| Plant                                | Capacity (tonnes/year) |
|--------------------------------------|------------------------|
| Multikimia Inti Pelangi              | 960                    |
| Gama Blue ND (natural)               | 6.5                    |
| PT. Dystar Colours Indonesia        | 24,150                 |
| PT. Indo Lysaght                    | 12,500                 |
| PT. Roha Lautan Pewarna              | 826                    |
| PT. Colorpark Indonesia Tbk.         | 12,500                 |
| PT. Dic Astra Chemicals              | 14,000                 |

(Obtained from: [http://www.emis.com/](http://www.emis.com/))

The national production capacity still cannot fulfill Indonesia demand for textile dye, the import value of synthetic dye is still increasing until now.

The price of natural dye are more expensive than the synthetic dye, for example, one of natural dye i.e. tannin cost $359,306 per tonne, compared with the famous synthetic dye, for instance, naphthol which costs as much as $37,103 per tonne. Although it has dangerous and serious health impact, the synthetic dyes are still utilized. Indonesia is the importer of tannin from various country around the world. Import Value of Tannin in 2018 is $ 1,589,100,000 , the trade quantity is 138183 tonnes.

The import of tannin in Indonesia is increasing recently. To reduce the import both of natural and synthetic dyes, natural dye production in Indonesia has to be increased. Several attempts have been made in order to produce natural dyes as a replacement of synthetic ones. It has been reported that textile dyes have been produced from several routes and also with various types of product, depending on the color (Geissler, 2009). The production of basic-color for natural dyes blue, yellow, and red from natural biomass also has been studied (Gulrajani, 2001). The yellow color, for example, can be produced from tannin.
Tannin is a polyphenolic compound, extracted from various types of plants. Due to its abundance, the raw material is more sustainable and reliable (Ismarani, 2012). Tannin has several applications. The applications are for skin tanner (to precipitate protein), textile dye, food preservative, pharmaceutical raw material, soap, cosmetics, and toothpaste material. It can form polyflavonoid as plywood adhesive by reacting it with formaldehyde. It also can be used for corrosion inhibitor. It can absorb the heavy metal release to the environment. In the natural dye aspect, tannin can produce a small range of color from yellow to brown and can be used for dyeing clothes, arts, and crafts (Danarto, 2011).

Indonesia has the various resources to produce natural dye and can be produced on a large scale. It will bring a better impact on the environment and human health. Based on our description above, it can be concluded that commercial natural dye production is very prospective not only for human health, and better environment but also for a financial aspect. Natural dye production is needed for Indonesia craftsmen, national textile industry and furthermore, for exporting.

In a wood chips industry that processes mangrove logs, there are tonnes of mangrove wood bark waste. The mangrove tree bark waste is only utilized for boiler fuel or to be dumped. The potential of tannin inside mangrove wood bark is very large and can be produced and sold commercially. Based on the research, mangrove tree bark contains high concentration of tannin, it is a potential raw material for producing tannin powder with high yield and purity. To produce tannin as natural dye, it is necessary to conduct a feasibility study of this project.

2. Material and Methods
2.1. Raw material specification
The raw material used in this plant is mangrove tree bark, with specification: water content 50 %, tannin 26 %, density 805 kg/m$^3$, hardness 812-1156 kg/cm$^2$.

2.2. Production capacity estimation
There are several types of mangrove in Bintuni Bay, that are used for making wood chips namely *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, *Bruguiera parviflora*, and *Ceriops tagal*. The *Rhizophora apiculata* has a production rate of bark waste about 250-500 tonne/month, other species will contribute the wood bark waste as much as 40 tonnes/month. The total production capacity is 540 tonnes/month or equal to 6480 tonnes/year, with extracted tannin as much as 10% of the total solid content, or 25-50 tonnes/month.

2.3. Process Description
The process of tannin production from mangrove bark consists of: size reduction, tannin extraction, and tannin purification. Mangrove tree bark is obtained from side product of the production activity of wood chips industry. Logs from logging activity will be carried into the plant, and then the mangrove bark will be peeled off. While the peeled woods processed inside the plant, the mangrove bark will be dumped and become waste. This huge pile of mangrove bark waste can be transported manually into the transporting facility that is belt conveyor and processed inside the shredder followed by hammer mill to reduce the size. The expected specification from hammer mill outlet is 100 mesh undersize.

Product of size reduction will be transported using pneumatic conveyor, due to its small size. Besides, the powder is mixed with the air from the hammer mill. The fine size raw material can be separated from pneumatic air, by using cyclone separator. Obtained solids will fall into a hopper so it can enter the mixer easily. This solid then will be processed inside extractor which consist of a mixer and a settler) with a batch process and the time cycle is 8 hours per day. This mixer-settler configuration is one stage. Fine mangrove bark enters the mixer and water as a solvent from leaf
filter enters the same stage. The extraction will take place inside the mixer. The mixture of water and fine mangrove bark, the solution contains tannin and water. The sediment consists of fine woods as residue, a small amount of tannin, and water. It is easily separated using batch press leaf filter. The residue can be used as boiler fuel. The large amount of solvent will be recycled back to the mixer.

The tannin solution will be transported to the evaporator, to reduce the water content so it can be dried using spray dryer. This equipment type is a forced circular vertical evaporator. The vapour produced from evaporator will be used as a heating agent for heating mantle in extractor. While the liquid remains from evaporation will be sprayed using a spray tower dryer. Inlet solid contents must not greater than 30% mass of solid, because it will block the nozzle of sprayer. Inside the spray dryer, dry air will carry out droplets of tannin and water and exit at the top side of a spray dryer. This tannin powder can be recovered using cyclone separator so the water content can be completely removed. The recovered tannin and remaining tannin from spray dryer in the form of powder will be mixed and stored inside the hopper, and ready for manual packaging.

2.4. The design steps

The process description and scenario has been made. Also, we have obtained the production rate of mangrove tree bark data for designing our plant. We can use the raw material data and material characteristic as input data. In addition, the mass flow rate of another raw material that is water will be considered as input data. With the known degree of freedom, we calculate overall heat and mass balance from individual equipment heat and mass balance.

This mass and heat balance, along with each equipment operating condition can provide the necessary data for calculating each equipment dimension. We can estimate the cost, by using six-tenths rule from previously calculated equipment cost.

The influence of time towards equipment cost is provided by Equation (1)

$$\frac{C_A}{C_B} = \frac{l_A}{l_B}$$  \hspace{1cm} (1)

The influence of equipment capacity towards equipment cost is provided by Equation (2)

$$\frac{C_A}{C_B} = \left(\frac{S_A}{S_B}\right)^{0.6}$$  \hspace{1cm} (2)

With a specified dimension, we can estimate the investment cost of its equipment. After that, we will calculate the economic feasibility of this natural dye plant. There are several parameters to determine whether the investment of the plant is financially feasible. The parameters are Return on Investment (ROI), Payout Time (POT), Net Present Value (NPV), Internal Rate of Return (IRR), and Discounted Cash Flow Rate of Return (DCFRR). To determine the parameter, we can use the equation (3)-(7).

$$\%ROI = \frac{\text{Annual Sales}}{\text{Fixed cost}} \times 100\%$$  \hspace{1cm} (3)

$$POT = \frac{\text{Annual sales+depreciation}}{\text{Fixed cost}}$$  \hspace{1cm} (4)

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$  \hspace{1cm} (5)

$$NPV = 0 = \sum_{t=0}^{n} \frac{R_t}{(1+IRR)^t}$$  \hspace{1cm} (6)

$$NPV = 0 = \sum_{t=0}^{n} \frac{D_{Ct}}{(1+DFRR)^t}$$  \hspace{1cm} (7)
Equation (5) to (7) calculates NPV, IRR, and DCFRR respectively. Although the equations are similar, the numbers that need to be input are different. While IRR and NPV use regular cash flow, the DCFRR does not count the depreciation and finance.

3. Results and Discussion

3.1. Raw material feasibility
Mangrove is a wild plant which grows in shallow bay shore, estuary, delta river, and conserved seashore. As long as the environment supports the growth and development of the plant, it will reproduce continuously within specified times. It has a very large root, protected buds with sharp leaves, and fruit that has root since it still lives within the tree. It can grow naturally in the environment with a wide range of salinity. It is also resistant against high water level and sea tide, making the plant is not affected when immersed with water or when the sea tide is high. Mangrove can grow even when the soil has high sand content and a high concentration of sludge. Mangrove stem can be utilized as fuel and made into charcoal. The wood bark can also be used to make natural dye and medicine. The tree height can reach about 27-30 meters tall. Its diameter can reach a maximum number of 70 cm. This large tree dimension provides maximum benefit to the user who utilizes its every part. It can be predicted that the tannin content inside mangrove bark is about 20-30%. This is a fairly large number which is applicable for the textile industry to utilize the powder. (Cahyani et al., 2016). With an area of 42,550 km² of total mangrove woods, and with 45 species growing at the current time, this provides attention to the wood industry to utilize this wood.

Mangrove tree, contains three types of natural dye, namely tannin, flavonoid, and quinone. These substances will produce several types of color. Tannin can produce dark-red or brown color, flavonoid will form yellow, red, or blue color, and quinone will form pale yellow to dark color.

PT BUMWI (PT Bintuni Utama Murni Wood Industry), produces Mangrove woodchips from Mangrove trees in Bintuni Bay, West Papua, with effective production area of 52,115 hectares. In 30 years, it has the approximate productivity 250-270 m³ mangrove/Ha. To produce the chips, the mangrove tree must be peeled from its bark. The bark produced from production activity becomes waste and it is only utilized as a fuel, or dumped to cultivate the land. The waste is not utilized well, and the idea is to utilize this waste to synthesize natural dyes. With the above mentioned facts, the availability of raw material is assured.

3.2. Technology Process feasibility
The specification of the expected product: powder (100 mesh undersize), purity 95 %, impurities (flavonoid, quinone, water), cost $ 6.5/kg.

The mass balance can be seen in Figure 2. From mass balance aspect, our designed plant is effective and efficient. In only needs a small amount of water. It is not only cheap, but also safer in process operation. This plant is effective and efficient because its separation efficiency is excellent. The calculated extraction efficiency also high because we used an optimum solvent to wood bark ratio.

The waste is not harmful to the environment and can be utilized directly. The residue of extraction can be used as fuel in the boiler. The recovered water can be recycled to the extractor, to increase the efficiency of material used. The plant does not use any hazardous material. Hence, the process safety in this plant is assured.
At the beginning of the process, we don’t use any drying apparatus to reduce the water content. The drying is not necessary since the water is the solvent of this process. At the synthesis unit, there is no complicated reactor but only stirred tank, which is relatively cheap and easy to design. For the separation of the extract, we used a single evaporator. The solid-gas separation is using the cyclone and the spray dryer equipment which is easy to design and cheap too.

![Mass Balance Diagram]

**Figure 1.** Mass Balance of Tannin Plant (mass flow in kg/hour)

**Table 2. Heat Balance of Tannin Plant**

| Component            | Input, kW | Output, kW |
|----------------------|-----------|------------|
| Tannin Enthalpy      | 0.1446    | 1.8809     |
| Impurities Enthalpy  | 0.9813    | 9.8112     |
| Water Enthalpy       | 2.3901    | 31.8205    |
| Mixer Heat Duty      | 11.2824   | -          |
| Belt press Heat duty | -         | 7.5647     |
| Condenser Heat duty  | -         | 360.3672   |
| Evaporator Heat duty | 362.7361  | -          |
| Spray dryer heat duty| 31.6053   | -          |
| Subtotal             | 437.2376  | 415.5732   |
| Heat loss            | -         | 21.6644    |
| Total                | 437.2376  | 437.2376   |

Table 2 shows the energy demand of this plant. From energy needs standpoint, this plant has a low energy consumption, less than half of megawatt power needs. It has 437 kW of gross energy input and output, making it possible to use national electricity instead of using power generation method.
The plant is energy friendly because it does not need steam power plant which requires coal or natural gas. This plant has 22 kW of energy loss, which can be recovered for producing steam. This plant has an opportunity for energy integration and recovery to minimize the cost. With those strategies applied, this plant could achieve higher energy efficiency and better profit.

3.3. Market analysis and business model
From our calculation and estimation, this plant is going to fulfill the demand for about 13.98% from total tannin demand, while PT Dystar Colour Indonesia product will fulfill the 64% of the demand and other synthetic dye will fulfill the rest of the demand. However, this number can be increased annually for penetrating national market slowly. In the future, this shows a great prospect for achieving an even higher number.

This plant will be built on the land nearby the wood chips plant, with the area of 3.6 Ha. The plant will be operated by 20 labor, assigned to each different shift and each different process equipment. In Table 3, below are the calculation of the plant detailed cost.

| Parameter                     | Value                     |
|-------------------------------|---------------------------|
| Raw Material Supply, tonne/month | 300                       |
| Plant capacity, tonne/year    | 286                       |
| Cost of Wood Bark, Rp/tonne   | 0                         |
| Fixed capital                 | Rp24,231,000,000          |
| Working capital               | Rp 4,576,500,000          |
| Production Cost               | Rp17,771,500,000          |

Assumed the sales of tannin is constant within 10 years, we can get desired revenue every year. To guarantee that our plant has sufficient revenue every month, we just compare our tannin import value with our plant capacity. Our plant capacity which is 285.871 tonnes/year still is not able to fulfill the import value that is 138,182 tonnes in 2018.

The elements of this cash flow are fixed capital, working capital, salvage value, depreciation, and revenue. The first year is initial step of the plant which needs fixed capital and working capital. The next 10 years will be fulfilled by the net annual cash flow obtained from profit. At the end of year 10, it has a salvage value and full value of working capital. The expected value is that the plant will gain profitability that pays back our investment in less than 5 years, and this plant will surpass the expectation.

3.4. Profitability Analysis
Table 4 shows the profitability analysis results of this plant. The payout time before tax gains a relatively short time. It only reaches less than 3 years to achieve a payback of both scenarios. Even so, the after-tax payout time surpasses the 3 years limit for the chemical industry. This number is still lower than 5 years of general industry. This makes this plant is sustainable to operate for many years ahead. The plant has a rather high rate of return. It reaches a value of 27 %, surpassing the minimum targeted ROI for a low-risk industry (Aries and Newton, 1955). The same thing occurs at scenario B which reaches 41 % ROI. Since the rate of return surpasses the minimum value expected by the industry, the plant will support the economic growth of the country and profit.
sharing is applicable. As for Net Present Value and IRR, it shows that this investment scenario of the plant is feasible.

By using a simple linear model, the BEP and SDP will be determined. The profitability calculation summary is shown in Table 4.

### Table 4. Profitability Calculation Summary

| Profitability Aspect          | Value               |
|------------------------------|---------------------|
|                              | Before Tax | After Tax |
| Return on Investment         | 41.86%      | 27.21%   |
| Payout Time, years           | 1.9662      | 2.77     |
| Internal Rate of Return      | 9.9 %       |          |
| Net Present Value            | Rp 7,601,000,000.=-. |          |
| Breakeven Point              | 40.85 %     |          |
| Shutdown Point               | 10.25 %     |          |

3.5. **Sensitivity Analysis**

Sensitivity result of the plant is shown in Figure 2a-2b and 2c. From IRR and POT standpoint, the plant shows an insignificant effect of product cost change, fixed cost, and labor cost, but from NPV standpoint, the plant shows a great effect from product cost change. The plant NPV is vulnerable towards product cost change. The most influencing factor of plant profitability is product cost, followed by fixed cost and the last is labour cost. As the product cost changes slightly, it affects the plant profitability of various factor (NPV, IRR, and POT) greatly. The slope is much steeper than fixed cost and labour cost, which is very sloping. If the profit margin is increases, it can affect all of the profitability factors drastically, making this plant is very attractive. If the selling price of product is decreases, it will affect all profitability parameters. Theoretically it is safe to decrease the product price without affecting the plant profitability drastically, but the selling price must be adjusted, so that the plant can be operated in any external condition (weak economics state and other problem caused by market sector). With adjusting the proper product price, the plant can gain profit and the sustainability of production is assured. Thus, the customer of product prefers the cheaper product in market, and is able to start using natural dye.
Figure 2. Sensitivity of raw material (blue line) and product cost (red line) towards various parameter of Scenario A (a) NPV (b) IRR (c) Payout Time

4. Conclusion

The plant raw material sustainability is assured, proven by the trend of mangrove bark production rate that meets the plant demand. Hence, the raw material will support the operation of the plant throughout the year. The process design is feasible and it meets the expected target of the plant where waste emission and the energy consumption is minimized. This natural dye plant is fit the business model, along with its market penetration strategy. The supply of natural dye from this plant will fulfill a small amount from the total demand of textile dye in Indonesia. Based on profitability parameters stated above, this natural dye plant is economically captivating and the margin between obtained and expected value is rather high, making this project surely operated in the safe profitable condition in the future. This plant is not vulnerable to labor cost and fixed cost change between the range of -10% and +10%. On the other hand, this plant is very vulnerable to product cost change. Although this project continuance has a great prospect in the near future, further calculation is needed to make sure the plant can maintain the instability of product cost and raw material change.

Nomenclature

\%RoI = Percent Return on Investment
PoT = Payout Time
NPV = Net Present Value when \( i = \) current national bank interest rate
\( R_t \) = Net Revenue at the year of \( t \)
\( i \) = interest rate of bank at the study period
\( n \) = total study period
\( t \) = expected year
IRR = Internal rate of return when NPV is equal to zero
\( DCFRR \) = Discounted Cash Flow Rate of Return

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