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Current Tapioca Starch Wastewater (TSW) Management in Indonesia

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Abstract: This paper presents a current tapioca starch wastewater (TSW) management in Indonesia, for both technologies and regulations. Finding about the current TSW management is presented. Indonesia is the third largest tapioca starch producer in the world after Thailand and Brazil. As a result, tapioca starch wastewater (TSW) is increasing. TSW pollutes the environment if it is discharged untreated. Several treatments have been used for TSW treatment. Indonesia has regulations related to effluent quality standard for TSW. Currently, regulation is not working properly on some industrial sites. High BOD and COD in TSW can make TSW into valuable products such as methane as a fuel of power plant. Using fermentation method, TSW can be used as organic fertilizer for vegetable crops. TSW still contain starch and fibrous so that it can be used as raw material for manufacture of nata de cassava. The government is urged to find a sustainable technology for TSW management. Biodegradable plastic (polyhydroxyalkanoates) producing technology from TSW can be applied in Indonesia. This technology treats the TSW into valuable product.

Key words: Cassava · Tapioca starch · Tapioca starch wastewater · Methane · Nata de cassava · biodegradable plastic

INTRODUCTION

Cassava is a shrubby, tropical, perennial plant that is not well known in the temperate zone. For most people, cassava is most commonly associated with tapioca. The plant grows tall, sometimes reaching 15 feet. Leaves have variation in shape and size. The edible parts are the tuberous root and leaves. The tuber (root) is somewhat dark brown in color and grows up to 2 feet long. Cassava thrives better in poor soils than any other major food plant. As a result, fertilization is rarely necessary. Yields can be increased by planting pieces of stem on well drained soil. Cassava is a heat-loving plant. For growing, cassava requires a minimum temperature of 80 degrees F. Cassava can survive in dry season with low soil moisture and high humidity. Harvesting time of cassava is 7 months. Cost production of cassava is relatively cheap (www.cassavachips.com) [1]. Total harvesting area of cassava in Indonesia from 2000 to 2009 has decreased. However, harvesting area of agricultural of palm oil and cocoa has increased from 2000 to 2009 (Table 1a and 1b).

The total cassava production from 2000 to 2009 and other crops production can be seen in Table 2a and 2b. Table 2a and 2b show that crop plantation increased from 2000 to 2009.

Tapioca starch is derived from cassava (*Manihot Utilissima*). Indonesia tapioca starch industry began to bloom in the 1980s. Indonesia tapioca starch industry is one of food industry. Tapioca starch is a raw materials and auxiliary materials for textile industry, paper industry and others. One ton of cassava produces 400 kg of tapioca starch [2]. Several countries also produce tapioca starch. Figure 1 shows world tapioca starch production.

Market of tapioca starch is domestic and international. Domestic demand mainly comes from Java Island such as Bogor, Tasikmalaya and Indramayu. International demand comes from several ASEAN countries and Europe (Bank of Indonesia, 2009) [3]. Indonesia can be rightly considered as an agrarian economy. The agriculture sector has contributed 14.4% to the country's GDP in 2009. Indonesia's agricultural sector

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Table 1a: Harvesting area of agricultural in 2000-2004 (Indonesia) [4]

Commodities	Unit	2000	2001	2002	2003	2004
Cocoa	Ha	749,917	821,449	914,051	961,107	1,090,960
Rubber	Ha	3,372,421	3,344,767	3,318,359	3,290,112	3,262,267
Palm Oil	Ha	4,158,079	4,713,435	5,067,058	5,283,557	5,284,723
Cassava	Ha	1,284,040	1,317,912	1,276,533	1,244,543	1,255,805

Table 1b: Harvesting area of agricultural in 2005-2009 (Indonesia) [4]

Commodities	Unit	2005	2006	2007	2008	2009
Cocoa	Ha	1,167,046	1,320,820	1,379,279	1,425,216	1,587,136
Rubber	Ha	3,279,391	3,346,427	3,413,717	3,424,217	3,435,270
Palm Oil	Ha	5,453,817	6,594,914	6,766,836	7,363,847	8,248,328
Cassava	Ha	1,213,460	1,227,459	1,201,481	1,204,933	1,175,666

Source: Ministry of Agriculture of Republic Indonesia, 2011

Table 2a: Agricultural production in 2000-2004 (Indonesia) [5]

Commodities	Unit	2000	2001	2002	2003	2004
Cocoa	Ton	421,142	536,804	619,192	695,361	691,704
Rubber	Ton	1,501,428	1,607,461	1,630,359	1,792,348	2,065,817
Palm oil	Ton	7,000,507	8,396,472	9,622,344	10,440,834	10,830,389
Cassava	Ton	16,089,020	17,054,648	16,912,901	18,523,810	19,424,707

Table 2b: Agricultural production in 2005-2009 (Indonesia) [6]

Commodities	Unit	2005	2006	2007	2008	2009
Cocoa	Ton	748,827	769,386	740,006	803,593	809,583
Rubber	Ton	2,270,891	2,637,231	2,755,172	2,751,286	2,440,347
Palm oil	Ton	11,861,615	17,350,848	17,664,725	17,539,788	19,324,293
Cassava	Ton	19,321,183	19,986,640	19,988,058	21,756,991	22,039,145

Source: Ministry of Agriculture of Republic Indonesia, 2011

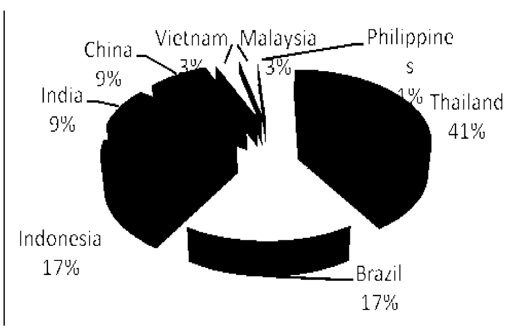

Fig. 1: World tapioca starch production in 2001
Source: Sriroth *et al.,* 2002 [7]

can be categorized into food crops, non-food crops, horticulture, animal products, fish products and forest products. In 2006, income of the country from food crops is worth 213,529,700 million rupiahs. This value was 35% more than the 2003 level (http://www. economywatch. com) [6].

To produce tapioca starch, roots are peeled, washed, chipped, pressed, ground or milled, dried and then sieved. Tapioca starch produced should contain 15-19 % moisture content [2].

Tapioca starch industry uses large amounts of water to wash cassava, starch extraction and washing equipment [8]. One ton of cassava roots need about 5-11 m^3 of water (www.fao.org) [9]. Liquid waste as much as 40-60 m^3 will be produced during processing (Akhirruliawati, 2009) [10]. TSW still contains 1.9 to 2.5% of carbohydrate, glucose of 425-1850 mg/L and total nitrogen of 97-182 mg/L (http://www.florabiz.net) [11]. Organic substances undergo microbial conversion. Conversion of organic substances by microorganism causes unpleasant smell and lower dissolved oxygen content that can disrupt the balance of aquatic biota. TSW treatment is required in order to prevent environmental pollution[12].

Tapioca Starch Processing: Fresh cassava roots are transported to cassava mills. Several unit operations are involved in cassava starch extraction process. The main stages of tapioca starch processing are shown in Fig. 2.

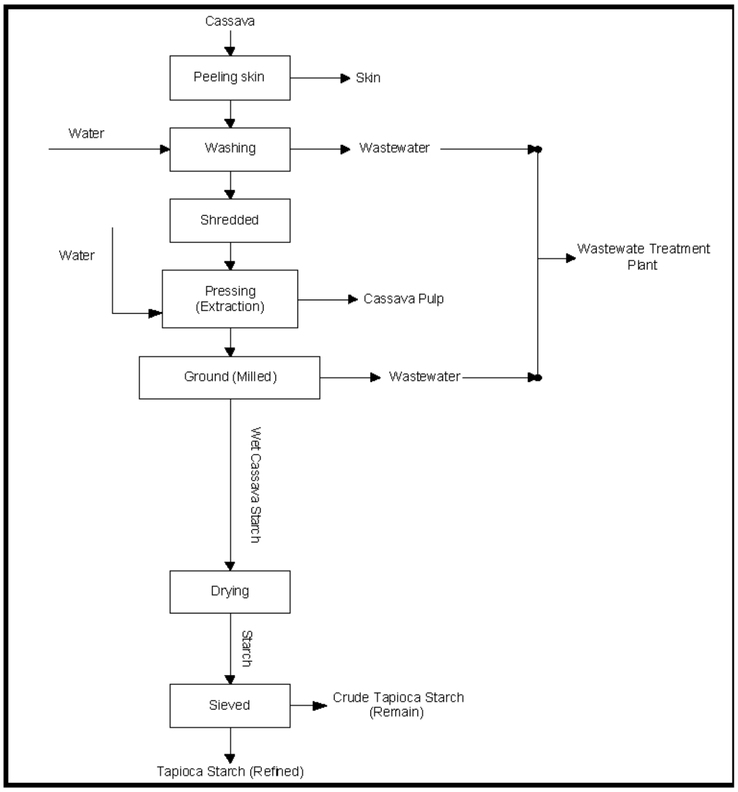

Fig. 2: Process involved in milling of cassava
[Source: Department of Agriculture of RI, 2005] [2]

First stage is peeling of skin of cassava. Peeling is done manually. The aim is to separate the flesh from cassava peel. During stripping, sorting is also done. The aim is to select high-quality cassava from other cassava. Low quality cassava is not processed into tapioca. It becomes fodder.

After skin of cassava is peeled, next step is washing of cassava. Washing is done by hand with wringing cassava in a tub filled with water. The aim is to remove dirt on cassava and to remove mucus beneath the skin of cassava. Washing should be done using a constant flow of water, so water is always replaced.

Next step is shredding. Cassava is inserted into a machine. Cassava is shredded into pulp grated cassava. The grater machine is washed with water. This water slurry flows into a tub. In the tub, slurry is shaken.

Pressing/extraction cassava slurry is done by hand using a filter cloth. Then, it is kneaded by adding water. The fluid obtained is starch. The starch is stored in a bucket. Another method is to use a rock sieve. Cassava slurry is placed on top of the filter. The filter is driven with an engine. During shaking the sieve, water is added through perforated pipes. The resulting starch is collected in settling tanks.

Ground/milled is intended to separate pure starch from other parts such as pulp and other elements. In this step tapioca starch granules are produced. Granules contain proteins, fats and other components. Granules are stable and complex components. So, it is difficult to separate the starch granules with other components. Alcohol compounds and organic acids are among components. They have a distinctive odor. Starch granules obtained are about 4-24 microns (one micron is 0.001 mm). The nature of viscosity of tapioca fluid is not much different from ordinary water. Specific gravity of starch granules is 1.5 g/cm^3. Precipitation velocity is determined by the size of starch granules and colloidal substances. Precipitation of grains (granules) generally lasts for 24 hours. It produces approximately 30 cm thick sediment of cassava starch.

Drying is a method to evaporate water content. The final aim is to obtain dry tapioca starch. The drying process relies on sun's heat or artificial heating. Batch drier, oven driers, cabinet drier and drum drier are often used as artificial drying. During precipitation semi-liquid starch is formed. It has a moisture content of about 40%. By drying directly, moisture content reduces to 17%. The temperature should not exceed 70-80°C. Drying

Table 3: Characteristics of tapioca starch wastewater and regulatory discharge limit of RI

Parameters	Value [a)]	Regulatory discharge limits [b)]
BOD5 (mg/L)	3,000 - 7,500	200
COD (mg/L)	7,000 - 30,000	400
pH	4 - 6.5	6 - 9
TSS (mg/L)	1,500 - 5,000	150
Cyanide (CN), mg/L	1.46 [c)]	0.5
Limit of waste discharge (m^3/ton products)	40 - 60	60

Sources: a): Akhirruliawati, 2009 [10]; b): Ministries of Environmental Decree of RI no. 51 year 1995 [13]; c): Marjuki, 2001 [14].

Table 4: Effluent quality standard for TSW (Ministries of Environment Decree No. 51/1995) [15]

Parameters	Maximum Level (mg/L)	Maximum Pollution Load (kg/tones tapioca)
BOD5	200	12.0
COD	400	24.0
TSS	150	9.0
Cyanide (CN)	0.5	0.03
pH	6.0 - 9.0	
Maximum waste discharge	60 m^3 per tones tapioca	

Source: Ministries of Environment of Republic Indonesia, 1995

temperatures are below 70°C. After drying, clumps of starch are destroyed in order to obtain desired powder. Roller crushes are used to crush dry tapioca starch. The results of crushing generate coarse starch. To obtain fine powder, it is filtered or sieved. The aim of sieving is to get tapioca starch with particular subtlety.

Tapioca Starch Wastewater (TSW): Characteristics of TSW depend on quality of cassava roots. Extraction of tapioca starch from cassava roots requires large amount of water. It has been estimated that one ton cassava roots need about 5-11 m^3 of water for its processing. About 40-60 m^3 of water ends up as TSW [10]. TSW still contains some organic materials (Table 3). The Ministry of Environment of Indonesia categorizes two major steps responsible for producing wastewater. Washing up of cassava roots and extracting (pressing) starch from cassava slurry contributes 25% and 75% of wastewater, respectively [15]. Based on data of Bank of Indonesia (2009) about 15-16 million tones of tapioca starch is produced every year in Indonesia. It means about 2,400 million m^3 of TSW is generated every year [3].

Wastewater composition depends mainly on season, raw material quality and particular operations. Typically, pH of TSW is low. When starch dissolved in water, dissolved oxygen reduces. Range of pH of TSW is about 4-6.5. Wastewater also contains large amount of total solids (1,500-5,000 mg/L). Some of TSW contains cyanide around 1.46 mg/L [14]. Wastewater contains dissolved constituents such as a high concentration of carbohydrate, glucose and total nitrogen. It may be converted into useful materials using microbial processes. TSW can cause considerable environmental problems, if discharged untreated [12]. The challenge of converting TSW into an environmental friendly waste requires an efficient treatment and effective disposal technique.

Findings: Tapioca starch industry has been thriving in Indonesia. Indonesia demonstrates a set of environmental policies. These policies can be very effective to control industrial pollution in a developing country. Indonesia has Government Regulations related to Water Quality Management and Water Pollution Control. This regulation was known as Government Regulation No. 82/2001. Ministries of Environmental RI issued regulations related to effluent quality standards for industrial activities. The regulation name is the Minister of Environment Decree No. 51/1995. This rule (Appendix A. VIII) sets maximum levels (mg/L) and maximum pollution load (kg/tones tapioca) of wastewater discharged into the environment [13]. The effluent quality standard ordinarily applicable to TSW is presented in Table 4.

Indonesia is identified as the country that produces the largest pollution load in water environment. Karadenan Village, Bogor Regency, West Java is one area that shows an indication of water environment pollution caused by TSW. Well waters are contaminated by TSW. Generally, resident use well waters for daily activities. This village is in an inaccessible area of Local Regional Water Company. Intensive utilization of groundwater and increase in wastewater generation cause changes of groundwater quality. Utilization of well water by resident is to meet needs of local resident, such as drinking water, latrines and tapioca starch industry.

Almost all tapioca industry in Bogor is a small scale industry. Tapioca starch industry drains wastewater in a terraced pond as a reservoir through a small ditch. Terraced ponds facilitate drainage of TSW regularly but these ponds have disadvantages. In the dry season bad smell is generated from the ponds. In rainy season, overflow happens in the ponds and flow goes into lower ponds. This condition makes death of fish. TSW also pollutes Ciparigi River that passes through Karadenan Village. Karadenan Village case shows weak regulation related to Government Regulation and effluent quality standards for industrial activities [16]. Due to this fact, the tapioca industry faces the challenge of balancing environmental protection, one of the state revenue and sustainable development. There is urgent necessity to find an approach to preserve the environment while keeping country's economic growth.

Fresh TSW is cold and acidic (pH between 4-6.5) and has a specific color dependent on process, high concentration of organic materials, (7,000 - 30,000 mg/L) and high amounts of total solids (1500 - 5000 mg/L). Some cassava contains cyanide (1.46 mg/L). The effluent color of wastewater from washing process is generally brownish white. The effluent color from pressing or extracting process is creamy. Fresh TSW has smell same as cassava roots. The characteristics of TSW are given in Table 3 [10, 15, 17]. According to Bank of Indonesia data about 2,400 million m^3 of TSW is generated every year [2]. During tapioca starch processing, no chemical is added. Some cassava contains cyanide. Organic cyanide will be removed by using aeration [18,26]. However, it also contains small amounts of N, P, Ca, Na and Mg [12], which are nutrient elements for plant growth [19]. Due to the non toxic nature and fertilizing properties, TSW can be used as an organic fertilizer [19]. According to Indarto [12] toxic metals, such as Fe, Cu, Pb and Zn are also contained in TSW, but the concentrations are usually below the standard [12]. Fe, Cu, Pb and Zn are found in TSW as a result of contamination from air pollution, plastics, metal pipes, tanks, containers and groundwater [12].

The tapioca starch processing generates liquid wastes. TSW may have a significant impact on environment if they are not properly dealt with. It is necessary to find a proper technology for mitigating the impact of these wastes. Some countries study about TSW utilization. There are some ways of TSW utilization. Among them are methane as a fuel of power plants, nata de cassava and liquid fertilizer for vegetable. Some regions in Indonesia have been utilizing TSW as useful products.

Methane is an odorless, colorless and flammable gas. It is used primarily as fuel to make heat and light. It is also used to manufacture organic chemicals. Methane can be formed by the decay of natural materials and is common in landfills, marshes, septic systems and sewers. Methane is produced by TSW (http://www.dhs.wisconsin.gov) [20] and solid waste as an immobilizer. Before released into adjacent river system, wastewater is treated through a number of anaerobic open lagoons to reduce components that have negative impacts on the environment. Methane gas is collected then fed into a new biogas power generator that replaces existing diesel generators. Generated electricity will be used in the tapioca starch industry. The technology is closed fermentation tank system that enables steady methane fermentation with a short hydraulic retention time (HRT). *Onggok* (solid waste of tapioca starch), which is a by-product in the tapioca production process, is added to the process at the initial stage as a bio immobilizer for a shorter HRT and stable fermentation activity [21]. The flow chart of the process can be seen in Figure 3.

Utilization of TSW as a fuel of power plant has been carried out in PT Wirakencana Adiperdana (PT Wira). This industry is located in Kedaton, East Lampung Regency, Lampung Province, Indonesia. As one of the largest tapioca producers in Lampung Province, PT Wira is an environment-conscious enterprise and was awarded a BLUE ranking in PROPER assessment, which means PT Wira satisfies the statutory and administrative requirements for environmental protection. Another industry is PT Budi Acid Jaya. Location of this industry is in Lampung Province, Indonesia. The industry has reported this technology to UNFCC as a CDM Project in 2007 (http://cdm.unfccc.int) [22].

Other utilization of TSW is nata de cassava. Nata de cassava is innovation in fiber foods. Nata de cassava is very worthy entry in the competition for the food industry in Indonesia. Nata product dominates the market. Currently, nata de coco has a problem within limits of their raw materials in form of coconut water. Using TSW is an opportunity for replacing position of nata de coco in a market of nata in Indonesia. Nata de cassava would appear to be a solid product due to its raw materials derived from cassava. The process is more economical. The manufacture of nata de coco still requires addition of sugar, so in production scale nata de cassava is more economical and efficient. In addition, nata de cassava is produced more supple, thicker and whiter. Some advantages of nata de cassava over other nata products are high fiber content (proven by lab tests), cheap raw

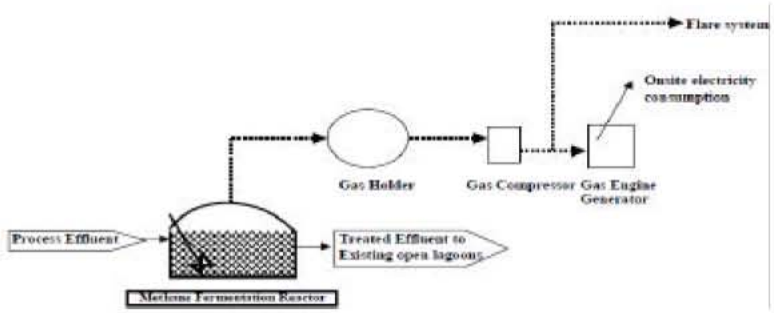

Fig. 3: Flowchart of methane process as a fuel of power plant [21]

Table 5: Nutrition content in TSW [12]

Nutrition	Content (per 100 grams TSW)
Carbohydrate	25.37 grams
Grease	0.19 grams
Fibrous	1.2 grams
Protein	0.91 grams

Source: Indarto, 2010

Table 6: Utilization of TSW in Asian Countries

Utilization of TSW	Country	Condition of TSW	Operation Type	Result	References
Fuel for power plant	Thailand	Volume = 8000 m^3/day COD > 32000 ppm BOD5 > 16000 ppm TSS > 15000 ppm TDS > 14500 ppm pH = 3.8 - 4.2 SO42- < 300 ppm	Facultative Lagoon System T = 38 - 40°C Working volume = 9.5 m Volume of active bacterial mass = 7 m Covered with HDPE (high-density polyethylene) = 1 mm	Average electricity generated = 71,000 kWh/day	Plevin Richard & David Donnelly, 2004 [23]
Food products (Animal food: Fish culture)	Vietnam	Flow rate = 2500 m^3/day COD = 4000 - 21000 ppm BOD5 = 2000 - 16000 ppm SS = 570 -2900 ppm Organic Nitrogen = 63 - 470 ppm	Un definition	Produce fish food for fish culture = 43,040 m^3/ year for fish culturing area = 16.14 ha	A. P. J Mol & Tran Thi My Dieu, 2006 [24]
Fertilizer	Vietnam	TSS = 0.15% N2 content = 14.6 mg/L From concentration 28.5 ppm diluted till concentration HCN become = 10-20%	Use as a direct fertilizer for duckweed	Growth rate more rapidly	FAO, 2000 [25]

material and no requirement of sugar as in manufacture of nata de coco. Thus, production costs could be reduced (http://natadecassava.wordpress.com) [7]. Table 5 shows nutrition content in TSW.

Nata de cassava can open a new business by enhancing economic value of tapioca waste. Raw materials are plentiful and inexpensive. These two aspects are main strength of nata de cassava. Stability of product is supported by simple processes and materials that make this technology a viable business (http://natadecassava.wordpress.com) [7]. Currently, nata de cassava technology and products has been spread in Ngawi, Cilacap, Central Java Province. This innovation was developed by Diponegoro University, Central Java Province, Indonesia [16].

The fermentation of TSW as long as six weeks could increase the pH from acid condition (pH 3.74 - 4.10) to neutral condition (pH 6.50 - 7.00). Application of TSW as liquid fertilizer (organic fertilizer) once, twice and three times a week showed no significant difference compared with control (inorganic fertilizer) on spinach, swamp cabbage and mustard greens [19]. This technology has been applied in Bogor, West Java Province since 1998 [19].

Utilization of Tsw in Asian Countries: Utilization of TSW as a fuel of power plants, food products and liquid fertilizer for vegetable are not only done in Indonesia but others Asian countries have been doing. Table 6 shows others countries that have been doing utilization of TSW.

Sustainable Technology for Tsw Management in Indonesia: Plastics (petroleum-based) wastes become big problem in Indonesia since 2000 because usage of plastics has been increasing by 350 pieces/person/year (Marwan, 2011) [17]. On the other hand, Indonesia faced a big problem of TSW. Bioplastic or biodegradable plastics, which are plastics derived from natural and renewable feedstock, has been currently recognized as a new wave in green industrial development. Being renewable, biodegradable and sustainable are comparative advantages of bio plastics over petroleum-based plastics. Thus, bio plastics are more environmental friendly than petroleum-based plastics. There are many kinds of developed bio plastics such as starch plastics, poly lactic acid (PLA), polyhydroxyalkanoate (PHA) etc. Among these bio plastics, PHA is a plastic produced under unbalanced growth conditions from agricultural wastewater through the PHA fermentation and recovery process. This technology can be applied in Indonesia. According to Moniaga *et al.* [15] PHA production can be carried out in Indonesia based on the capacity of TSW that are available in some areas in Indonesia (Pati, Central Lampung and Banjarnegara). Total production capacity is expected to reach 10,000 tons in 2008, which is divided in several factories with a capacity each of 1,500 tons/year. Production design has been done through the determination process line, the selection of process equipment, product recovery method, the calculation of the mass-energy balance and economic analysis. The total investment cost for capacity of 1,500 tons/year is U.S. $ 6,774,803 with a production cost of only U.S. $ 2.7/kg PHA. Feasibility analysis of the plant [Break Even Point (BEP) of 27.08%, the Internal Rate of Return (IRR) of 32.82%, Return on Investment of 26.25% and Payback Period of 6 years from the construction period] indicates that this design is quite feasible to be realized [15].

CONCLUSIONS

Indonesia is the third largest tapioca starch producer in the world (17%) after Thailand (41%) and Brazil (17%). As the world tapioca starch is increasing, generation of wastewater also is increasing. If discharged untreated, it may cause serious problem to environment. About 2,400 millions m^3 of tapioca starch wastewater is generated every year. Indonesia has regulations related to effluent quality standard for tapioca starch wastewater. Currently, regulation is not working properly on some industrial sites. Thus, emphasis should be given to environmental management through wastewater management. There is a need of appropriate technology which should be easy to operate and cost effective. TSW is non-toxic and can be used for methane production, food material and fertilizer. Methane production from TSW as a fuel of power plant is helpful in reducing nutrients content. Using TSW as a raw material of food is an option to reuse existing nutrients in tapioca starch wastewater. Besides adding a variety to food that currently exists, it can also increase revenue for the industry or individuals. By using fermentation, acidic TSW can be changed into neutral and can be used as organic fertilizer for vegetable crops. These three technologies will help in maintaining sustainability of ecosystem. Other Asian countries have been utilizing tapioca starch wastewater as a fuel for power plant, animal food and fertilizer. The government is urged to find a sustainable technology for TSW management. Biodegradable plastic (polyhydroxyalkanoates) technology from TSW can be applied in Indonesia. This technology treats the TSW into valuable product. PHA production can be carried out in Indonesia based on the capacity of TSW that are available in some areas in Indonesia (Pati, Central Lampung and Banjarnegara).

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