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Clean technology for the tapioca starch industry in Thailand

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ABSTRACT

The tapioca processing industry is considered to be one of the largest food processing industrial sectors in Thailand. However, the growth of the tapioca starch industry has resulted in heavy water pollution as it generates large amount of solid waste and wastewater with high organic content. This study explores the applicability of clean technology options to improve the environmental performance of tapioca starch-processing plants in Thailand. Eight Tapioca starch plants were selected for an exclusive analysis of the dynamics of clean technology development and adoption. Proposed options mainly involve water reduction and energy conservation. These include reuse and recycling of water, technology modification in the production process, and use of biogas to substitute fuel oil for burners. Implementation of these proposed alternatives to real companies shows that the reduction of starch loss, and water and fuel cost savings can be achieved.

1. Introduction

Apart from the rice and cane sugar industries, the tapioca starch-processing industry has played an important role in the Thailand's agricultural economy. Known as the world's largest producer and exporter of tapioca starch, Thailand produced over seven million tons of starch in 2004. Approximate annual revenue from tapioca starch export is 38,805 million baht or 1060 million dollars [1]. Tapioca is produced from treated and dried cassava (manioc) root and used in the food, paper, and toothpaste industries. Only 20% of the cassava root harvested in Thailand is delivered to starch-processing plants, while the rest is used in the production of pellets and chips. Currently, Thailand has 92 tapioca processing plants with a total production capacity of native and modified starch at about 16,910 and 4350 ton/day, respectively [1]. Normally, these tapioca plants operate 24 h a day for 8–9 months, from September to May.

The production of native starch from cassava root involves seven major stages. These include root washing, chopping and grinding, fibrous residue separation, dewatering and protein separation, dehydration, drying, and packaging. The production facilities expect a number of environmental problems such as the consumption of large volumes of water and energy, and the generation of high organic-loaded wastewater and solid waste. The starch extraction process requires a vast volume of water which in turn produces large amount of wastewater. According to the study of Tanticharoen and Bhumiratanatries [2], the generation of wastewater at the tapioca starch plants averages 20 m^3 for every ton of starch being produced. Similarly, Hien et al. [3] reported the characteristics of wastewater from the Vietnam tapioca starch plants with the values of 11,000–13,500 mg COD/l, 4200–7600 mg SS/l, and pH of 4.5–5.0. The approximate generations of wastewater and solid waste (fibrous residue and peel) are 12 m^3 and 3 kg per ton of starch, respectively.

Typically, the tapioca starch plants cope with these environmental problems by end of pipe technology. However, this technique does not allow the reduction of the pollution at sources that can lead to significant amount of energy and raw material savings. Cleaner production, an integrated change in the production process, is introduced as it is a preventive strategy to minimize wastes and emissions released to the environment. Simultaneously, it promotes the efficient use of raw material, energy, and natural resources, resulting in the reduction of production costs [4]. Therefore, the Department of Industrial Works (DIW) of Thailand launched a program in 2005 to develop pollution prevention measures for tapioca starch plants. Their program yielded implementation guidelines or a "code of practice" for the country's tapioca starch manufacturers. In this study, as part of the DIW comprehensive program, the possible options of clean technology are explored for enhancing the production efficiency and improving the environmental performance of the tapioca starch industry. The study focuses mainly on water conservation, reduction in raw material loss, and energy conservation. Results from implementation to real-world tapioca starch plants are shown in terms of cost savings.

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2. Methodology for implementation of cleaner production

2.1. Selection of a case study

Since the size variation of plants can influence their economic efficiency and environmental profile, eight tapioca starch plants were selected that cover all size categories. The representative plants were classified according to their size or investment cost into three groups as shown in Table 1. A detailed analysis in this study considered existing data on the production process and environmental performance of the tapioca starch plants.

2.2. Procedures for implementation of cleaner production

In this study, a systematic methodology to achieve a better environmental performance of the tapioca starch industry consists of four steps as follows:

Step 1: Analysis of the existing production process and gathering of the plant information associated with the use of material resources, generation of wastes, and production costs; selection of key factors determining the production efficiency includes water consumption, electricity consumption, fuel oil consumption, and starch loss.
Step 2: Detailed evaluations and measurements of the four key factors; analysis of material mass and water mass balances.
Step 3: Conclusions of the measurements; selection of appropriate approaches for prevention and minimization of waste generation.
Step 4: Design and implementation of potential clean technology options to the tapioca starch plants; evaluation of the implementation results in terms of resource reductions and cost savings.

Table 1
Description of the selected starch-processing plants

Size	Investment cost (million baht)[a]	Number of studied plants
Large	>200	1
Medium	50–200	4
Small	<50	3

[a] US $1 = approximately 30 baht.

Measurements of the four key factors determining the production efficiency were conducted for 24 h. Water consumption was recorded from plant water meters, while electricity consumption was recorded by a power meter. Fuel oil consumption and starch losses were obtained from the plant information. Note that wastewater generation was measured by the investigators.

3. Overview of Thailand tapioca starch industry

3.1. Production process

In Thailand, processing of tapioca starch is similar among the plants, but it may be different in techniques and machines used in each production stage. Shown in Fig. 1 is the production process of tapioca starch to which no reuse and recycling of water in the production lines are applied. Although most of the studied plants reuse and recycle water at some point, this processing scheme is intended to show potential sources of water consumption and wastewater generation. The total amount of water used, wastewater generated, sand and peel, and fibrous residues were averaged from the eight studied plants. The portions of water used and wastewater generated in each production stage were obtained from the previous study team [5]. The wet matter mass and water mass balances are based on 1 ton of produced starch. Moisture contents of the matter streams are stated in parentheses.

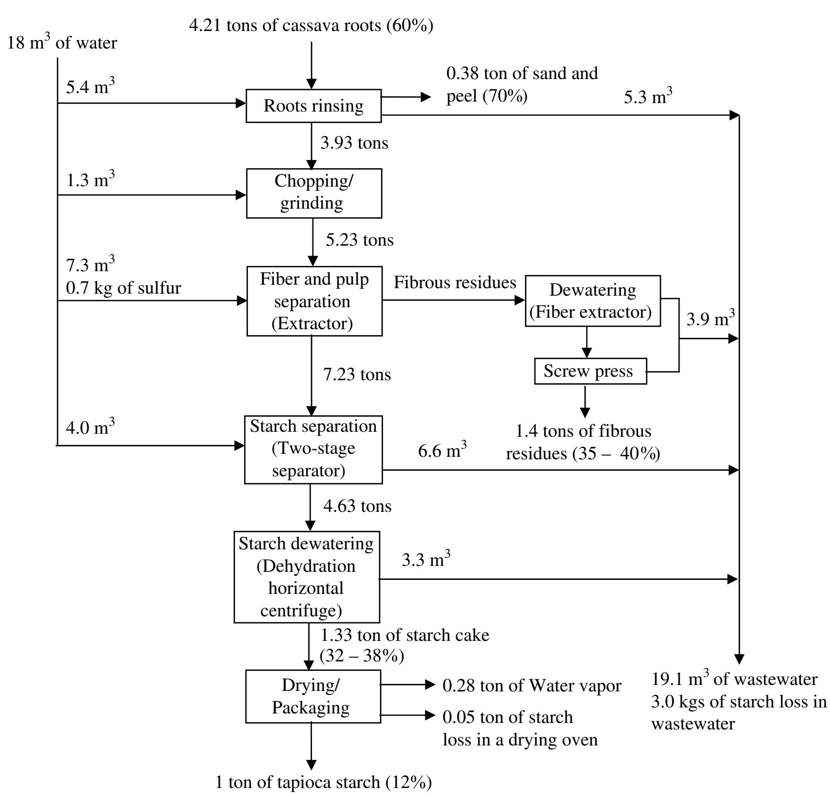

Fig. 1. Process of tapioca starch production and a wet matter mass and water mass balance. Note that numbers in parentheses represent moisture contents.

Cassava roots are firstly delivered to a sand removal drum and then to a rinsing gutter for cleansing and peel separation. After washing, the clean cassava roots are sent to a chopper to chop into small pieces (approximately 20–25 mm) and then taken to a rasper. During rasping, water is added to facilitate the process. The resulting slurry, consisting of starch, water, fiber, and impurities, is then pumped into the centrifuges for extraction of the starch from the fibrous residue (cellulose). The extraction system consists of three or four centrifuges in series. There are two types of extractors: a coarse extractor with a perforated basket and a fine extractor with a filter cloth. Suitable amount of water and sulfur-containing water are constantly applied to the centrifuges for dilution and bleaching of the starch. The starch slurry is then separated into starch milk and fibrous residue. The coarse and fine pulp is passed to a pulp extractor to recover the remaining starch and the extracted pulp is then delivered to a screw press for dewatering. The dewatered fibrous residue is sold to a feedstock mill. The starch milk from the fine extractor is pumped into a two-stage separator for impurity removal from the protein. After passing to a second dewatering machine, the starch milk has the starch content up to 18–20° Baumé. Then, the concentrated starch milk is pumped into dehydration horizontal centrifuges (DHC) to remove water before drying. The DHC consists of filter cloth placed inside, rotating at about 1000 rpm to remove water from the starch milk. The resulting starch cake has a moisture content of 35–40%. The starch cake is taken to a drying oven consisting of a firing tunnel and drier stack. Drying is effected by hot air produced by oil burners. During the drying process, the starch is blown from the bottom to the top of the drier stack and then fallen into a series of two cyclones in order to cool down the starch. The dried starch with a moisture content of less than 12% is conveyed through a sifter for size separation and finally packaging.

3.2. Analysis of water consumption and waste generations

In the processing of tapioca starch, cassava root, water, and energy are important resources, while the generation of wastewater and solid waste are of great concern in terms of environmental performance. As shown in Fig. 1, the volume of water required in cassava root washing and fiber separation is made up to 70% of the total water consumption. Types of the processing machines used also affect water consumption. In this study, the total amount of water required for manufacturing a ton of tapioca starch is approximately 18 m^3, while generating about 19 m^3 of wastewater with BOD loading of 135 kg. It implies that the plants' measures for reuse and recycling of water are insufficient and ineffective. Table 2 shows a relatively high variation of water consumption among the selected plants. Since starch-processing plants usually use surface water, which is free of charge, and the cost of water treatment is as low as 2.50 baht/m^3, some starch-processing companies have not been overly concerned with water conservation. Moreover, the tapioca starch industry produces large quantities of solid wastes such as fibrous residue, root peel and sand. Basically, 1 ton of fresh root yields 0.24, 0.33, and 0.09 ton of native starch, fibrous residue, and root peel and sand (on a wet basis), respectively. In other words, 0.34 ton of fresh root is lost during the production processes, which in turn results in low production capacity for native starch.

Table 2
The average amount of raw materials and wastes produced in the eight selected plants

Input/output[a]	Quantity
Inputs	
• Cassava root (ton)	4.21 ± 0.28
• Water (m^3)	18.0 ± 11.3
• Electricity (MJ)	608 ± 135
- Chopping and grinding (MJ)[b]	62.2 ± 8.82
- Starch separation (MJ)[b]	118 ± 24.9
- Starch dewatering (MJ)[b]	84.9 ± 24.8
• Fuel oil (MJ)	1303 ± 324
• Sulfur (kg)	0.70 ± 0.29
Outputs	
• Starch (ton)	1
• Wastewater generation (m^3)	19.1 ± 9.32
• BOD loading (kg)	135 ± 112
• Fibrous residue (ton)	1.40 ± 0.40
• Peel and sand (ton)	0.38 ± 0.32

[a] Input and output units are based on 1 ton of starch (a moisture content of 12%).
[b] Energy used for the major starch-processing stages.

3.3. Analysis of energy consumptions

Energy consumption in the tapioca starch processing can be divided into electricity used for machine motors and fuel oil (heating oil) used for a drying oven. As shown in Table 2, the studied plants consumed twice the amount of energy from fuel oil compared to electricity. Note that two of the eight studied plants used rice husk and steam instead of fuel oil when this study was conducted. Measurements of the machines' electricity usage show that a chopper and grinder, starch separator, and DHC (for starch dewatering) account for 44% of the total electricity consumption in the tapioca starch processing. Unsurprisingly, the energy consumptions have smaller variations than does the water consumption. This is mainly because most plants are concerned about energy consumption efficiency, which accounts for a significant proportion of their production cost (Fig. 2).

3.4. Production costs

This study shows a wide variation in the costs of production among the studied plants depending on their production efficiency. Fig. 2 shows the average proportion of relative production costs according to the eight selected plants. Note that machine depreciation is excluded from the cost estimation. The majority of the production costs in the tapioca starch industry is the expenditure on purchasing unprocessed cassava root, which makes up to 83% of the costs. The rest are the costs of electricity (9%), fuel (5%), water supply (1%) and labor (2%).

Fig. 3 illustrates the production costs of the eight studied plants in accordance with the four key factors determining the production efficiency. The cost of water supply shows a significantly high variation among the plants, while the other costs are not relatively different. Interestingly, all plants lose starch in fibrous residue and wastewater greater than 130 baht/ton of produced starch. This means that the plants with production capacity of 100 ton/day lose more than 390,000 baht/month.

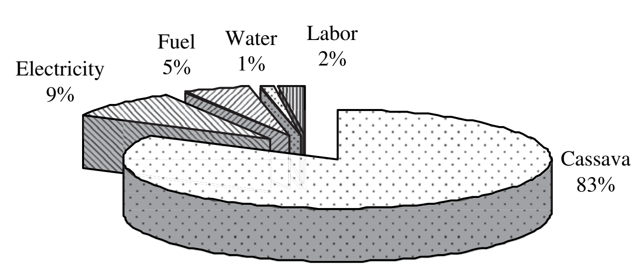

Fig. 2. Average production costs of the studied tapioca starch plants.

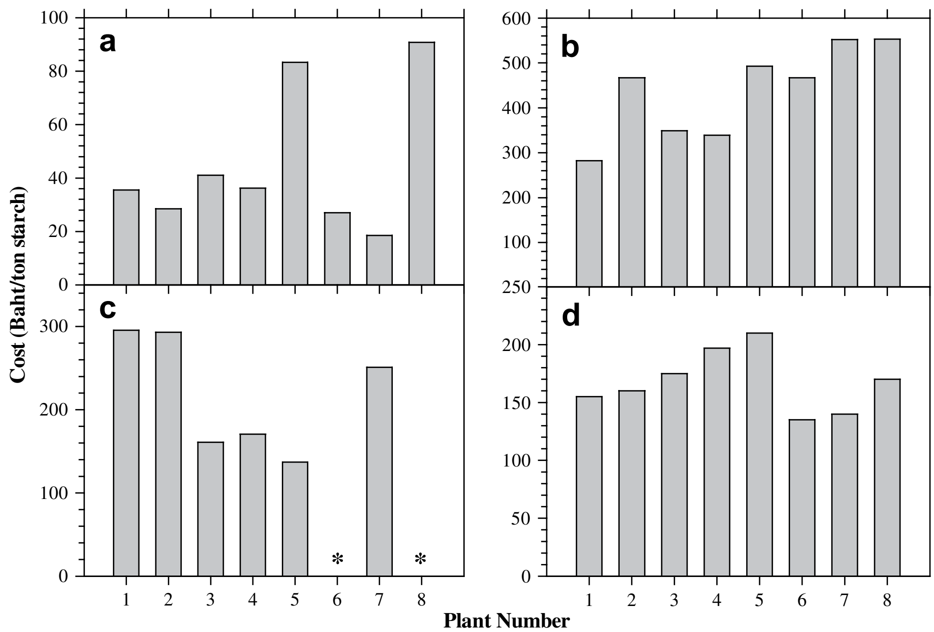

Fig. 3. Production costs according to the key factors determining the production efficiency: (a) water, (b) electricity, (c) fuel oil, and (d) starch loss in fibrous residue and wastewater. Note that an asterisk represents the plants not using fuel oil.

4. Development and implementation of clean technology

From analysis of the starch production processes, various options of clean technology were postulated and have been potentially implemented to reduce the production cost and to improve production efficiency in the selected plants. There are two groups of clean technology options proposed according to their cost of investment. In the first option, companies can adopt to modify their existing processes immediately since there are no additional investment costs. The other group involves technology modification, which requires detailed economic analysis prior to making a decision. Shown in Table 3 is a summary of clean technology options that have been implemented to the selected plants and their cost savings. Details for each option are presented as follows.

4.1. Water conservation

4.1.1. Improved housekeeping

Good housekeeping measures can often be implemented at little or no cost. The following steps have been adopted in all eight plants.

- Management of water consumption such as installation of flow meters and recording water usage per ton of product.

Table 3
Cost benefit analysis for a tapioca starch plant using a vertical screen system[a]

Environmental benefits	
Reduction of starch losses	2.5 kg/ton starch
Reduction of water consumption	2 m^3/ton starch
Reduction of Electricity consumption	18 MJ/ton starch
Economic analysis	
Total investment cost[b]	400,000 baht
Cost of starch recovery	450,000 baht
Cost of water saving	150,000 baht
Cost of electricity saving	375,000 baht
Net profit	975,000 baht
Payback period	0.4 year

[a] The plant with production capacity of 30,000 ton starch/year.
[b] Two sets of vertical screen system.

- Use of high-pressure pumps that are used for cleaning floors, machines, and extractor's filter cloth.
- Regular check and reparation of piping leakages.
- Take up all product spills from the floor before cleanup once a day in the morning. This helps to reduce the amount of wastes flushed down the drains.
- Collecting leftover starch from machines after shutting down. The dried starch can be sold as the second grade starch.

4.1.2. Reuse/recycling of water in the production processes

Since a great amount of water is required in tapioca starch processing, most of the studied plants have water reuse and recycling at some point. However, their measures are demonstrated ineffective. The following practices are proposed.

- *Reuse of wastewater from a maturation pond for plant cleaning.* Most tapioca starch plants employ conventional biological treatment systems. The systems comprise anaerobic and facultative ponds in series. Since the properties of treated wastewater in the finishing pond meet the Thai effluent standard, the wastewater is reusable for the purpose of floor cleaning.
- *Recycling of water in the production process*. As shown in Fig. 1, a typical plant without water recycling generates wastewater streams from almost all of the starch-processing stages. To minimize wastewater sources, a starch processor should consider water recycling in the production lines. Shown in Fig. 4 is the proposed water recycling to one of the studied plants. In the existing process, the reclaimed water from the second starch separator and starch dewatering centrifuge was returned for use in the fine fiber separating and first starch dewatering stages, respectively. To obtain more efficient use of water, the reclaimed water from the second dewatering stage is reused in the coarse fiber-separating stage. Since the used water from the first dewatering stage contains protein impurity, it is not suitable to be reused in the other stages except for root washing. In the fibrous residue handling streams, the reclaimed water from a screw press can be reused in the fibrous dewatering stage, while the used water from this stage can be returned to the chopper and grinder because the water contains extracted starch. This proposed water recycling indeed

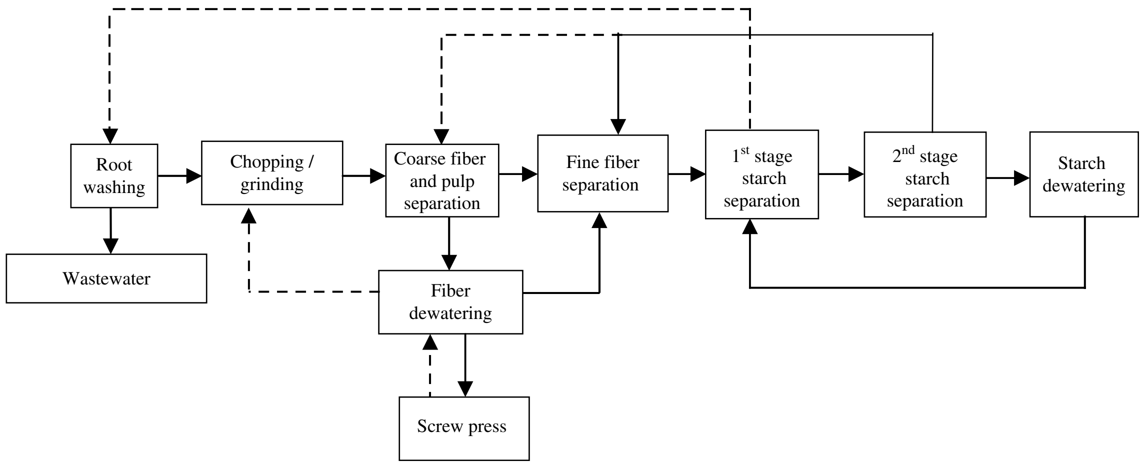

Fig. 4. Schematic diagram of the existing water usage in the production process (solid lines) and proposed modification of water recycling measures (dotted lines).

results in the sole source of wastewater being from the root washing stage, while the other stages in the process line are closed. This helps to reduce fresh water in the root-washing and fiber-separating stages. The modified process requires water only for the first and second starch separators. The implementing plant, which has production capacity of 180 ton/day and average water use of 33 m^3/ton starch, can reduce water consumption by approximately 5 m^3 or 12.5 baht per ton of starch. The annual cost saving is approximately 540,000 baht.

4.2. Technology modification for reduction of starch losses

In the tapioca starch manufacturing process, starch losses occur mainly at the centrifugal screen extractors used for removal of fiber and pulp from the starch slurry. The starch-processing plants usually use a two- or three-stage fiber separation screen arrangement of various sizes, i.e., coarse, medium, and fine. A conical screen extractor works by centrifugal force that passes the starch slurry through a filter cloth. One of the studied companies employed a two-stage extraction system, including coarse and fine screens. Each stage contained eight conical screen extractors. The data showed that the company had lost starch in fiber extraction by 30.1 kg/ton starch. The conventional system also required additional fresh water of 2 m^3/ton starch for dilution. To reduce the loss of starch and water consumption, the company has replaced four fine-screen extractors with two sets of a vertical screen system. A vertical screen extractor system consists of a vertical screener and high-pressure pump. The system uses the high-pressure pump to filter fine fiber out of the ground cassava mixture. The filtered mixture is then stored in a container prior to pumping to the starch separator for concentration.

The vertical screen extractors are highly efficient in terms of water consumption because there is no need for additional water to mix the ground cassava. The company can reduce the water usage of 150,000 m^3/ year, which represents the additional water required for the conical screen extractors. Furthermore, a vertical screen system requires less energy consumption since it consists of no moving parts. The starch loss is reduced by 2.5 kg of starch per ton of raw material. The total investment cost was 400,000 baht, while the company has gained 975,000 baht from starch recovery, and water and electricity savings as shown in Table 3. The company has gained profit within 5 months after replacement of a screen system. Note that the savings are compared with the use of four fine-screen conical extractors.

4.3. Energy conservation

Electricity cost contributes to the second largest portion of the starch-processing plants' expenditure. Companies can increase the efficiency of their electricity consumption and reduce the electricity cost using several methods. Since starch production relies on many different machines that employ motors, installation of motor load control (MLC) can help to increase the motor efficiency while running. Four of the studied plants installing MLC at a dehydration machine and grinding machine can reduce the electricity cost by approximately 58,000–290,000 baht/year as shown in Table 4. In addition to installation of MLC, the use of fluorescent lighting in plants can provide a more efficient use of electricity than incandescent light bulbs at an equivalent brightness. One of the companies that changed its lighting system from 80 sets of incandescent light bulbs to 2 × 36 W fluorescent lamps can save the electricity cost up to 181,000 baht/year with a payback period of a year. Moreover, two of the studied companies have used the exhaust air released from the drier stacks to preheating the fresh air that is delivered into the hot air generator for the drying unit. This approach helps to reduce energy for generating hot air.

Table 4
A summary of implementation of proposed clean technology options to the studied plants

Option	Investment cost (× 1000 baht)[a]	Saving cost (× 1000 baht/year)[a]	Payback period (year)	Number of implementing plants
Recycling of water in the production process	–	540	Immediately	1
Replacement of centrifugal screen with Dutch State Mines Screen (DSM)	400–780	925–980	0.4–0.8	2
Installation of motor load control at a dehydration drying machine and grinding machine	264–1190	58–290	2.5–5.2	4
Replacement of incandescent light bulbs with two-tube, 36 W fluorescent lamps	23–181	18–181	0.8–1	4
Use of exhaust air from a drier stack for preheating flesh air	20–400	125–741	0.2–1.3	2
Recovery of biogas to replace fuel oil for a burner	24,000–55,000	13,800–24,000	1.7–2.3	5

[a] US $1 = approximately 30 baht.

4.4. Use of biogas for burner fuel

Biogas recovery from a wastewater treatment system has shown great potential for tapioca starch processors. Since the price of fuel oil has increased significantly over the past decade, tapioca starch plants have been using biogas to replace fuel oil for burners that generate hot air for drying moist starch. Small- and middle-size starch plants typically use a cover lagoon system to reclaim biogas from anaerobic ponds, while large plants implement a more complicated system such as an up-flow anaerobic sludge blanket (UASB). An UASB system has double the investment cost of a cover lagoon system, however, it produces 2–3 times greater rate of biogas [6]. Five of the studied companies have recently constructed a biogas recovery system.

One of the Thailand tapioca starch companies that recently changed its wastewater treatment system from conventional open ponds to a UASB system shows a significant saving on fuel oil used for the burners of drying machines. The company has production capacity of 350 ton starch/day and generates wastewater of 2000 m^3/day. The construction cost was approximately 55 million baht and the UASB system was able to produce the maximum capacity of biogas at 13,500 m^3/day after initial operation. The recovered biogas is being used to substitute fuel oil of 8100 l/day. This helps to reduce the fuel cost by approximately 25 million baht/year. Note that the calculation is based upon the cost of fuel oil at 13 baht/l. Furthermore, the company provides treated effluent from the last polishing pond for nearby community irrigation. The closed treatment system also relieves the impact of odorous gases on communities around the plant.

5. Conclusion

Tapioca starch processing requires large volumes of water. It also generates a large amount of solid waste and wastewater. The Department of Industrial Works, Thailand has launched a program to develop pollution prevention measures for tapioca starch plants. This study, as a part of this program, shows that the implementation of clean technology in the eight selected tapioca starch-processing plants can successfully reduce water consumption and sources of wastewater. The proposed measures of clean technology include good housekeeping, reuse of the wastewater from a polishing pond for plant cleanup, and recycling of water in the production line. In addition to water conservation measures, a technological change by replacement of conical screen extractors with vertical screen system can contribute to production cost savings. Recovery of biogas from a wastewater treatment system can also be another alternative option for energy use in tapioca starch plants. The companies that have implemented these proposed clean technology options show success in improvements of consumption efficiency of raw materials and energy resources, and reduction in production cost.

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