บทความวิจัย

ปัจจัยที่ส่งผลกระทบต่อการลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังในกระบวนการอบแห้ง

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บทคัดย่อ

ในปี พ.ศ. 2561 ประเทศไทยมีการส่งออกแป้งมันสำปะหลังดิบ 3.1 ล้านตัน มูลค่า 1,037.0 ล้านดอลลาร์สหรัฐฯ และแป้งมันสำปะหลังดัดแปร 1.0 ล้านตัน มูลค่า 617.8 ล้านดอลลาร์สหรัฐฯ และคาดการณ์มูลค่าการส่งออกจะเพิ่มขึ้นทุกปี ดังนั้นการลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังจะช่วยเพิ่มความหนาแน่นรวม สามารถเพิ่มน้ำหนักบรรจุด้วยถุงบรรจุภัณฑ์ขนาดเท่าเดิม ทำให้ปริมาณขนส่งต่อสูงขึ้นซึ่งจะช่วยประหยัดค่าใช้จ่ายในการส่งออกได้ จุดประสงค์ของงานวิจัยนี้คือการศึกษาปัจจัยที่ส่งผลกระทบต่อการลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลัง โดยออกแบบ สร้าง รวมถึงติดตั้งใช้งานเครื่องลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังในกระบวนการผลิตแป้งมันสำปะหลัง ทั้งนี้กำหนดอัตราการไหลของมวลอากาศผ่านเครื่องลดขนาดไว้คงที่เท่ากับ 60,000 ลูกบาศก์เมตรต่อชั่วโมง และกำหนดปัจจัยหลัก 5 ปัจจัย คือ ชนิดแป้งมันสำปะหลัง อัตราการป้อน ความชื้นของแป้งมันสำปะหลัง รูปแบบใบพัด และความเร็วปลายใบพัด ในงานวิจัยนี้เครื่องลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังจะถูกติดตั้งในกระบวนการอบแห้งแบบพาหะลม ซึ่งใช้วัตถุดิบเป็นแป้งมันสำปะหลังดิบ และแป้งมันสำปะหลังดัดแปร ในการทดลองได้วัดค่าการใช้พลังงานไฟฟ้าด้วยเครื่องกิโลวัตต์มิเตอร์ ค่าความหนาแน่นของแป้งมันสำปะหลังด้วยเครื่องวัดความหนาแน่นรวม และขนาดอนุภาคของเม็ดแป้งคัดขนาดด้วยตะแกรงร่อนมาตรฐาน โดยประยุกต์ใช้การออกแบบการทดลองแบบแฟกทอเรียลในการวิเคราะห์ผลทางสถิติ จากการทดลองพบว่าผลกระทบของปัจจัยหลักที่ส่งผลต่อการลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังมากที่สุดคือรูปแบบของใบพัด ตามด้วยความเร็วปลายใบพัด ชนิดของแป้งมันสำปะหลัง ความชื้นของแป้งมันสำปะหลัง ตามลำดับ ในขณะที่อัตราการป้อนเป็นผลกระทบหลักที่ส่งผลต่อการลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังน้อยที่สุด ซึ่งขนาดอนุภาคของเม็ดแป้งมันสำปะหลังดิบหลังผ่านเครื่องลดขนาดมีขนาดอนุภาคของเม็ดแป้ง D80 ลดลงจากเดิม 61.90 ไมโครเมตร เป็น 54.71 ไมโครเมตร ที่ D50 ลดลงจากเดิม 53.21 ไมโครเมตร เป็น 41.82 ไมโครเมตร และค่าความหนาแน่นรวมเพิ่มขึ้นจาก 575.12 เป็น 720.54 กิโลกรัมต่อลูกบาศก์เมตร ในส่วนของแป้งมันสำปะหลังดัดแปรหลังผ่านเครื่องลดขนาดมีขนาดอนุภาคของเม็ดแป้ง D80 ลดลงจากเดิม 56.77 ไมโครเมตร เป็น 49.92 ไมโครเมตร ที่ D50 ลดลงจากเดิม 42.26 ไมโครเมตร เป็น 37.54 ไมโครเมตร และค่าความหนาแน่นรวมเพิ่มขึ้นจาก 575.14 เป็น 703.70 กิโลกรัมต่อลูกบาศก์เมตร ทั้งนี้ค่าดัชนีการใช้พลังงานพบว่าผลกระทบของปัจจัยหลักที่ส่งผลต่อค่าดัชนีการใช้พลังงานมากที่สุดคือความเร็วปลายใบพัด รองลงมาคือรูปแบบของใบพัด ชนิดของแป้งมันสำปะหลัง อัตราการป้อน ตามลำดับ ในขณะที่ความชื้นของแป้งมันสำปะหลังเป็นผลกระทบหลักที่ส่งผลต่อค่าดัชนีการใช้พลังงานน้อยที่สุด โดยแป้งมันสำปะหลังดิบมีค่าดัชนีการใช้พลังงานเพื่อลดขนาดอนุภาคเท่ากับ 9.52–12.92 กิโลวัตต์ชั่วโมงต่อตันแป้ง และแป้งมันสำปะหลังดัดแปรมีค่าดัชนีการใช้พลังงานอยู่ในช่วง 9.22–12.52 กิโลวัตต์ชั่วโมงต่อตันแป้ง

คำสำคัญ: การลดขนาด แป้งมันสำปะหลัง ความเร็วปลายใบ ดัชนีการใช้พลังงาน การออกแบบการทดลองแบบแฟกทอเรียล

การอ้างอิงบทความ: วรรณลภย์ บุญรอง สมศักดิ์ ศิวดำรงพงศ์ และ สุภกิจ รูปขันธ์, “ปัจจัยที่ส่งผลกระทบต่อการลดขนาดอนุภาคของเม็ดแป้งมันสำปะหลังในกระบวนการอบแห้ง,” *วารสารวิชาการพระจอมเกล้าพระนครเหนือ*, ปีที่ 30, ฉบับที่ 1, หน้า 60–70, ม.ค.–มี.ค. 2563.

Research Article

Parameters Affecting Particle Size Reduction of Tapioca Starch in Drying Process

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Abstract

In 2018, Thailand exported 3.1 million tons of native tapioca starch, worth 1,037.0 million US dollars. And modified tapioca starch, 1.0 million tons, worth 617.8 million US dollars. And forecast the export value will increase every year. Therefore, reducing the particle size of tapioca starch helps increase tapped bulk density. It can increase the weight with the same size packaging bag resulting in higher transportation volumes which will help save on export costs. The objective of this research was to determine the parameter that affects to a particle size reduction of tapioca starch. Involved with design, fabrication and installation on factory to produce tapioca starch. For the test method, the flow of air through with reducing machine is constant of 60,000 $m^3 h^{-1}$. Which are consisted of five parameters; type of tapioca starch, feed rate, moisture of material, type of blade and tip speed of blade. In addition, this machine was installed on drying process. The test material used as native tapioca starch and modified tapioca starch. The energy was measured by kilowatt-hour meter. A bulk density to analysis with tapped bulk density equipment and analysis of particle size with a sieve analyzer. This research was conducted under a factorial design, which is the most commonly used method for screening the primary and the combined effect of each factor. It was found that the strongest main factor influence a particle size reduction was the type of blade, followed by tip speed of blade, type of tapioca starch, the moisture of material and feed rate respectively. It was found that a particle size of native tapioca starch after through from reducing machine with flat blade type, particle size cut off on D80 were decrease from 61.90 micron to 54.71 micron and on D50 were decrease from 53.21 micron to 41.82 micron and the tapped bulk density increased from 575.12 to 720.54 kg m^{-3}. And modified tapioca starch was found particle size cut off on D80 were decrease from 56.77 micron to 49.92 micron and on D50 were decrease from 42.26 micron to 37.54 micron and the tapped bulk density increased from 575.14 to 703.70 kg m^{-3}. On the energy consumption was found that tip speed has to significant influence followed by type of blade, type of tapioca starch, feed rate and moisture of material respectively. And the energy index for native tapioca starch was 9.52–12.92 kWh ton^{-1} and modified tapioca starch was 9.22–12.52 kWh ton^{-1}.

Keywords: Particle Size Reduction, Tapioca Starch, Tip Speed, Energy Index, Fractional Factorial Design

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1. Introduction

Tapioca Industry of Thailand consist of tapioca starch production, tapioca processing industry and the continuous industry that uses the products of processing. The main products of the tapioca processing industry are tapioca chips and tapioca starch. Exports amounted to 3.84 million metric tons. It is worth 1,795 million dollar [1]. The export value of tapioca starch is likely to increase, respectively. If you can increase the weight of transportation to the cabinet. By the method of increasing total density of tapioca starch. This makes it can increase the weight of the package by the same size, reduce the cost of export by 9.7%, or about 16.5 million dollar per year, and reduce amount of packaging by 10.5% or about 6.5 million dollar per year [2]. It also reduces the burden of waste that occurs after use of the packaging.

Particle size reduction is the process by which smaller particles are compressed by compression, shear, impact, rubbing, and cutting. It is found that each method can be used in different constraints, depending on the type and size of the material [3]. Reduction of particle size of tapioca starch, The average particle size was 45–63 micron at 10–14% of moisture base on dry basis [4]. The appropriate method is to strike by centrifugal force from the blades, tapioca starch has the right angular velocity. The impact force against the impact plate or wall of the machine. Then the particles of tapioca starch are broken down and separated from each other until the particle size decreases. Average diameter of 5–35 micron according to standard size of tapioca starch [5].

The purpose of this research is to study the factors affecting the reduction of tapioca starch particle size as well as to design and install the particle size reduction system of tapioca starch installed at the tapioca starch factory. The scope of this research is determination of factors expected to affect the reduction of particle size of tapioca starch. The type of tapioca starch, tip speed of blade, type of blade, feed rate and moisture content of tapioca starch. The results from tapped density, cumulative distribution and the particle size of tapioca starch were evaluated. Because the particle size of the tapioca starch varies with tapped bulk density.

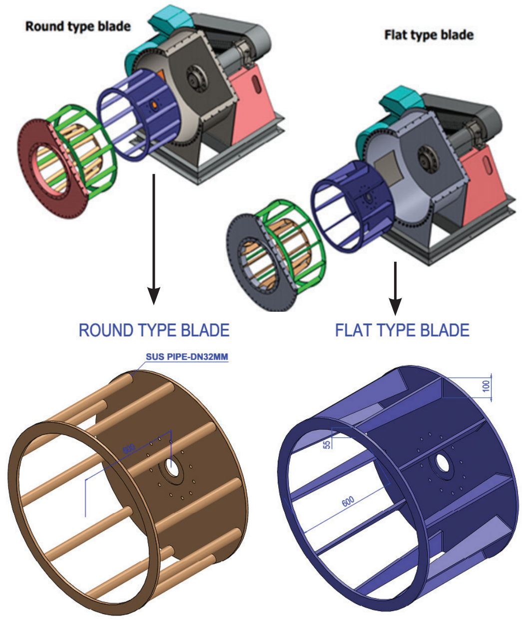

Figure 1 The reducing machine model of round type blade and flat type blade.

2. Methodology

2.1 Experiment apparatus

This research was designed by using a 3D program (Solid works), which has a different type of blade. They have round and flat type blade, as shown in Figure 1, and then installed in a drying

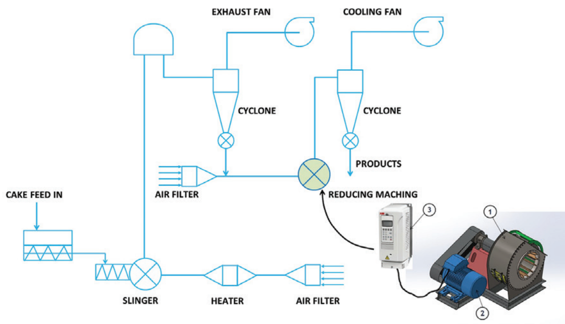

Figure 2 Install location and components of the reducing machine.

process in a starch factory. The main components consist of three phase induction motor, 110 kW, a speed control with variable speed drive (VSD) as shown in Figure 2. The machine was experimented with the system as planned.

2.2 Technique

This research was conducted under a factorial design, which is the most commonly used method for screening the primary effects of each factor

Table 1 Experimental design and experimental results.

Std Order	Type of Starch	Blade Type	Feed Rate (kg h^{-1})	Moisture (%)	Tip Speed (m s^{-1})	Tapped Bulk Density (kg m^{-3})	Power consumption (kWh)
1	Native	Flat	7000	11.4	76	695.01	73.57
2	Native	Flat	7000	12.4	76	680.57	75.41
3	Native	Flat	8000	11.4	76	681.31	76.14
4	Native	Flat	8000	12.4	76	688.74	77.29
5	Native	Round	7000	11.4	76	645.23	62.24
6	Native	Round	7000	12.4	76	640.58	63.48
7	Native	Round	8000	11.4	76	642.39	64.42
8	Native	Round	8000	12.4	76	640.87	65.06
9	Modified	Flat	7000	11.4	76	672.15	71.27
10	Modified	Flat	7000	12.4	76	668.76	72.70
11	Modified	Flat	8000	11.4	76	665.36	73.76
12	Modified	Flat	8000	12.4	76	658.28	74.50
13	Modified	Round	7000	11.4	76	641.18	60.51
14	Modified	Round	7000	12.4	76	631.71	61.72
15	Modified	Round	8000	11.4	76	642.15	62.63
16	Modified	Round	8000	12.4	76	631.24	63.25
17	Native	Flat	7000	11.4	88	720.54	90.49
18	Native	Flat	7000	12.4	88	699.25	88.23
19	Native	Flat	8000	11.4	88	705.12	89.85
20	Native	Flat	8000	12.4	88	702.87	90.15
21	Native	Round	7000	11.4	88	658.49	75.56
22	Native	Round	7000	12.4	88	650.58	74.28
23	Native	Round	8000	11.4	88	653.51	76.21
24	Native	Round	8000	12.4	88	651.64	75.89
25	Modified	Flat	7000	11.4	88	703.70	87.66
26	Modified	Flat	7000	12.4	88	701.73	85.05
27	Modified	Flat	8000	11.4	88	698.57	87.26
28	Modified	Flat	8000	12.4	88	691.47	86.90
29	Modified	Round	7000	11.4	88	655.57	74.43
30	Modified	Round	7000	12.4	88	646.23	72.21
31	Modified	Round	8000	11.4	88	649.23	74.09
32	Modified	Round	8000	12.4	88	641.28	73.78

and the combined effect of each factor. Which are consisted of five parameters; type of tapioca starch, feed rate, moisture of material, type of blade and tip speed of blade. All trials (25) as 32 experiments. The production volume of 1,000 tons of starch was tested. And Table 1 was experimental design and experimental results.

3. Results

3.1 Analysis of impact factors the affecting of tapped bulk density

Data analysis was performed using the Minitab V16 Variance Table. The Variance Table shows the main effects and the effect of any factors that affected the response at significant level 0.05. Analysis of impact factors the affecting of tapped bulk density. The ANOVA in Table 2 shows the main effects of factors affecting total density, Which are consisted of type of tapioca starch, feed rate, moisture of material, type of blade and tip speed of blade. The *p*-value of this factor is less than 0.05 and R-square (adj) is 99.98%. There is just enough to acceptable for data fitting.

Figure 3 shows the proportion of major impacts and the combined effects of factors affecting tapped bulk density of tapioca starch. It is obvious that the propeller pattern is the main effect that results in the highest tapped bulk density.

3.2 Analysis of impact factors affecting the energy consumption

The ANOVA in Table 3 shows the main effects of factors affecting the energy consumption. Which are consisted of type of tapioca starch, feed rate, moisture of material, type of blade and tip speed of blade. The *p*-value of this factor is less than 0.05

Table 2 Analysis of variance (ANOVA) for tapped bulk density

Source	DF	Adj SS	Adj MS	F-Value	*P*-Value
Model	15	20781.8	1385.5	66.86	0.000
Linear	5	19973.2	3994.6	192.78	0.000
Type of starch	1	781.0	781.0	37.69	0.000
Blade type	1	15822.0	15822.0	763.58	0.000
Feed rate	1	141.3	141.3	6.82	0.019
Moisture	1	336.1	336.1	16.22	0.001
Tip speed	1	2892.8	2892.8	139.61	0.000
2-Way Interactions	10	808.6	80.9	3.90	0.008
Type of starch*Blade type	1	147.4	147.4	7.12	0.017
Type of starch*Feed rate	1	12.1	12.1	0.58	0.457
Type of starch*Moisture	1	3.6	3.6	0.17	0.683
Type of starch*Tip speed	1	77.0	77.0	3.72	0.072
Blade type*Feed rate	1	33.5	33.5	1.62	0.222
Blade type*Moisture	1	0.4	0.4	0.02	0.893
Blade type*Tip speed	1	464.3	464.3	22.41	0.000
Feed rate*Moisture	1	53.1	53.1	2.56	0.129
Feed rate*Tip speed	1	9.6	9.6	0.46	0.505
Moisture*Tip speed	1	7.7	7.7	0.37	0.552
Error	16	331.5	20.7		
R-sq = 100% R-sq(adj) = 99.98% R-sq(pred) = 99.55%					

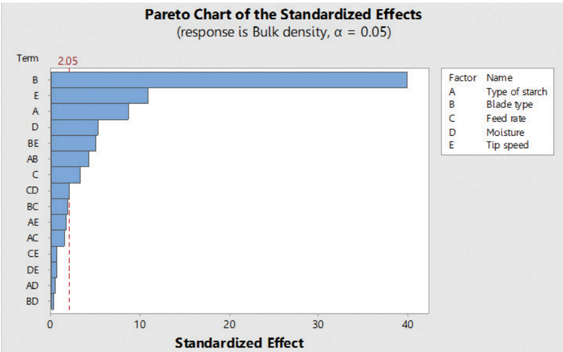

Figure 3 Pareto graph showing the proportions of the main effects and the combined effect of the factors affecting tapped density.

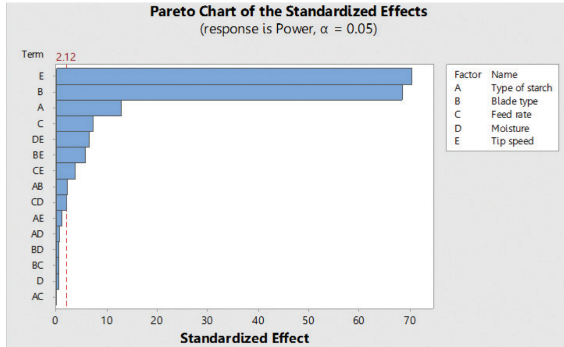

Figure 4 Pareto graph showing the proportion of major impacts and the combined effect of factors affecting energy consumption.

and R-square (adj) is 99.95%. There is just enough to acceptable the data.

Figure 4 shows the proportion of major impacts and the combined effects of factors influencing energy consumption on the reduction of particle size of tapioca starch. It is clear that the tip speed of blade is the main effect that results in the most energy consumption. Secondly, similar to the type of blade Which can be do that both the tip speed and the blade type are the main factors that affect the energy consumption index in reducing the particle size of tapioca starch.

Table 3 Analysis of variance (ANOVA) for energy consumption

Source	DF	Adj SS	Adj MS	F-Value	*P*-Value
Model	15	2643.00	176.20	666.12	0.000
Linear	5	2616.20	523.24	1978.09	0.000
Type of starch	1	44.06	44.06	166.58	0.000
Blade type	1	1243.38	1243.38	4700.58	0.000
Feed rate	1	14.27	14.27	53.95	0.000
Moisture	1	0.04	0.04	0.17	0.688
Tip speed	1	1314.43	1314.43	4969.18	0.000
2-Way Interactions	10	26.80	2.68	10.13	0.000
Type of starch*Blade type	1	1.32	1.32	5.01	0.040
Type of starch*Feed rate	1	0.00	0.00	0.00	0.965
Type of starch*Moisture	1	0.10	0.10	0.39	0.543
Type of starch*Tip speed	1	0.28	0.28	1.07	0.316
Blade type*Feed rate	1	0.08	0.08	0.29	0.597
Blade type*Moisture	1	0.09	0.09	0.32	0.578
Blade type*Tip speed	1	8.83	8.83	33.38	0.000
Feed rate*Moisture	1	1.17	1.17	4.41	0.052
Feed rate*Tip speed	1	3.73	3.73	14.11	0.002
Moisture*Tip speed	1	11.20	11.20	42.33	0.000
Error	16	4.23	0.26		
R-sq = 100% R-sq(adj) = 99.95% R-sq(pred) = 99.50%					

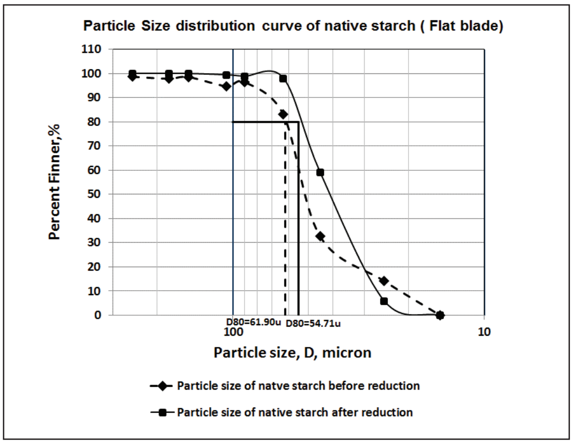

Figure 5 Distribution of native tapioca starch granules on D80 Before and after using flat blade cutter.

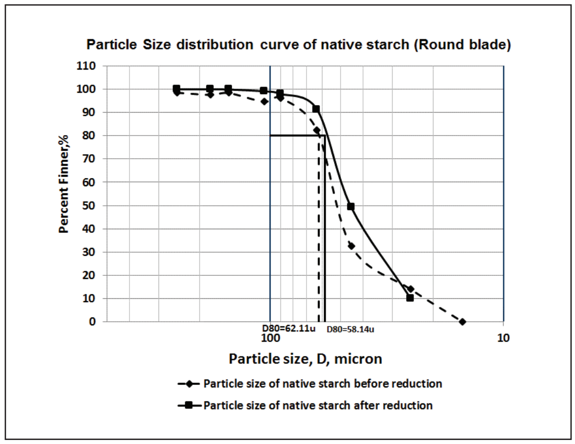

Figure 7 Distribution of native tapioca starch particles on D80. Before and after using round blade cutter.

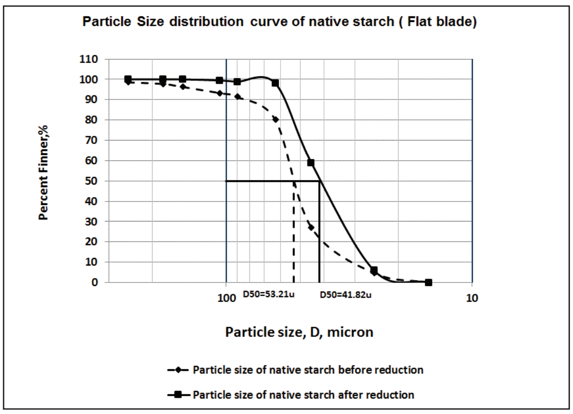

Figure 6 Distribution of native tapioca starch particles on D50. Before and after using flat blade cutter.

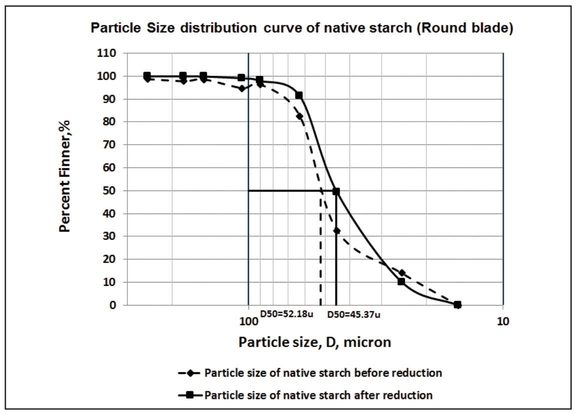

Figure 8 Distribution of native tapioca starch particles on D50. Before and after using round blade cutter.

3.3 Analysis of powder particle distribution

Analysis of particle distribution by sieving through a standard sieve to determine the weight of each granule. The particle size of tapioca starch (D80) was decreased after using flat blade from 69.10 to 54.71 micron as shown in Figure 5. And D50 was decreased after using flat blade from 53.21 to 41.82 micron as shown in Figure 6. Similarly, using round blade D80 was decreased from 62.11 to 5814 micron as shown in Figure 7. And D50 was decreased after using round blade from 53.21 to 41.82 micron as shown in Figure 8. The result showed the ability of flat blade to reduce particle size of native tapioca starch was better than round blade, respectively.

Figure 9 shows the particle size of modified tapioca starch (D80) was decreased after using flat blade from 56.77 to 49.92 micron. And D50 was decreased after using flat blade from 42.26 to 37.54 micron as shown in Figure 10. Similarly, after using round blade D80 was decreased from 56.85 to

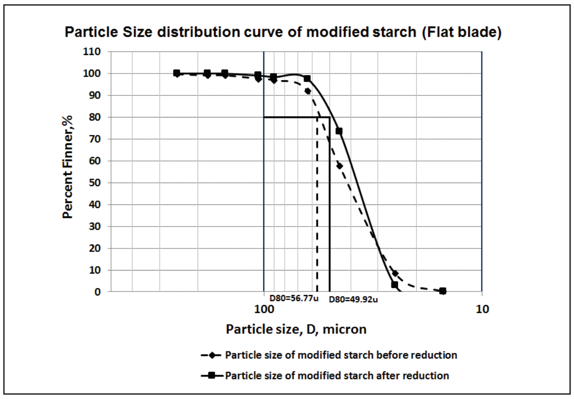

Figure 9 Distribution of modified tapioca starch particles on D80. Before and after using flat blade cutter.

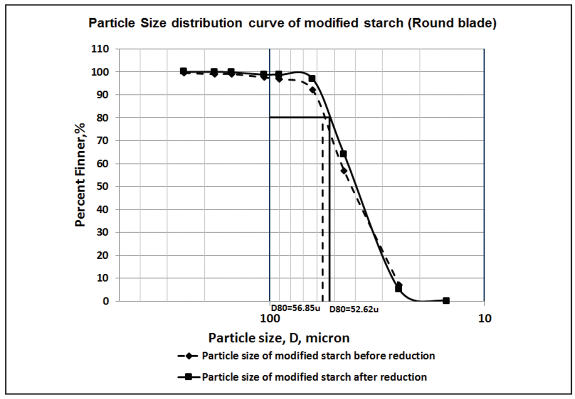

Figure 11 Distribution of modified tapioca starch particles on D80. Before and after using round blade cutter.

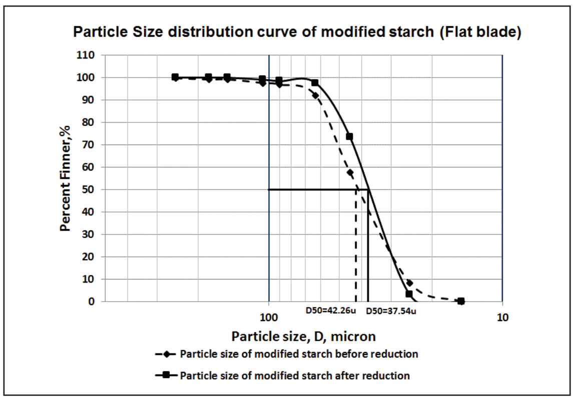

Figure 10 Distribution of modified tapioca starch particles on D50. Before and after using flat blade cutter.

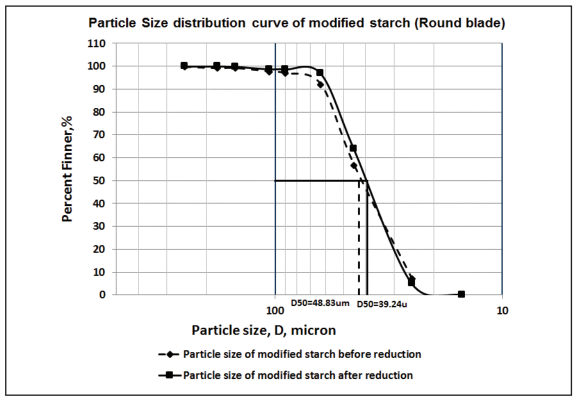

Figure 12 Distribution of modified tapioca starch granules on D50. Before and after using round blade cutter.

52.62 micron as shown in Figure 11. And D50 was decreased after using flat blade from 48.83 to 39.24 micron as shown in Figure 12.These result supports to the ability of flat blade to reduce particle size of modified tapioca starch was better than round blade as same as tapioca starch in previous test.

3.4 Analysis of Tapped Bulk Density and Energy Consumption

Tapped bulk density is determined by the Digital Tapped Density Apparatus and the energy measured by the Power Meter. According to Table 4 and Figure 13 showed the tapped bulk density of tapioca starch after using flat blade increased from 575.12 to 720.54 kg m^{-3}. The power consumption was used 12.93 kWh ton^{-1}. Similarly, using round blade was showed the tapped bulk density increased from 573.41 to 658.49 kg m^{-3}. The power consumption was 10.94 kWh ton^{-1}.

Similar experiments were performed for modified tapioca starch and similar trend of the results was observed. Tapped bulk density after using flat blade

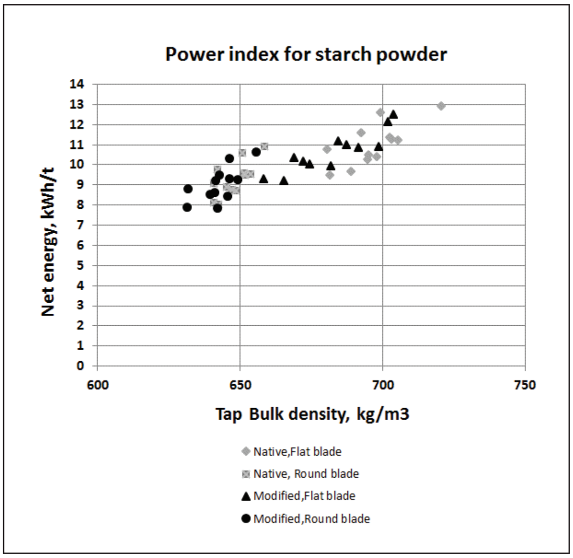

Figure 13 The total density and energy consumption to reduce the particle size of tapioca starch and modified tapioca starch.

increased from 575.14 to 703.70 kg m^{-3}. The power consumption was used 12.52 kWh ton^{-1}. Similarly, using round blade was showed the tapped bulk density increased from 571.60 to 655.57 kg m^{-3}. The power consumption was 10.63 kWh ton^{-1}.

Table 4 Tapped bulk Density and Energy Consumption

Type of starch	Blade type	Tapped Bulk density (kg per cubic meter)		% Increase	Net energy (kWh ton^{-1})
		Before	After		
Native starch	Flat	575.12	720.54	27.59%	12.93
Native starch	Round	573.41	658.49	14.84%	10.94
Modified starch	Flat	575.14	703.70	24.98%	12.52
Modified starch	Round	571.60	655.57	14.69%	10.63

4. Discussion

This study investigates the factors that are expected to affect the particle size reduction of tapioca starch. The particle size of the tapioca starch is varied with the tapped bulk density [7]. Two factorial design experiments were used. Five factors were used: type of tapioca starch, feed rate, moisture of material, type of blade and tip speed of blade.

From the experiment, it was found that the propeller pattern was the main factor affecting the particle size reduction of the most tapioca starch. Followed by the tip speed. And the third factor is Types of Tapioca Starch. The flat type blade has a greater impact on the reduction of the size of the powder particles than the round type. This means that the rotor blades, which have a more exposed surface area, can pass over the impact force more than round blade with less exposed surfaces Causing the particle size of the tapioca starch to be smaller. Which the particle size of tapioca starch after reduce with reducer. The particle size of 25 micron of starch granules increased from 22.9 percent to 53.4 percent and the tapped bulk density increased from 575.1 to 720.5 kg m^{-3}. In the modified tapioca starch after reducing, the particle size of 25 micron of starch granules increased from 46.2 percent to 67.5 percent and the tapped bulk density increased from 575.1 to 703.7 kg m^{-3} [6]. The next factor is the tip speed of 88 m s^{-1}. Affecting the particle size reduction of starch granules at a speed of 76 m s^{-1}, due to the high force impact on starch granules caused by angular velocity [8]. And the lasted factor affecting the size reduction is the type of tapioca starch. Found that the native tapioca starch has passed through the reducing machine. With particle size of starch granules smaller than modified tapioca starch this is because the bond strength between the particles is less than that of not adding chemicals [9].

The factors influencing the energy consumption in reducing the particle size of tapioca starch were: tip speed of blade, type of blade, type of tapioca starch and feed rate, respectively. And the moisture of material did not affect to energy consumption of tapioca starch. The result indicated that energy of reducing the particle size of tapioca starch relatively to tip speed of blade.

Distribution of tapioca starch and modified tapioca starch before and after using reduction process, Flat type blades have greater effect than round type blades for dispersion of tapioca starch and modified tapioca starch. The D80 was 54.17 micron for tapioca starch and D80 was 49.92 micron for modified tapioca starch, respectively.

In conclusion, we have utilized the reducing machine to give the smaller particle size of tapioca starch. The flat type blade could be reduced the particle size with high capacity for the relatively smooth blade, which exhibited more forceful impact than round blade. The tapped bulk density of tapioca starch and modified tapioca starch up to 27.59% and 24.98%, respectively. In terms of power consumption, the reducing machine in the presence of flat type blade used more energy than round type blade in 12.93 and 12.52 kWh ton^{-1}, respectively for modified tapioca starch.

5. Conclusion

In this study was found that the strongest main factor influence to a particle size reduction was type of blade, followed by tip speed of blade, type of tapioca starch, moisture of material and feed rate respectively. It was found that a particle size of native tapioca starch after through from reducing machine with flat blade type, particle size cut off D80 were decrease from 61.90 micron to 54.71 micron and on D50 were decrease from 53.21 micron to 41.82 micron and the tapped bulk density increased from 575.12 to 720.54 kg m^{-3}. And modified tapioca starch was found particle size cut off on D80 were decrease from 56.77 micron to 49.92 micron and on D50 were decrease from 42.26 micron to 37.54 micron and the tapped bulk density increased from 575.14 to 703.70 kg m^{-3}. On the energy consumption was found that tip speed have to significant influence followed by type of blade, type of tapioca starch, feed rate and moisture of material respectively. And the energy index for native tapioca starch was 9.51–12.92 kWh ton^{-1} and modified tapioca starch was 9.22–12.52 kWh ton^{-1}.

6. Acknowledgements

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