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MACHINE DESIGN IMPROVEMENT FOR TUNA FLAKE FILLING IN CANS

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A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Engineering in Engineering Management

(CU-Warwick)

Faculty of Engineering

Chulalongkorn University

Academic Year 2018

การปรับปรุงการออกแบบเครื่องจักรสำหรับการเติมเศษปลาทูน่าในกระป๋อง

นายพิรุฬห์ เหรียญวัจนะวงศ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
สาขาวิชาการจัดการทางวิศวกรรม ศูนย์ระดับภูมิภาคทางวิศวกรรมระบบการผลิต
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2561

Thesis Title	MACHINE DESIGN IMPROVEMENT FOR TUNA FLAKE FILLING IN CANS
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Field of Study	Engineering Management
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การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อปรับปรุงกระบวนการบรรจุเศษปลาทูน่าในกระป๋องโดยการพัฒนาผลิตภัณฑ์ที่มีศักยภาพขั้นต่ำ (Minimal Viable Product, MVP) เพื่อทดสอบความเป็นไปได้ของการปรับปรุงกระบวนการครั้งนี้ นอกจากนี้การศึกษาครั้งนี้ยังรวมไปถึงการตรวจสอบกระบวนการก่อนและหลังอื่นๆที่เกี่ยวข้องเพื่อค้นหาความเป็นไปได้ที่จะเพิ่มความถูกต้องและความแม่นยำของการบรรจุ การทดลองระหว่างการศึกษาทำให้ได้มาซึ่งข้อกำหนดคุณสมบัติที่เหมาะสมที่สุดของเครื่องและสภาวะที่เหมาะสมในกระบวนการผลิตและวัตถุดิบเพื่อให้เป็นไปตามมาตรฐานการบรรจุ ผลการวิจัยพบว่าการปรับปรุงกระบวนการตรวจสอบวัตถุดิบที่เป็นสิ่งจำเป็นเพื่อให้การเติมมีเสถียรภาพมากขึ้น ขนาดของเศษปลาทูน่าเป็นปัจจัยที่นำไปสู่ความพึงพอใจในการเติมเพื่อให้ได้น้ำหนักที่ถูกต้องและแม่นยำตามความต้องการของผู้ผลิตปลาทูน่ากระป๋อง นอกจากนี้ยังแสดงให้เห็นว่าการปรับปรุงในขั้นตอนการตรวจสอบวัตถุดิบ พร้อมกับเครื่องเติมเศษปลาทูน่าซึ่งควบคุมปริมาตรการเติมสามารถนำมาใช้แทนพนักงานที่เกี่ยวข้องในกระบวนการแก้ไขน้ำหนักเติมซึ่งปัจจุบันต้องมีถึง 6-8 คนในกระบวนการนี้

สาขาวิชา	การจัดการทางวิศวกรรม	ลายมือชื่อนิสิต	....
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5971231521 : MAJOR ENGINEERING MANAGEMENT
KEYWORD: Tuna Flake Filling, Machine Design Improvement

Phirun Reonwajanawong : MACHINE DESIGN IMPROVEMENT FOR TUNA FLAKE FILLING IN CANS. Advisor: Asst. Prof. Dr. Somchai Puajindanetr

This study aims to improve the process of tuna flake filling in cans by developing a minimum viable product (MVP) to test the feasibility of the improvement. It also examines other related prior and subsequent processes to discover possibilities to increase the accuracy and precision of the filling. Experiments have been carried out during the study to determine the most appropriate features of the machine and suitable conditions of incoming material in order to satisfy the filling standard. The result of the study shows that an improvement in the incoming material investigation process is needed to gain more stable size range of tuna flakes which leads to satisfied fill weight accuracy and precision by the canned tuna flake manufacturer. It also suggests that improvement in the incoming material investigation procedure along with volume controlled granular filler can be used to replace the workers involved in the weight correction process which currently requires 6-8 people in the process.

Field of Study: Engineering Management		Student's Signature ....
Academic Year: 2018		Advisor's Signature ....

ACKNOWLEDGEMENTS

First of all, I would like to thank you my advisor Asst. Prof. Somchai Puajindanetr for his support and guidance throughout the dissertation from the beginning until completion. Secondly, I would also like to express my gratitude to the Chairman of the committee of the thesis, Prof. Dr. Parames Chutima, and, members of the committee, Assc. Prof. Dr. Jeerapat Ngaoprasertwong and Assoc. Prof. Dr. Vanchai Rijiravanich for their great valuable comments during the stage of proposal and final thesis presentation.

Thirdly, I would like to thank my company Sutthiphong Engineering and my production staffs for supporting me in constructing the minimal viable product (MVP) making all the experiments in the research possible. Lastly, my gratitude also goes to all the WMG tutors who provide the knowledge for me throughout the courses. The visiting professors have enlightened me so much in class and also allow me to become a better person at work.

Phirun Reonwajanawong

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CHAPTER 1 INTRODUCTION

This chapter illustrates the current method of tuna flake filling process in cans among Thailand leading manufacturers; objectives, hypothesis and scopes of the research; and the expected outcome of the research.

1.1 Background

Sutthiphong Engineering Company is a can closing machine and high precision can tooling manufacturers, which was established in 1977 in Bangkok, Thailand. Its customers are divided into 2 business sectors which are canned food and beverage manufacturers, and can manufacturers. The proportion of sales revenue in each business sector is shown in Figure 1. The company supplies can closing machines to its customers in the canned food and beverage manufacturing sector, whereas high precision can tooling is supplied to the can manufacturing sector. Within the food and beverage sector, its customer categories can be separated into canned seafood, canned fruit and canned beverage, having seafood manufacturers as the majority of customers.

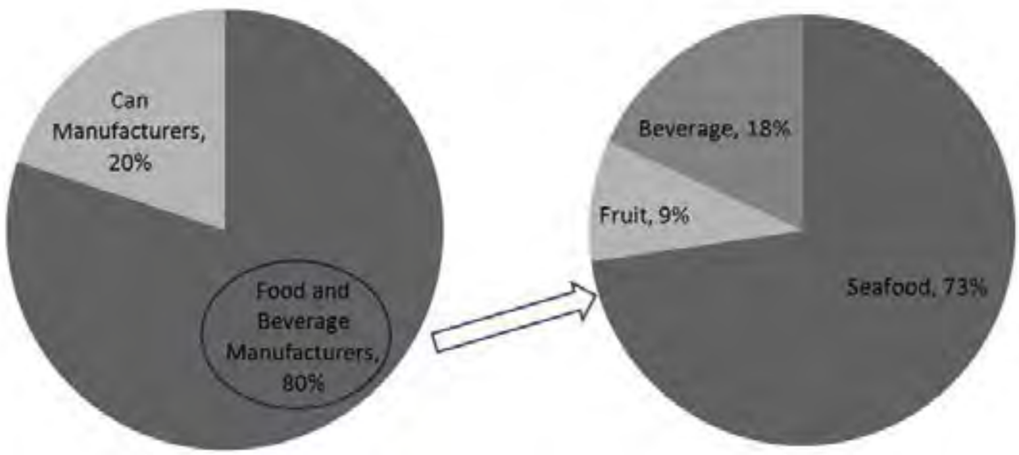


Figure 1: *Proportion of sales revenue in 2017*

In the global perspective, Thailand is considered as the “Kitchen of the world” with the export sales of 24 Billion USD (768.4 Billion Baht) in 2016, the country is one of the world largest food manufacturers, and is the largest in Southeast Asia region (The Nation, 2018). Canned Tuna industry plays an important role in the food exports industry in the country, as Thailand global market share in the industry is 44 percent in 2016 (BOI, 2018).

In the seafood sector, the company has supplied their can closing machines to many leading canned tuna manufacturers in Thailand including Tropical Canning (Thailand) PCL., Unicord PCL. and Thai Union Group PCL. for decades.

With its strong relationship with Thailand leading canned tuna manufacturers, the company decided to develop a machine for the tuna flake filling process which the market has the demand for however it is still un-captured. The current equipment used in the industry is semi-automatic and requires a number of workers in the process.

In comparison, the hourly wage for an average worker had increased by 105% from 1990 to 2007, whereas the average cost of robots reduced by 48% (Caldwell, 2013). With the realisation of technology development to assist traditional working processes and rooms for improvement in canned food manufacturing processes, this thesis intends to determine necessary features to develop an optimal Tuna Flake filling machine and other control procedures which together are able to achieve the required filling condition with both accuracy and precision.

1.2 Problem statement

Tuna Flake filling is a process that requires 7-9 workers, having one of the workers filling the material into the bowl of the machine which semi-automatically fills the product into each can, while the rest of the workers are working on the accuracy of the filling weight by handpicking the product in and out the cans.

1.2.1 Tuna Flake Filling Process Flow

The process flow of the tuna flake filling inside a typical production line is shown in Figure 2, the sequence of the production can be explained according to the procedure in each station as follows.

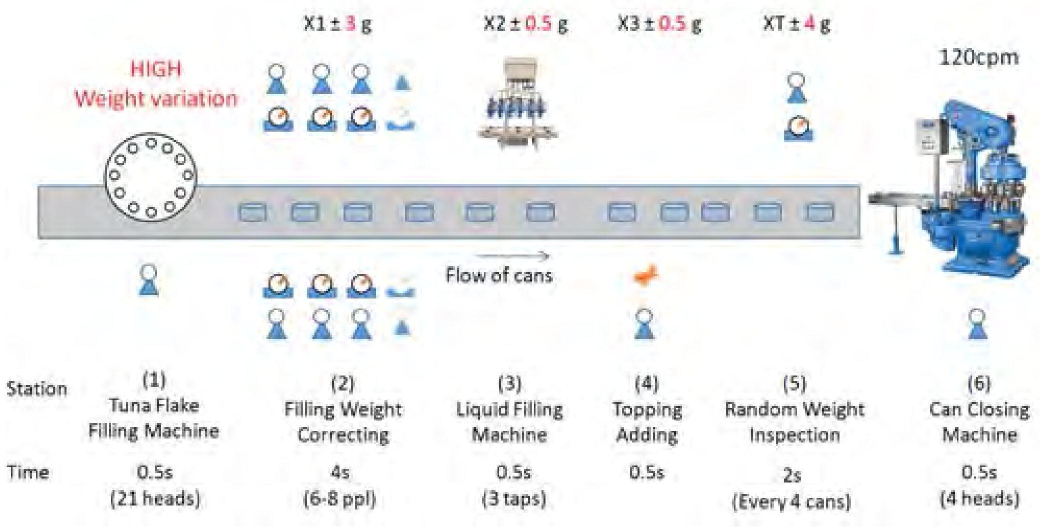


Figure 2: *Current Tuna Flake Filling Process Flow*

(1) Tuna flake filling machine: The current Tuna Flake Filling machine is semi-automatic. After pouring a tray of 10kg of tuna flake into the bowl of the machine, the worker at this station wipes the tuna flake into the cans by hand. The demonstration of the current filling process is shown in Figure 3 and 4. It can be seen that due to the large gap between the bottom of the bowl and the cans, there is a waste of at the station from tuna flake falling out of the cans. Moreover, due to the inconsistency of the filling weight by semi-automatic machine, the filling weight correcting station is required.

(2) Filling weight correcting: In this station, each worker picks up one pre-filled can from the conveyor at a time and weighs the can with the weighing machine in front of them (Figure 5). The weight correction is done by handpicking the tuna flake in and out of the can until the ±3g accuracy is achieved. This station requires 6-8 workers depending on the skills of the worker and the capacity of the production.

(3) Liquid filling machine: The liquid filling process is done by machine feeding constant flow of liquid product to the cans flowing through the conveyor (Figure 6). The speed of the conveyor and the flow rate of the liquid filling determine the volume of the liquid being filled in the cans.

(4) Topping adding: This process is done by handpicking the topping into the cans flowing through the conveyor (Figure 6). One worker is required at this station.

(5) Random weight inspection: Every one out of four cans in the filling process is picked up at this station to check the accuracy of the weight (Figure 6). The accuracy required in the whole filling process is ±4g. This station requires one worker.

(6) Can closing machine: After weight accuracy is controlled, the cans are closed at the speed of 120 cans per minute (cpm) using can closing machine which is a product of Sutthiphong Engineering.

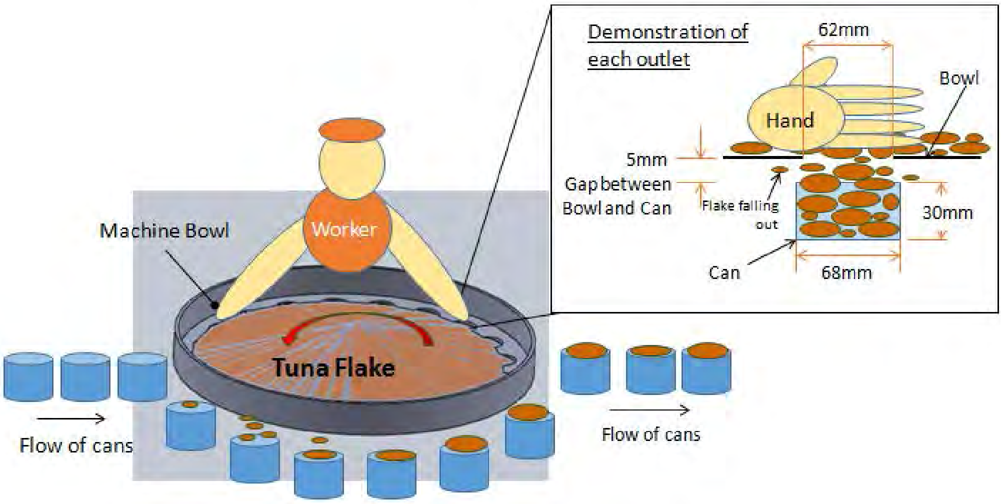


Figure 3: *Current Filling Machine Demonstration Diagram*

Figure 4: *Actual Operation of Current Filling Machine*

Figure 5: *Actual Operation of Filling Weight Correcting Process*

Figure 6: *Actual operation of Liquid Filling Machine, Topping Adding and Random Weight Inspection*

1.2.2 Current Filling machine process capability

In mass production manufacturing, the processes involved cannot be kept stable enough to produce an ideal exact replica of products. As a result, statistical analysis and process capability indices are commonly used to determine the capability of the process (Deleryd, 1998). The filling target for this particular tuna flake product is 43g with the allowance of ±3g tolerance. From the 100 samples of data, the current filling process capability can be analysed as follows.

(1) Statistical Analysis

The performance of the current filling machine is shown through the histogram in Figure 7. The curve is skewed to the right giving negative value of skewness of -0.701 indicating that the larger portion of the samples is overfilled. Moreover, only 33 percents of the samples achieve the filling target. The sample has a very high standard deviation (SD) of 7.4, demonstrating that the current filling process has low performance.

(2) Process Capability indices (PCIs)

PCIs are able to present a numerical measure to show whether the production process is capable of manufacturing the products within the specified limit of target. The two commonly used PCIs in manufacturing are C_p and C_{pk}, which are determined by the following equations (Chen et al., 2003).

$$C_p = \frac{USL-LSL}{6\sigma} \tag{1-1}$$

$$\mathrm{C_{pU}} = \frac{\mathrm{USL}-\mu}{3\sigma} \tag{1-2}$$

$$\mathrm{C_{pL}} = \frac{\mu-\mathrm{LSL}}{3\sigma} \tag{1-3}$$

$$C_{pk} = \min\{C_{pU}, C_{pL}\} \tag{1-4}$$

Where USL refers to the upper specification limit, LSL refers to the lower specification limit, μ refers to the mean of the process and σ refers to the standard deviation of the process.

C_p and C_{pk} of the current process are 0.135 and 0.094 respectively indicating that the process is very far from achieving its control target, as C_p and C_{pk} value of greater than 1 identifies a capable process. Therefore, the root causes of the inconsistency and the suggestion for improvement are to be identified in this research.

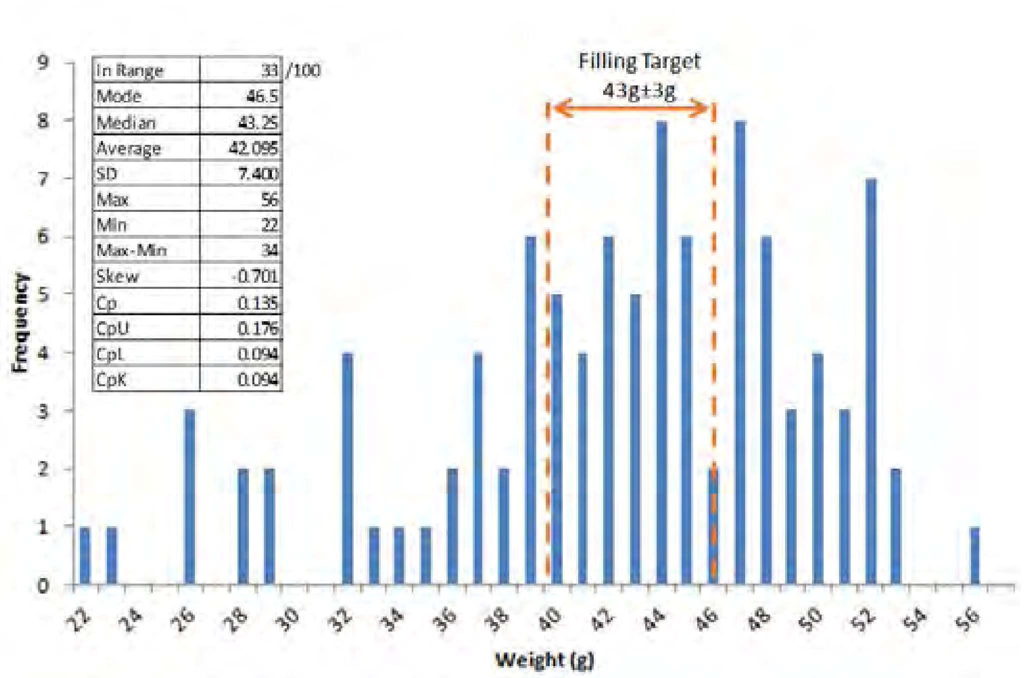


Figure 7: Current filling process capability

1.3 Research Objective

This research aims to develop the necessary features for designing a tuna flake filling machine and other incoming material and production control methods to improve the efficiency of tuna flake filling process in cans which includes the following factors,

(1) Weight Controllability: Achieving target filling weight accuracy of ±3g using tuna filling machine and additional incoming material and production control methods.

(2) Flowability: With the additional design features, the product is able to flow inside the tuna filling machine and into the cans without obstacles to achieve target filling weight.

(3) Cost Effectiveness: With incoming material and production control methods and investment in the newly designed machine, the tuna filling process is able to achieve cost merit and reach return within 2 years.

1.4 Research Questions

(1) How can the current tuna flake filling machine be improved?

(2) Will additional control processes be required for the incoming material to improve the tuna flake filling process?

(3) Can the number of workers in the filling weight correction process be reduced?

(4) Are the process improvements cost effective, what is the rate of return?

1.5 Hypothesis Development

With the four research questions, hypotheses can be developed using existing knowledge and empirical verifications as follows.

(1) The initial filling process by the tuna flake filling machine can be improved by adding new features to the machine such as fixed volume filling and wiper.

(2) Additional control processes such as product grain size control and moisture control will be required to improve the accuracy of the filling.

(3) The improvement in the accuracy and precision of the filling weight by the machine will reduce the number of workers in the filling weigh correction.

(4) The reduction of the number of workers required, additional control processes required and the improvement of the filling machine will determine the cost effectiveness of this project.

1.6 Scopes of Research

This research focuses on the efficiency improvement of the tuna flake filling process by working on the followings.

(1) New design features required for the tuna flake filling machine to improve the initial filling process and its contribution to accuracy improvement which will be studied through a minimum viable product

(2) Additional control processes of the incoming material which affects the filling weight including its potential in accuracy improvement

(3) Cost merit from the reduced number of workers against the new machine investment and additional control processes.

However, the scope of this research does not include the building a tuna flake filling machine.

1.7 Expected Outcome

A combination of design features including its optimal settings and machine materials together with incoming material control procedures for tuna flake filling process which result in the following benefits.

(1) Accuracy and precision in the initial tuna flake filling process

(2) Cost Effectiveness due to the reduced number of workers required in the process

(3) Product portfolio increase creating an opportunity for new income for the company

CHAPTER 2 LITERATURE REVIEW

This section contains the technology of filling machines available in the market and granules related knowledge such as grain size, structure, moisture and flowability. In addition, it also includes tuna meat related information such as density and machine related material and the definition of minimum viable product used in the research.

2.1 Granule Filling Techniques

At present, Granular material can be filled using 2 different techniques which are weight controlled and volume controlled. There are many manufacturers who supply weight controlled and volume controlled granule fillers in the market. Some of the examples of manufacturers and the technical information of their machines will be explained in this section.

2.1.1 Weight controlled filler

Weight controlled fillers for industrial uses normally contain a number of weighing heads and discharge points which are determined by their filling capacity. In this type of fillers, the products are usually automatically fed to the machine using conveyors. Once the product reaches the machine, it is distributed into each weighing head and the weight is recorded by the computer. The product with recorded weight is then dropped into a hopper, which is now ready to be dispatched into a filling container. With the recorded weight in each hopper, the computer calculates to find a combination of hoppers such that the target weight is achieved (Fellows, 2017).

Figure 8 illustrates the logic of the filling machine in achieving a target weight of 250g, while the picture of weight controlled filler by a machine manufacturer is shown in Figure 2-2.

Although the machine manufacturer claims that the accuracy of the filling is between 0.5 to 1g (Scanvaegt, 2018), after discussing with a process engineer of a canned tuna manufacturing plant, the filling method is only suitable for dry products with low friction against the stainless steel weighers and hoppers. These characteristics are totally different to tuna flakes which are damped and are easily trapped in the machine internal parts causing inaccuracy in filling.

Figure 8: Logic of weight controlled filler (Fellows, 2017)

Figure 9: Bilwinco weight controlled filler (Scanvaegt, 2018)

2.1.2 Volume controlled filler

Similar to weight control fillers, volume controlled filler also contain multiple filling heads and the products are normally fed to the machine using conveyors, however the filling amount is controlled by volume rather than weight. As shown in Figure 10, in operation, the product is wiped into a volume controlled cup, levelled to the target volume and released into a container using air blow. The machine shown in Figure 11 is designed for filling homogenous products such as corns and beans in which the weight accuracy can be easily achieved.

The current tuna flake filling process uses volume controlled filling method as the machine is less likely to cause the trapping of product inside the machine mechanism while filling and as the machine is less costly than the weight controlled type. However the current machine used in the production does not contain a pre-measured mechanism before filling and releasing mechanisms. In order to fully control the filling with the ±3g tolerance target, the granular structure of the input and its controlled method are to be studied in depth.

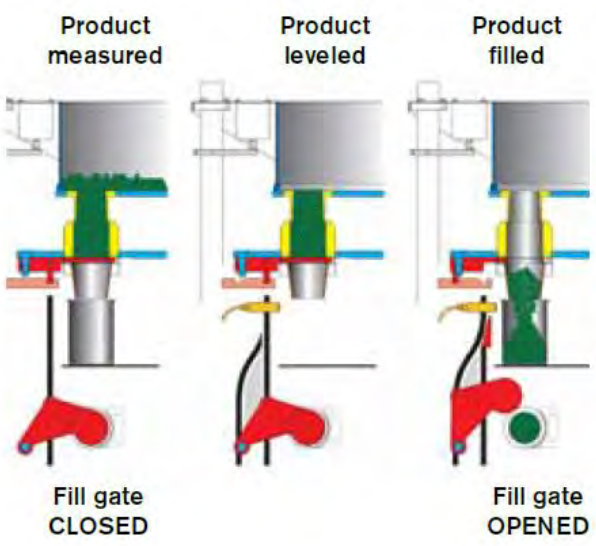


Figure 10: *Mechanism of volume controlled filler (JBT, 2018)*

Figure 11: *JBT volume controlled filler (JBT, 2018)*

2.2 Granule and Grain Size Measurement

Granular medium is an engineering concept which refers to a type of aggregate formed by a collection of granules which are related to each other. Considering water content and stickiness, the medium can be separated into 2 types, (1) ideal granular medium and (2) non-ideal granular medium. The former refers to the medium with water content and stickiness, whereas the latter refers to the medium without water content and stickiness (Wu and Sun, 2008).

2.2.1 Volumetric Equivalent Diameter Measurement

Due to the large variation in size of granular material, its measurement of particle size also varies dramatically from micrometer to microscope for the optical method, and sieving to fluid mechanic related measurement process such as terminal velocities, sediment rates and permeability for mechanical method. Moreover, electrical method can also be used by flowing a diluted suspension of granules between electrodes to measure the change in electrical resistance which determines the size of the particles (Nedderman, 1992).

Most granular materials are not in perfect spherical form, however, its diameter can be determined in equivalent spherical format by using volume of the particle using the formula,

$$\boldsymbol{D_s = \left(\frac{6V}{\pi}\right)^{1/3}} \tag{2-1}$$

Where D_s refers to the equivalent spherical diameter, mm; V refers to the volume of the particle.

2.2.2 Projected Area Equivalent Diameter Measurement

In the case where the volume of granular particle is difficult to be found, image analysis can also be used to find the area equivalent diameter based on the projected area of the particle (Nedderman, 1992).

$$\mathbf{D_A = \sqrt{\frac{4A_p}{\pi}}} \tag{2-2}$$

Where D_A refers to area equivalent diameter, mm; A_p refers to the project area of the particle.

2.2.3 Feret Diameter Measurement

Another common particle measurement method is Feret diameter. The diameter is the measurement taken between two extreme tangents which are parallel to an arbitrary direction i.e. the longest dimension across the particle (Figure 12).

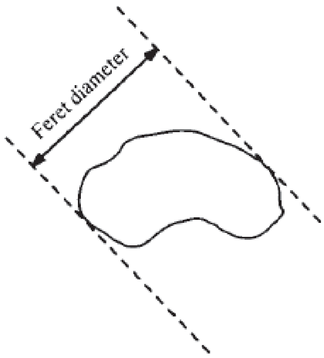


Figure 12: *Feret diameter (Nedderman, 1992)*

The range of particle sizes for agricultural products such as seeds are normally much smaller than those granular products produced by crushing of larger material (Nedderman, 1992).

In this research, as the tuna flake is made by crushing larger chucks of meat into smaller bits with large range of particle sizes, its diameter will be measured and analysed statically by taking crushed samples from the actual machine used by manufacturer. Moreover, due to the easily damped characteristics which is inappropriate for volume measurement, the grain size of tuna flake will measured using Feret diameter for simplicity.

2.3 Granular Density and Bulk Density

Using volumetric filling method with a weight as a target, the density of tuna flake is to be found in order to determine the dimension of the measuring cup. The theories reviewed in the research consist of both granular density and bulk density which refers to the density of mixture of particles and mixture of particles in a container respectively.

2.3.1 Granular Density

According to Wu and Sun, 2008, density of granular material can be expressed by its mass per volume.

$$\boldsymbol{\rho_s = \frac{m_s}{V_s}} \qquad (2\text{-}3)$$

Where ρ_s refers to the granular density, kg/m^3; m_s refers to the mass of solid granular, kg; V_s refers to granular volume, m^3.

With the variation in stacked conditions, granular density can normally be divided into free stacking density and dynamic compaction stacking density. Coefficient of compactness is a ratio of dynamic compaction stacking density and free stacking density which can be used to identify the compactness of granular media (Wu and Sun, 2008).

$$\boldsymbol{K_m = \frac{\rho_m}{\rho_d}} \qquad (2\text{-}4)$$

Where K_m refers to the coefficient of compactness; ρ_m refers to the dynamic compaction stacking density, kg/m^3; ρ_d refers to the free stacking density, kg/m^3.

2.3.2 Bulk Density

However, the bulk density refers to the density of granular media inside a container which includes both solid granules and interstitial gas (Nedderman, 1992). Bulk density can be determined using the below formula.

$$\rho_b = \frac{m_b}{V_b} \qquad (2\text{-}5)$$

Where ρ_b refers to the bulk density, kg/m^3; m_b refers to the mass of bulk of granular, kg; V_b refers to volume of the container, m^3.

The relation between granular density and bulk density can be governed by the following equation (Nedderman, 1992).

$$\rho_b = \rho_s(1 - \varepsilon) \qquad (2\text{-}6)$$

Where ρ_s refers to the density of the actual granules and ε refers to the void fraction as the granular material inside a container is occupied by interstitial gas.

Consulting with the manufacturer, the tuna flake is to be loosely filled with low density, therefore it is to have as close to free stacking density as possible.

2.3.3 Tuna Meat Density

Pornchaleompong et al. (2012) studied the physical properties of Skipjack tuna which includes weight, dimensions, volume, weight, surface area, projected area and apparent density. The physical properties are shown in Table 1 and each physical property was found using the below method.

I. The weight of the tuna was measured by electric balance weighing scale
II. The dimensions were measured using flexible tape (Figure 13).
III. The volume was determined using substitution principle.
IV. The surface area was determined using wax based method
V. The projected area was found using photographic method.
VI. Apparent density was determined by calculation of weight divided by volume.

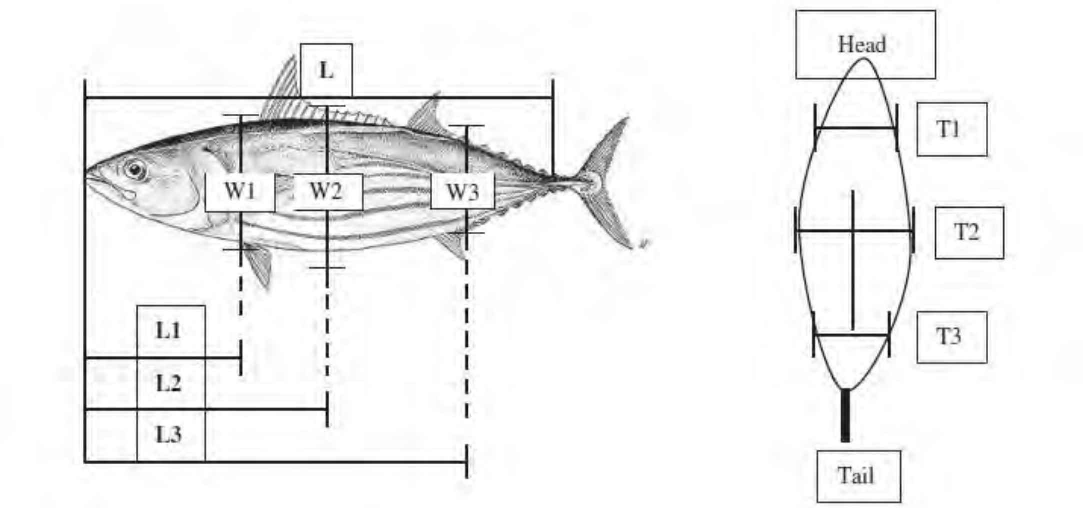


Figure 13: ***Dimensions of Tuna (Pornchaleompong et al., 2012)***

The apparent density of tuna meat is 1.07 g/cm3 in average, however, the density in the research refers to a mixture of tuna parts which also contain bones, blood and other parts which are not a part of tuna flake in the study.

***Table 1**: Average Physical Properties of Skipjack Tuna (Pornchaloempong, 2012)*

Physical properties	Sample number	Average	max	min	SD
Weight, kg	70	2.25	3.56	1.66	0.41
Length along body (L_b), cm	70	44.07	53.00	39.00	4.05
Length (L), cm	70	42.78	52.00	37.60	3.84
Length 1 (L1), cm	70	14.87	17.60	12.00	1.05
Length 2 (L2), cm	70	23.04	28.00	20.50	1.77
Length 3 (L3), cm	70	31.89	37.50	18.00	2.74
Width 1 (W1), cm	70	11.40	13.51	10.21	0.71
Width 2 (W2), cm	70	12.21	14.48	10.51	0.75
Width 3 (W3), cm	70	10.59	11.98	8.86	0.74
Thick 1 (T1), cm	70	8.01	9.87	7.00	0.55
Thick 2 (T2), cm	70	8.66	11.14	7.41	0.72
Thick 3 (T3), cm	70	7.54	9.75	5.99	0.74
Perimeter 1 (B1), cm	30	32.72	36.80	30.00	1.48
Perimeter 2 (B2), cm	30	35.21	39.00	32.50	1.67
Perimeter 3 (B3), cm	30	30.09	37.00	25.60	2.80
Volume, cm^3	70	2108.87	3441.26	1482.61	423.96
Surface area, cm^2	70	1072.86	1632.81	791.68	163.32
Projected area from side view, cm^2	70	483.76	690.49	379.86	60.85
Projected area from top view, cm^2	70	391.23	546.56	285.81	56.60
Apparent density, g/cm^3	70	1.07	1.22	1.01	0.04

Rahman et al. (2002) studied the characteristics of dried tuna using different drying methods. The study particularly concerns with the porosity in the dried product in order to determine other physic-chemical properties such as moisture diffusivity and thermal conductivity which are required when designing the production process of tuna meat.

According to Rahman et al. (2002), air-dried batch refers to the tuna meat being treated with constant heat at the temperature of 70°C. Vacuum-dried refers to the batch being heated with vacuum oven at the same temperature, while Freeze-dried refers to the batch being frozen at -40°C before being put into an automatic controlled freeze drier with chamber temperature of -20°C and condensing temperature of -60°C.

The porosities in the products of different drying process were evaluated using the mercury porosimetry. Table 2 shows the density and porosity related properties of fresh and dried tuna using three different processes.

Table 2: *Density and porosity related properties of fresh and dried tuna (Rahman et al., 2002)*

Sample	Apparent Density ρa (g/cm3)	Substance Density ρs (g/cm3)	True Density of mixture ρT (g/cm3)	Apparent Porosity Ɛa	Specific Excess Volume Fraction Ɛex
Fresh	1.098	1.098	1.071	0.00	-0.025
Air-dried	0.960	1.255*	1.312	0.24	0.043
Vacuum-dried	0.709	1.309	1.319	0.46	0.008
Freeze-dried	0.317	1.259	1.319	0.76	0.045

The definition of each property is as follows,

I. Apparent density (ρa) is the density of the product including porosity.

II. Substance density (ρs) is the density of the pieces of product which have been broken adequately to ensure that there is no existence of pores.

III. True density of the mixture (ρT) is the density of a mixture calculated by using the summation of true densities of individual pure components.

IV. Apparent porosity (εa) is the void fraction concerning with apparent density and substance density as shown in Equation 2-7 (Rahman, 1995).

$$\varepsilon_a = 1 - \frac{\rho_a}{\rho_s} \qquad (2\text{-}7)$$

Specific excess volume fraction (εex) is the void fraction concerning with substance density and true density of mixture as shown in Equation 2-8 (Rahman, 1995).

$$\varepsilon_{ex} = 1 - \frac{\rho_s}{\rho_T} \qquad (2\text{-}8)$$

The substance density (ρs) will be used in the analysis of the result of the experiments, as the density contains no pores and hence the actual void without porosity can be found.

2.4 Granular Structure

Granular structure is the form of arrangement of granules and pores. Structures that can be seen by human eyes or by a simple magnifying glass are described as macrostructures, however, those structures that can only be seen through a microscope are described as microstructures. (Wu and Sun, 2008)

The structures can be categorised into 3 types as follows.

(1) Single-grain structure. A structure of multiple particles with no or negligible coupling forces among each other. This type of structure can be further categorised as loose structure and compact structure (Figure 14). A loose structure can be converted into a compact structure through applied force and/or vibration.

(2) Honeycombed structure. A structure with granules that form a side-side or side-face bonding creating special properties in porosity, elasticity and viscidity. The structure looks similar to a honeycomb, as shown in Figure 15.

(3) Glomerogranular texture. Assembling of granules in face-face form.

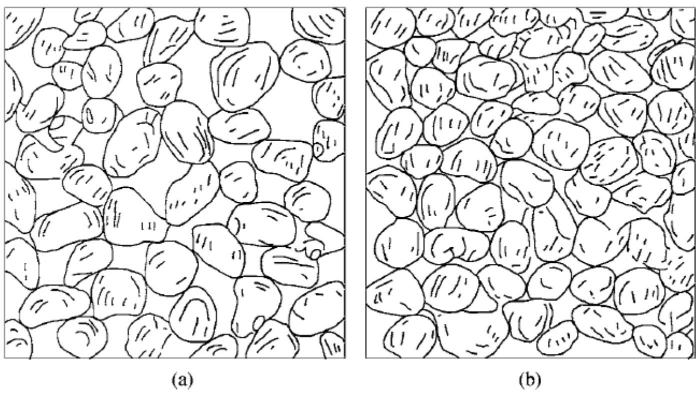
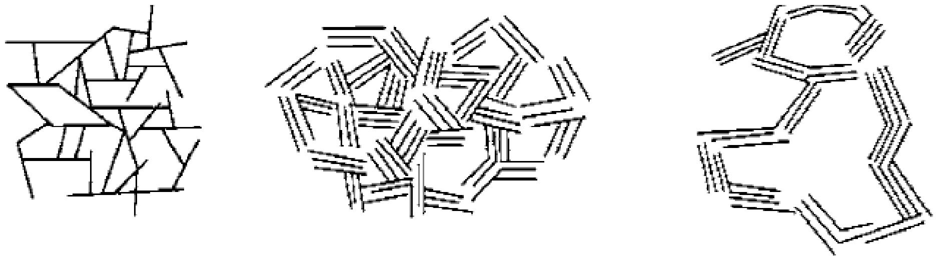


Figure 14: *Single grain structure (Wu and Sun, 2008)*



(a) (b) (c)

(a) Single-grain,side-side or side-face flocculation;
(b) Clay granules or side-face flocculation; (c) Side-side flocculation

Figure 15: *Honeycombed structures (Wu and Sun, 2008)*

As tuna flake structure can be seen by human eyes and it is to be loosely filled into cans, it is considered as macrostructure with single grains.

2.5 Moisture in Granular Media

Moisture content in granular media refers to the amount of water in a particular sample of granular medium. The moisture content is generally expressed by the ratio water and dried granular media (Wu and Sun, 2008).

$$\mathbf{M} = \frac{\mathbf{m_s} - \mathbf{m_g}}{\mathbf{m_g}} \times \mathbf{100}, \% \qquad (2\text{-}9)$$

Where M refers to the moisture content; m_s refers to the mass of granular media with mixture of water, kg; m_g refers to the mass of dried granular media, kg.

2.6 Natural Repose Angle in Granular Media

As granular media is the state at which its property is in between solid and liquid, its flowability is limited. Granular media can only maintain in a stacking form at a limited angle made with a horizontal plane. This limited angle is known as natural repose angle, βc. (Wu and Sun, 2008) The illustration for natural repose angle of a granular media is shown in Figure 16.

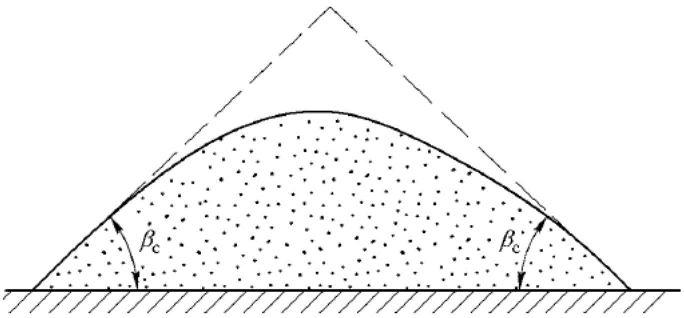


Figure 16: *Natural repose angle of granules (Wu and Sun, 2008)*

Moisture content has an influence in the cohesion between granules, the cohesion increases with respect to the moisture content to a certain limit, however, once the saturated point is met, water occupies all the pores in the media causing decrease in cohesion. This can be seen thorough the change of natural repose with the change of moisture content in Table 3.

In order to control the filling weight as well as flowablity of tuna flake, its moisture is to be determined and controlled.

Table 3: *Relation of Natural Angle of Repose and Moisture (Wu and Sun, 2008)*

Name of granules	Natural Angle of Repose (°)		
	Dried	Wet	Wettest
Scree	32 - 45	36 - 48	30 - 40
Sands	28 - 35	30 - 40	22 - 27
Sandy Clay	40 - 50	35 - 40	25 - 30

2.7 Flowability Theory in Granular Media

Flow of dense granular material behaves similar to visco-plastic material due to two broad reasons. Firstly, there is a flow threshold in the material, however the threshold is expressed by friction rather than yield stress. Secondly, during flowing the behaviour of the material is shear rate dependent. (Duplantier et al., 2011)

The behaviour of a granular flow of rigid material with young modulus being much larger than exerted pressure can be governed by a dimensionless parameter named inertial number, I.

$$\boldsymbol{I = \frac{\dot{\gamma} d}{\sqrt{P/\rho_p}}} \qquad (2\text{-}10)$$

$$\boldsymbol{\dot{\gamma} = \frac{V_w}{L}} \qquad (2\text{-}11)$$

Inertial number is given by shear rate ($\dot{\gamma}$), diameter of particles (d), exerted pressure (P) and density of particles (ρ_p). Given that shear rate is governed by velocity (V_w) and the width of the channel (L).

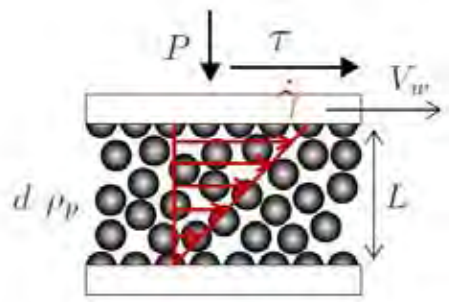


Figure 17: *Plane shear at the constant pressure (Duplantier et al., 2011)*

Having volume fraction ϕ as a function of I only, and shear stress being proportional to normal stress, the constitutive laws can be derived as,

$$\tau = P\mu(I) \ and \ \emptyset = \emptyset(I)$$

Where μ(I) refers to friction efficient which is a function of I.

From the above visco-plastic theory, it can be illustrated that flowablity of a granular material such as tuna flake is a function of particle diameter, density, shape of the container, and, moisture and container material which are related to friction coefficient. As a result, these factors are to be considered in tuna flake filling machine design.

2.8 Numerical Simulation of Granular Flow

Discrete Element Method (DEM) is a numerical method to determine the moving behaviour of bulk materials (Cundall and Strack, 1979). The method has been widely used by researchers to simulate the behaviour of granular flows of different sizes and purposes.

Kang and Chen (2017) used DEM to simulate the granular flow entrainment of debris in two-dimensional format. Schmelzle and Nirschl (2018) employed DEM to simulate the mixing of dry and wet granular materials with different contact angles inside a rotor with 3 mixing blades. Similarly, Umer and Sriraj (2018) studied the behaviour of wet and dry polydisperse dry and wet granular flows over a single blade. The dimension of the mixer container and blade is shown in Figure 18, whereas an example of simulation result of the mixture of granular flow after a single pass of the blade is shown in Figure 19. Li et al. (2018) used the method to imitate the micro-mechanical behaviour of granular material gravity-induced stress gradient.

Although numerical method has the advantage of simple altering of variables involved in the simulation to verify the result, it is very complex to initially set up a set of sensible values for all variables. Experimental method will be used in this research for simplicity, and accuracy of the experiments will be enhanced by repetitions of trails under a particular fixed experimental condition.

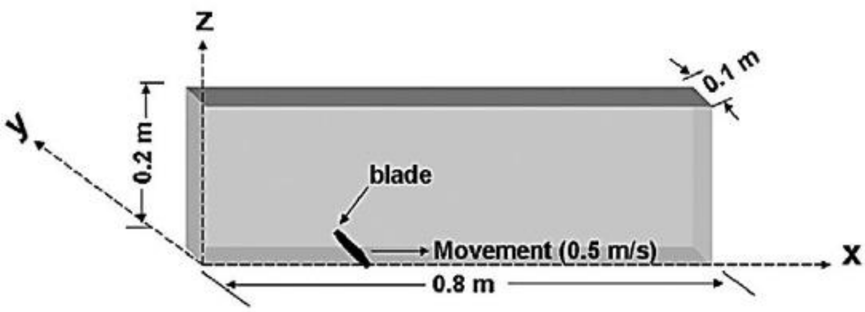


Figure 18: *Dimension of single blade mixer (Umer and Sriaj, 2018)*

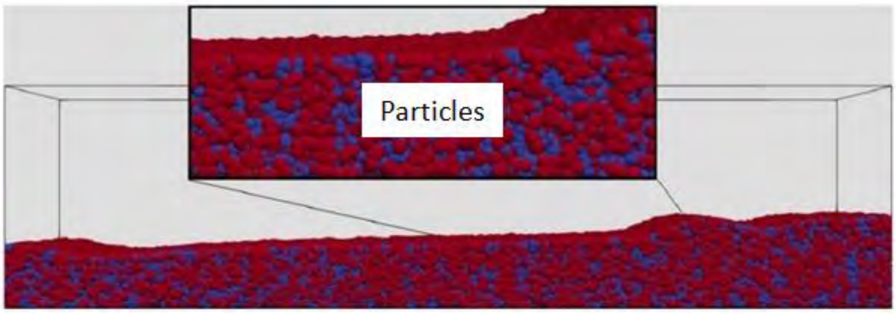


Figure 19: *Particle distribution for wet system at the end of simulation (Umer and Sriaj, 2018)*

2.9 Product Design Specification

Clear needs of a customer are to be developed and agreed in order to avoid the conflict over the performance of a product. Design specifications are the minimum acceptance criteria which product manufactures normally co-develop with their customers (Jack, 2013).

According to Pugh (1990), design process is linear and can be divided into 4 phases as illustrated in Figure 20. In the first phase, the need is gathered from the customer to form product specification. In the second phase, the specification is then translated into a number of concept designs. A few of these concept designs will be selected and elaborated to a detail design; hence it can be evaluated according to the performance needed. The selected detailed design is then elaborated to manufacturing design which will be used for mass production purpose for the market.

Ogrodnik (2013), however, describe the phases slightly differently which is according to the activities done by the involved designers. The first phase is called clarification, in this phase, the designers are to communicate with customers closely to gain as much understanding as possible regarding the need and the usage environment of the customers in order to develop a fully valid specification for the conceptual design phase. In this phase of design process, a number of conceptual designs are developed, nonetheless, one will be selected and developed into a prototype in the embodiment phase. Once the design is evaluated and accepted, it will converted into manufacturing design in the final documentation phase. The comparison between design model of Pugh (1990) and Ogrodnik (2013) is shown in Figure 21.

In this study, a prototype will be made to test the feasibility of the important key success factors in tuna flake filling process. This process is similar to the conceptual design phase in PDS. However, it is slightly different as only one prototype will be built instead of multiples. This particular of prototype is called Minimal Viable Product (MVP) which will be explained in the following section.

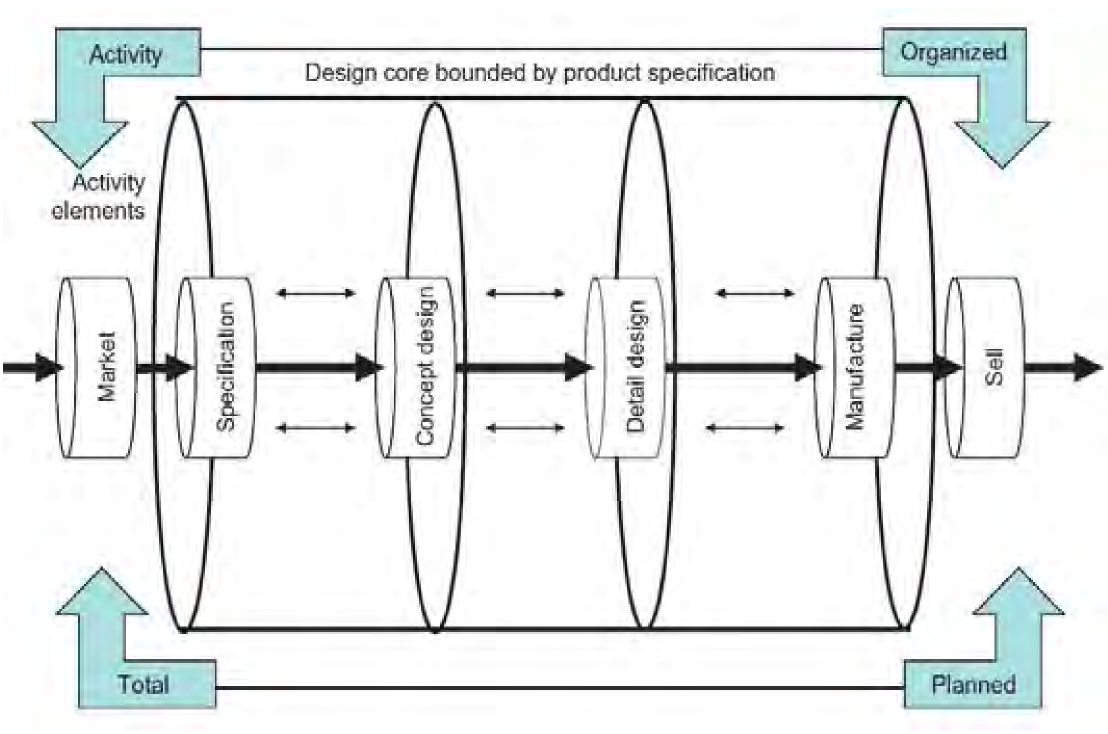


Figure 20: *Design Process by Pugh (Pugh, 1990)*

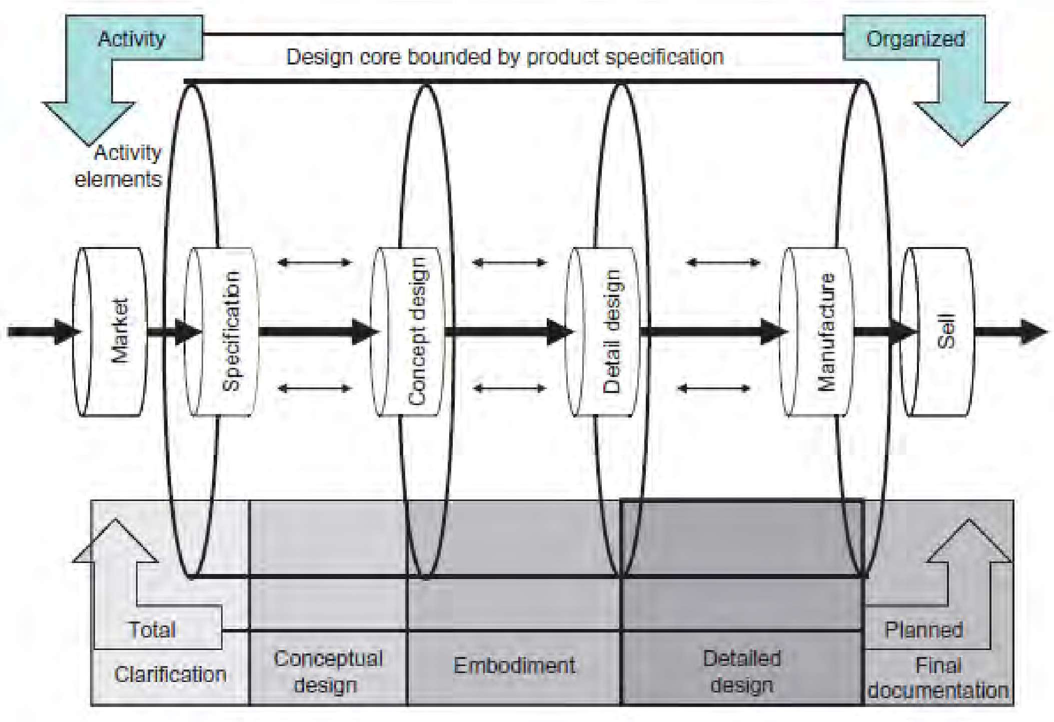


Figure 21: *Design Process by Ogrodnik aligned with Pugh's (Ogrodnik, 2013)*

2.10 Minimum Viable Product (MVP)

According to Ries (2011), minimum viable product (MVP) refers to a version of a new product that allows the product inventor to optimally study the product on the customers or early adopters to find the feedbacks for improvements using the least effort. The process is iterative which begins with idea creation, followed by prototyping, presentation to the early adopters and collection of data from the usage to analyse for future improvement.

However, MVP may only refer to an experimental object created to allow the developer to empirically test the value hypotheses (Jürgen Münch et al., 2013). In this research, MVP as an experimental object will be made to test the hypotheses in order to determine the additional incoming control process and required functions of the tuna filling machine.

2.11 Material Selection (S/S and Teflon)

The material selection is strategically decided by its satisfaction of design requirements which are related to design parameters and the properties of material (Jahan et al., 2016). The process of converting customer requirements into material selection and design selection including weighing factors of each decision is shown in Figure 22.

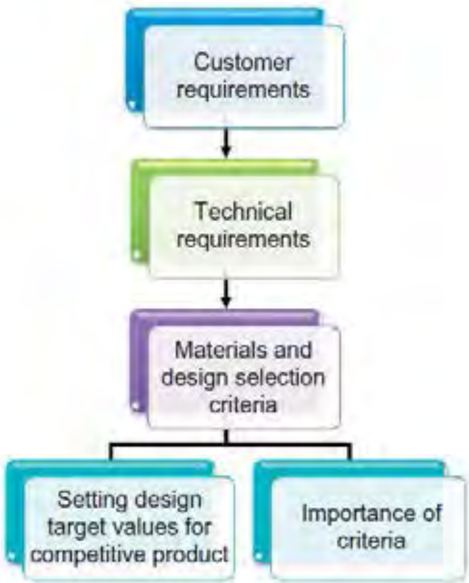


Figure 22: *Process of converting customer needs to target value settings and criteria weighing (Jahan et al., 2016)*

The frictional and wear properties of 316L Stainless steel with different types of surface treatments was studied by Dogan et al. (2002). The experimental condition of the study was using Al_2O_3 ball of 1N load at the speed of 10cm/s on 316L stainless steel discs for 4250 rotations.

It has been found that without any surface treatment the average frictional coefficient of the material is 0.68. Table 4 shows the frictional properties of the material.

Table 4: *Friction and wear relationship for substrate and surface treated samples of 316L Stainless Steel (Dogan et al., 2002)*

Experiment Type	Average friction coefficient	Change (%)	Volumetric wear (mm^3/Nmm)	Change (%)
Substrate	0.68	0	53×10^{-3}	0
N_2 implanted	0.63	7 (↓)	6.64×10^{-3}	87 (↓)
TiN coated	0.74	9 (↑)	5.1×10^{-3}	90 (↓)
Zr implanted	0.76	12 (↑)	6.5×10^{-3}	88 (↓)

The mechanical property specification of 316L stainless steel claimed by a material supplier is shown in Table 5.

The physical property of PTFE (Polytetrafluoroethylene, Teflon) claimed by a material manufacturer is shown in Table 6. The coefficient of friction of the material is 0.08-0.1, which was determined by testing the using dry specimen of ground steel under the load of 0.05 N/mm2 at the speed of 0.6 m/s.

In the comparison of the two materials, it can be seen that the strength of Stainless steel (316L) is 515MPa which is 26 times that of PTFE which has yield strength of 20MPa. However, the friction coefficient of PTFE is 1/68 times that of stainless steel. This material property is to be tested in accordance with the flow of tuna flake using MVP to determine the actual benefit of the two materials in the experimental section.

Table 5: *Mechanical Property Specification of 316L Stainless Steel (Atlas Steels, 2011)*

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50mm) min	Hardness	
				Rockwell B (HR B) max	Brinell (HB) max
316	515	205	40	95	217
316L	485	170	40	95	217
316H	515	205	40	95	217
316H also has a requirement for a grain size of ASTM No 7 or coarser.					

2.12 Analysis of Literature Review

The current available technology for granule filling techniques can be divided into 2 types which are weight controlled and volume controlled filler. Due to the construction of the weight controlled machine, although the fill weight can be controlled at accuracy of ±1g for dry products as claimed by the machine manufacturer. For the case of wet products such as tuna flake the filling material can get stuck in the machine and cause inaccuracy in filling weight lowering the performance of the machine. On the other hand, while the price of volume controlled machine is lower, it is also less likely for the products to be stuck in the machine while filling into the containers.

Grain size measurement can be performed using a few techniques such as volumetric equivalent diameter, projected area equivalent diameter and feret diameter. Due to the practicality purpose, feret diameter which is the measurement of the longest end to end distance of a granule is the most appropriate for the study.

Table 6: *Physical Properties of PTFE (Plastim, 2015)*

GENERAL PROPERTIES	Test Method	Units	Value
Density	ISO 1183	g/cm^3	2.16
Water absorbtion			
- at saturation in air of 23°C / 50% R.H.	ISO 62	mg	0.1
- at saturation in water 23°C	ISO 62	mg	0.02
MECHANICAL PROPERTIES			
Tensile stress at yield and break	ISO 527	N/mm^2	20
Elongation at break	ISO 527	%	300
Tensile modulus of elasticity	ISO 527	N/mm^2	0.4
Compression test	ISO 173/3C		
- 1% strain after 1,000 hrs	ISO 899	N/mm^2	10
Charpy impact strength - Notched	ISO 179-1/1eU	KJ/mm^2	KJ/mm^2
Charpy impact strength - Unnotched	ISO 179-1/1eA	KJ/mm^2	no break
Ball indentation hardness	ISO 2039	N/mm^2	28
Shore hardness D	ISO 2039	D	58
Coefficient of friction to steel[12]	ISO 8295	-	.08 - .1

In the term of granular flow study, it is possible to perform both simulation based experiment and practical experiment. However, due to the difficulty in assigning the complex variables such as shear rate, exerted pressure and density of particle, it is more appropriate to do practical experiments while using other flow prediction techniques such as natural repose angle to predict the moisture level that enhances the flow rate to select the most suitable level of moisture content for the experiments. Instead of building an actual mass production machine for the experiments, a minimal viable product (MVP) will be fabricated and tested at the conditions explained in the latter section due to the advantage in terms of both cost and lead time of the study.

CHAPTER 3 PRELIMINARY STUDIES

This section contains some of the preliminary studies which have been done in order to verify the feasibility of the research which include bulk density calculation, granular size analysis, and moisture calculation. Moreover, the effect of granular size control on weight control was also tested.

3.1 Bulk Density of Tuna Flake

The bulk density was studied using a sample of tuna flake from a canned tuna manufacturer. The detail of the study is explained below.

(1) Material

2 kg of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Can with 68mm diameter and 40mm height
II. Plastic wiper with 300mm length, 25mm width and 4mm thickness
III. Weighing scale

(3) Experimental method

Volume of the container was determined by filling the container with water, weighing the container, and calculating the volume with the net weight and density of water.

Bulk density of tuna flake was measured using mass and volume calculation by weighing the product in the container with fixed volume (Equation 2-5). The measurement is repeated 100 times.

(4) Result

The weights of 100 samples of tuna flake in fixed volume container were measured and the distribution of bulk density is shown in histogram in Figure 23. From the histogram, it can be seen that most of the density calculated ranges between 0.422 to 0.444 g/cm^3 which contributes to 80 percents of the calculated density. In the weight perspective, the difference between the maximum and minimum weight is 7g (Table 7), which is still greater than the target accuracy of ±3g.

As a result, the preliminary study will concentrate on other factors contributing to bulk density and weight variation, which will be illustrated in the following sections.

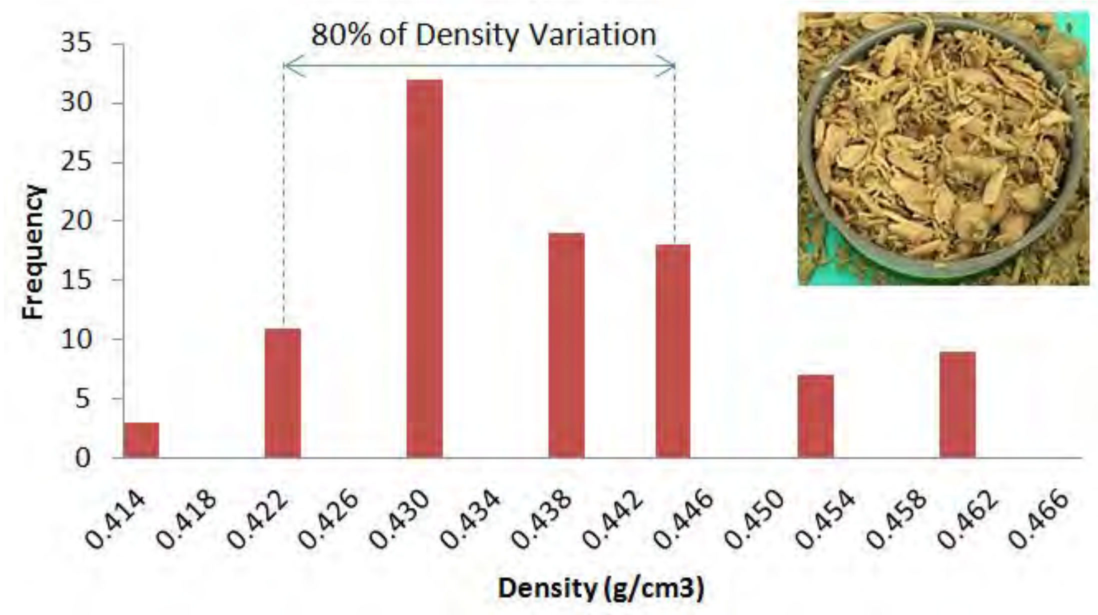


***Figure 23:** Tuna Flake Bulk Density Histogram*

***Table 7:** Bulk Density Statistics*

	Density (g/cm3)	Weight (g)
Mode	0.428	57
Median	0.435	58
Average	0.435	58
SD	0.012	1.576
CV	2.7%	2.7%
Max	0.465	62
Min	0.412	55
Max-Min	0.052	7
$\bar{x} \pm SD$	0.435±0.012	58±1.576

3.2 Feret Diameter Study of Tuna Flake

In this section, granular sizes of tuna flake samples are studied statistically to determine the range of variation. As a hypothesis, granular size is a factor which contributes to the variation in weight and bulk density.

(1) Material

2 kg of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Can with 68mm diameter and 40mm height

II. Vernier Caliper

(3) Experimental method

Granular size of the tuna flake was studied using Feret diameter (a) of the samples taken from actual production of a canned tuna flake manufacturer. The samples were measured from the top layer of tuna flake in 10 cans using Vernier Caliper which sums up to 655 pieces.

(4) Result

The variation of the tuna flake sizes is plotted in a histogram shown in Figure 24. It can be seen that the most of the tuna flake sizes range between 2.5mm to 13mm which contributes to 81 percents of the samples and only 25% of the incoming material are kept in the range of 10mm to 15mm, which is specified by the tuna flake manufacturer. However, when viewed in statistical method (Table 8), the variation in the granular size is rather high with the standard deviation of 4.860. The variation between the sizes in each can is also high as illustrated in Figure 25.

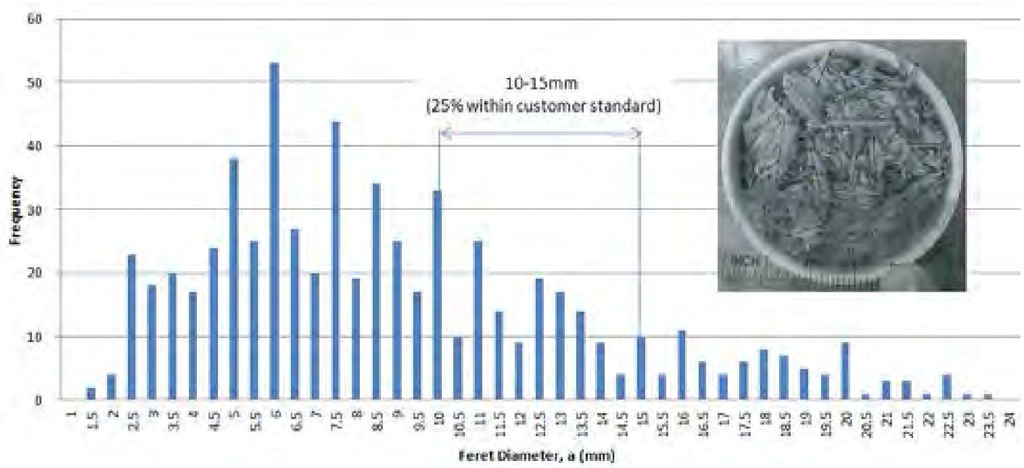


Figure 24: *Tuna Flake Feret Diameter (a) Summary Histogram*

Table 8: *Tuna Flake Feret Diameter (a) Statistics*

	Can1	Can2	Can3	Can4	Can5	Can6	Can7	Can8	Can9	Can10	ALL
Pieces	84	53	51	52	69	57	70	77	74	68	655
Pieces in Range	18	17	17	13	16	21	17	11	15	19	164
Percentage in Range	21%	32%	33%	25%	23%	37%	24%	14%	20%	28%	25%
Mode	6	8.5	7.5	5	5	8.5	6	6	6	5	6
Median	6.25	10	10	8	8.5	8.5	7.5	7	7.5	7.5	8
Average	8.1	10.9	11.4	9.9	9.7	9.3	8.5	7.6	8.7	8.8	9.1
SD	4.505	4.383	5.220	6.070	5.761	4.269	4.010	4.128	4.761	4.545	4.860
CV	55.7%	40.2%	45.7%	61.5%	59.2%	46.1%	47.2%	54.0%	54.9%	51.9%	53.3%
Max (mm)	19.5	20	21	32	23.5	22	19.5	21	21.5	21.5	32
Min (mm)	1.5	3.5	3	2.5	2	2.5	2.5	2	2.5	2	1.5
Max-Min (mm)	18	16.5	18	29.5	21.5	19.5	17	19	19	19.5	30.5
$\bar{x} \pm SD$	8.1±4.505	10.9±4.383	11.4±5.220	9.9±6.070	9.7±5.671	9.3±4.269	8.5±4.010	7.6±4.128	8.7±4.761	8.8±4.545	9.1±4.860

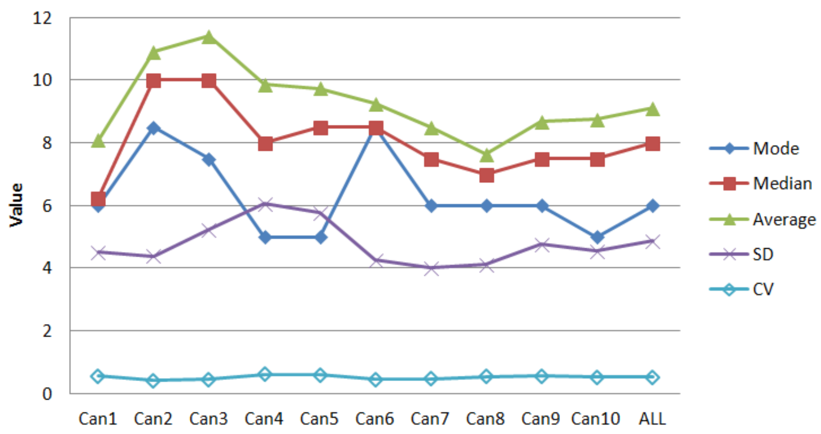


Figure 25: *Tuna Flake Feret Diameter (a) Statistics*

3.3 Granular Shape Study of Tuna Flake

In this section, the shapes of the tuna flake from samples received from a canned tuna flake manufacturer are studied statistically to analyse the variation in 2-dimensional shape.

(1) Material

2 kg of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Can with 68mm diameter and 40mm height

II. Vernier Caliper

(3) Experimental method

The granular shape of the tuna flake was studied using feret diameter (a) and the shortest dimension adjacent to the feret diameter (b). The illustration of the two dimensions is shown in Figure 26. These dimensions were measured using Verneir Caliper, the result of measurement of dimension a of each grain is divided by dimension b to determine shape due to the relation of the two dimensions. This fraction is called Elongation a/b in the study.

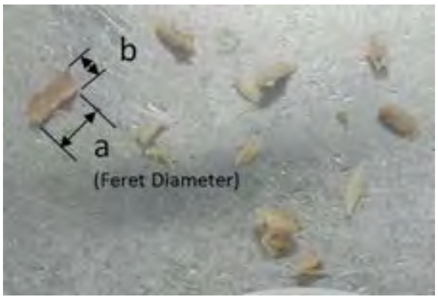


Figure 26: *Elongation a/b Dimension of tuna flake*

(4) Result

The variation in shape of the tuna flake is shown in histogram in Figure 27. From the result of the study, it can be seen that the shape of the tuna flake is rectangular with relative longer length than width. With the high value of elongation a/b, the voids between each grain also grow larger resulting in decrease in compaction ratio, however, high elongation also influences the flowablility of the granular media (Lumay et al., 2012).

From the result in Table 9, the standard deviation for the overall samples is 0.954 which is very large. When viewed in individual cans, it can be seen that the difference between each can is very large (Figure 28).

In order to control the weight which is due to the bulk density, the elongation a/b of the tuna flake being measured in a fixed volume cup also should be controlled.

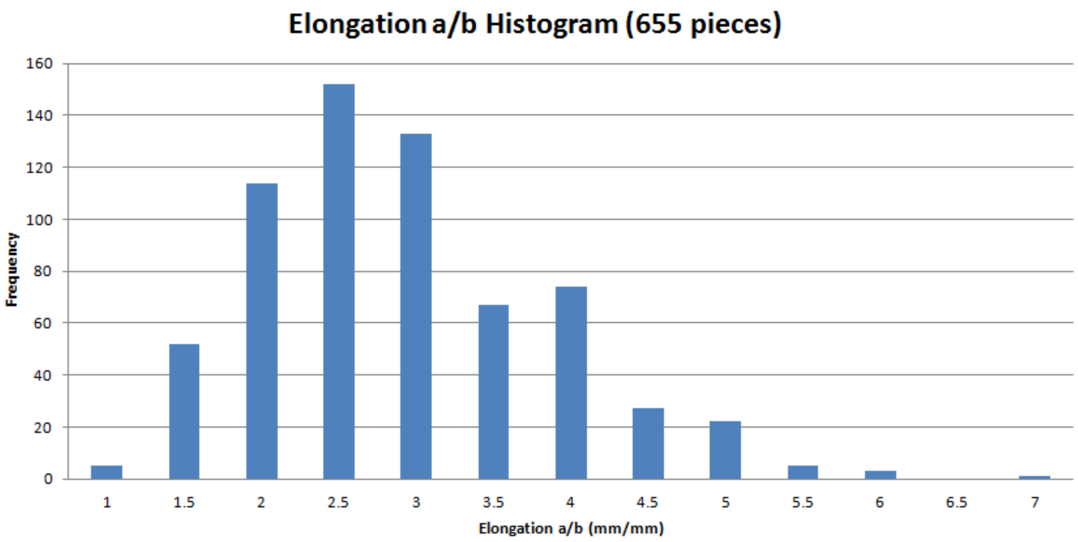


Figure 27: Tuna Flake Elongation a/b Histogram

Table 9: *Tuna Flake Elongation a/b Statistics*

	Can 1	Can 2	Can 3	Can 4	Can 5	Can 6	Can 7	Can 8	Can 9	Can 10	ALL
Pieces	84	53	51	52	69	57	70	77	74	68	655
Mode	1.5	4.0	3.0	2.0	3.8	2.5	4.0	3.0	2.0	2.0	3.0
Median	2.3	2.8	3.0	2.6	2.7	2.7	3.0	2.4	2.4	2.4	2.6
Average	2.3	3.0	3.1	2.8	2.8	2.9	3.0	2.6	2.5	2.6	2.7
SD	0.838	0.955	0.795	1.094	0.970	0.888	0.985	0.904	0.912	0.936	0.954
CV	36.0%	31.4%	25.7%	38.7%	34.9%	30.6%	32.7%	35.2%	36.0%	36.4%	34.9%
Max (mm)	5.0	5.5	5.0	7.0	5.9	5.6	5.1	6.0	4.6	5.3	7.0
Min (mm)	1.0	1.3	1.5	1.3	1.0	1.3	1.4	1.3	1.1	1.0	1.0
Max-Min (mm)	4.0	4.2	3.5	5.8	4.9	4.3	3.7	4.8	3.5	4.3	6.0
x̄ ± SD	2.3±0.838	3.0±0.955	3.1±0.795	2.8±1.094	2.8±0.970	2.9±0.888	3.0±0.985	2.6±0.904	2.5±0.912	2.6±0.936	2.7±0.954

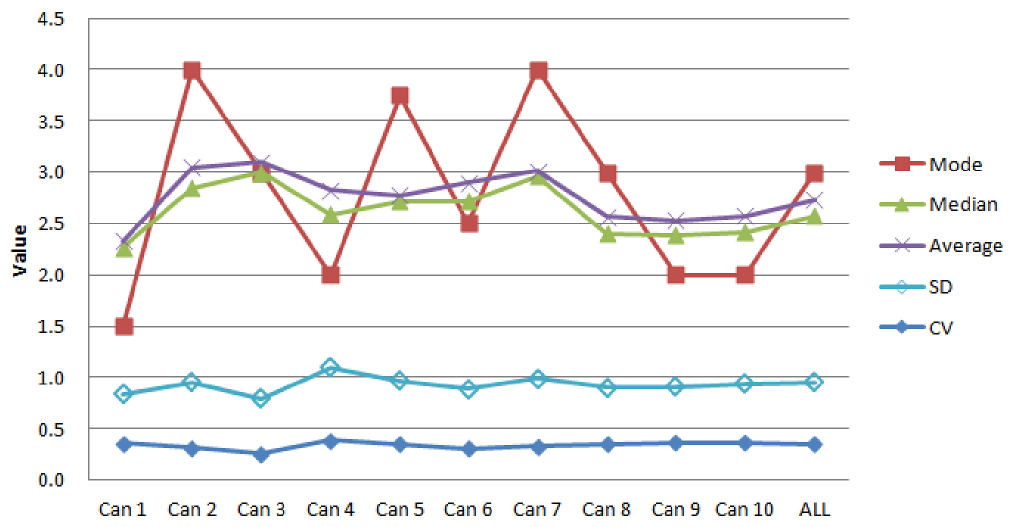


Figure 28: *Tuna Flake Elongation a/b Statistics*

3.4 Moisture

Variation in moisture in tuna flake affects the bulk density in a product sample which consequently affects the weight accuracy in the filling process. Furthermore, moisture also affects the flowability of the product.

(1) Material

1 kg of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Can with 68mm diameter and 40mm height
II. Plastic wiper with 300mm length, 25mm width and 4mm thickness
III. Weighing scale
IV. Oven

(3) Experimental method

In the preliminary study, the moisture of tuna flake was found by calculating the difference between weight of 5 samples of wet and dried tuna flake which underwent 150 °C heating for 4 hours, the procedure is shown in Figure 29. The formula used for the calculation is shown in Equation 2-9.

(4) Result

The variation in moisture is shown in Table 10 which can contribute up to 0.893g of filling weight variation having 45g as maximum target filling weight specified by a canned tuna flake manufacturer.

Figure 29: *Moisture measurement procedure*

Table 10: *Moisture calculation*

	Wet Flake (g)	Dry Flake (g)	Moisture (%)
Can1	119	56	64.95%
Can2	125	60	63.11%
Can3	130	62	62.96%
Can4	128	60	64.15%
Can5	139	65	63.25%
Average	128.2	60.6	**63.68%**
SD	7.328	3.286	0.846
MAX-MIN	-	-	1.99%

Max Filling weight 45g

Max weight variation 0.893 g (1.99%)

Moisture can play an important role in filling weight variation. This factor should be controlled by the canned tuna flake manufacturer in the actual filling procedure in order to limit the weight variation effectively.

3.5 Effect of Filling Material Shape on weight control

In the preliminary study, in order to justify the effect of granular size and shape in weight controllability, an experiment was conducted to determine the variation in weight of beans at various conditions using 5 types of beans, (1) Red Kidney beans, (2) Peanuts, (3) Mung beans, (4) Soy beans and (5) Black beans, as shown in Figure 30. The beans have been used in this experiment to emphasis the variations in size of beans which are much smaller in comparison with tuna flake, the highest variation is found in peanuts with 4 mm dimension range (Table 11). Hence, the weighing experiment can be conducted in a much more controlled condition.

In the experiment, the 100 samples of beans were put in a cylindrical container with fixed volume and weighed. Both single type and multiple types of mixtures was test at various conditions.

Figure 30: *5 types of beans*

Table 11: Beans specification

Beans	Feret diameter (mm)	Elongation a/b	Pieces	Weight (g)	Weight/piece (g)
Red Kidney	16±1	2	20	12	0.600
Peanuts	15±2	2.333	20	13	0.650
Mung	5±1	1	30	2	0.067
Soy	8±1	1.333	30	5	0.167
Black	10.5±1.5	1.8	30	7	0.233

3.5.1 Single Type Bean Experiment

The single type bean experiment is conducted to determine the effect of Elongation a/b on the weight controllability.

(1) Material

I. 1kg of peanuts
II. 1kg of mung beans
III. 1kg of soy beans

(2) Equipment

I. Can with 68mm diameter and 40mm height
II. Plastic wiper with 300mm length, 25mm width and 4mm thickness
III. Weighing scale

(3) Experimental method

In the single type bean experiment, 100 samples of peanuts, mung beans and soy beans were each put separately into a fixed volume container and weighed.

(4) Result

Although the allowable weight tolerances are the same for all the beans (±3g) which have different bulk density and hence different weights when put in the containers with the same volume, Table 12 shows the result of the weighing which illustrates that despite the higher weight, beans with smaller granular sizes and elongation a/b have a much better weight controllability, as the Cp and Cpk are highest in mung beans and smallest in peanuts.

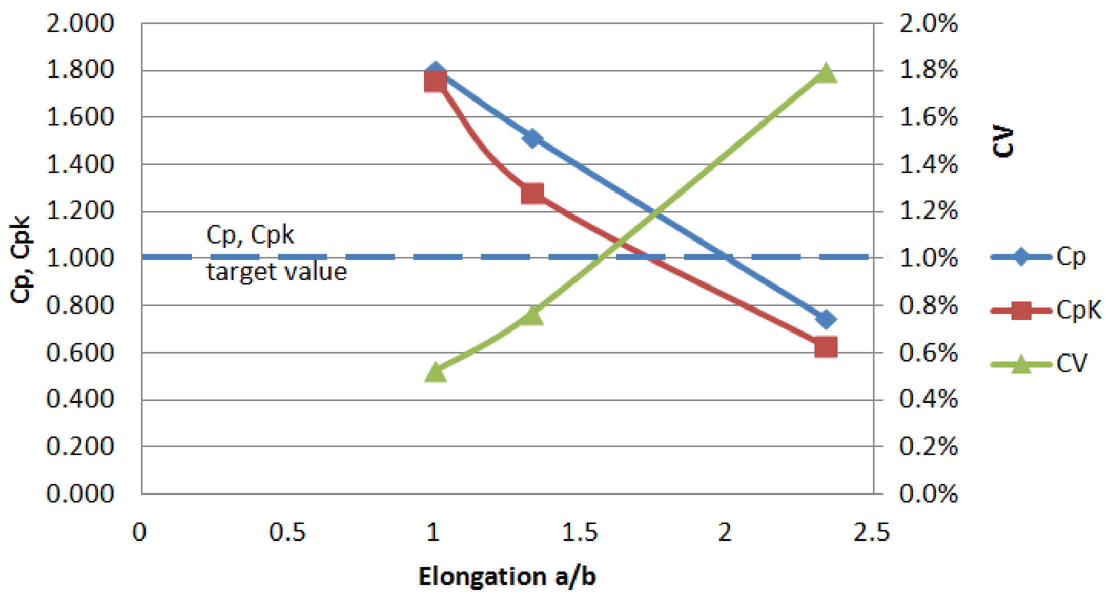


Figure 31: *Elongation a/b and Weight Controllability Relation*

Table 12: Single type bean statistics

Single Bean	Lot1 (Peanuts)	Lot2 (Soy)	Lot3 (Mung)
Peanuts (15±2mm)	100%	-	-
Mung (5±1mm)	-	-	100%
Soy (8±1mm)	-	100%	-
Average Elongation a/b	2.333	1.333	1
Mode (g)	74	85	106
Median (g)	74	85	106
Average (g)	74.5	85.5	105.9
SD	1.337	0.658	0.555
CV	1.8%	0.8%	0.5%
x̄ ± SD	74.5±1.337	85.5±0.658	105.9±0.555
Max (g)	78	87	107
Min (g)	71	84	105
Max-Min (g)	7	3	2
Assumed Upper Limit (g) Assumed Lower Limit (g)	74±3	85±3	106±3
Cp	0.748	1.519	1.801
CpU	0.628	1.281	1.843
CpL	0.868	1.757	1.759
CpK	0.628	1.281	1.759

Note: Fixed volume container was used.

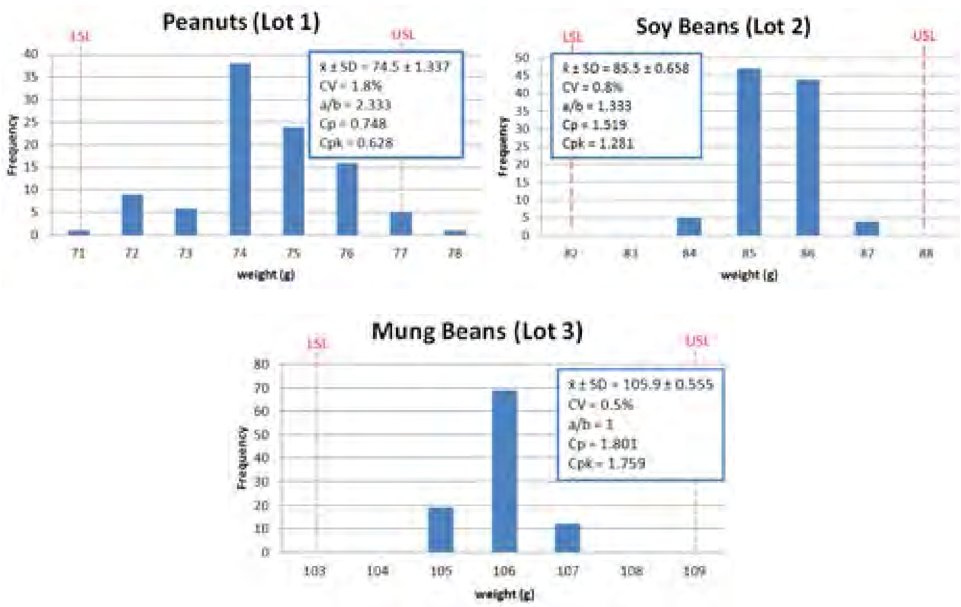


Figure 32: Single type bean histogram

Figure 31 shows the trend of weight controllability in comparison against elongation a/b, it can be seen that the weight controllability decreases, as the elongation increases. The result of the variation is also shown by histogram graphs in Figure 32.

3.5.2 Multiple Type Bean Experiment

The multiple type bean experiment is conducted to determine the effect of Feret diameter (a) on the weight controllability.

(1) Material

I. 1kg of red kidney beans
II. 1kg of peanuts
III. 1kg of mung beans
IV. 1kg of soy beans
V. 1kg of black beans

(2) Equipment

I. Can with 68mm diameter and 40mm height
II. Plastic wiper with 300mm length, 25mm width and 4mm thickness
III. Weighing scale

(3) Experimental method

In the multiple type bean experiment, 100 samples of different mixtures of red kidney beans, peanuts, mung beans, soy beans and black beans were put into a fixed volume container and weighed.

(4) Result

Table 13 shows the result of the weighing which illustrates that the mixture with greater portion of smaller beans (Lot 7) has better weight controllability than the mixture with greater portion of larger beans (Lot 8). Moreover, the trend of the process controllability against estimated feret diameter (a) also states the same according to Cp, Cpk and CV shown in Figure 33.

From the experiment of samples of beans of various sizes, it can be concluded that granular size is an important key in weight controllability. As a result, in order to satisfy the weigh range target, the granular size of tuna flake should be controlled using sieves.

Table 13: *Multiple type beans statistics*

Multiple Beans	Portion (g)				
	Lot4	Lot5	Lot6	Lot7	Lot8
Red Kidney (15-17mm)	20.0%	12.5%	30.4%	4.2%	18.9%
Peanuts (13-17mm)	20.0%	12.5%	30.4%	4.2%	47.2%
Mung (4-6mm)	20.0%	25.0%	13.0%	41.7%	11.3%
Soy (7-9mm)	20.0%	25.0%	13.0%	25.0%	11.3%
Black (9-12mm)	20.0%	25.0%	13.0%	25.0%	11.3%
Estimated a	10.900	9.750	12.500	8.000	12.755
Mode	91	93	88	96	86
Median	92	93	88	96	86
Average	91.7	93.2	88.2	96.4	86.0
SD	1.176	0.949	1.184	0.892	1.159
CV	1.3%	1.0%	1.3%	0.9%	1.3%
$\bar{x} \pm$ SD	91.7± 1.176	93.2± 0.949	88.2± 1.184	96.4± 0.892	86.0± 1.159
Max (g)	94	96	91	99	89
Min (g)	90	91	86	95	84
Max-Min (g)	4	5	5	4	5
Assumed Upper Limit (g) Assumed Lower Limit (g)	92±3	93±3	88±3	96±3	86±3
Cp	0.850	1.054	0.845	1.121	0.863
CpU	0.935	0.976	0.794	0.990	0.854
CpL	0.765	1.131	0.895	1.252	0.872
CpK	0.765	0.976	0.794	0.990	0.854

Note: - Estimated a is calculated from percentage of beans and average bean size of each type.

- Fixed volume of container was used.

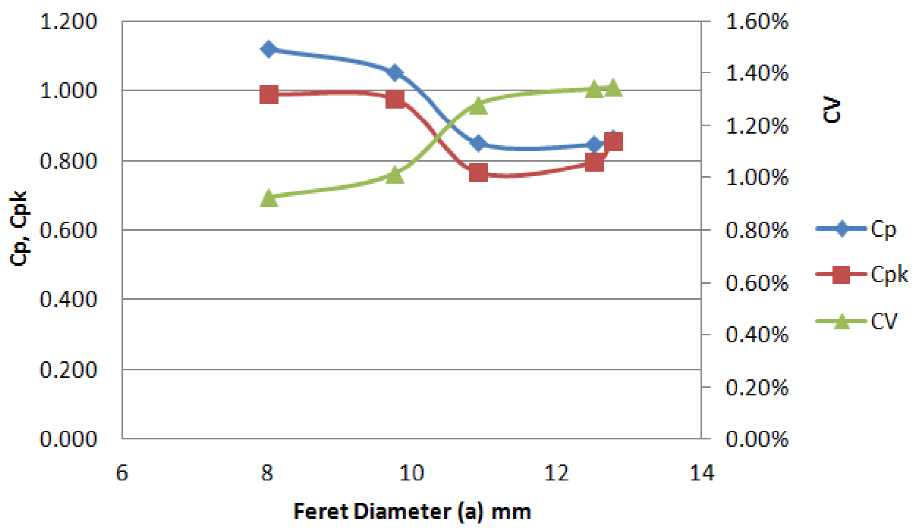
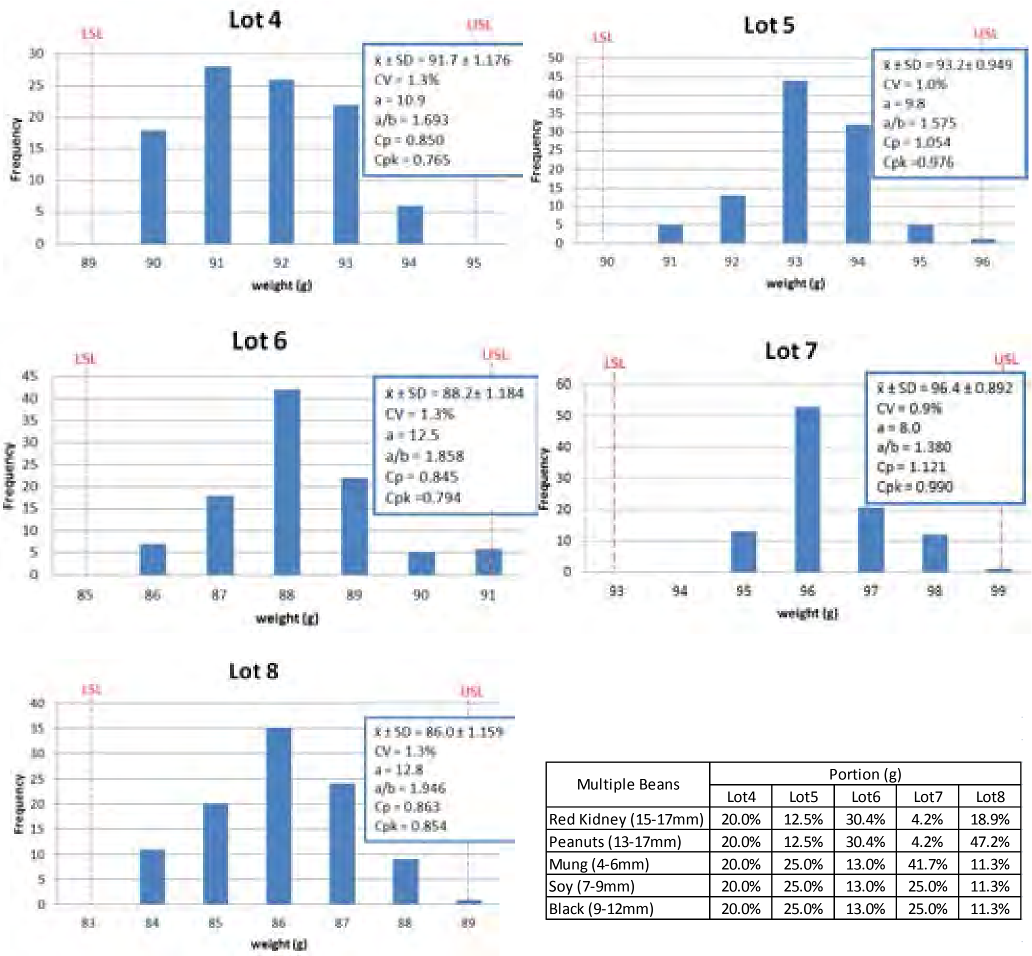


Figure 33: *Feret Diamter (a) and Weight Controllability Relation*



Multiple Beans	Portion (g)				
	Lot4	Lot5	Lot6	Lot7	Lot8
Red Kidney (15-17mm)	20.0%	12.5%	30.4%	4.2%	18.9%
Peanuts (13-17mm)	20.0%	12.5%	30.4%	4.2%	47.2%
Mung (4-6mm)	20.0%	25.0%	13.0%	41.7%	11.3%
Soy (7-9mm)	20.0%	25.0%	13.0%	25.0%	11.3%
Black (9-12mm)	20.0%	25.0%	13.0%	25.0%	11.3%

***Figure 34:** Multiple type beans histogram*

3.6 Chapter Conclusion

In this chapter, it has been identified that due to the variation in grain sizes of tuna flake, the bulk density among each can being filled also varies in such degree that it is greater than the fill weight tolerance allowed by the canned tuna flake manufacturer of ±3g.

With regards to grain sizes variation, although the tuna flake manufacturer has their standard range of allowance for feret diameter, in this case for the particular lot of flakes, the range is 10-15mm, in reality they can only keep 25% of the samples in the required range. This has great reflection in bulk density variation and hence results fill weight uncertainty.

It has also been found that the moisture content in the incoming material is 63.68% in average, and with the variation in the samples received, setting the fill weight target of 45g which is the maximum desired by the tuna flake manufacturer, the variation could lead to 0.893g of fill weight uncertainty. The effect of the moisture on the fill weight is to be studied in details in the experimental sections.

Moreover, in order to verify the feasibility of the study on the effect of filling material shape and size on the fill weight control, 5 types of beans at various sizes have been investigated and experimented. It has been found that the greater the size and greater the elongation of the filling material, the greater the variation in resulted fill weight. This hypothesis will be studied in detail for the tuna flake in the experimental section.

CHAPTER 4 RESEARCH METHODOLOGY

This chapter aims to summarise the approaches and the methods being used in the research in order to accomplish the objectives. The overall outline of the research methodology is shown in Figure 35. The procedures of the thesis begin with (1) customer requirement collection, followed by (2) verifying the acceptance process of incoming material, (3) designing machine features and testing on MVP. Finally the (4) cost estimation of the before and after change in tuna filling process will be studied.

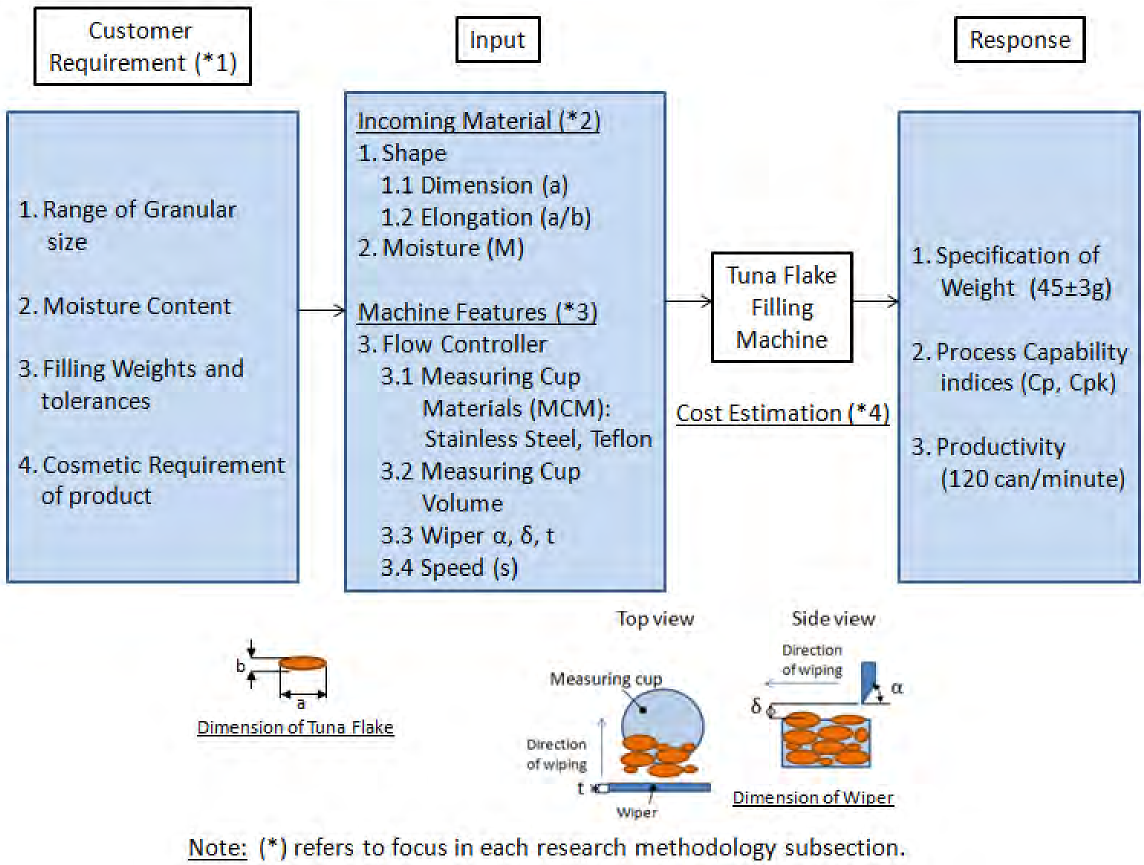


Figure 35: Research Methodology Overall Outline

4.1 Customer Requirement Collection

It is extremely important to understand the requirement of the tuna flake filling process of the customer. This part of the research will be done by constructing a meeting with the production manager and investigating the actual operation on site. The specifications of the process may include the following elements.

[1] Range of Granular sizes

[2] Moisture Content in the product

[3] Filling weight and tolerances

[4] Cosmetic requirement of the product

4.2 Incoming Material Investigation Study

As seen in the preliminary study (Section 3.3) with the volume controlled filling method, the factors which contribute to tuna flake filling weight accuracy are (1) granular sizes and shapes, and, (2) moisture of the tuna flake. The two factors also give rise to changes in (3) Bulk Density of the incoming material. Therefore, the effect of the incoming material from the three mentioned factors on weight accuracy will be studied in this section in order to justify the necessity of the additional control process of incoming material to determine the standard practice in granular sizing, moisture control and bulk density.

4.3 Minimum Viable Product Set-up

Minimum Viable Product (MVP) will be constructed and used in order to perform various experimental conditions which includes measuring cup material effect on flowability, wiper dimensions effect on flowability, machine speed effect on flowablity and granular shape effect on flowability.

In order to execute the above experiments, the MVP should contain the following features.

(1) Bowl: Incoming material will be filled in the bowl.

(2) Wiper: There are two wipers in the machine, both wipers contains the dimensions: thickness (t), clearance from the bottom of the machine bowl (δ) and tip angle (α). The dimensions of wipers are shown in Figure 36. The functions of the two wipers are as follows.

(2.1) Wiper 1: This wiper will be used to wipe the incoming material into the measuring cup.

(2.3) Wiper 2: This wiper will be used to level the material to in the measuring cup to achieve the desired volume.

(3) Variable Speed Motor: The speed of both wipers will be controlled using a variable speed motor.

(4) Adjustable Volume Measuring Cup: The measuring cup will be used to control the volume of the incoming material being filled into the cans.

(5) Opening-Closing Valve: Once the measuring cup is filled and the incoming material is levelled, it will be released into the cans using this valve.

The illustration of the features above is shown in Figure 37 and Figure 38.

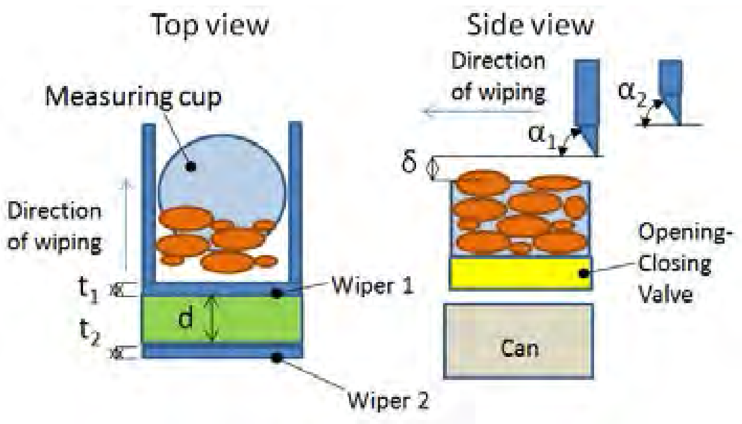


Figure 36: *Wiper dimensions*

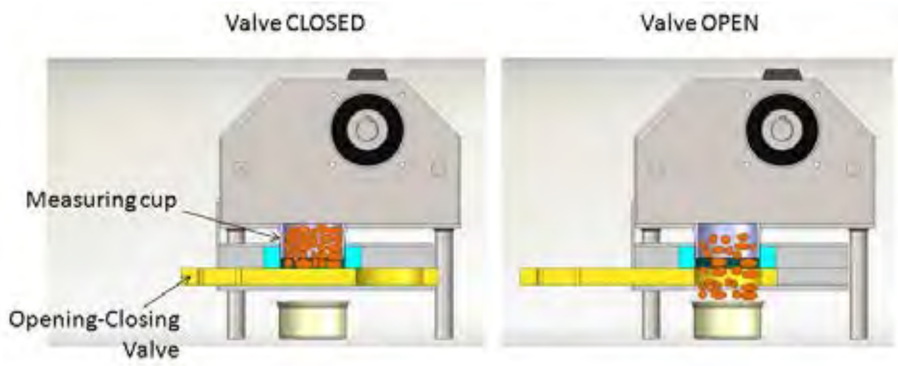


Figure 37: *Measuring cup and opening-closing valve*

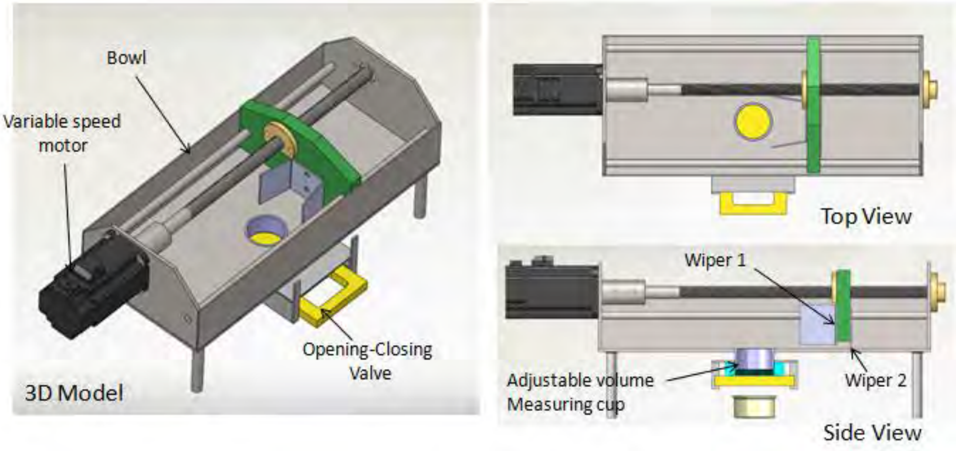


Figure 38: *MVP Features*

4.4 Best Condition Verification Study

In this section, in order to minimise the experimental time while optimising the advantageous results, the methodology that leads to best condition verification is explained. This section features both machine function related experiments such as measuring cup material and wiper dimensions. Moreover, it also covers incoming material related experiments such as moisture effect and bulk density.

4.4.1 Measuring Cup Material Effect on Flowability

Flowability of the tuna flake is another factor to be considered to determine the required function of the filling machine and its ability to allow flow of filling material. As the machine uses volumetric filling method, the material of the measuring cup with the best flow rate of the product is to be determined. The material of the measuring cup will be selected between stainless steel and Teflon (Polytetrafluoroethylene).

The measuring cup of the same volume will be made using stainless steel and Teflon material with open top and bottom sides, the bottom side of the cup will be closed with stainless steel plate which will be opened during the flow rate measurement.

(1) Material

2 kg of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Stainless steel cylinder measuring cup
II. Teflon rectangular cylinder measuring cup
III. MVP
IV. Stop watch

(3) Experimental method

The comparison between the flowability performances of the two materials will be evaluated using stop watch. The repeatability for each material is 50 times.

(4) Result Judgement

The material with the highest flow rate will be selected as the measuring cup standard shape for the tuna flake filling machine. The number of the measuring cups required in the machine will be determined based on the flowability of tuna flake in the two materials, however, in the case that the number of cups exceeds 21 which is the number of the filling head for the existing granular filling machine offered by the machine manufacturer, pusher feature at the end of filling procedure will be considered to enhance flow.

4.4.2 Moisture Effect on Weight Accuracy

In the preliminary study, only 5 samples of tuna flake were used to determine the moisture in the product. 5 samples from 10 working days will be gathered to determine the moisture and its contribution to weight filling accuracy using the same method.

4.4.3 Moisture Effect on Flowability

One of the simplest ways to measure flowability of a granular material is natural repose angle measurement. The increase in repose angle indicates the decrease in flowability.

(1) Material

160g of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Can with 68mm diameter and 79mm height

II. Plastic wiper with 300mm length, 25mm width and 4mm thickness

III. 5ml Syringe

IV. Protractor

(3) Experimental method

The experiment will be done by putting tuna flake in a fixed volume can, before turning the can upside down to measure the repose angle of the tuna flake. Once the first measurement is over, the tuna flake will be re-put in the same can with addition of 5ml of water using syringe to increase the moisture in the tuna flake. The can of tuna flake will then be turned upside down again to measure the repose angle. The experiment will be continued until the water dropped in the tuna flake reaches 175ml. The demonstration of the experimental method is shown in Figure 39.

Figure 39: *Repose angle measurement*

(4) Result Judgement

The moisture content with the minimal repose angle which is within the tolerance required by the canned tuna flake manufacturer will be chosen as the standard moisture for incoming material checking, as minimal repose angle signifies high level of flowability of a granular media.

4.4.4 Bulk Density Effect on Weight Accuracy

Bulk Density is another factor contributed to the resulted fill weight which is to be studied in accordance to the fill weight tolerance required by the tuna flake manufacturer. The method of bulk density measurement is explained in Section 4.2.

4.4.5 Wiper Dimensions Effect on Flowability

Wiper as a component of the tuna flake filling machine will be used to wipe the product from the bowl into each measuring cup. The following factors of the wiper will be considered and tested to determine the best practice of each. The dimension of each factor in the wiper is shown in Figure 36.

(1) Material

2 kg of uncontrolled granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. An MVP of a tuna filling equipment with bowl for material input, measuring cup for 45g of tuna flake, opening-closing mechanism to allow the controllability of flow of tuna flake and a wiper with the following characteristics will be designed and used for the experiment.

(1) Thickness (t1, t2): Three wipers with different thicknesses will be made, 5mm, 10mm and 15mm.

(2) Angle (α1, α2): Each of the wipers will have 2 ends, one will be made flat with zero degree angle, while the other which is in contact with the bowl and tuna flake will be made with 0-45 degree angle.

(3) Distance (δ1, δ2): The distance between the bottom of the bowl and the wiper will be altered between 0 to 10mm with 1mm step between each.

(4) Gap (δ3): The gap between the two wipers which will be 20mm.

II. Weighing scale

(3) Experimental method

Tuna Flake will be put into the bowl and wiped into the measuring cup using the wipers at different condition of t, α and δ. The repeatability for each condition is 100 times. The result of the loss amount per stroke of each condition will be measured using weighing scale and will be plotted in a histogram and calculated for process control indices.

(4) Result Judgement

The operating condition with the result that contains the least amount of loss will be used as a standard practice for the tuna flake filling machine design.

4.5 Process Accuracy and Precision Study of As-received Incoming Material

Once the best condition has been identified, it is then important to justify the accuracy and precision of the filling process using the tuna flake filling machine MVP. This section concentrates on describing the experimental conditions related to machine speed and granular shape which reflect on different results of fill weight accuracy and precision.

The speed of the machine is the key component to the productivity of the process. The material, equipment and experimental procedures including judgement method is explained in this section.

(1) Material

2 kg of 10-15mm and 20-30mm as received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

An MVP of a tuna filling equipment with bowl for material input, measuring cup for 25g, 35g and 45g of tuna flake, opening-closing mechanism to allow the controllability of flow of tuna flake and variable speed motor to control the speed of the wiping process.

(3) Experimental method

Tuna Flake will be put into the bowl and wiped into the measuring cup at the speed of 100-350mm/s with 50mm/s increasing step. The result of the performance of each condition will be measured using weighing scale and will be plotted in a histogram and calculated for process control indices in the same format as in preliminary study section.

(4) Result Judgement

The results of the fill weight are analysed in two aspects which are precision and accuracy. The details of the analysis for each aspect are as follows.

- Precision Analysis

Based on the resulted fill weight and the weight tolerance allowance of ±3g, the process precision is analysed using Cp, Cpk and CV.

Once the results are analysed the maximum speed that allow Cp and Cpk that are 1 and above will be considered as the standard practice for the tuna flake filling machine design.

- Accuracy Analysis

Similar to precision analysis, the process accuracy is analysed using resulted fill weight which is viewed using bias percentage and void percentage.

4.6 Process Accuracy and Precision Study of As-sieved Incoming Material

From the experiment with beans, as granular sizes and shapes are ones of the strongest factors to weight controllability, in order to verify the same effect on tuna flake, an experiment will be conducted with controlled granular size of tuna flake using 5 different sizes of sieves.

(1) Material

2 kg of 10-15mm as-received granular sized tuna flake from the canned tuna manufacturer

(2) Equipment

I. Can with 68mm diameter and 40mm height
II. MVP
III. Weighing scale
IV. 5mm, 7mm, 10mm, 12mm and 15mm sieves

(3) Experimental method

Firstly the tuna flake will be divided into different sample sizes which are 5mm, 7mm, 10mm, 12mm and 15mm using sieves of different diameters of holes. Once the tuna flake is divided into different lot sizes, the sample of each size will be put into separate cans, the elongation of 10 pieces of tuna flake in each can will be measured before each can is weighed.

The variation of the weight in different granular sizes and shapes will be statistically recorded and analysed. The measurement of weight will be repeated 100 times for each size of the sample. The illustration of the experimental method is shown in Figure 40.

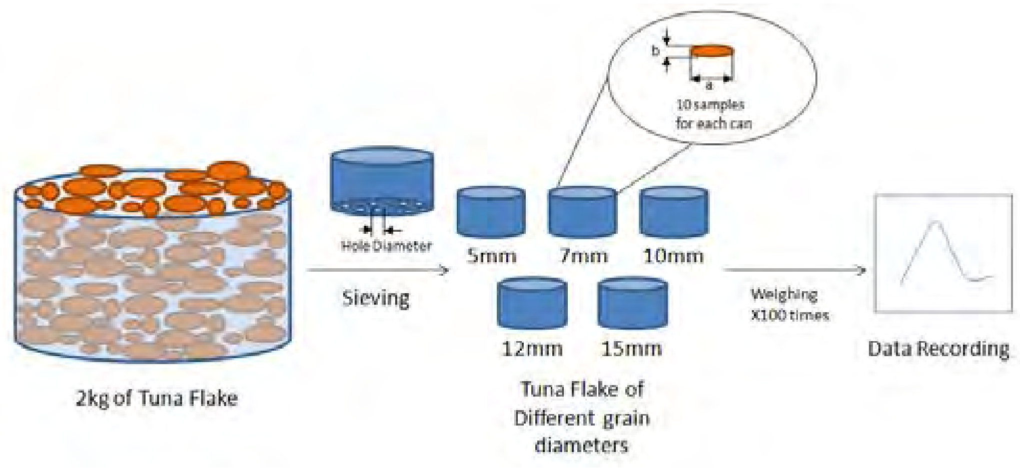


Figure 40: *Granular Shape effect on weight accuracy*

(4) Result Judgement

The results of the fill weight are analysed in two aspects which are precision and accuracy. The details of the analysis for each aspect are as follows.

- Precision Analysis

Based on the result of the fill weight and the tolerance of ±3g, Cp, Cpk and CV will be used to analyse the precision of filling process at various grain size of tuna flake.

The largest sample sizes with fill weight within ±3g tolerance target and Cp and Cpk values larger than 1 will be considered as a standard practice for granular size sieving.

- Accuracy Analysis

Similar to the accuracy analysis for the machine speed, the accuracy of various grain size of tuna flake is analysed using percentage of bias and void.

4.7 Experimental Plan Layout

This section aims to summarise the experiments which will be conducted in the research and the functions of the MVP which will be designed and used to test the tuna filling process.

4.7.1 Experimental conditions

The experimental conditions are summarised in Table 14, where the variable factors are divided into 4 categories which are (1) Incoming Material, (2) Measuring Cup, (3) Wiper and (4) Machine.

4.7.2 Experimental Responses

The responses of the experiments which is the net weight of the tuna flake in various experimental conditions will be recorded in the following formats.

[1] **Statistics:** Mode, Mean, Average, Standard deviation (SD), Coefficient of variance (CV), Histogram

[2] **Process Capability Indices**: Cp and Cpk

[3] **Productivity:** Material Output/ Material Input

Table 14: *Tentative Experimental conditions summary*

No	Variable Factors	Unit	Level		
			Low	Medium	High
(1) Incoming Material					
1	a	mm	5 7 10 12 15		
	a/b	mm/mm	2	2.5	3
2	Mositure	%	65	70	75
(2) Measuring Cup					
3	Material		Stainless Steel		
4	Volume & Weight	cm3 (g)	64 (28g)	80 (35g)	103 (45g)
(3) Wiper 1, 2					
5	α1, α2	°	0	30	45
6	δ1 , δ2	mm	0 - 10 (1mm step)		
7	δ3	mm	10	15	20
8	t1	mm	2 5 10 15		
9	t2	mm	5	10	15
(4) Machine					
10	Speed	mm/s	100 150 200 250 300		

Remark: (1) a,b are the incoming material dimensions, for detail, refer to Figure 26

(2) $\alpha 1$, $\alpha 2$, $\delta 1$, $\delta 2$, $\delta 3$, t1 and t2 are the MVP wiper dimensions, for detail, refer to Figure 39.

4.8 Research Cost Estimation

This section is divided into 2 parts which are testing material and MVP, which refers to the cost of tuna flake and the cost of the testing equipment respectively. The total cost estimation is summed up to be 56,350 Baht which is shown in Table15. The details of cost are shown in the following sections.

Table 15: *Research Total Cost Estimation*

Item	Cost
(1) Tuna Flake of 20kg (2) Testing Equipment	10,400 45,950
Total Cost	56,350 Baht

4.8.1 Testing Material

In this research, 20kg of Tuna Flake will be required for the experiments. Fortunately, all the material required for testing will be funded by a canned tuna flake manufacturer. However, according to the market price provided by an ingredient wholesaler, Food Project (2019), as of February 2019, the price for steak grade tuna loin is 520 Baht per kg.

As a result, the material cost for the research is estimated to be 10,400 Baht.

4.8.2 MVP

The MVP used for the experiment will be made in-house at Sutthiphong Engineering Company.

The component parts and their estimated costs are listed in Table 16. The parts listed in Component 1 to Component 15 are purchased from the suppliers of the company and are processed in-house, the cost shown in the table are the summations of material and labour costs without other operating costs.

Component 15 and 16 are bought-in parts, and the costs shown in the table is the cost of purchase. In summary the overall cost of the machine is estimated to be 45,950 baht with the major of the cost from the bought-in parts.

4.9 Research Schedule

The research is scheduled take place between October 2018 and March 2019, the procedures involved within the mentioned timeline include the making of MVP, experiments, result analysis and conclusion, and the writing of the thesis book. The Gantt chart of the research is shown in Table 17.

Table 16: MVP Cost Estimation

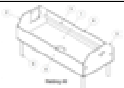
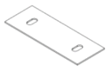
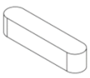
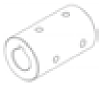
No.	Picture of Part	Part Number	Part Name	Pieces	Cost per Unit (Baht)	Total Cost (Baht)
1		TF-EX-01	TRAY TABLE	1	2,000	2,000
2		TF-EX-02	MEASURING CUP	1	400	400
3		TF-EX-03	VALVE SLIDE	1	500	500
4		TF-EX-04	ADJUSTING NUT	1	100	100
5		TF-EX-05	VALVE	1	200	200
6		TF-EX-06	FILLING PLATE	1	500	500
7		TF-EX-07	FILLING PLATE Thickness: 5mm, 10mm, 15mm	3	100	300
8		TF-EX-08	C-PUSHER	1	200	200
9		TF-EX-09	C-PUSHER SPACER Thickness: 3mm, 5mm, 10mm	3	100	300
10		TF-EX-10	NUT	1	300	300
11		TF-EX-11	BUSHING	1	300	300
12		TF-EX-12	DRIVE SCREW	1	500	500
13		TF-EX-13	KEY	1	100	100
14		TF-EX-14	DRIVE SCREW HUB	1	250	250
15		TF-EX-15	VARIABLE SPEED MOTOR	1	10,000	10,000
16		TF-EX-16	DRIVE SCREW HUB	1	30,000	30,000
Total Estimated Cost						45,950

Table 17: *Gantt chart of research schedule*

No	Acitivity	Oct-18				Nov-18				Dec-18				Jan-19				Feb-19				Mar-19			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Study weight controllability																								
	1.1 MVP designing																								
	1.2 MVP fabrication																								
	1.3 Granular size experiment																								
	1.4 Moisture control experiment																								
2	Study Flowablity																								
	2.1 MVP designing																								
	2.2 MVP fabrication																								
	2.3 Measuring cup shape experiment																								
	2.4 Measuring cup material experiment																								
	2.5 Wiper experiment																								
	2.5 Machine speed experiment																								
3	Cost Estimation																								
	3.1 Traditional method cost																								
	3.2 Additional incoming material control processes																								
	3.3 Machine cost																								
	3.4 Rate of return																								
4	Writing the Thesis Book																								
	4.1 Outlining the thesis book																								
	4.2 Drafting the thesis book																								
	4.3 Finalising the thesis book																								

CHAPTER 5 RESULT AND ANAYLSIS

This chapter contains the result and analysis of customer requirement collection and experiments on incoming material and experiments using MVP. The chapter is divided into 5 major parts which are (1) Customer requirement collection, (2) Incoming material investigation, (3) Best condition verification which includes both incoming material and machine features and the settings, (4) Process accuracy and precision of as-received incoming material and (5) Process accuracy and precision of as-sieved incoming material.

The illustration of the procedures followed in this chapter is shown in Figure 41.

5.1 Customer Requirement Collection Result

After discussing with production managers, assistant production managers and assistant engineering managers from 2 canned tuna flake manufacturers, the specification of the canned tuna flake product can be summarised as shown in Table 18.

Figure 42 illustrates the procedures of the experiments; it includes 3 essential elements in each stage which are Variables, Tools and Output, where,

[1] **Variables** refer to the requirement of the product by customer in Customer Requirement step, and refer to the elements that each experimental step is investigating in Input 1, Input 2 and Input 3.

[2] **Tools** refer to the equipment used in each experimental step.

[3] **Output** refers to the form of result gathered and analysed in each experimental step.

The procedures start from Customer Requirement Collection followed by Incoming Material Investigation (Input 1), Best Condition Verification (Input 2) to optimise the study time, and Accuracy and Precision (Input 3) to verify the efficiency of the method. Variables contained in Input 1 can be tested using simple measuring equipment such as Vernier Caliper, digital weighing scale, however, those variables in Input 2 and Input 3 are to be tested using MVP along with those simple tools used in the experiment of Input1.

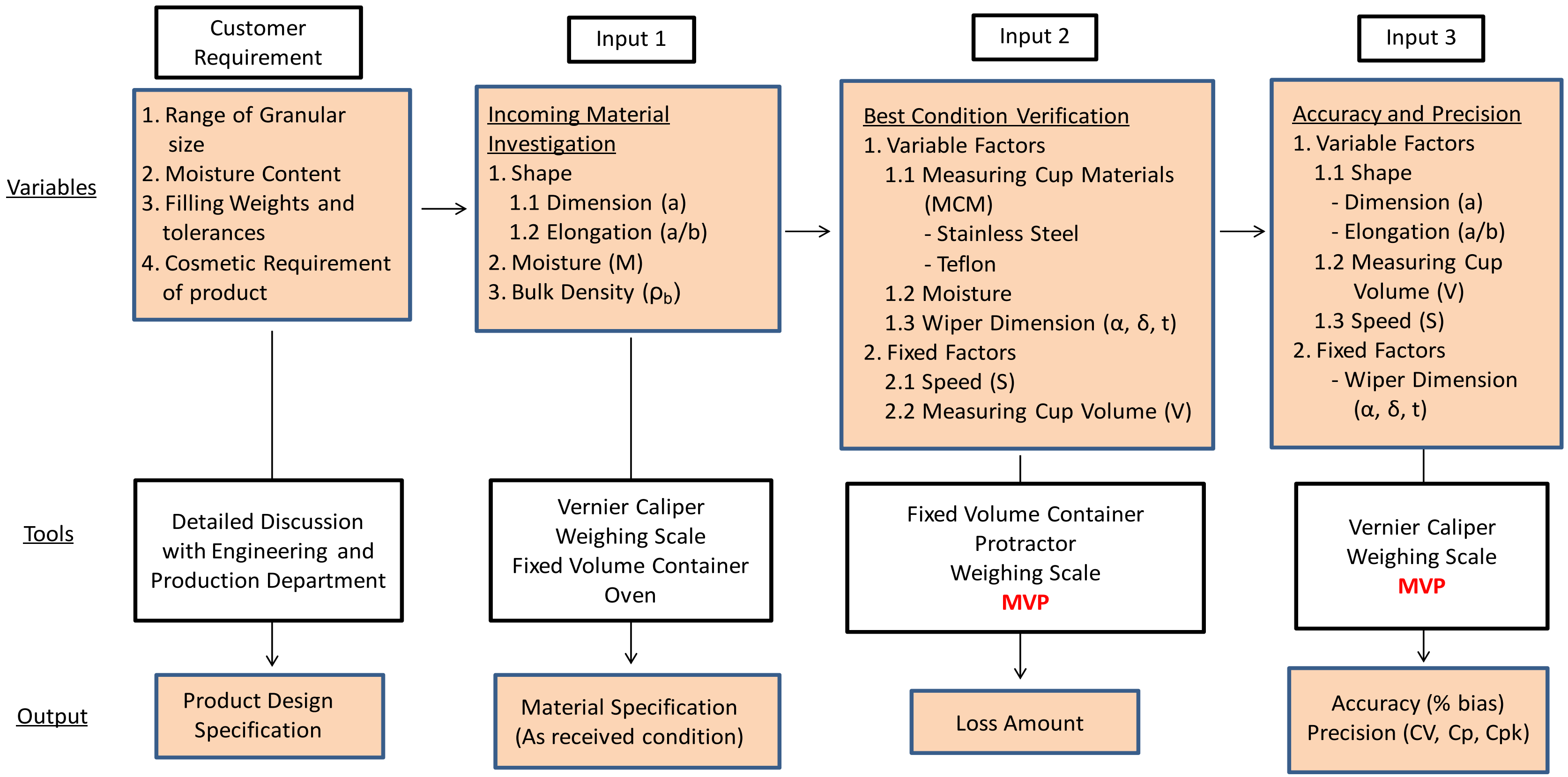


Figure 41: *Illustration of Technical Data Result and Analysis*

Table 18: Product Design Specification of Machine

Variable	Specification	
1. Range of Granular Sizes	3 - 5 mm 10 - 15 mm 20 - 30 mm	70% of Tuna Flake are within specified range by visual inspection
2. Moisture content in Product	65-70%	
	Recored values, however not controlled	
3. Filling weight and tolerances	28 to 45 ± 3g	
4. Cosmetic requirement	Low density, liquid product can penetrate through the tuna flake	
5. Can size	ϕ 209.5 - 300 (66.9 mm - 76.2 mm)	
6. Speed of filling	120 cpm	

5.2 Incoming Material Investigation

2 Samples of tuna flakes were provided by a canned tuna flake manufacturer, this particular manufacturer only produces 2 sizes of tuna flake product which are 10-15mm and 20-30mm. The photos of the received samples are shown in Figure 42.

Remark: a^{*1}, a^{*2} = Average Size of Feret Diameter (a) as per customer specification for small (10-15mm) and large size (20-30mm), respectively.

Figure 42: Photo of As-received Incoming Material

The investigation on the incoming material includes checking of the granular shape, moisture and bulk density.

5.2.1 Granular Shape

During the study, 100 pieces of each sample were randomly selected and measured the longest dimension (Feret Diamter, a) and shortest dimension (Elongation a/b). The summary of the shape study result is shown in Table 19.

(1) Feret Diameter (a)

Although the tuna flake manufacturer set their dimensional accuracy target at 70%, the accuracies of both samples received are much below target. Only 46% and 7% for 10-15mm sized sample and 20-30mm sized sample are with the size target, respectively.

The variation in 20-30mm is higher than 10-15mm, according to the result of the coefficient of variance of 51.7% and 46.2% correspondingly.

With the average size of feret diameter (a) of 12.9mm and 11.9mm for 10-15mm and 20-30mm sequentially, it can be concluded that in average the two samples received are almost identical in Feret Diameter as shown in Table 19 ($a^{*1} = a^{*2} = a$).

(2) Elongation a/b

The variation in Elongation a/b for 10-15mm sample is slightly higher than 20-30mm sample. The coefficient of variance for 10-15mm sized sample is 41.2%, whereas it is 36.2% for 20-30mm.

Table 19: *Dimension Summary of As-received Tuna Flake*

Variable	Unit	a*1 = 10-15mm			a*2 = 20-30mm		
		a	b	a/b	a	b	a/b
Number of Pieces	pieces	100	100	100	100	100	100
a in range	pieces	46	-	-	7	-	-
Mode	a, b (mm) a/b (mm/mm)	9.0	3.0	3.0	6.0	4.0	3.0
Median	a, b (mm) a/b (mm/mm)	12.0	4.0	3.0	11.0	4.0	2.5
Average	a, b (mm) a/b (mm/mm)	12.9	4.2	3.3	11.9	5.1	2.5
SD	-	5.94	1.64	1.34	6.14	2.69	0.90
CV	-	46.2%	39.5%	41.2%	51.7%	52.6%	36.2%
Max	a, b (mm) a/b (mm/mm)	37.0	9.0	9.0	37.0	16.0	6.0
Min	a, b (mm) a/b (mm/mm)	4.0	2.0	1.2	5.0	2.0	0.9
Max-Min	a, b (mm) a/b (mm/mm)	33.0	7.0	7.8	32.0	14.0	5.1
x̄ ± SD	-	12.9 ± 5.94	4.2 ± 1.64	3.3 ± 1.34	11.9 ± 6.14	5.1 ± 2.69	2.5 ± 0.9

Remark: a* = Feret diameter as per customer specification

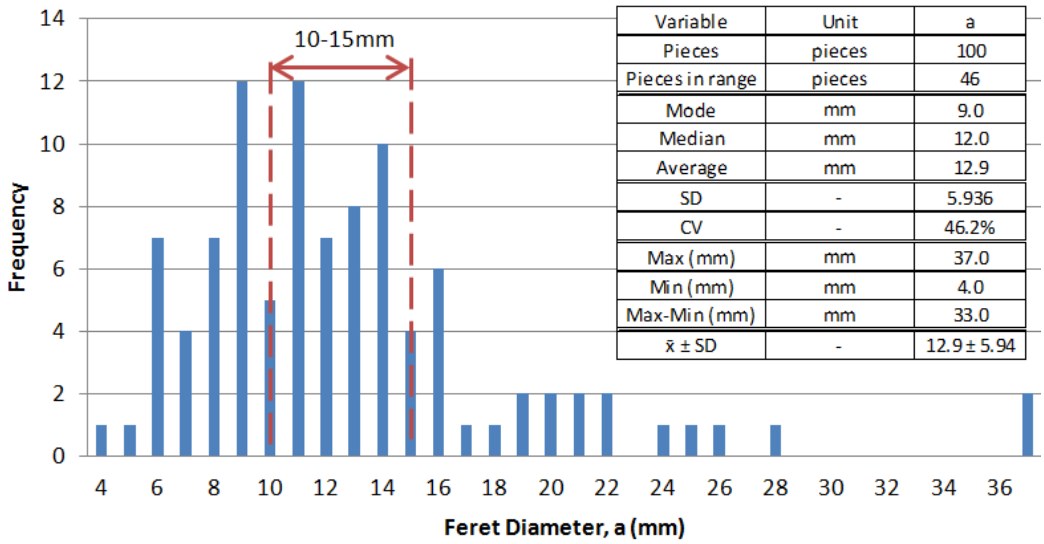
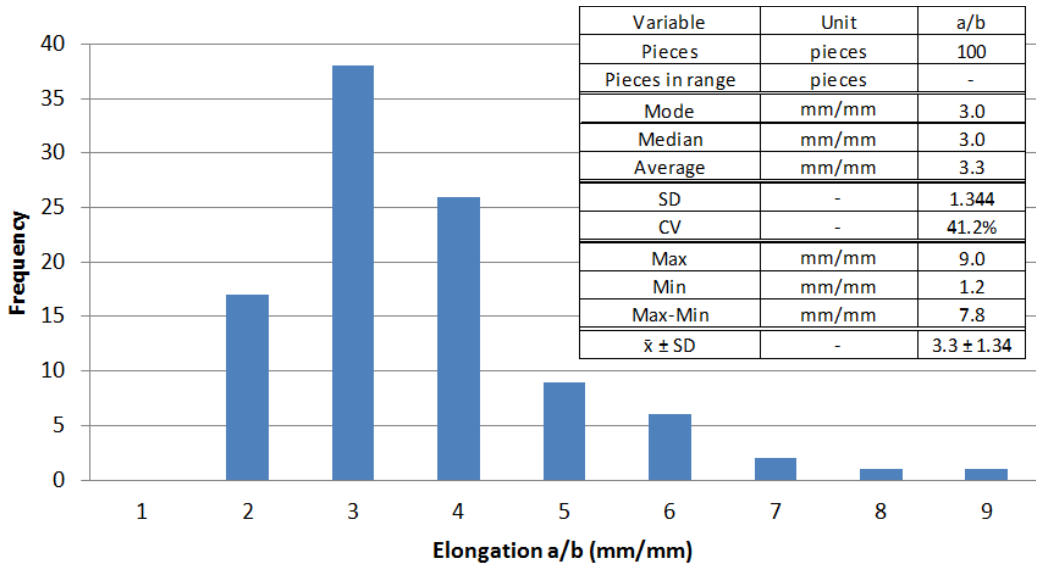
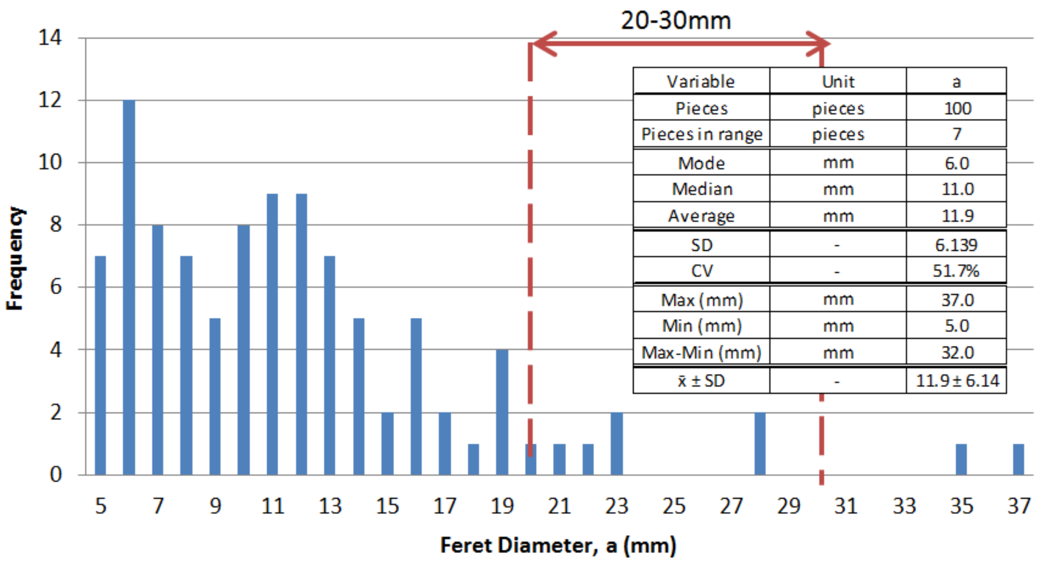


Figure 43: *Feret Diameter (a) Histogram of 10-15mm Sample*



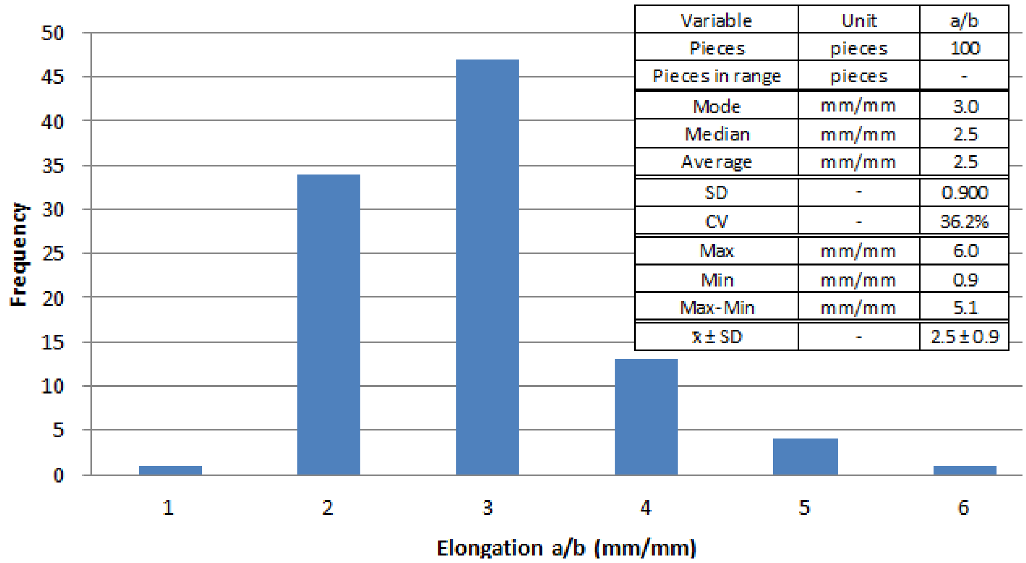
Variable	Unit	a/b
Pieces	pieces	100
Pieces in range	pieces	-
Mode	mm/mm	3.0
Median	mm/mm	3.0
Average	mm/mm	3.3
SD	-	1.344
CV	-	41.2%
Max	mm/mm	9.0
Min	mm/mm	1.2
Max-Min	mm/mm	7.8
x̄ ± SD	-	3.3 ± 1.34

Figure 44: *Elongation a/b Histogram of 10-15mm Sample*



Variable	Unit	a
Pieces	pieces	100
Pieces in range	pieces	7
Mode	mm	6.0
Median	mm	11.0
Average	mm	11.9
SD	-	6.139
CV	-	51.7%
Max (mm)	mm	37.0
Min (mm)	mm	5.0
Max-Min (mm)	mm	32.0
x̄ ± SD	-	11.9 ± 6.14

Figure 45: *Feret Diameter (a) Histogram of 20-30mm Sample*



Variable	Unit	a/b
Pieces	pieces	100
Pieces in range	pieces	-
Mode	mm/mm	3.0
Median	mm/mm	2.5
Average	mm/mm	2.5
SD	-	0.900
CV	-	36.2%
Max	mm/mm	6.0
Min	mm/mm	0.9
Max-Min	mm/mm	5.1
$\bar{x} \pm$ SD	-	2.5 ± 0.9

Figure 46: *Elongation a/b Histogram of 20-30mm Sample*

5.2.2 Moisture

The samples of 10-15mm and 20-30mm sized tuna flake received from the manufacturer were selected and tested for the moisture content contained in the product using the method explained in Section 3.4. The result of the experiment is shown in Table 20.

According to the standard of control level of moisture content of 65-70% instructed by the canned tuna manufacturer, the samples received are within the standard. However, when considering the effect of moisture on the weight accuracy using the maximum fill weight of 45g, it can have the effect up to 1.3g and 0.5g for 10-15mm and 20-30mm sample respectively.

Table 20: *Moisture Content in 10-15mm and 20-30mm Sample*

	10-15mm Sample			20-30mm Sample		
	Wet Flake (g)	Dried Flake (g)	Moisture (%)	Wet Flake (g)	Dried Flake (g)	Moisture (%)
Can 1	111	50	68.5%	119	52	69.1%
Can 2	112	52	66.7%	118	51	69.8%
Can 3	111	49	69.7%	119	52	69.1%
Can 4	111	51	67.4%	119	51	70.1%
Can 5	110	50	68.2%	120	52	69.4%
Average	111	50.4	68.1%	119	51.6	69.5%
MAX		69.7%		70.1%		
MIN		66.7%		69.1%		
MAX-MIN		3.0%		1.0%		
Accuracy effect at 45g		1.3g		0.5g		

5.2.3 Bulk Density

The bulk densities of 10-15mm and 20-30mm sized tuna flake samples were found using the experimental method explained in Section 3.4, where tuna flakes are put into a container with fixed volume with the diameter of 84mm and height of 45mm and weighed. The bulk density is calculated using Equation 2-5.

The result of the bulk density is shown in Table 21, it can be seen that the 20-30mm sample are slightly denser than the 10-15mm sample with the average bulk density of 0.477 g/cm3 and 0.445 g/mm3 for 20-30mm sample and 10-15mm sample respectively.

Using the true density of fresh tuna of 1.071g/cm3 studied by Rahman et al. (2002), and Equation 2-7 to calculate void, it has been found that compared to the true density of tuna meat, the void fraction for both samples are very high at 0.584 for 10-15mm sample and 0.554 for 20-30mm sample. The effect of void to fill weight accuracy and precision will be studied in Section 5.4.

Table 21: *Bulk Density of 10-15mm and 20-30mm Samples*

	10-15mm Sample				20-30mm Sample			
	Weight (g)	Volume (cm3)	Bulk density (g/cm3)	Void Fraction	Weight (g)	Volume (cm3)	Bulk density (g/cm3)	Void Fraction
Can 1	111		0.445	0.584	119		0.477	0.554
Can 2	112		0.449	0.581	118		0.473	0.558
Can 3	111	249.4	0.445	0.584	119	249.4	0.477	0.554
Can 4	111		0.445	0.584	119		0.477	0.554
Can 5	110		0.441	0.588	120		0.481	0.551
Average	111	249.4	0.445	0.584	119	249.4	0.477	0.554

5.2.4 Incoming Material Summary

After investigating the raw material received from a customer who is a canned tuna flake manufacturer, it has been found that the moisture content in the incoming material can be practically kept with their 65-70% standard.

However, in terms of grain size, although the customer categorises the product into 2 sizes according to the feret diameter (a) which are 10-15mm and 20-30mm, the two sizes of material are very similar and that although the standard of size control states that 70% of the raw material are to be controlled within the size range verified, in reality according to this particular time of investigation 46% are within the range for 10-15mm sample and only 7% are within the range for 20-30mm sample.

The Elongation a/b is a dimension not controlled by customer, however has effect in weight controllability of the filling process. After the investigation, the variation in elongation a/b of 10-15mm sample is higher than 20-30mm. The coefficient of variance found for the raw material is found to be 41.2% and 36.2% for 10-15mm and 20-30mm respectively.

5.3 MVP Best Condition Verification Study

In order to optimise the time consumption of the study, the best condition of MVP adjustment is studied prior to granular shape effect and machine speed effect on the weight accuracy and precision of the filling process. This part of the study includes effect of material of measuring cup, moisture in the incoming material, additional moisture requirement, bulk density and wiper dimensions.

5.3.1 Measuring Cup Material Effect on Flowability

An experiment was conducted to determine the difference in flowability of Teflon (PTFE) and Stainless Steel using the method explained in Section 4.3. However, due to the minimal time taken for the tuna flake to flow through the measuring cups of the two materials which is roughly one second, it is extremely difficult to determine the exact time.

Figure 47 shows the photo of the two materials used in the experiment and Figure 48 shows time taken for the product to flow through the measuring cup in the MVP. The time at the valve closed position is 00:11 and the valve open position is 00:12, during the experiment the product flows through the measuring cup right at the instance when valve opened. The time taken for the flow is extremely difficult to measure without additional equipment such as a sensor.

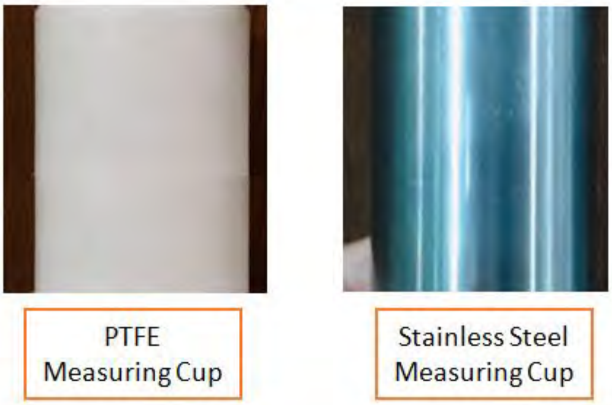


Figure 47: *PTFE and Stainless Steel Measuring Cups*

Figure 48: *Valve closed and opened VDO Clip Capture*

Although the coefficients of friction of the two materials are significantly different according to the data provided by Plastim (2015) and Dogan et al. (2002), in this particular type of application the difference between the flow performances of the two materials is unnoticeable by the equipment used.

From the strength perspective PTFE is almost 26 times weaker than stainless steel and from the price perspective the cost of PTFE is 5.1% higher than stainless steel, which is almost negligible. The prices of the two materials are obtained from local material suppliers. The coefficient of friction, yield strength and cost of material of both materials is shown in Table 22.

In summary, considering the strength of the material and the actual flow performance of this application, it is better to use stainless steel to make the measuring cup. As the outer part of the measuring cups of the MVP is to be threaded by lathe machine to allow volume adjustment, the strength of the material becomes necessary.

Table 22: *Material Property and Cost Comparison of PTFE and 316L Stainless Steel*

Material	Unit	PTFE	316L Stainless Steel
Coefficient of Friction	-	0.08-0.1	0.68
Yield Strength	MPa	20	515
Cost per kg	THB/g	0.482	0.012
Cost of Part	THB/piece	4600	4375

Note: The Cost of Material shown is for Bar-shaped material of 75mm diameter and 1000mm length for both materials.

5.3.2 Moisture Effect on Weight Accuracy

As explained in the preliminary study section (Section 2.5), since volumetric measurement is used to control the weight of the product, moisture in the product can contribute to the accuracy of the filling if not sufficiently monitored.

The method used for the study is explained in Section 4.2, 10 samples of 800g of 10-15mm sized tuna flakes are received from the canned tuna flake manufacturer on different dates of production. The duration of the experiment is 30 days. The statistics of moisture percentage (M) is summarised in Table 23.

Table 23: *10 Day Moisture Percentage Statistics*

Day	% Moisture						Effect in 45g filling (g)
	Average	SD	CV	MAX	MIN	MAX-MIN	
1	68.1%	0.011	1.7%	69.7%	66.7%	3.0%	1.3
2	67.0%	0.009	1.3%	67.8%	65.6%	2.2%	1.0
3	67.8%	0.011	1.6%	69.3%	66.7%	2.7%	1.2
4	67.6%	0.012	1.8%	68.5%	65.6%	3.0%	1.3
5	69.8%	0.008	1.1%	70.8%	68.9%	1.9%	0.9
6	66.7%	0.009	1.3%	67.8%	65.6%	2.2%	1.0
7	68.0%	0.004	0.6%	68.5%	67.4%	1.1%	0.5
8	67.6%	0.007	1.1%	68.5%	66.7%	1.9%	0.8
9	66.8%	0.011	1.6%	68.5%	65.6%	3.0%	1.3
10	68.3%	0.009	1.3%	69.7%	67.4%	2.2%	1.0
Overall	67.8%	0.012	1.8%	70.8%	65.6%	5.2%	2.4

From the statistics, it can be seen that the maximum moisture is on Day 5 which is 70.8% and hence slightly over the customer standard of 65-70%, however, the difference in moisture content on that day only causes 0.9g of filling accuracy.

In general, the averages of moisture content in the 10 day trials are practically within the standard with only one reading on Day 5 being 0.8% above standard. The swing of moisture content on each day is quite low according to the CV which is between 0.6% and 1.7%. However, from the result of the study, it can be concluded that at 45g of product filling moisture inaccuracy can cause 1.3g difference in weight using the volumetric filling method.

5.3.3 Moisture Effect on Flowability

According to Wu and Sun (2008), Natural angle of repose (θ) identifies the degree of cohesion between granules in granular media and hence flowability. Repose angles of 10-15mm sized tuna flakes sample at different content of moisture are measured and analysed using the methodology explained in Section 4.2.

It can be seen through and graph of relationship between moisture content and repose angle in Figure 49 and the photos in Figure 50 that as moisture content increases the repose angle of also increases indicating that adding of water adds cohesion to the granules and decreases the flowability of the granular media.

As a result it can be concluded that adding of liquid to the tuna flake prior to the filling process does not advance the flow of the material and hence is not advisable. Not only the water will reduce the flowablity of the tuna flake, it will also affect the weight controllability of the product if not mixed evenly throughout the product.

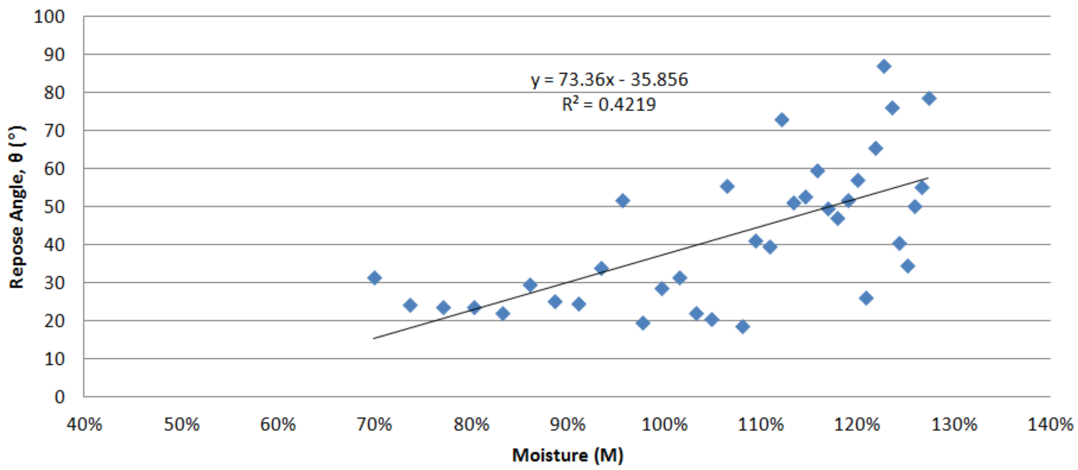


Figure 49: *Moisture Effect on Flowability*

Figure 50: *Repose Angle at Different Level of Moisture Content*

5.3.4 Bulk Density Effect on Weight Accuracy

Since the accuracy of filling is controlled by the volume of the measuring cup, the density of the product can play a big role in the weight accuracy; hence its variation is to be studied.

The study method of bulk density is described in Section 4.2, 10 samples of 800g of 10-15mm sized tuna flakes were received from the tuna flake manufacturer on different production dates. This experiment is done alongside with the moisture experiment during the same 30 days duration. The statistics of bulk density is summarised in Table 24.

The overall average bulk density of the 10 day sample is 0.446g/cm3 with the range between 0.441 and 0.449g/cm3 which is relatively small according to the maximum CV of 0.8%. The differences in the bulk densities during the experimental period can cause up to 0.4g difference in product weight.

Table 24: *10-Day Bulk Density Statistics*

Day	Bulk Denisty (g/cm3)						Effect in 45g filling (g)
	Average	SD	CV	MAX	MIN	MAX-MIN	
1	0.445	0.003	0.6%	0.449	0.441	0.008	0.4
2	0.447	0.002	0.5%	0.449	0.445	0.004	0.2
3	0.444	0.003	0.8%	0.449	0.441	0.008	0.4
4	0.447	0.002	0.5%	0.449	0.445	0.004	0.2
5	0.444	0.003	0.8%	0.449	0.441	0.008	0.4
6	0.447	0.002	0.5%	0.449	0.445	0.004	0.2
7	0.444	0.003	0.8%	0.449	0.441	0.008	0.4
8	0.445	0.003	0.6%	0.449	0.441	0.008	0.4
9	0.448	0.002	0.4%	0.449	0.445	0.004	0.2
10	0.445	0.003	0.6%	0.449	0.441	0.008	0.4
Overall	0.446	0.003	0.6%	0.449	0.441	0.008	0.4

5.3.5 Wiper Dimensions Effect on Flowability

As mentioned in the research methodology section, it was assumed that the dimensions of the wipers would have an effect on the flowability of the tuna flake. In this section of the experiment, an MVP is used to determine the flow performance through amount of loss per stroke. The dimensions of the wipers which are thickness (t), clearance distance (δ) and tip angle (α) are varied at different conditions to determine the flowablity of the material thorough the measurement of loss per stroke.

The dimensions of the wipers are shown on Figure 39, and the photos of the Layout of the MVP are shown in Figure 51.

The photos of the MVP in actual operation are shown in Figure 52, the operation of the machine includes,

[1] **Fill in Product:** 70g Product is filled into the bowl of the machine.

[2] **Run Machine:** The wiper is run past the measuring cup at constant desirable speed.

[3] **Release Product:** The product is released into the can by pulling the valve.

[4] **Weight:** Once the product is released into the cans. The achieved amount of tuna flake is weighed and recorded.

Figure 51: *Photos of Actual MVP Layout*

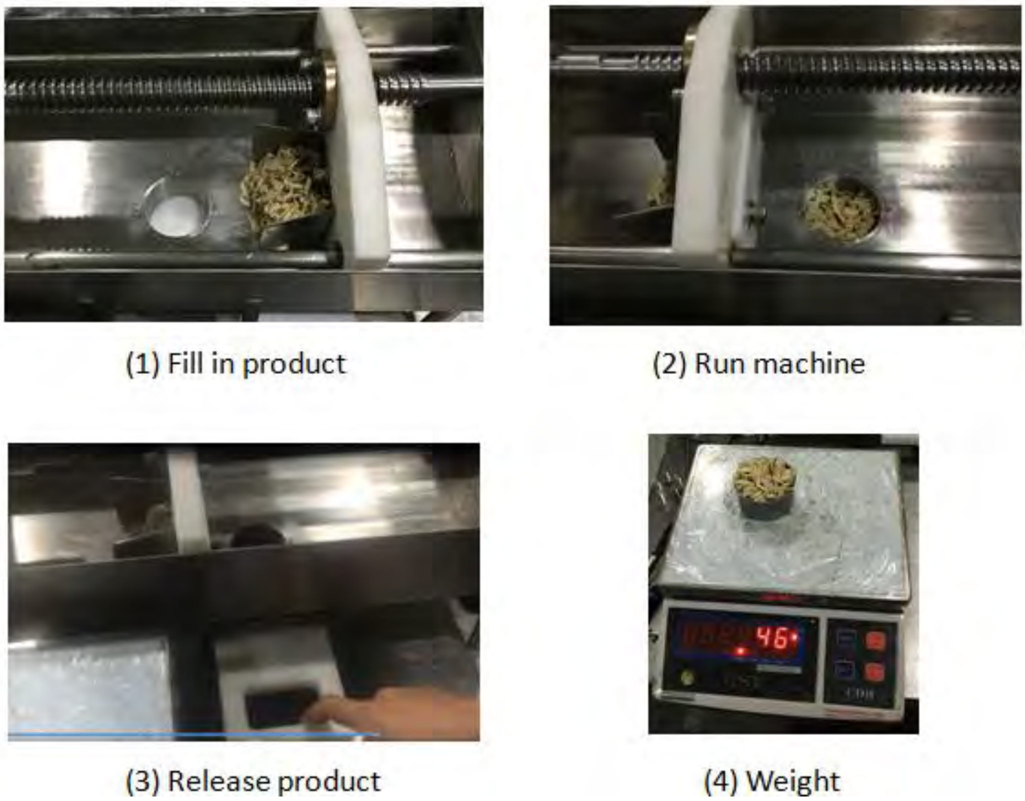


Figure 52: *Photos of Actual MVP in Operation*

In this part of the experiment, after the wiper runs past the measuring cup due to different settings of the wipers and machine speeds, the amount of loss per stroke of product also differs.

The definition of loss per stroke in this experiment is illustrated in Figure 53. The explanation of the mass balance of the product is, as follows,

[1] **m1:** Original amount of tuna flake put into the machine bowl

[2] **m2:** Amount of tuna flake in the measuring cup, this part of the product will be released into the can. The weights of the tuna in cans will be measured and recorded statistically to determine the accuracy and precision of the filling process. This part of the study is performed in Section 5.4.

[3] **m3:** Amount of the tuna flake that is pushed through to the other side of the bowl after the measuring cup.

[4] **m4:** Amount of left-over tuna flake which is one the floor of the bowl and the part that sticks on the wipers. This part of the tuna flake is considered as loss per stroke in the study. The example of m4 during machine operation is shown in Figure 54.

5.3.5.1 Thickness Effect on Flowability

The thickness of the 2 wipers is the factor of the filling machine that is assumed to be a contributor to loss amount of product during operation. In this experiment 10-15mm tuna flake with as-received condition from the tuna flake manufacturer is used to fill in the cans using MVP at the target weight of 45g.

The filling amount into the bowl is also controlled at 70g to ensure the consistency of the experiment. During the experiment the following factors are kept constant.

[1] **Speed** of the machine (S) is kept at 100mm/s

[2] **Angle** of the tip of the wipers (α) for both wipers is kept at 0°.

[3] **Clearance** of the wiper from the bowl bottom ($\delta 1$, $\delta 2$) is kept at 0mm, while the horizontal distance between the two wipers ($\delta 3$) is kept at 20mm.

The experiment is divided into 2 parts. In the first part, the effect in loss of front wiper is tested. The thickness of the front wiper is varied from 2, 5, 10 and 15 mm, while the rear is kept at 5mm. In the second part of the experiment, the thickness of the front wiper is kept at 5mm, while the rear is varied from 5, 10 and 15 mm.

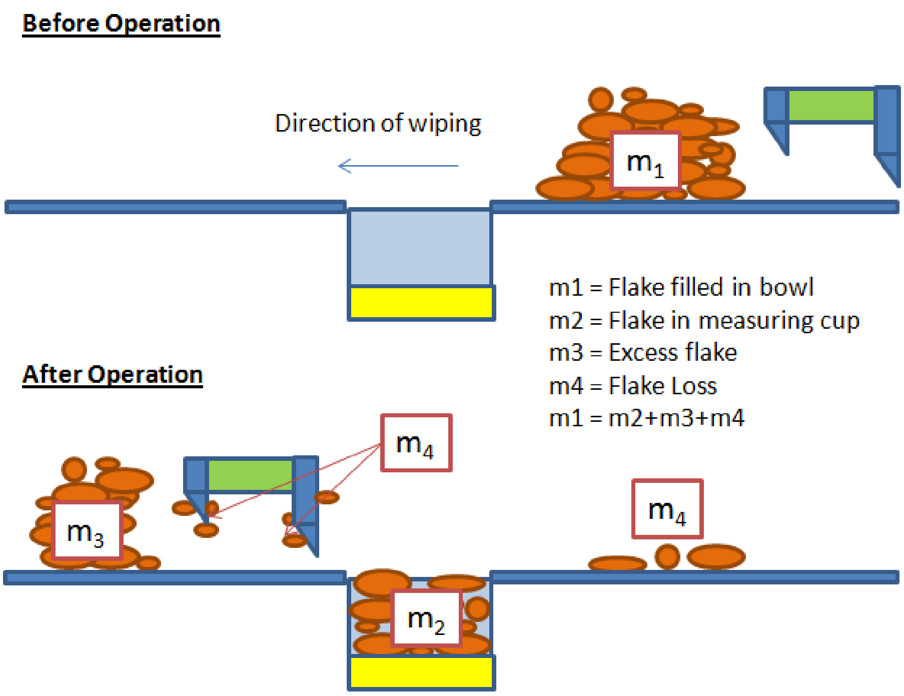


***Figure 53:** Material Balance Illustration for Determination of Loss per Stroke*

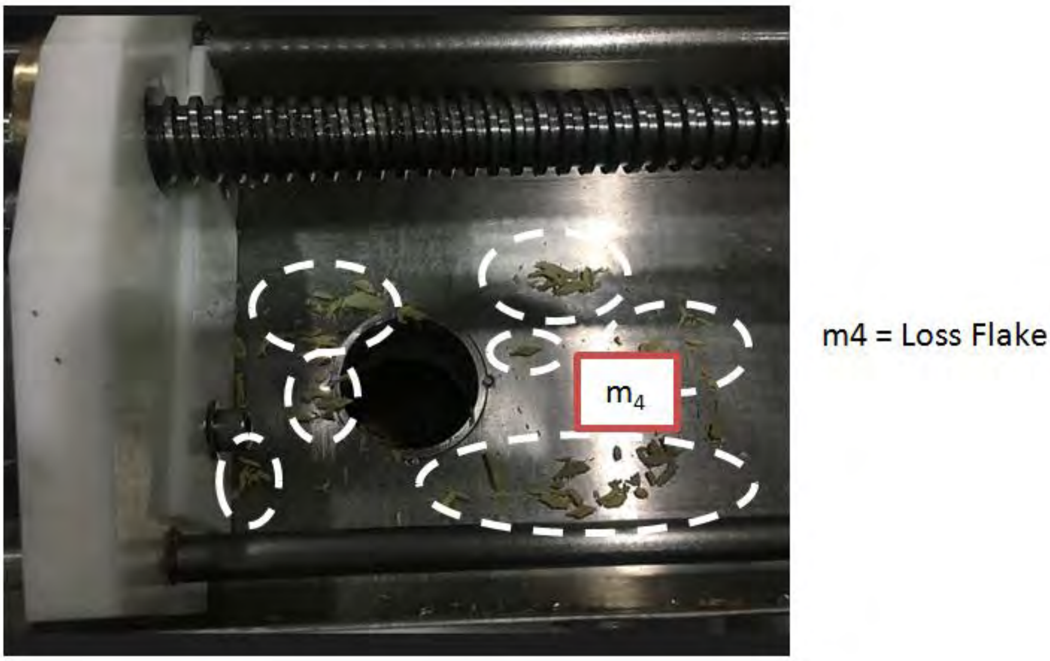


***Figure 54:** Loss in Process while machine in Operation (Shown in White Dotted Circle)*

The condition and result of the experiment is displayed in Table 25, whereas the trend of the experimental result is shown in Figure 55, omitting the result of 2mm thickness of front wiper (t1), it can be seen that the loss effect of both wipers are very similar, however the thickness of the rear wiper has a slightly stronger effect than the front with the slope of 0.12 and 0.15 for the front wiper and the rear respectively.

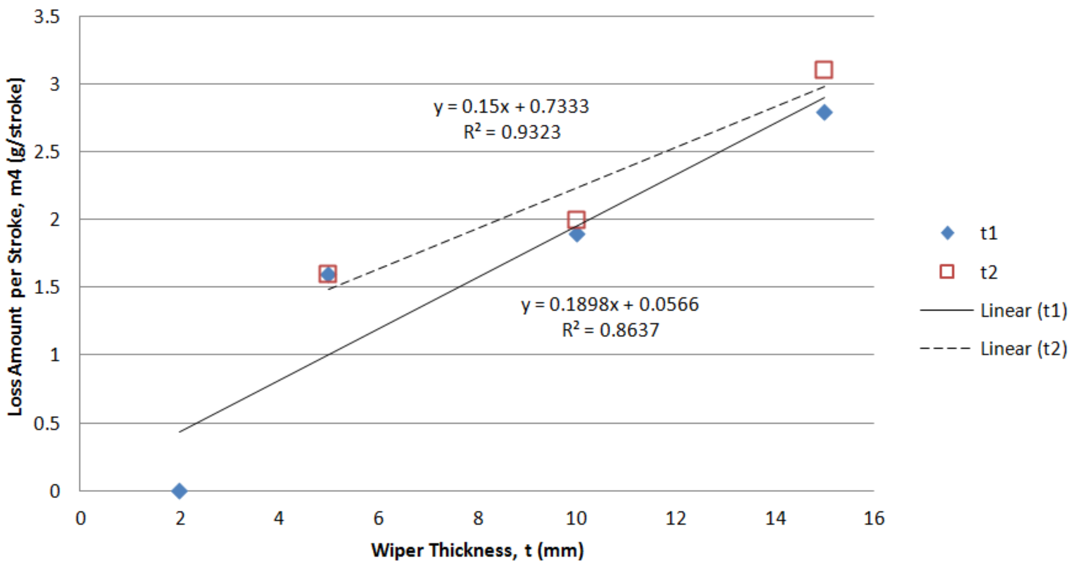


Figure 55: *Relationship between Wiper Thickness (t) and Loss per Stroke (m4)*

However, when t1 thickness of 2mm is considered, it can be concluded that the minimal thickness of wipers is the best condition of the machine setting; this is due to the minimal surface contact between the 3 elements which are wiper, tuna flake and bowl. Therefore 2mm thickness of t1 and 5mm of t2 will be the condition used for Process Accuracy and Precision Study in Section 5.4.

5.3.5.2 Clearance Effect on Flowability

The clearance between the bottom of the bowl and the tip of the wipers (δ) is another factor assumed to be a contributor to loss of product during machine operation. 10-15mm as received conditioned tuna flake is the filling product used in the experiment to be filled in can by MVP at the target weight of 45g.

The amount of the product filled in the bowl is kept constant at 70g to avoid inconsistency of the experiment. The following machine factors are kept constant throughout the experiment.

[1] **Speed** of the machine (S) is kept at 100mm/s

[2] **Angle** of the tip of the wipers (α) for both wipers is kept at 0°.

[3] **Thickness** of the wiper (t1, t2) is kept at 2mm and 5mm for the front and rear wiper respectively.

This experiment is separated into 3 parts. In the first part of the experiment the loss due to the front wiper is tested, the clearance between the bowl bottom and front wiper (δ1) is varied between 0, 2, 4, 6, 8 and 10mm, while the clearance for the rear wiper (δ2) is kept constant at 0mm. In the second part, δ1 is kept constant at 0mm whereas δ2 is varied between 0, 2, 4, 6, 8 and 10mm. The purposes of the first 2 parts are to study the effect of the clearance (δ) of each wiper.

In the third part of the experiment, in order to study whether the speed of the machine (S) also affect the loss amount when combined with clearance, δ1 and δ2 are both kept constant at 4mm while S is varied between 100, 150, 200, 250, 300 and 350 mm/s.

The condition and the result of the first 2 experiments are shown in Table 26, while those of the third are shown in Table 27. From the trend shown in Figure 56, it can be concluded that the loss amount per stoke due to δ1 has greater effect than that of δ2, as the slope of δ1 is steeper than that of δ2 with the value of 1.3114 for δ1 and 0.3929 for δ2. As the front wiper has greater surface contact with the product than the rear, it creates the majority of the loss amount (m4) in Figure 53, which then gets passed along to the rear wiper and due to the clearance among component parts of machine, m4 is bypassed through the rear wiper creating the residual of m4 at the end of the stroke.

In combination with machine speed, the clearance shows greater effect in loss amount with the increase of speed. The trend of the increasing loss amount with increasing speed is shown in Figure 57. This is also due to the clearance of the machine parts which vibrates more at higher speed.

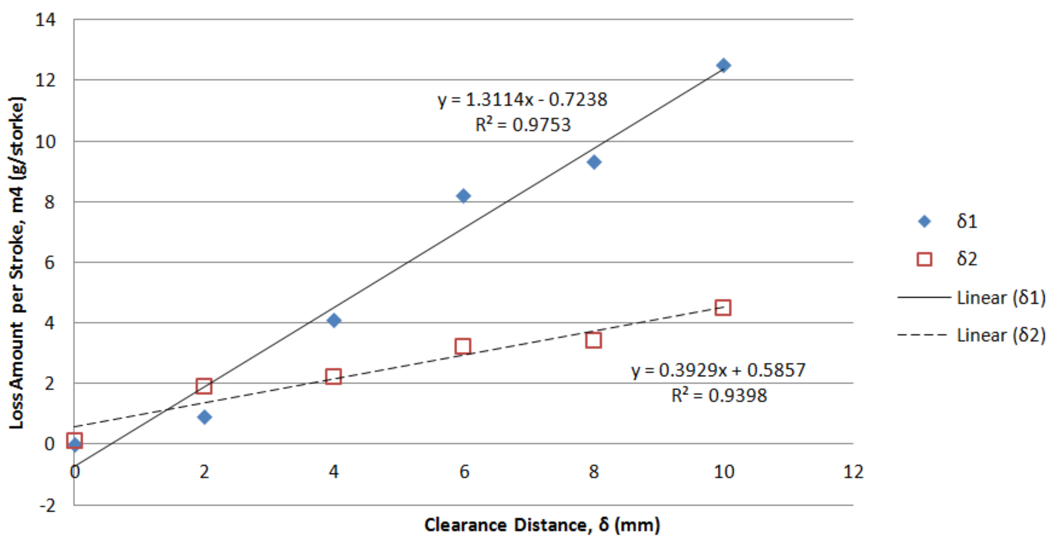


Figure 56: *Relationship between Wiper Clearance Distance (δ) and Loss per Stroke (m4)*

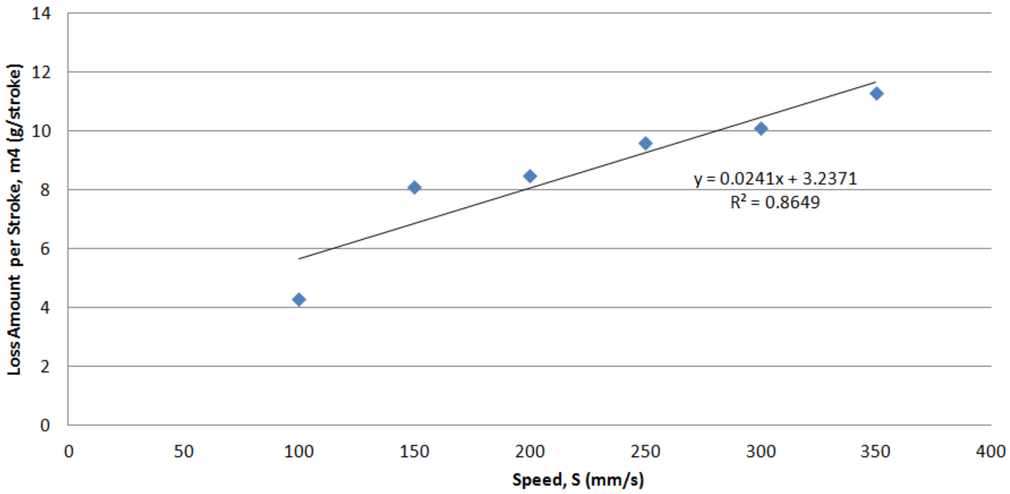


Figure 57: *Relationship between Speed (S) and Loss per Stroke (m4) at Wiper Clearance Distance (δ) of 4mm for both Wipers*

5.3.5.3 Tip Angle Effect on Flowability

The Tip Angle of the wipers (α) is also another factor which is assumed to create product loss during the operation of the machine. In this part of the experiment, 10-15mm as- received condition tuna flake is to be filled in cans using MVP at the 45g of target weight.

In order to keep the consistency of the experiment, 70g of tuna flake is filled into the bowl in front of front wiper throughout the whole experiment. Along with the filling product, the following factors are also kept constant during the experiment.

[1] **Speed** of the machine (S) is kept at 100mm/s

[2] **Clearance** of the wiper from the bowl bottom (δ1, δ2) is kept at 0mm, while the horizontal distance between the two wipers (δ3) is kept at 20mm.

[3] **Thickness** (t2) and **Angle** at tip ($\alpha 2$) of the rear wiper is kept at 5mm and 0° for thickness and tip angle respectively.

In this experiment only the tip angle of the front wiper ($\alpha 1$) is tested due to the effectiveness of the variable in the wiper clearance experiment which can be seen in Figure 56. The loss per stroke is found by varying the angle of the wiper tip ($\alpha 1$) of each thickness of the front wiper (t1). The variation of the tip angle is in the range of 0°, 15° and 45°, and the thickness of t1 is 2mm, 5mm, 10mm and 15mm.

The condition and the result of the experiment can be found in Table 28 for the wiper thickness of 2mm and 5mm, and Table 29 for the thickness of 10mm and 15mm. The experimental results are summarised in Figure 58, Aside from thickness of 2mm which generates minimal loss, the trends of the wiper angle (α) effectiveness in loss amount per stroke prevention are similar for all wiper thicknesses (t) where the increase in angle effectively decreases the amount of loss per stroke. The effectiveness of the loss prevention performance is especially apparent for the higher thickness, this can be seen from the slope of the linear equation in Figure 58, where the slope is -0.031 for the thickness of 15mm, while the slope is -0.0162 and -0.0167 for thickness of 5mm and 10mm respectively.

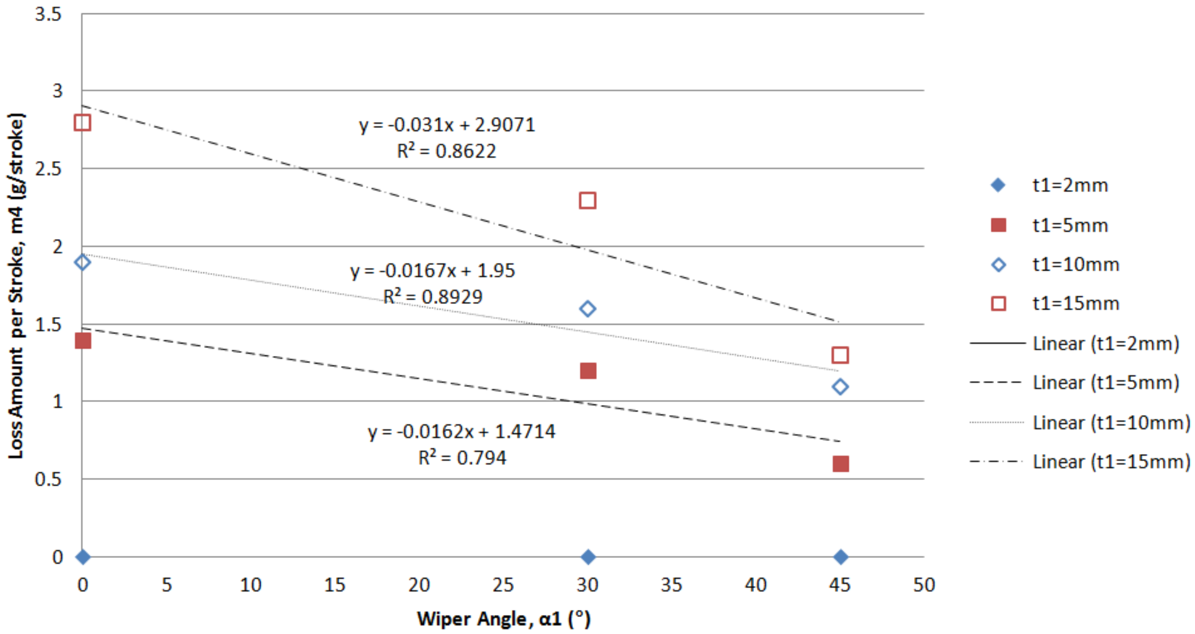


Figure 58: *Relationship between Wiper Angle of Front Wiper (α1) and Loss per Stroke*

The angle of the tip of the wipers can be used effectively to prevent the loss amount of product due to the direction of the angle which tends to wipe the product into the measuring cup, moreover, it also decreases the surface contact between the filling product, the wiper and the bottom of the bowl which is a contributor to loss of product per stroke during machine operation.

5.3.5.4 Wiper Dimensions Effect on Flowability Section Summary

In this section, the dimensions of wiper effects on flowablity of the tuna flake are studied through the measurement of loss of product during the machine operation. During the study, it has been found that the effectiveness is in the order of clearance (δ), thickness (t) and Tip Angle (α), respectively.

In the order of effectiveness, clearance at the front wiper ($\delta 1$) has greater influence on flowability than the rear ($\delta 2$) where minimal clearance results in better flowablity of product. However, the thickness of front wiper (t1) has greater influence than the rear (t2) where minimal thickness also results in better flow rate of product. In addition, the effect on flowablity of angle of the tip of the wiper (α) grows with the thickness of the wiper. From the observation of result, it can be concluded that all dimensions of wiper that lead to minimal surface contact between the wiper, filling product and bowl also lead to better flowability of product.

As a result, it is suggested that the clearance between the wiper and the bottom of the bowl (δ) and wiper thickness (t) should be kept minimum, however, the tip angle of the wiper (α) should be increased where higher thickness of wiper is required.

5.3.5.5 MVP Best Condition Verification Summary

In this section of the study, the MVP has been tested at various conditions in order to verify the best condition to optimise the time taken in the process accuracy and precision study. After the study, it has been found that the measuring cup of the machine is to be made of stainless steel rather than PTFE due to the unnoticeable disadvantage in flowablity of the material in this particular application and the strength advantage.

The internal process of moisture control in raw material preparation at customer factory may lead to 0.9g of filling inaccuracy which is slightly higher when compared to the difference in bulk density of product which leads to 0.4g of in accuracy. It has also been found that addition of liquid product prior to the filling process does not advance the flowability of the tuna flake, in fact, not only it has no effect in flowability, if not properly mixed throughout the product it would also cause inaccuracy in the fill process.

In the MVP adjustment study, it has been verified that minimum clearance of wiper and bowl (δ) and wiper thickness (t) is suggested, however, in the use of thick wiper, tip angle of wiper (α) can be used to minimise the loss amount of product.

Table 25: Experimental Result for Loss per Stroke (m4) using Wiper Thickness (t1, t2) as Variable

Factor Category	Variable	Unit	Collected Data						
			t1 as variable				t2 as variable		
Incoming Material	Feret Diameter (a)	mm	10-15mm as received (a = 12.9mm)						
	Elongation a/b	mm/mm	10-15mm as received (a/b = 3.3)						
Machine Set up	Target weight	g	45g						
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°						
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3= 20mm						
	Wiper thickness (t1) *	mm	2	5	10	15	t1 = 5mm		
	Wiper thickness (t2) *	mm	t2 = 5mm				5	10	15
	Speed (S)	mm/s	100mm/s						
	Filling Amount (m1)	g	70g						
Result	Loss Amount per Stroke (m4)	g/stroke	0	1.6	1.9	2.8	1.6	2	3.1

Remark: * as variables

Table 26: Experimental Result for Loss per Stroke (m4) using Wiper Clearance Distance (δ1, δ2) as Variable

Factor Category	Variable	Unit	Collected Data											
			δ1 as variable						δ2 as variable					
Incoming Material	Feret Diameter (a)	mm	10-15mm as received (a = 12.9mm)											
	Elongation a/b	mm/mm	10-15mm as received (a/b = 3.3)											
Machine Set up	Target weight	g	45g											
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°						α1 = 0°, α2 = 0°					
	Wiper Clearance (δ1) *	mm	0	2	4	6	8	10	δ1 = 0mm					
	Wiper Clearance (δ2) *	mm	δ2 = 0mm						0	2	4	6	8	10
	Wiper Clearance (δ3) *	mm	δ3 = 20mm											
	Wiper thickness (t)	mm	t1 = 2mm, t2 = 5mm											
	Speed (S)	mm/s	100mm/s											
	Filling Amount (m1)	g	70g											
Result	Loss Amount per Stroke (m4)	g	0	0.9	4.1	8.2	9.3	12.5	0.1	1.9	2.2	3.2	3.4	4.5

Remark: * as variables

Table 27: Experimental Result for Wiper Clearance (δ) and Loss per Stroke (m4) using Speed (S) as Variable

Factor Category	Variable	Unit	Collected Data					
			Machine Speed as variable					
Incoming Material	Feret Diameter (a)	mm	10-15mm as received (a = 12.9mm)					
	Elongation a/b	mm/mm	10-15mm as received (a/b = 3.3)					
Machine Set up	Target weight	g	45g					
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°					
	Wiper Clearance (δ1)	mm	δ1 = 4mm					
	Wiper Clearance (δ2)	mm	δ2 = 4mm					
	Wiper Clearance (δ3)	mm	δ3 = 20mm					
	Wiper thickness (t)	mm	t1 = 2mm, t2 = 5mm					
	Speed (S) *	mm/s	100	150	200	250	300	350
	Filling Amount (m1)	g	70g					
Result	Loss Amount per Stroke (m4)	g/stroke	4.3	8.1	8.5	9.6	10.1	11.3

Remark: δ1, δ2 fixed at 4mm

* as variables

Table 28: Experimental Result for Loss per Stroke (m4) using Tip Angle of Wiper of Front Wiper (α1) as Variable (t1 = 2mm and 5mm)

Factor Category	Variable	Unit	Collected Data					
			t1=2mm			t1=5mm		
Incoming Material	Feret Diameter (a)	mm	10-15mm as received (a = 12.9mm)					
	Elongation a/b	mm/mm	10-15mm as received (a/b = 3.3)					
Machine Set up	Target weight	g	45g					
	Wiper Angle (α1) *	°	0	30	45	0	30	45
	Wiper Angle (α2)	°	α2 = 0°					
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3= 20mm					
	Wiper thickness (t)	mm	t2 = 5mm					
	Speed (S)	mm/s	100mm/s					
	Filling Amount (m1)	g	70g					
Result	Loss Amount per Stroke (m4)	g/stroke	0	0	0	1.4	1.2	0.6

Remark: * as variables

Table 29: *Experimental Result for Loss per Stroke (m4) using Tip Angle of Wiper of Front Wiper ($\alpha 1$) as Variable (t1 = 10mm and 15mm)*

Factor Category	Variable	Unit	Collected Data					
			t1=10mm			t1=15mm		
Incoming Material	Feret Diameter (a)	mm	10-15mm as received (a = 12.9mm)					
	Elongation a/b	mm/mm	10-15mm as received (a/b = 3.3)					
Machine Set up	Target weight	g	45g					
	Wiper Angle (α1) *	°	0	30	45	0	30	45
	Wiper Angle (α2)	°	α2 = 0°					
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3= 20mm					
	Wiper thickness (t)	mm	t2 = 5mm					
	Speed	mm/s	100mm/s					
	Filling Amount	g	70g					
Result	Loss Amount per Stroke (m4)	g	1.9	1.6	1.1	2.8	2.3	1.3

Remark: * as variables

5.4 Process Accuracy and Precision Study of As-received Incoming Material

In the previous section, the best condition for the MVP setting and incoming material specification were verified. In this section, the accuracy and precision of the process using MVP as a tool for experiments will be further investigated in relations with machine speed adjustment and granular shape of the incoming materials.

In this part of the experiment, the effect of the speed of the machine on flowability of the filling material is studied. The MVP is used as a tool of study and is tested under the speed range of 100, 150, 200, 250, 300 and 350 using the 10-15mm and 20-30mm sized tuna flake received from the manufacturer without any sieving process or liquid addition process.

The 10-15mm sample is tested at fill weight of 28g, 35g and 45g which covers all the fill weight range desired by the canned tuna flake manufacturer, whereas the 20-30mm is test at the fill weight of 45g as the two samples are technically similar in granular size.

5.4.1 Precision Analysis

Precision of measurement refers to the closeness between measurement results achieved under a specified condition (ISO, 1998). According to Chen et al. (2003), Cp and Cpk are one of the most common process capability identifier. In general, process capability is studied using Cp and Cpk in the range of 1 to 2, where 1 is equivalent to 3 sigma and 2 is equivalent to 6 sigma (Mottonen et al., 2008).

The precision of the process at different speed of machine is evaluated using the results of the fill weight at the repeatability rate of 100 times, the data is then analysed using Cp, Cpk and CV.

(1) Cp Analysis

Figure 59 shows the result of the process capability at various speed of the machine using Cp. From the graph it can be seen that the Cp for lower filling weights are greater than that of higher fill weights. This is due to the fact that the tuna flake manufacturer sets the same ±3g tolerance for all fill weights. When the tolerance is viewed in percentage of the target fill weight, it can be seen in Table 30 that there is a major difference between the tolerance percentage of 28g and 45g target fill weight which are 21.4% and 13.3% respectively.

The similarity in fill weight precision can be observed from the result of the 10-15mm and 20-30mm at the same target fill weight of 45g. This is due to the similarity in shape of the two samples which although are categorised as different sizes by the manufacturer, they are practically the same according to the observation result in Section 5.2.1.

From the overall result of Cp shown in Figure 59, it can be concluded that without any grain size screening process, the received sample of tuna flake from the manufacturer cannot be filled at a general quality of process precision which is standardised at Cp of 1.

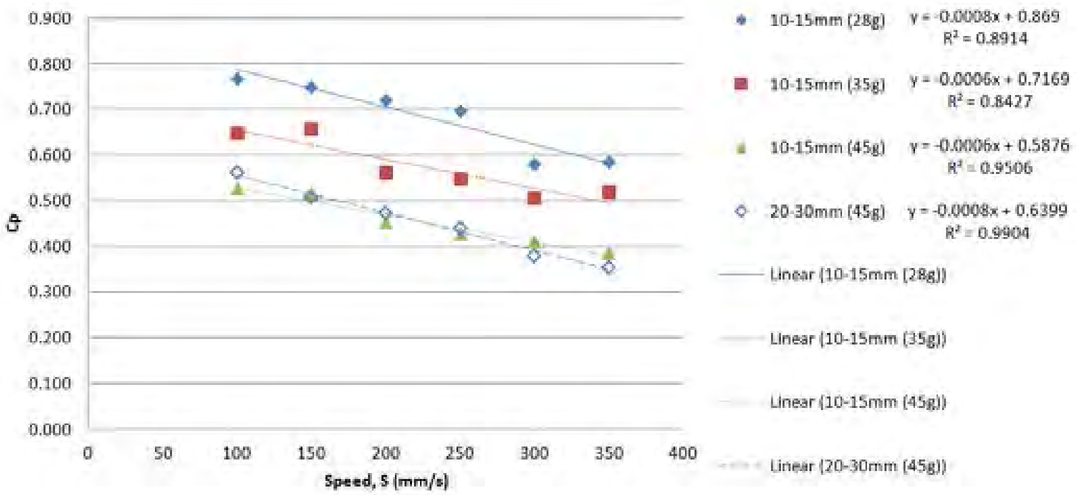


Figure 59: Process Capability Analysis by Cp at Various Speed using as-received incoming material

Table 30: Fill Weight and Tolerance Percentage

Target Fill weight (g)	Tolerance (g)	Tolerance (%)
28	±3	21.4%
35	±3	17.1%
45	±3	13.3%

(2) Cpk Analysis

Similar to Cp, the result of Cpk is plotted in the same manner at various machine speeds and target fill weights in Figure 60. From the graph, it can be seen that only for the speed of 100mm/s and 200mm/s, the results of Cpk appear greater than one.

At the higher speeds the results are negative which is not sensible, this due to the fact that Cpk would only be valid in that case that the outputs are normally distributed with symmetrical variation and the target of the result is at the centre of the distribution of result (Deleryd, 1998). Therefore the precision of the fill weight result against machine speed has to be viewed using other methods.

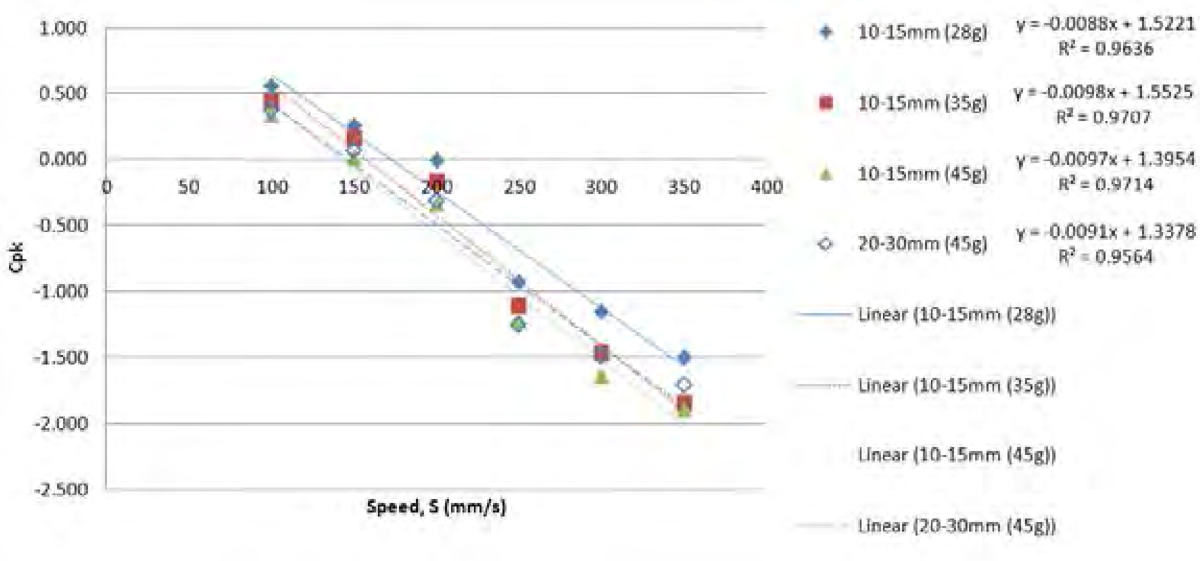


Figure 60: Process Capability Analysis by Cpk at Various Speed using as-received incoming material

(3) CV Analysis

Coefficient of Variance (CV) is another numerical index used to analyse the precision of the process in this study. Figure 61 shows the relationship between the CV and machine speed at various filling conditions using both 10-15mm and 20-30mm product samples. The 10-15mm sample is filled at the weight of 28g, 35g and 45g, while the 20-30mm sample is filled at the weight of 45g only.

From the result shown in Figure 61, the value of CV grows larger with increase in machine speed for all filling conditions, indicating greater fill weight variation at the higher speed.

(4) Precision Measurement Summary for As-received Incoming Material

The precision of the filling process is analysed using 3 different process capability indicators which are Cp, Cpk and CV. From the result of the analysis, it can be concluded that tuna flake samples with the original condition received from the manufacturer are not capable of being filled within the ±3g tolerance required by the canned tuna flake manufacturer, as the results of Cp for all filling conditions are less than 1. The highest Cp of 0.768 is achieved when the 10-15mm sample is filled at target weight of 28g with the machine speed of 100mm/s (Table 31).

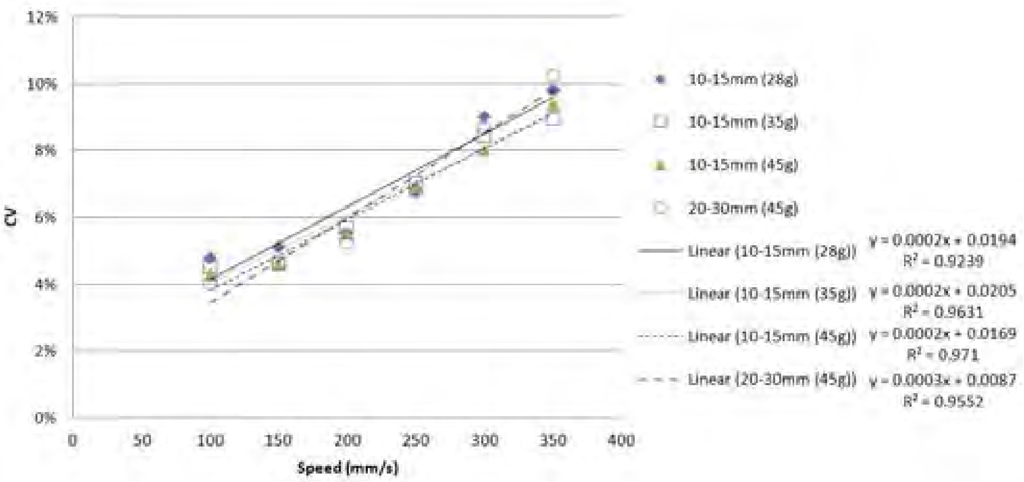


Figure 61: *Process Capability Analysis by CV at Various Speed using as-received incoming material*

Another observation is that the precision becomes lower with respect to the increase in speed according to the result of Cp (Figure 59) and CV (Figure 61). This is true for both 10-15mm and 20-30mm sized tuna flake. Moreover, precision of process is worse for the case of higher target fill weight, due to the same tolerance allowance of ±3g for all the fill weight. It is suggested that the tolerance should be set in percentage of target weight rather than the current fixed tolerance.

Table 31: *Experimental Result of 10-15mm Sample at 28g Target Fill Weight at Various Speed*

Factor Category	Variable	Unit	Collected Data					
Incoming Material	a	mm	10-15mm as receieved (a = 12.9mm)					
	a/b	mm/mm	10-15 mm as received (a/b = 3.3)					
	Bulk Density (ρ_b)	g/cm3	0.445g/cm3					
Machine Set up	Measuring Cup Height (H)	cm	4.2mm					
	Measuring Cup Volume (V)	cm3	92.7cm3					
	Target Weight (W)	g	28g±3g					
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°					
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3 = 20mm					
	Wiper Thickness (t)	mm	t1 = 2mm, t2 = 5mm					
	Speed (S)	mm/s	100	150	200	250	300	350
Result	$\bar{x}$ ± SD	g	27.2±1.303	26.0±1.333	25.0±1.389	21.0±1.432	19.1±1.722	17.4±1.708
	CV	%	5%	5%	6%	7%	9%	10%
	Cp	-	0.768	0.750	0.720	0.698	0.581	0.586
	CpK	-	0.563	0.255	-0.007	-0.924	-1.150	-1.493
	Bias	%	2.9%	7.1%	10.7%	25.0%	31.8%	37.9%
	Void (ε)	%	34.1%	37.0%	39.4%	49.1%	53.7%	57.8%
	Specific Bulk Density ($\rho_{b'}$)	g/cm3	0.293	0.280	0.270	0.227	0.206	0.188
	Substance Density (ρs)	g/cm3	1.255					
	Relative Density Pecentage	%	23%	22%	21%	18%	16%	15%

Table 32: *Experimental Result of 10-15mm Sample at 35g Target Fill Weight at Various Speed*

Factor Category	Variable	Unit	Collected Data					
Incoming Material	a	mm	10-15mm as receieved (a = 12.9mm)					
	a/b	mm/mm	10-15 mm as received (a/b = 3.3)					
	Bulk Density (ρ_b)	g/cm3	0.445g/cm3					
Machine Set up	Measuring Cup Height (H)	cm	5.2mm					
	Measuring Cup Volume (V)	cm3	114.7cm3					
	Target Weight (W)	g	35g±3g					
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°					
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3 = 20mm					
	Wiper Thickness (t)	mm	t1 = 2mm, t2 = 5mm					
	Speed (S)	mm/s	100	150	200	250	300	350
Result	$\bar{x}$ ± SD	g	34.0±1.540	32.8±1.520	31.1±1.779	26.0±1.828	23.3±1.975	21.4±1.921
	CV	%	5%	5%	6%	7%	8%	9%
	Cp	-	0.649	0.658	0.562	0.547	0.506	0.521
	CpK	-	0.439	0.164	-0.172	-1.103	-1.463	-1.845
	Bias	%	2.9%	6.3%	11.1%	25.7%	33.4%	38.9%
	Void (ε)	%	33.4%	35.7%	39.1%	49.1%	54.4%	58.1%
	Specific Bulk Density ($\rho_{b'}$)	g/cm3	0.296	0.286	0.271	0.227	0.203	0.187
	Substance Density (ρs)	g/cm3	1.255					
	Relative Density Pecentage	%	24%	23%	22%	18%	16%	15%

Table 33: *Experimental Result of 10-15mm Sample at 45g Target Fill Weight at Various Speed*

Factor Category	Variable	Unit	Collected Data					
Incoming Material	a	mm	10-15mm as receieved (a = 12.9mm)					
	a/b	mm/mm	10-15 mm as received (a/b = 3.3)					
	Bulk Density (ρ_b)	g/cm3	0.445g/cm3					
Machine Set up	Measuring Cup Height (H)	cm	6.7mm					
	Measuring Cup Volume (V)	cm3	147.8cm3					
	Target Weight (W)	g	45g±3g					
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°					
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3 = 20mm					
	Wiper Thickness (t)	mm	t1 = 2mm, t2 = 5mm					
	Speed (S)	mm/s	100	150	200	250	300	350
Result	$\bar{x}$ ± SD	g	43.9±1.901	42.1±1.928	39.8±2.203	33.4±2.328	30.1±2.425	27.4±2.578
	CV	%	4%	5%	6%	7%	8%	9%
	Cp	-	0.526	0.519	0.454	0.430	0.412	0.388
	CpK	-	0.340	0.016	-0.334	-1.226	-1.630	-1.889
	Bias	%	2.4%	6.4%	11.6%	25.8%	33.1%	39.1%
	Void (ε)	%	33.3%	36.0%	39.5%	49.2%	54.2%	58.3%
	Specific Bulk Density ($\rho_{b'}$)	g/cm3	0.297	0.285	0.269	0.226	0.204	0.185
	Substance Density (ρs)	g/cm3	1.255					
	Relative Density Pecentage	%	24%	23%	21%	18%	16%	15%

Table 34: *Experimental Result of 20-30mm Sample at 45g Target Fill Weight at Various Speed*

Factor Category	Variable	Unit	Collected Data					
Incoming Material	a	mm	10-15mm as receieved (a = 12.9mm)					
	a/b	mm/mm	10-15 mm as received (a/b = 3.3)					
	Bulk Density (ρ_b)	g/cm3	0.445g/cm3					
Machine Set up	Measuring Cup Height (H)	cm	6.7mm					
	Measuring Cup Volume (V)	cm3	147.8cm3					
	Target Weight (W)	g	45g±3g					
	Wiper Angle (α)	°	$\alpha 1 = 0°$, $\alpha 2 = 0°$					
	Wiper Clearance (δ)	mm	$\delta 1$ = 0mm, $\delta 2$ = 0mm, $\delta 3$ = 20mm					
	Wiper Thickness (t)	mm	t1 = 2mm, t2 = 5mm					
	Speed (S)	mm/s	100	150	200	250	300	350
Result	$\bar{x} \pm SD$	g	43.9±1.901	42.1±1.928	39.8±2.203	33.4±2.328	30.1±2.425	27.4±2.578
	CV	%	4%	5%	6%	7%	8%	9%
	Cp	-	0.526	0.519	0.454	0.430	0.412	0.388
	CpK	-	0.340	0.016	-0.334	-1.226	-1.630	-1.889
	Bias	%	2.4%	6.4%	11.6%	25.8%	33.1%	39.1%
	Void (ε)	%	33.3%	36.0%	39.5%	49.2%	54.2%	58.3%
	Specific Bulk Density ($\rho_{b'}$)	g/cm3	0.297	0.285	0.269	0.226	0.204	0.185
	Substance Density (ρ_s)	g/cm3	1.255					
	Relative Density Pecentage	%	24%	23%	21%	18%	16%	15%

5.4.2 Accuracy Analysis

According to ISO (1998), accuracy is the closeness between the result of a measurement obtained using a tool and the actual measurement. However, the accuracy in the study refers to the difference between the mean of the target and the resulted fill weight. The accuracy of the filling process is analysed using bias percentage. Moreover, as the bias plays a significant role in the testing, it is then further analysed in terms of void percentage and calculated bulk density which can be used to estimate the volume of the measuring cup required at various speed of machine.

(1) Bias Percentage

The bias calculation in this study is related to difference between target fill weight and the average of the obtained weight, the formula used for the calculation is shown in Equation 5-1.

$$\%Bias = \frac{|Target\ Weight - \bar{x}|}{Target\ Weight} \times 100\% \tag{5-1}$$

The result of the bias is shown in histograms in Figure 62, Figure 63, Figure 64 and Figure 65. From the result, it can be observed that the average measurement of the achieved weight reduces as the speed of the machine increases. This indicates that the void of the product in the measuring cup increases as the speed increases.

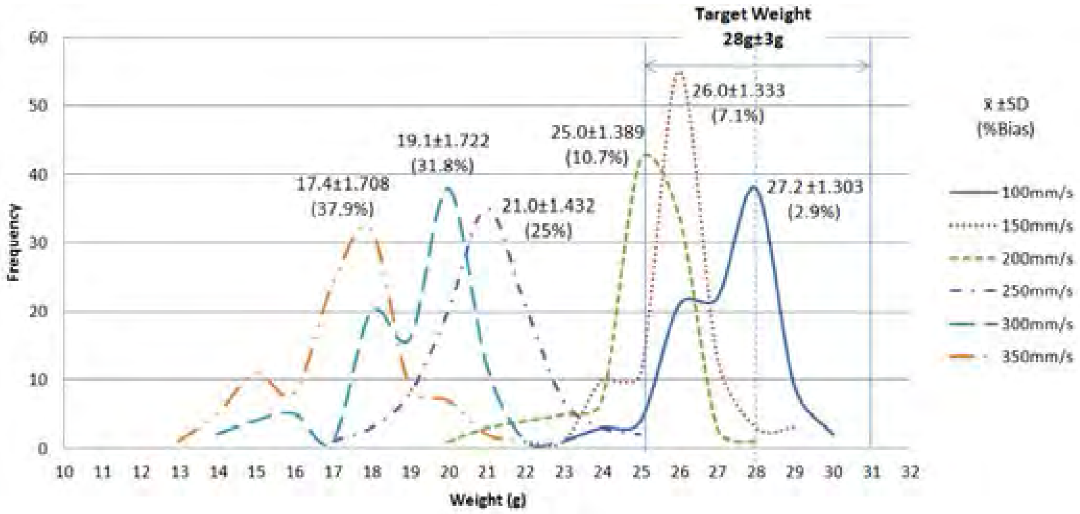


Figure 62: Histogram of 10-15mm Seized Tuna Flake filled at 28g of Target Weight at Various Speeds showing %Bias

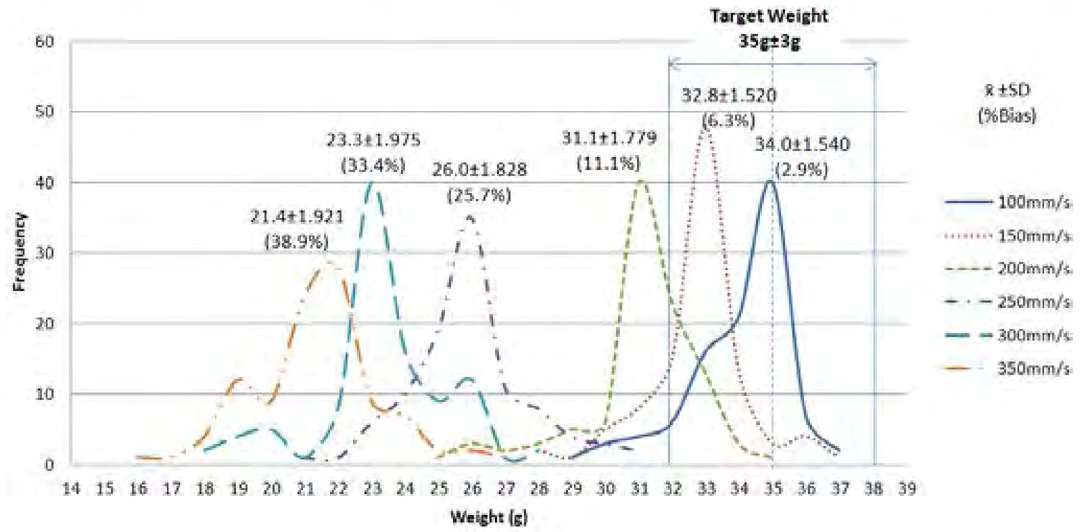


Figure 63: Histogram of 10-15mm Sized Tuna Flake filled at 35g of Target Weight at Various Speeds showing %Bias

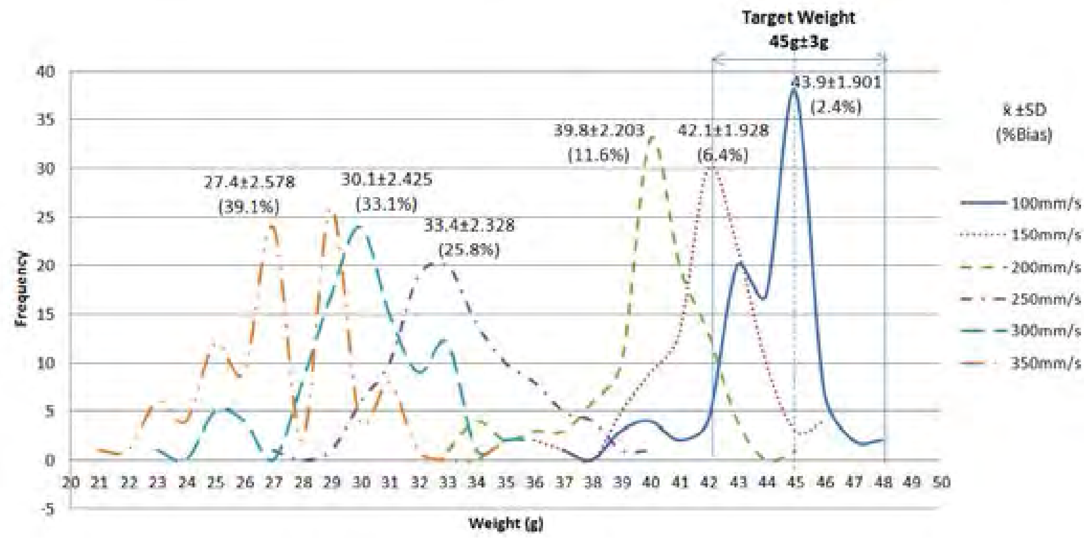


Figure 64: Histogram of 10-15mm Sized Tuna Flake filled at 45g of Target Weight at Various Speeds showing %Bias

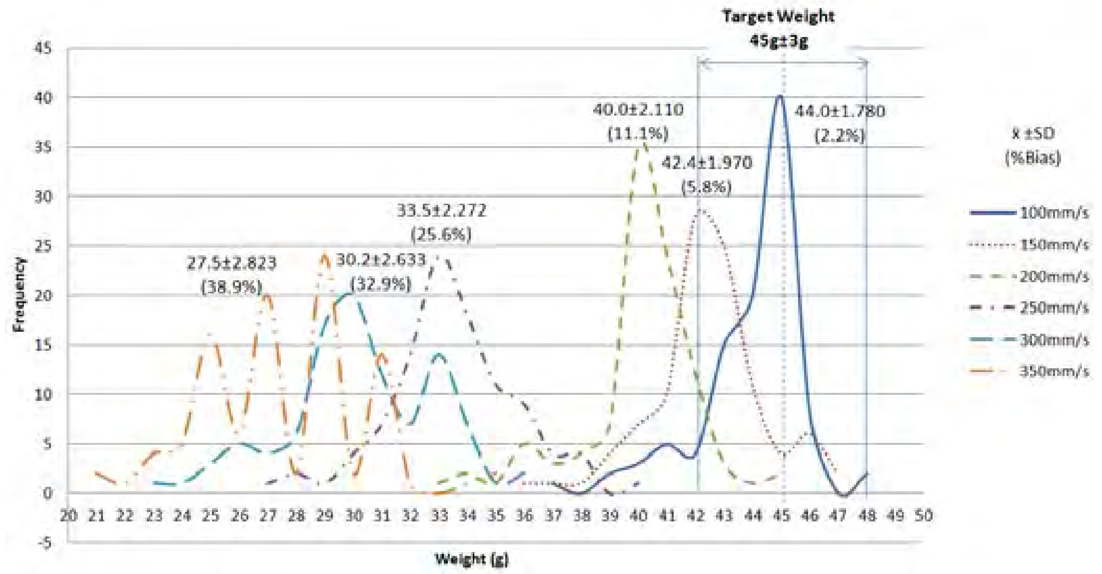


***Figure 65:** Histogram of 20-30mm Sized Tuna Flake filled at 45g of Target Weight at Various Speeds showing %Bias*

(2) Void Analysis

Since void plays in important role in the experiment, it should be analysed and considered closely for the future use of information gained. It can be noticed in Figure 5-26 that the percentage of bias reaches as high a 39.1% due to the inefficient of flow of material which causes an immense amount of void.

Unlike the definition of void by Nedderman (1992) and Rahman (1995) which calculates void using the substance density against apparent density or bulk density, the void in this study is calculated based on the bulk density of the tuna flake and the density of the tuna being wiped in the measuring cup during the machine run. The formula for the calculation of void (ε) is shown in Equation 5-2.

$$\varepsilon = \frac{(\rho_b \cdot V) - \bar{x}}{(\rho_b \cdot V)} \times 100\% \qquad (5\text{-}2)$$

Where ρ_b refers to the bulk density of the incoming material, V refers to the volume of the measuring cup and $\bar{x}$ refers to the average of the achieved weight in each experimental condition.

Once void is calculated, it is worthwhile to further determine for actual density of the tuna flake in the measuring cup, as this information can be used to estimate the height of the adjustable measuring cup to attain the desired weight of material during the filling process.

The formula used for the calculation of the specific bulk density (ρ_b') of the tuna flake at various speed is shown in Equation 5-3.

$$\rho_b' = \rho_b \cdot (1 - \varepsilon) \qquad (5\text{-}3)$$

Where ρ_b' refers to the specific bulk density at a given speed and ε refers to void in the measuring cup.

The result of the relationship between specific bulk density (ρ_b') and the machine speed (S) at various condition of filling is shown in Figure 66. The result for all filling conditions shows very similar trend of reduction in specific bulk density, and can be concluded that the estimate density (ρ_b') at a certain speed can be given as 0.3511-0.0005S.

Moreover, the result can also be summarised using relative density percentage (%Rel) of specific bulk density (ρ_b') against the substance density of tuna meat (ρs). The value of substance density used is 1.255 g/cm3 which is processed using air-dried method.

The result of the summary is shown in Figure 67. It can be seen that the relative density (ρ_b') is relatively low for lower speed and extremely low for higher speed. (%Rel = below 15% at S = 350 mm/s)

(3) Accuracy Measurement Summary

From the result of the experiments, it can be concluded that as the speed of the machine increases, the achieved weight reduces with increase in bias percentage. This is true for both sizes of granules and for all fill weight tested.

With respect to the weight reduction, the void (ε) and specific bulk density (ρ_b') in the measuring cup at various machine speeds have been analysed and identified in order to simplify and speed up the machine setting process.

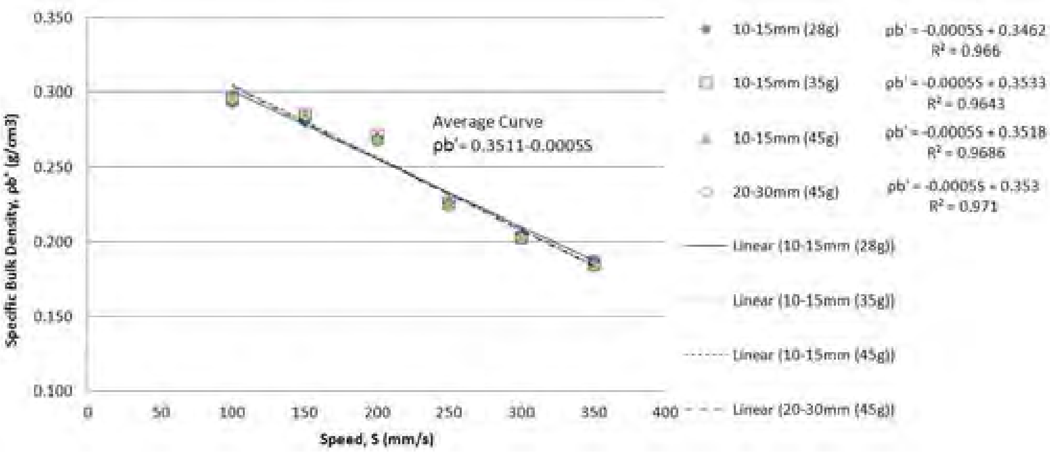


Figure 66: *Specific Bulk Density of 10-15mm As-received Tuna Flake at Various Speed of the Machine*

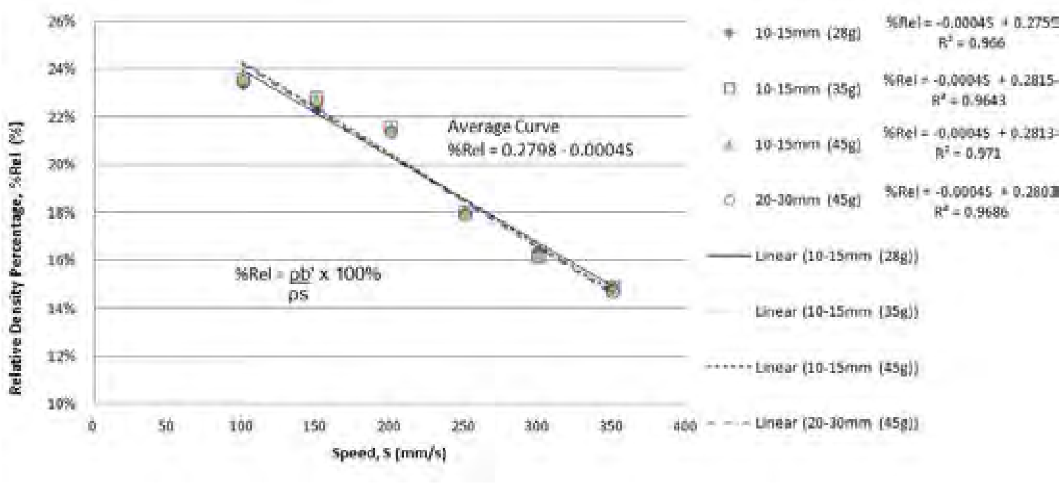


Figure 67: *Relative Density Percentage of 10-15mm As-received Tuna Flake at Various Speed of the Machine*

5.4.3 Summary

In this section, it can be concluded that lower speed of machine enhancement both precision and accuracy of the fill process. Accuracy of the filling can also be summarised through the lens of Bias and Void (ε) in the material. As a result, an equation was created in order to be used as a guide for machine cup height setting for various running speed.

5.5 Process Accuracy and Precision Study of As-sieved Incoming Material

In the preliminary study section of effect of filling material shape on weight control (Section 3.5), with the usage of various sizes and kinds of beans it has been identified that the shapes of the granules also have an effect on the achieved fill weight accuracy.

In this section of the study, the relationship between the shape of the tuna flake samples and the fill weight accuracy will be studied, analysed and identified.

After the tuna flakes are divided into various sizes using sieves, they are tested on the MVP at fixed speed of 100mm/s for 100 times of repeatability for each condition. The condition and results of the experiments are summarised in Table 68. The results of the experiments are analysed in the aspect of precision and accuracy.

5.5.1 Precision

The precision of the process is analysed similarly to the speed variation experiments using Cp, Cpk and CV.

(1) Cp and Cpk Analysis

Figure 67 shows the relationship between the process capability (Cp and Cpk) and the size of granules (Feret Diamter, a). Without the result of the samples (10-15mm and 20-30mm) as received, the trends of process capability at various conditions of sieved granules are plotted. The tuna flakes were divided into 5 sizes of Feret Diameter (a), which are filled at the target weight of 45g using the machine speed of 100mm/s. The condition of this experiment is shown in Table 35. From Figure 67, it can be seen that as the size of the grain grows larger the process capability and precision worsen correspondingly. Setting Cp at 1 as a target, at the fill weight of 45g only the grains with Feret Diameter (a) of 5mm and 7mm achieve the process capability target. However, when setting the same target for Cpk only the sample with diameter of 5mm achieves the process capability.

The relationship between the process capability and Elongation (a/b) of incoming material is shown in Figure 68. The result shows very similar trend to the Feret Diameter's, where larger elongations results in process incapability. Moreover, only the tuna flake with a/b of 2.5 and below are able to achieve the Cp target, and 2.35 for the Cpk target.

(2) CV Analysis

The result of the relationship between Feret diameter (a) and CV is shown in Figure 69, whereas the Elongation is shown in Figure 70. The result of both relationships are very similar where the larger value of Feret Diameter (a) and Elongation a/b leads to lower process precision i.e. lower CV.

(3) Precision Measurement Summary

From the analysis result of precision measurement based on the shape of the material, it can be concluded that if the incoming materials come in controlled sizes, based on the experiments the following assumptions can be made.

- Feret Diameter (a)

  Based on the analysis of Feret Diameter, 3 possible conclusions can be made.

  (1) Cp = Cpk = 2.125, a = 3.58mm: According to the plotted curves, at the point where the two curves intersects Cp and Cpk equals 2.125 while Feret Diameter equals 2.125.

  (2) Cp = 1, Cpk = 0.790, a = 7.90mm: In the case where Cp equals 1, Feret diameter of 7.90mm is obtained, while Cpk at the point equals 0.790.

  (3) Cpk = 1, Cp = 1.197, a = 6.54mm: On the other hand when Cpk equals 1, Feret diameter of 6.54 is obtained, while Cp of 1.197 is achieved

  Based upon the above 3 possible conclusions, the third is the most suitable for standard setting as both the Cp and Cpk are above 1. As a result, Feret diameter of 6.5mm and below should be set as a standard diameter in order to obtain precision in fill weight.

- Elongation a/b

  (1) Cp = Cpk, a/b = N/A: Based on the equations generated from the experimental data, the intersection of Cp and Cpk for Elongation a/b cannot be found.

(2) Cp = 1, Cpk = 0.787, a/b = 2.60: Setting Cp = 1 as a target for precision of the process, a/b is to be 2.60 or below, while at this point Cpk equals 0.787.

(3) Cpk = 1, Cp = 1.203, a/b = 2.35: In contrast, setting Cpk =1 as a target, a/b is to be 2.35 mm or below. At this point, Cp equals 1.203.

Similar to Feret diameter, Cpk =1 should be used as a precision setting target, as the Cp at this point is also above 1. In conclusion, a/b should be 2.3 and below.

From the above discussion, the accuracy of the fill weight can be controlled within the manufacturer tolerance of ±3g and controlled within the Cp and Cpk value of 1 and above, when Feret Diameter equals 6.5mm and below and Elongation equals 2.3 and below, which satisfies the 3 sigma precision level.

Moreover, from the results in Figure 5-28 and Figure 5-29, the overall trends of the analyses for Cp, Cpk and CV are the same where the larger Feret Diameters (a) and Elongations (a/b) leads to greater process uncontrollability, resulting in lower Cp and Cpk, and larger CV.

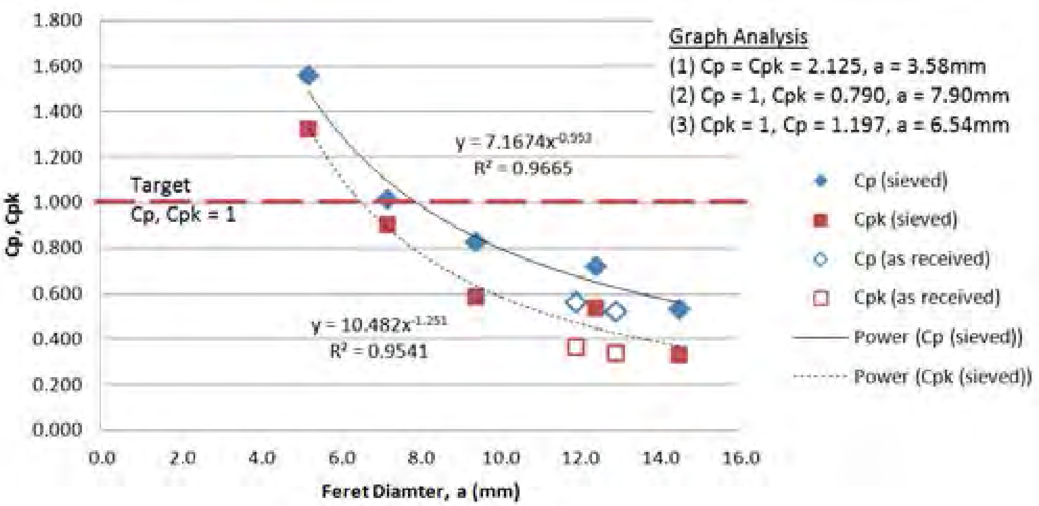


Figure 68: *Process Capability Analysis at Various Feret Diameters using Cp and Cpk*

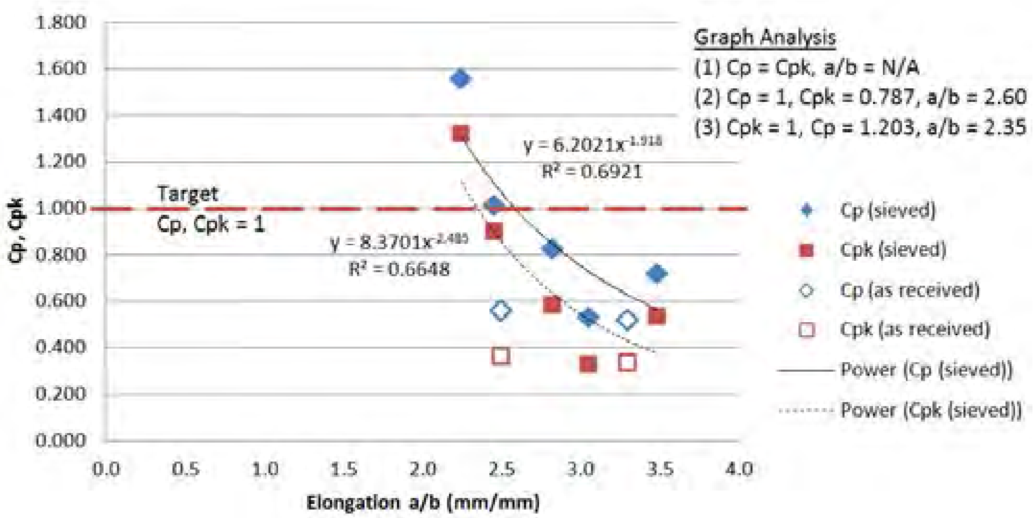


Figure 69: *Process Capability Analysis at Various Elongations using Cp and Cpk*

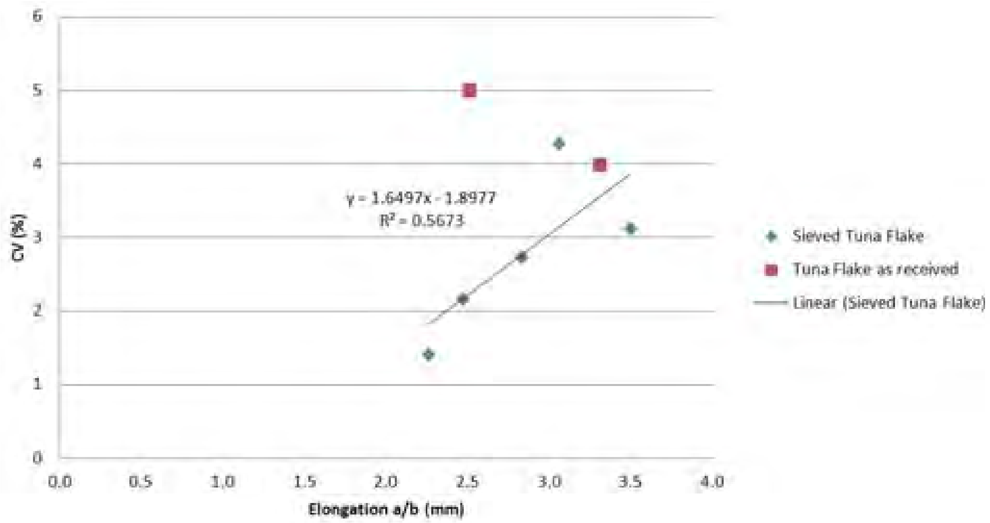


Figure 70: *Process Capability Analysis at Various Feret Diameters using Coefficient of Variance (CV)*

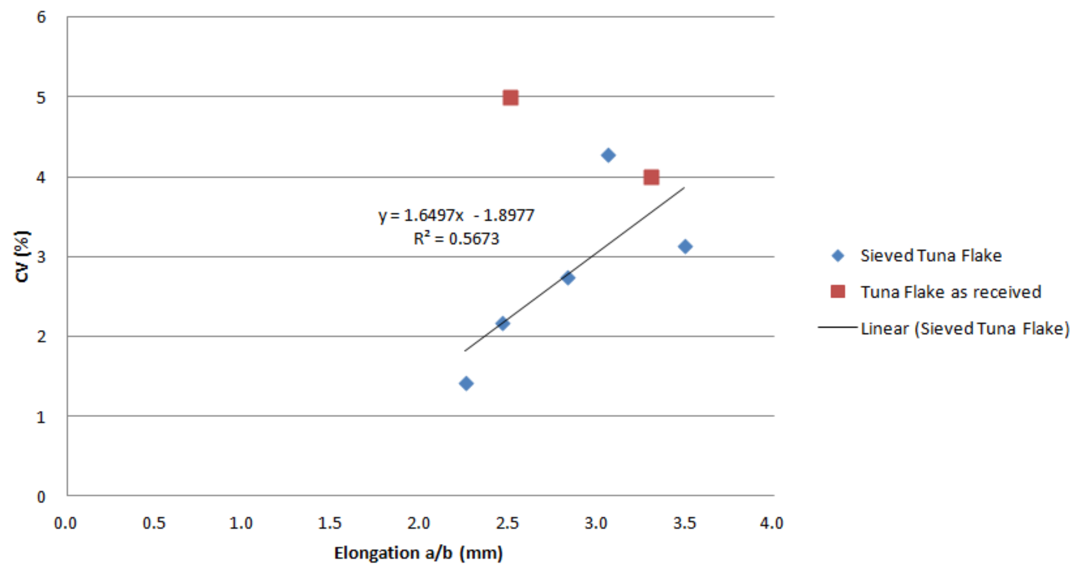


Figure 71: *Process Capability Analysis at Various Elongations using Coefficient of Variance (CV)*

5.5.2 Accuracy Analysis

The accuracy of the filling at various conditions of shapes of incoming material is summarised using bias percentage. Figure 71 shows the histogram of the results of the fill weight of tuna flake at various sizes of Feret Diameter (a) achieved by the machine running at speed of 100mm/s. The bias is written in bracket next to average achieved weight ($\bar{x}$) and standard devisation (SD) of each the incoming material condition in the diagram.

Although the precision of the process decreases along with the increase of grain size, the bias is kept at a very similar and constant level. This clearly illustrates and confirms the conclusion in the previous section (Section 5.4.1) that the speed of the machine is the source of void (ε) in the material and hence bias.

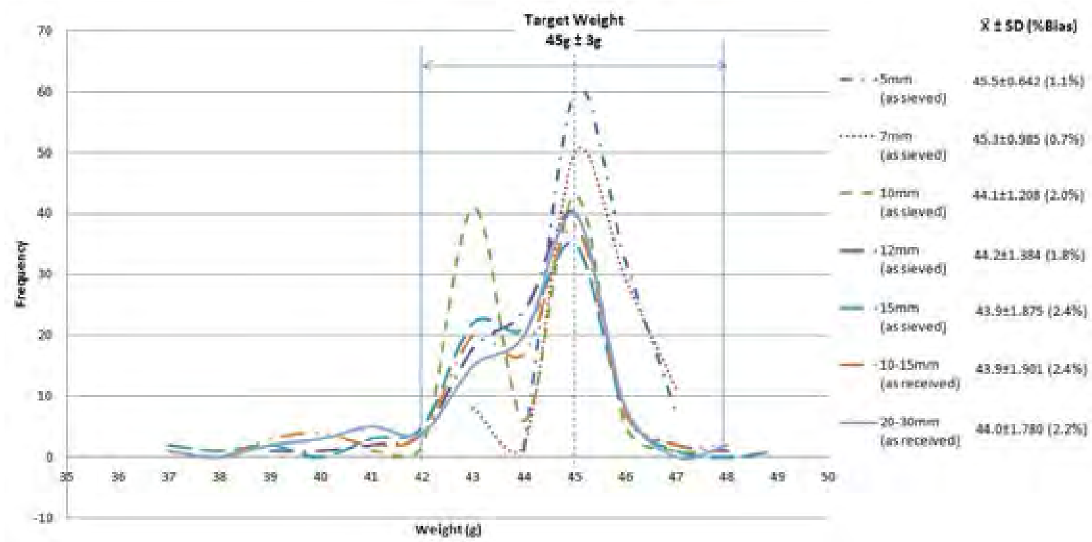


Figure 72: *Histogram of Tuna Flake sized by sieving process and unprocessed condition filled at 45g of Target Weight at Constant speed (S) of 100mm/s*

5.5.3 Summary

In this section of the study, it has been shown that the incoming material from the tuna flake manufacturer cannot be filled to satisfy the tolerance ±3g standardised by the manufacturer. This conclusion is supported by the value of Cp and Cpk achieved which are lower than 1 which signifies 3 sigma precision standards.

Table 35: *Experimental Result of Fill weight at Various Grain Sizes*

Factor Category	Variable	Unit	Sieved Tuna Flake					Tuna Flake as received	
			5mm	7mm	10mm	12mm	15mm	10-15mm	20-30mm
Incoming Material	a	mm	5.2	7.2	9.4	12.4	14.5	12.9	11.9
	a/b	mm/mm	2.3	2.5	2.8	3.5	3.1	3.3	2.5
Machine Set up	Target Weight (W)	g	45.0g						
	Wiper Angle (α)	°	α1 = 0°, α2 = 0°						
	Wiper Clearance (δ)	mm	δ1 = 0mm, δ2 = 0mm, δ3 = 20mm						
	Wiper Thickness (t)	mm	t1 = 2mm, t2 = 5mm						
	Speed (S)	mm/s	100mm/s						
Result	x̄ ± SD	g	45.5±0.642	45.3±0.985	44.1±1.208	44.2±1.384	43.9±1.875	43.9±1.901	44.0±1.970
	CV	%	1%	2%	3%	3%	4%	4%	5%
	Cp	-	1.559	1.015	0.828	0.722	0.533	0.526	0.562
	Cpk	-	1.325	0.903	0.585	0.537	0.331	0.340	0.369
	Bias	%	1.1%	0.7%	2.0%	1.8%	2.4%	2.4%	2.2%

However, once the incoming materials are divided into sizes by sieving, the sample with Feret Diameter (a) of 6.5 mm and below, and Elongation of 2.3 and below are able to achieve the Cp and Cpk of greater than 1. It is highly suggested that the tuna flake manufacturer improve their process control in grain size separation in order to reduce the number of workforce required for the rework process of weight adjustment.

5.6 Chapter Conclusion

In this chapter, the requirements of the customer for the tuna flake filling process were collected and compared with the actual conditions of the incoming material and also the result of the filling process using the MVP constructed.

With regards to the shapes and sizes of the granules, it has been found that the sizing separation and its tolerance has to be improved in order to achieve the low filling tolerance desired by the tuna flake manufacturer which is ±3g. With the current process, only 46% and 7% of the raw material are within the size limit range given by the tuna flake manufacturer, this is for the 10-15mm diametrical sized and 20-30mm diametrical sized samples respectively, whereas the actual target is 70%.

In terms of machine adjustment, it has been verified that the smaller the gap between the wiper and the bottom of the filling bowl (δ1), and the thinner the wiper (t1), the smaller the loss of the material in the filling process. Moreover, it has also been verified that the machine speed (S) has the effect on the accuracy and precision of the fill weight result. At lower speed (S), the machine can achieve both higher accuracy and precision. However, specific bulk density (ρ_b') at various speed has to be verified in the case that different speed is to be run on the machine to allow the machine user to use as a reference for the simplicity in machine setting.

As assumed in the preliminary study section that the granular shape has the effect on the weight control in the filling process, the actual result of the experiments is in agreement with the assumption. Only with the tuna flake that has the granular size of a= 6.5mm, a/b = 2.3 and below which requires additional sizing process prior to filling are able to be filled at ±3g fill weight tolerance, and, achieve Cp and Cpk of 1 which matches the 3 sigma process capability standard. The summary of the experimental results are shown in Table 36.

The experimental results of (1) as-received tuna flake of 10-15mm size and (2) as-sieved of a = 5.2mm and a/b = 2.3 size which is the size that satisfies both Cp and Cpk standard is shown in Table 37. In the target fill weight of 45g, from the difference of result shown in (3) % Difference column, it can be seen that there is an improvement in all area of quality standard which include SD, %CV, %Biasm Cp and Cpk. It can be noticed that only the target fill weight of 45g has the result for as-seived condition, this is due to the limitation of tuna flake provided by the manufacturer, however, it can also be noticed that the Cp and Cpk for 45g fill weight are the lowest. In the case that this condition can be made positive, other filling conditions can also be made positive too.

Lastly, the summary of the factors for tuna flake and MVP in relation with accuracy and precision indicators are summarised in Table 38. From the result, it can be summarised that low a, a/b, moisture, t, δ, S leads to improvement in filling, however for α, it is the opposite where higher value leads to improvement in filling.

Table 36: *Experimental Results Summary*

No	Variable Factors	Unit	Testing Level/ Condition			Best Condition*
			Low	Medium	High	
(1) Incoming Material						
1	a	mm	5 7 10 12 15			6.5mm and below*
	a/b	mm/mm	2	2.5	3	2.3 and below*
2	Mositure	%	65	70	75	65%
(2) Measuring Cup						
3	Material		Stainless Steel and PTFE			Stainless Steel
4	Volume & Weight	cm3 (g)	64 (28g)	80 (35g)	103 (45g)	28g
(3) Wiper 1, 2						
5	α1, α2	°	0	30	45	45mm
6	δ1 , δ2	mm	0 - 10 (1mm step)			0mm
7	δ3	mm	10	15	20	10mm
8	t1 , t2	mm	5	10	15	5mm
(4) Machine						
9	Speed	mm/s	100 150 200 250 300			100mm/s

Remark: As-seived Tuna Flake

Table 37: *Experimental Summary for As-received and As-sieved Tuna Flake Being Filled at Best Condition*

Weight Target	(1) As-received Tuna (a*=10-15mm)	(2) As-seived Tuna (a=5.2mm, a/b = 2.3)	(3) % Difference (3) = ((2)-(1)/(1)) x 100%	Note
A. 45±3g				All results are improved when tuna flake is divided into sizes by seiving
1) $\bar{x}$ ± SD	43.9±1.901	45.5±0.642	-66% (O)	
2) %CV	4%	1%	-75% (O)	
3) %Bias	2.4%	1.1%	-54% (O)	
4) Cp	0.526	1.559	196% (O)	
5) Cpk	0.340	1.325	208% (O)	
B. 35±3g				
1) $\bar{x}$ ± SD	34.0±1.540			
2) %CV	5%			
3) %Bias	2.9%	-	-	-
4) Cp	0.649			
5) Cpk	0.439			
C. 28±3g				
1) $\bar{x}$ ± SD	27.2±1.303			
2) %CV	5%			
3) %Bias	2.9%	-	-	-
4) Cp	0.768			
5) Cpk	0.563			

Table 38: *Tuna Flake and MVP Factors Effect on Accuracy and Precision Indictor Summary*

Factors	Accuracy and Precision Indicators				
	Tuna Flowablity (m_4)	%Bias	CV	Cp	Cpk
A) Tuna Flake					
1) a (↑)	↓	↑	↑	↓	↓
2) a/b (↑)	↓	↑	↑	↓	↓
3)Moisture (↑)	↓	↑	↑	↓	↓
B) MVP					
1) t (↑)	↓	↑	↑	↓	↓
2) α (↑)	↑	↓	↓	↑	↑
3) δ (↑)	↓	↑	↑	↓	↓
4) S (↑)	↑	↑	↑	↓	↓

CHAPTER 6 ECONOMIC DATA COLLECTION AND ANALYSIS

In this chapter, the economic data and process design of the tuna flake filling method of the existing condition will be analysed in comparison with the new design suggestions. It also includes the price establishment of the new machine which will then be analysed thorough the lens of both the machine maker and the canned tuna flake manufacturer.

6.1 Traditional Method Cost

As explained in the problem statement (Section 1.1), with the existing method the tuna filling process can consume up to 8 workers in the weight reworking process due to the process capability. As the equipment used in the current process has been assets of the tuna flake manufacturer for more than 10 years, its cost will be omitted. The cost of the traditional method consideration will focus on the labour required in the process.

Figure 74 shows the process flow of tuna flake filling and packing, the detail of each station in the existing method is explained in Section 1.1. However, the cost of labour considered consists of Station 1 and Station 2 only.

According to Trading Economics (2018), the minimum wage has increased by almost 58% from 2010 to 2018. The trend of the minimum wage is shown in Figure 74 which shows possibilities of further growth. In this study, the cost of the traditional method is considered using the current minimum wage which is 325 Baht per day.

As the current number of workers required in Station 1 and Station 2 is 9 for the maximum case, the labour cost per year is 2.738M Thai Baht (THB), using the formula shown in Equation 6-1.

$$\text{Labour Cost per Year} = \text{Minimum Wage} \times \text{Number of Shifts} \times \text{Number of Working days} \times \text{Number of Weeks} \times \text{Number of Workers} \tag{6-1}$$

$$= 325 \times 3 \times 6 \times 52 \times 9$$

$$= 2{,}737{,}800 \text{ Baht per year}$$

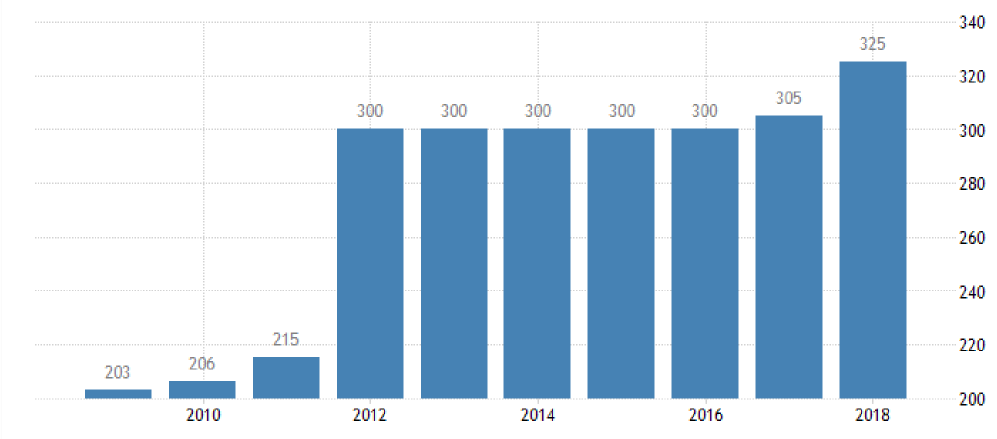
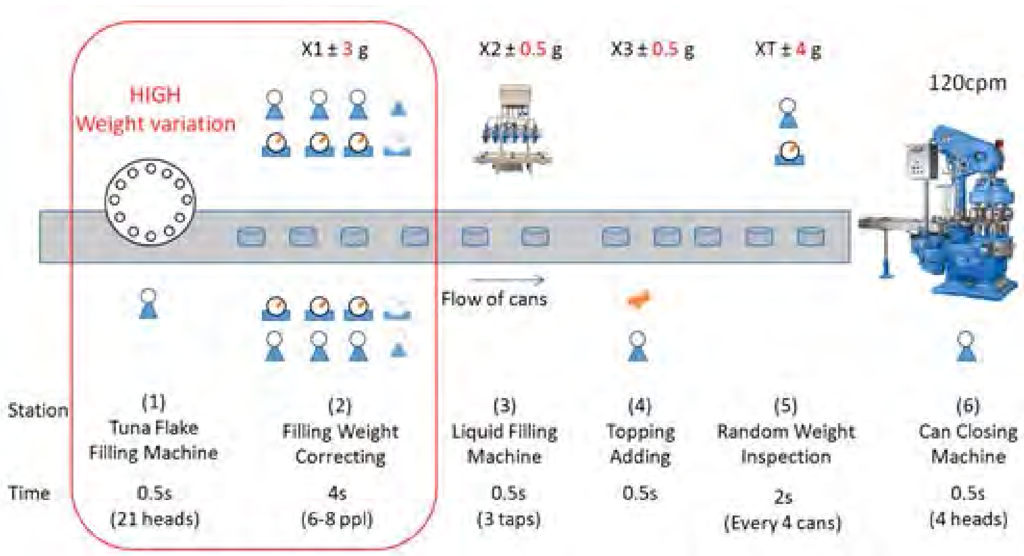
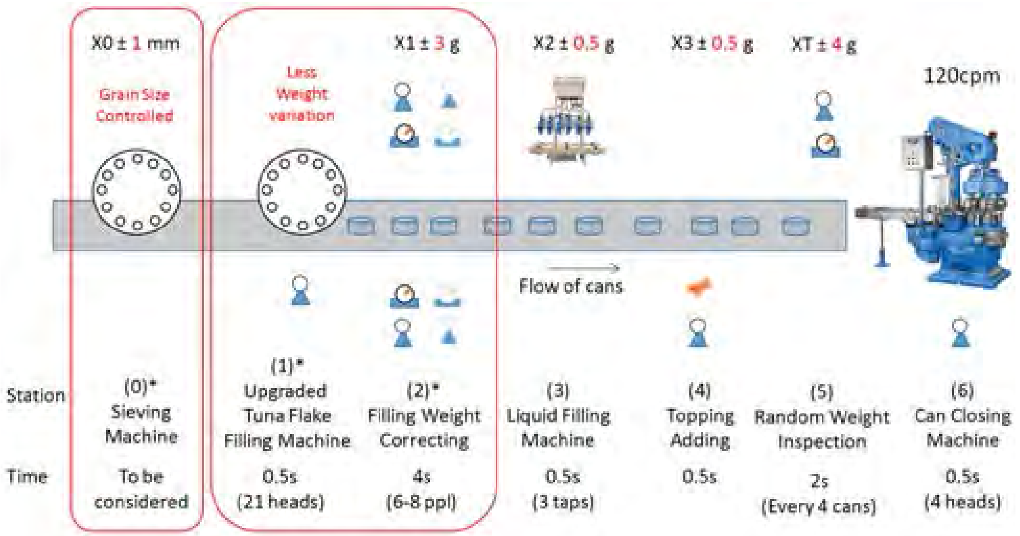


Figure 73: *Trend of Thailand Minimum Wage from 2010 to 2018 (Trading Economics, 2018)*

Existing Process



Suggested Process



Note: * indicates change in process.

***Figure 74:** Existing Tuna Flake Filling Process and Suggested Process*

6.2 Additional Material Sizing Process

In section 5.2, the incoming materials of the two sizes have been studied and found that the sizes of tuna flakes received from the canned tuna flake manufacturer were not within the standard they established. Moreover, when tested on the MVP, it has been found that the variation in grain size plays a major role in uncontrollability of the filling process.

As a result, it is suggested that material sizing process is to be added prior to the tuna flake filling station; the diagram of the new process design is shown in Figure 74.

Figure 75 shows an example of a sieving machine built by an Indian Manufacturer. Although the machine is designed specifically for powder products, its technology can be applied for the tuna flake, as stainless steel of 3 layers from coarser to finer to separate the materials into the desired sizes along with ultrasonic to enhance flow performance.

Figure 75: *Sieving Machine by an Indian Manufacturer (Russell, 2019)*

6.3 Machine Design

From the experimental result of process accuracy and precision study in Section 5.4, it has been found that the speed of the machine (S) has a major effect on the accuracy and precision of the fill weight achieved. The conversion from linear speed in MVP design to circular speed conversion and new design suggestions will be shown in this section.

6.3.1 Linear Speed to Circular Design Conversion

The circular speed of the current machine used at the production of the canned tuna flake manufacturer can be converted into linear speed of 299mm/s. Figure 76 shows the logic of the conversion, the linear speed is calculated using the speed of the machine in cans per minute (cpm) along with the pitch diameter of the machine (D) and the number of the filling heads or measuring cup (N). The linear speed is then calculated into the filling time using the diameter of the outlet of the tuna flake, the filling time for the existing machine is 0.217s.

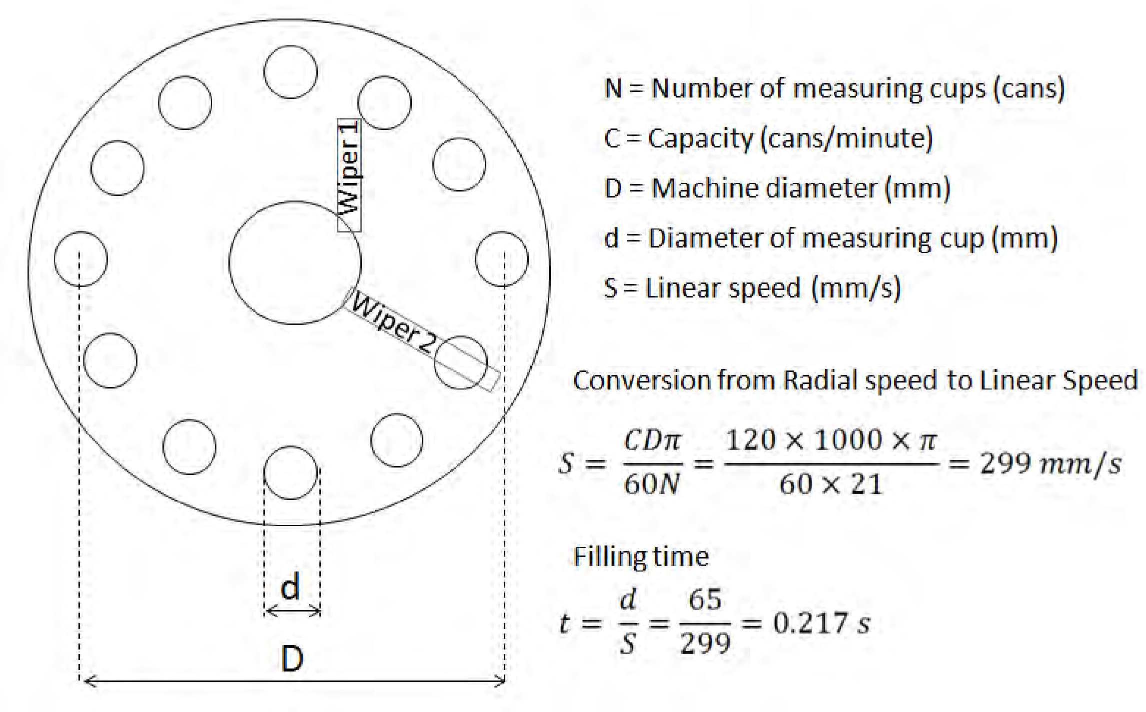
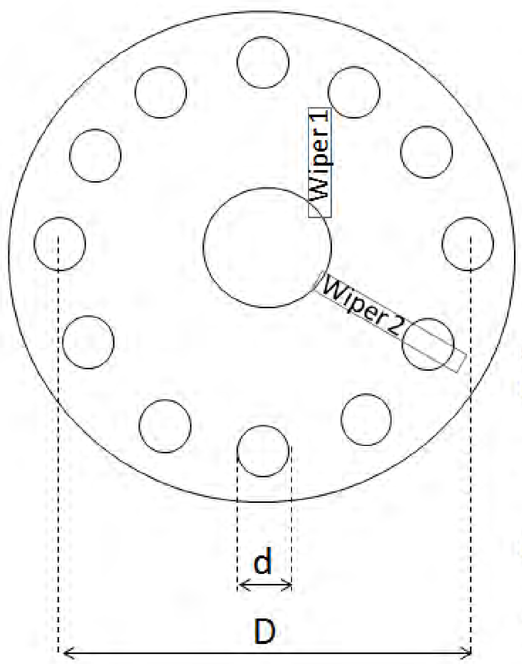


Figure 76: *Circular Speed Conversion to Linear Speed for the Current Tuna Flake Filling Machine used in the Production Line of the Manufacturer*

6.3.2 Requirement for Design Precision

Using the concept of calculation shown in Section 6.3.1 at the speed of 100mm/s as required for precision and accuracy explained in Section 5.4 and the same machine diameter (D), the number of the filling heads (N) required for the new machine with measuring cup which results in reduced flow rate (according to the experimental results) can be calculated with the result of 63 filling heads which are 200% more than those of the current filling machine.

One the other hand, the filling time is 0.53s, which is 144% more than the current filling time. The detail of the calculation is shown in Figure 77.



N = Number of measuring cups (cans)

C = Capacity (cans/minute)

D = Machine diameter (mm)

d = Diameter of measuring cup (mm)

S = Linear speed (mm/s)

Conversion from Linear Speed to Number of Filling Heads

$$N = \frac{CD\pi}{60S} = \frac{120 \times 1000 \times \pi}{60 \times 100} = 63\ heads$$

Filling time

$$t = \frac{d}{S} = \frac{53}{100} = 0.53\ s$$

Figure 77: *Linear Speed Conversion to Number of Filling Heads for the New Machine Design with Measuring Cup function*

According to the major increase in number of filling heads required, it would not be viable to put 63 outlet heads in the machine as it will increase the dimension of the machine by roughly 3 times. As a result, it would be more feasible to increase the filling time, this can be done by including an additional feature in the machine bowl to allow more filling time which will be explained in the solution part of the section.

6.3.3 Solution Suggestion

As mentioned in the earlier section, addition of filling head as a solution is not as viable as increasing the filling time due to the size of the machine. As a result, a new solution is suggested in order to lengthen the filling time without increasing the diameter of the measuring cup.

The proposal of the new design of the machine to optimise the flow of material into the measuring cup is shown in Figure 78. The flow of material can be described as follows.

(1) Product Dumping Area: The raw material is dumped into the bowl here.

(2) Wiper 1: This wiper forces the flow of the material to move towards the outer diameter of the bowl into the measuring cups.

(3) Wiper 1.5: This wiper allows delay time for the material to be filled in the measuring cup without increasing the diameter of the cups.

(4) Wiper 2: After the measuring cups are filled to the slightly overfill condition, the excess tuna flake will be wiped and levelled by this wiper.

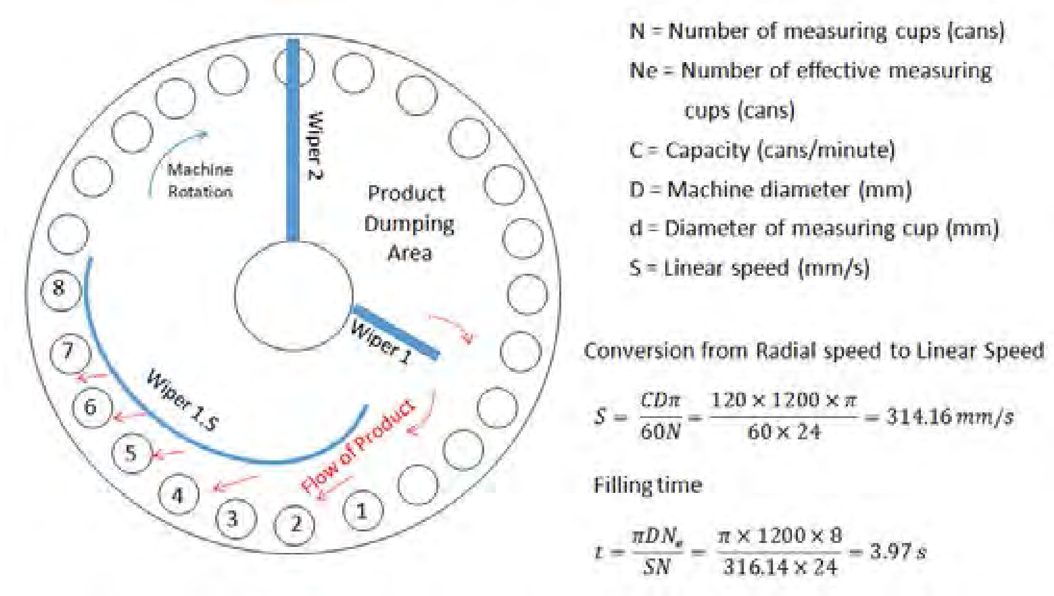


Figure 78: *Logic of New Design Proposal*

The calculation of the speed (S) and filling time (t) of the proposed design is shown in Figure 78. Although design results in the speed (S) of 314.16mm/s, due to the function of Wiper 1.5, its filling time (t) can be increased to 3.97s which is almost 7.5 times greater than the requirement supported by the experimental result.

6.4 Machine Price and Promotion Plan

Any equipment purchasing in the case where the product is to be used longer than a year and is depreciated over its life of usage is known as Capital Equipment Offering (Kotler and Armstrong, 2015). The marketing strategy behind this type of offering can be rather complex due to the involvement of the different divisions within the organisation of the customer. From the perspective of marketing, the communication to the right party required to enhance sales can be challenging.

In this part of the chapter the machine price is analysed and distinguished using marketing tools such as Ansoff Matrix, Product Life Cycle, Polar Diagram and Marketing Mix.

6.4.1 Ansoff Matrix

Ansoff matrix describes the products of an organisation which covers the status of existing products and potential new products, and the market currently served by the organisation (Strong, 2014). The new design of Tuna Flake Filling machine would fit into the Product Development, which is shown in Figure 79.

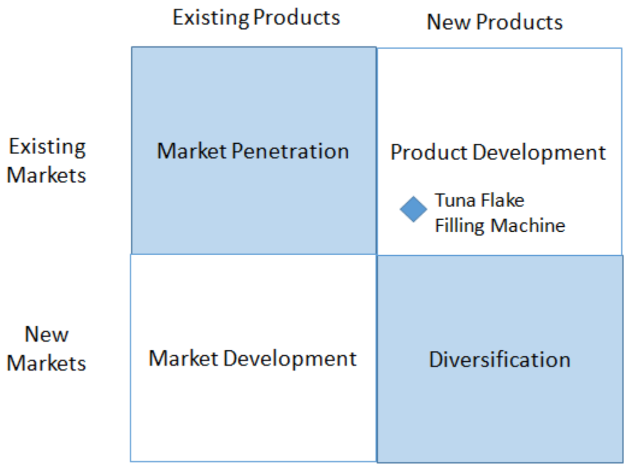


***Figure 79:** Ansoff Matrix (Adapted from Strong, 2014)*

According to Strong (2014), the following points are to be raised in order to analyse whether the new product is a feasible income source.

[1] **Product Definition:** Tuna Flake Filling Machine for Canned Products

[2] **Likely Customers:** Tuna Flake Manufacturers

[3] **Benefits for Customers:** In comparison with the traditional equipment, this machine is likely to reduce the number of workers required in the process.

[4] **Issues with Products:** Additional process prior to flake filling is required

[5] **Criteria for Buying Decision:** See Section 5.1

[6] **Customer Buying Habits:** B2B purchase with annual budget provision

[7] **Replacement of Existing Product:** This machine would replace the existing machine with lower filling performances.

[8] **Product Position**: High Quality with improved performance compared to the existing product in the market and existing product line up of the company.

[9] **Marketing Mix Features:** The marketing mix is explained in Section 6.4.4.

[10] **Price:** The price is explained under the marketing mix in Section 6.4.4.

Furthermore, the launching strategies are also to be planned which are as follows,

[1] **Distribution Channel:** B2B directly from the machine manufacturer to the canned tuna flake manufacturer.

[2] **Early adopters Attraction**: Precision and reduced number of workers required in the tuna flake filling process.

[3] **Awareness Gaining:** First sale to a globally renowned tuna manufacturer and using word of mouth marketing to spread the success of the adoption.

[4] **Expansion:** The expansion strategy is similar to the awareness gaining, word of mouth for the success of the few first machines will be used as a marketing tool to enhance the expansion of sales.

6.4.2 Product Life Cycle

Although the company has produced granular filler before, this is the first time it is specifically designed for tuna flake products. Therefore, the new design of the machine is considered as a new product which is in Emergence Stage (E) of a product life cycle. Figure 80 shows the product life cycle and the stage of the newly designed machine.

According to Ansoff et al. (2019), at Emergence Stage of the product life cycle, it is suggested that the firm concentrates on growth in the domestic markets. This is especially true for the tuna flake filler as the machine may still need minor improvement and adjustment which is to be done by the service staffs of the firm which would be costly and ineffective for the case of international customers. Moreover, at this stage the firm should focus on the quality of the product and the service assistance that may be required by customers for the beginning of the usage of the machine (Slack et al., 2004).

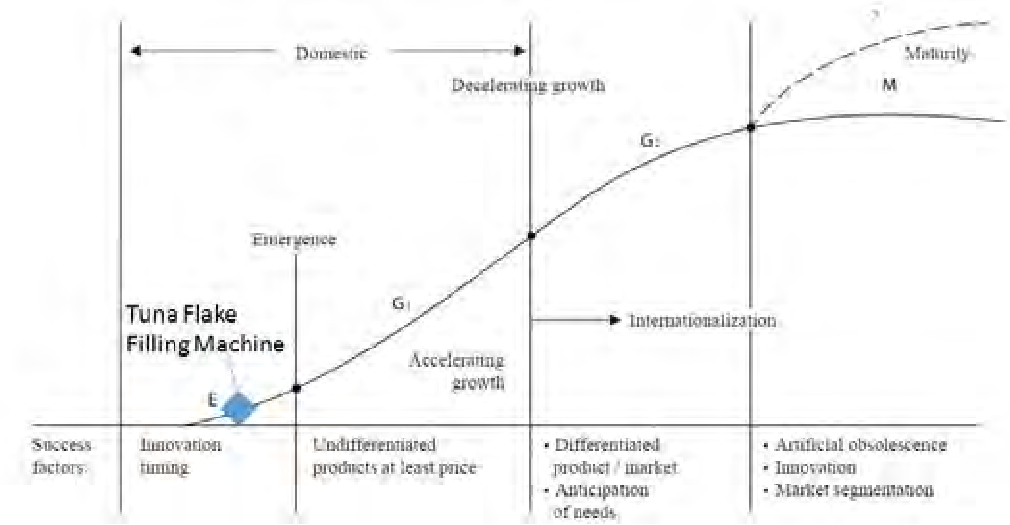


Figure 80: *Product Life Cycle and Typical Competitive Strategy at Different Stages (Ansoff et al., 2019)*

6.4.3 Polar Diagram

According to Slack et al. (2004), there are five performance objectives to be considered to formulate a strategy for survival of an organisation which includes,

[1] Cost: Capability to produce products at minimal costs.

[2] Quality: Capability to produce products according to the specified requirements without any error.

[3] Responsiveness: Capability to respond to the demand of the customers at speed whether services or products.

[4] Dependability: Capability to provide the services or products at the condition which initially agreed with the customers.

[5] Flexibility: Capability to allow change in operations. This includes volume, lead time, product variations and new product designs.

Figure 81 shows the performance objectives of the new product in comparison with other existing products in the format of Polar Diagram. In the diagram, it can be seen that there are trade-offs in a few areas for the new product. In general it is very likely that an organisation would have limited resources, therefore instead of pursuing all aspects of performance objectives, the performances are to be prioritised in line with the overall strategy for its survival (Skinner, 1969).

In the diagram, it can be seen that the new machine gives priority to quality, dependability and flexibility; however, it focuses less on cost and responsiveness. This is because there would be a few changes in machine features along with way to keep the specification agreed with the customers. However, for this particular machine in the beginning, it would be extremely difficult to control the cost and lead time of production due to the reasons mentioned.

On the other hand, in comparison with the existing products, due to the steady volume of sales and established robust design, the company can focus in all areas other than the flexibility especially for design change and product variations.

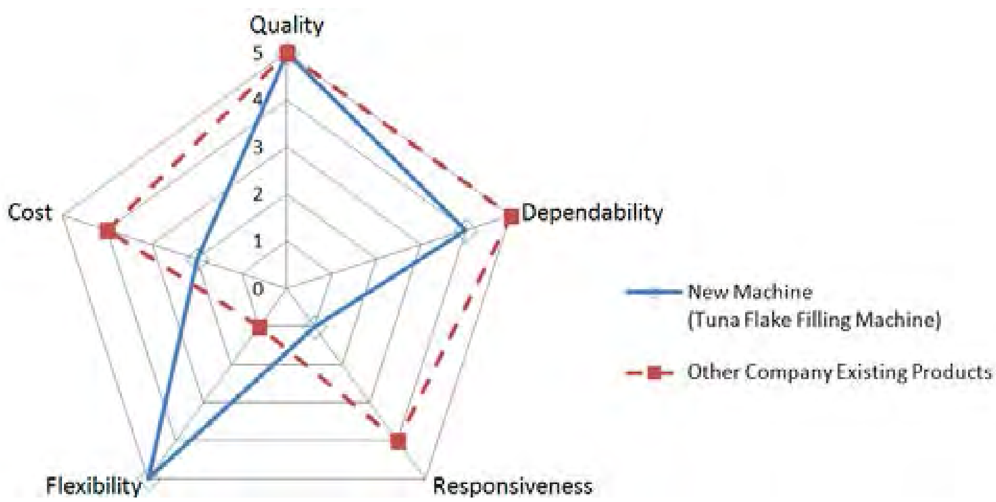


Figure 81: *Polar Diagram of New Machine in comparison with Other Existing Products*

6.4.4 Marketing Mix

According to Gordon (1981), marketing mix including product, price, place and promotion is the combination of marketing elements invented by marketers to respond and satisfy the demand of customer under different circumstances.

Product: Automatic Tuna Flake filling machine, the specification of the machine is explained in Section 4.1.

Price: Target Price for the beginning is 1 Million Baht, and then in the second phase in the first year the price will be set at 2.175 Million Baht.

The company has an existing model of machine which is called STP24V Pocket Granular filler (Figure 82) which is a machine designed for filling a product with high level of homogenous character such as sweet corn or coconut flake. The current offering price of the STP24V is 1.9 Million THB (Baht). The offering price for the new machine is targeted at this price plus the price of additional features, despite the fact that the complication of the machine is much more complex. The low price is in order to gain a position in the market place.

Place: B2B direct to tuna flake manufacturers only

This is the same for all the existing products, as the machine are to be set up and maintained by the company's technicians with expertise. It would be difficult to find a skilful and trust worthy agents or dealers to sell the product for the company.

Promotion: Low Price at introduction phase

The first machine will be offered at a bargain price of 1 Million THB to the well established and world well-known tuna manufacturer. After discussing with the particular customer and the marketing and design team of the company, it would be an appropriate action as the machine has never been proven successful in terms of performance for the mass production of tuna flake filling. This customer will not only evaluate the performance of the machine while in operation, once the prototype machine has been proven effective, due to the renown name of the customer, the machine can be promoted using the reputation gained.

Automatic Granular Filler Model STP24V Pocket	
Machine Model	STP24V Pocket
No. of F[illegible]ng Pockets	24
Recommended Speed	180 CPM
Minimum Can Diameter	202
Maximum Can Diameter	307
Motor Horsepower	3 HP
Products: Particulate products e.g. sacs, corn, beans	

Figure 82: *STP24V Pocket: Existing Granular Filling Machine*

6.4.5 Price Strategy Summary

Considering the estimated labour cost required in the tuna flake filling process which sums up to 2.738 Million Baht per year, the machine investment of 1 Million Baht would make an effective solution for the improvement of process. Although the machine manufacturing company will not make a profit in the first sales, it is a worthwhile beginning in the view of new product introduction to the market. The machine manufacturer has the opportunity to turn the new machine into larger income in the future once the process improvement by the machine proven successful.

6.5 Rate of Return

Using the same formula for labour cost calculation (Equation 6-1), and replacing the number of workers required by the potential reduction of number of workers which is 4, the potential cost reduction per year for the tuna flake filling process is calculated to be 1.217 Million Baht.

Using the machine price of 2.175Million Baht as a base price with additional functions as add-on prices, the price for the new machine is calculated to be 2,175,000 Baht. The detail of the cost estimation is shown in Table 6-1. The sketch of the additional functions in 3D drawing is shown in Section 7.1.

Table 39: *New Machine Price Estimation*

No.	Additional Functions	Price
1	Measuring Cup Volume Adjustment	105,000
2	Additional Wiper 1.5 and 2	7,000
3	Servo Motor	50,000
4	Driving Gear for Machine Pillar Vertical Movement	50,000
5	Measuring Cup Adjustment Clutch	30,000
6	Threaded Pillar for Bowl Vertical Movement	33,000
Additional Functions Total		275,000
Existing Machine Price		1,900,000
New Machine Price		2,175,000

Using machine price as an investment, based on the labour cost only, a tuna flake manufacturer can reach the break-even point within 93 weeks, the calculation for the return is shown in Equation 6.2.

$$\text{Rate of Return in weeks} = \frac{\text{Machine Investment}}{\text{Minimum Wage} \times \text{Number of Shifts} \times \text{Number of Working days} \times \text{Number of Workers reduced}} \quad (6\text{-}2)$$

$$= \frac{2{,}175{,}000}{325 \times 3 \times 6 \times 4} = 93 \text{ weeks } (1.8 \text{ years})$$

On the other hand, for the initial prototype machine, as mentioned before it the marketing mix (Section 6.4.4) the machine will be offered to a renowned tuna flake manufacturer at the price of 1 Million THB, considering this as a machine investment, this particular tuna flake manufacturer can receive their return for the investment within 42 weeks. However, this may not be the case as there may be design adjustment in the prototype machine which can delay the return period and additional grain sizing machine investment in order to control the incoming material to satisfy the filling tolerance required.

6.6 Chapter Conclusion

In this chapter, the cost incurred for the traditional method has been calculated based on the labour cost; the labour cost per year in the case equals 2.738 Million THB which is a considerably large amount when compared with the target price of the machine of 2.175 Million THB. The logic behind the price setting is based on marketing tools such as Ansoff Matrix, Product Life Cycle, Polar Diagram and Marketing Mix.

The design of the machine is based on the experimental result in Chapter 5 has also been analysed, it was found that for the machine to run at a precision and accuracy of requirement, which the original design of wiper, the machine is to have 63 filling heads making it almost impossible to fit in the production line of the tuna flake manufacturer considering the increase in dimension from a traditional machine with 21 filling heads and tight space. Consequently, the new design of wiper and material flows have been proposed to increase the time of filling without increasing the number of filling heads.

Moreover, using the target cost of 2.175 Million Baht, the machine has the potential to reach their return point in 82 weeks or roughly 1.8 years. The return calculation has been calculated based on the potential reduced number of workers.

CHAPTER 7 TENTATIVE MACHINE DESIGN AND EXPERIMENTAL BENEFITS

This chapter includes the tentative machine design which is the one that will be used for actual testing at customer facility in actual mass production condition. Moreover, it also includes benefits of the study from the perspective of both machine manufacture and its customer, research limitations and suggestions for future study.

7.1 Tentative Machine Design

After the design suggestions have been established in Section 6.3, in order to prepare the actual prototype for the mass production testing, this section elaborates on the necessary features of the machine by explaining those items over the 3D drawing of the machine. The detail explanation does not include precise dimensions of the each part of the machine; however, it is completed adequately to ensure that the features can be put into practice for the design structure of the machine as a whole

The necessary design features include 4 major parts; the explanation for each part is as follows,

7.1.1 Flow design of the filling material

The flow of filling material in the machine is designed in such a way to maximise the flow of the tuna flake into the filling containers or cans. The flow of the filling material is shown in Figure 83, which can be described in the following manner.

(1) Product Dumping Point: The filling material is dumped into the bowl of the machine at this area. This part of the machine is considered the beginning of the flow of the material. The flow of the material is shown in red arrow in Figure 83.

(2) Wiper 1: As the machine rotates clockwise, the flow of the material is counter-clockwise and moves pass Wiper 1. The angle of the wiper can be adjusted to enhance and decelerate flow according to the filling material and its flow behaviour to suit the fill weight needed.

(3) Wiper 2: The length of this wiper covers 9 measuring cups, it has 2 main functions.

(3.1) Flow Enhancer: The wiper enhances the flow of the filling material from Wiper 1 to Wiper 1.5.

(3.2) No Product Area: Over the length of the wiper, the area covered will have no product in the bowl. This is to ensure that the pre-filled product in the measuring cup flows freely into the cans without the viscosity of the material obstructing the flow.

(4) Wiper 1.5: As explained in Section 6.3.3, this wiper is designed to prolong the length of the filling period to maximise the flow of the material in the measuring cup.

(5) Opening-Closing Valve: This valve is activated and deactivated by pneumatic cylinder in the completely no product area, the valve opening and closing position is designed to be 5 measuring cups apart.

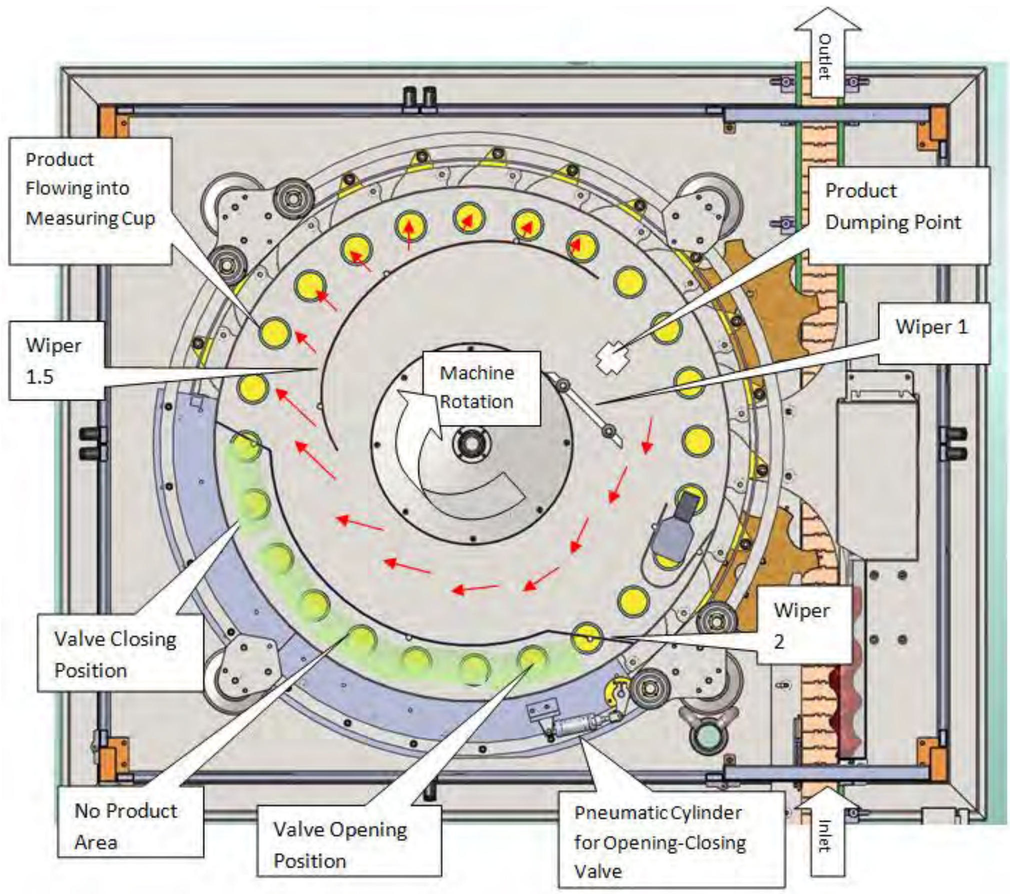


Figure 83: *Flow of Filling Material in Tuna Flake Filling Prototype Machine*

7.1.2 Flow design of the containers

In mass production of tuna flake in cans, flow of containers is necessary in the production line to enhance the capacity of the fabrication. In connection to the purpose, the container flow is designed, the layout of the design in shown in Figure 84, which consists of the following features in the tuna flake filling machine.

(1) Dynamic Guide and Conveyor: This part of the machine receives the flow of cans of the empty cans from the main conveyor of the production line and guides the flow of cans into the tuna flake filling machine.

(2) In-feed Screw: Once the flow of cans reaches the machine, it needs to be sorted in equal interval before entering the filling process.

(3) Star Wheel 1: This star wheel changes the flow of cans from linear to radial to synchronise with the each of the 21 filling heads.

(4) Static Can Stabiliser: This part of the machine stabilises the positions of the cans while in the filling procedures.

(5) Star Wheel 2: This star wheel changes the flow of cans from radial to linear in order to have the filled cans ready for the next process in the production line which is liquid filling.

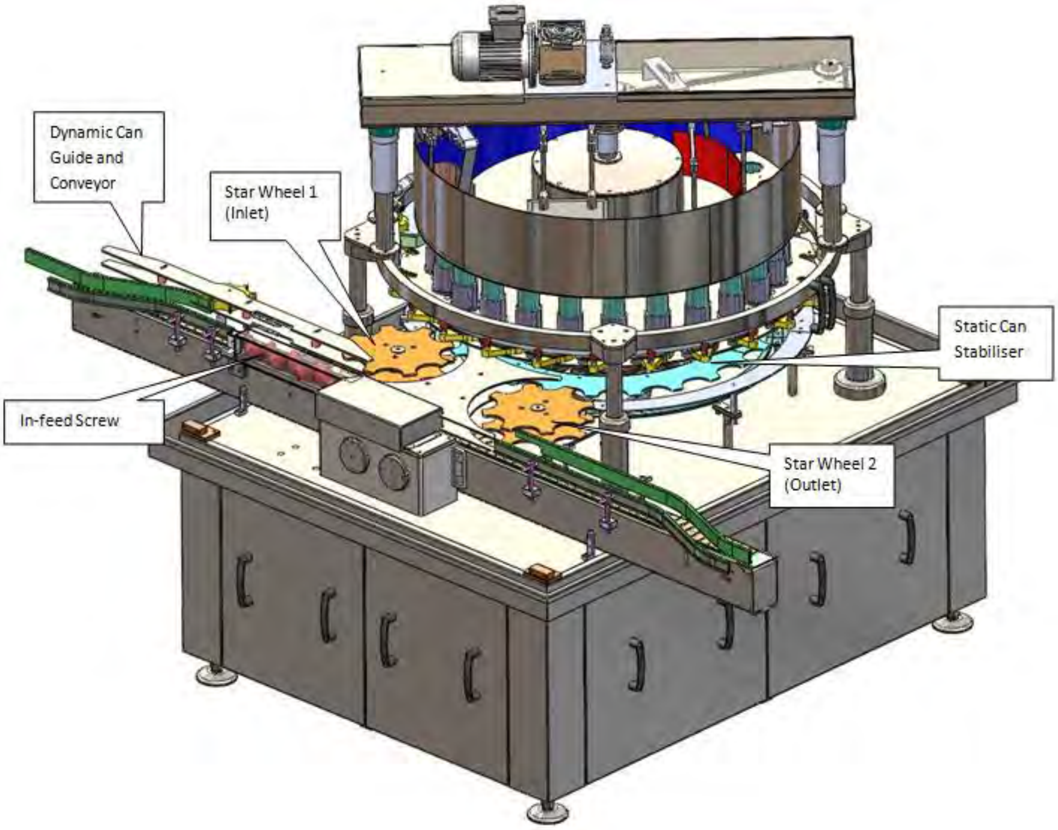


***Figure 84:** Container Flow Design in Tuna Flake Filling Prototype Machine*

7.1.3 Opening and Closing Value

As the filling machine uses volumetric method as a weight controller, each filling is to be pre-measured using volume by the measuring cups. The mechanism of the process in the machine is shown in Figure 85. During the pre-measuring process, the valve underneath the measuring cups are to be closed, however, once the measuring process is completed, the valves are to be opened to allow the tuna flake to flow into the cans.

The measuring cups are designed in such a way that their volume can be adjusted having upper and lower parts sliding fitted with each other. The adjustment of the volume is done using electrical motor and driving mechanism controlled by an inverter. The detail of the mechanism is explained in Section 7.1.4.

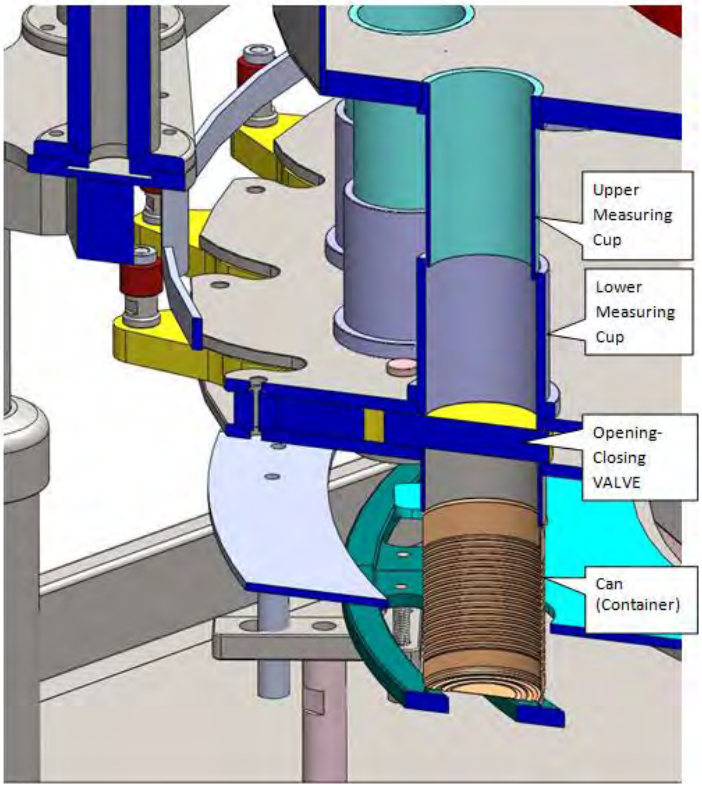


Figure 85: Measuring Cups and Valves in Tuna Flake Filling Prototype Machine

7.1.4 Measuring Cup Volume Adjustment

As mentioned in Section 6.3.3, as there is variation in density and grain sizes of the tuna flakes and also in order to allow the weight adjustment in accordance with the variety of weights of each product, the volume of the measuring cups are to be adjustable.

The adjustment is to be electrically controlled by an inverter with the following supporting parts and mechanism.

(1) Servo motor: This motor will be used an energy source for the volume adjustment mechanism.

(2) Driving Gear for machine pillar vertical movement: From the energy source, the force is transferred to the system through gears and chains.

(3) Measuring cup adjustment clutch: The clutch which engages and disengages the driving force from the gear trains to threaded pillar is activated and deactivated using electrical switch controlled by the inverter.

(4) Threaded Pillar for bowl vertical movement: 3 Threaded pillars underneath the bowl are the parts driving the vertical movement of the bowl.

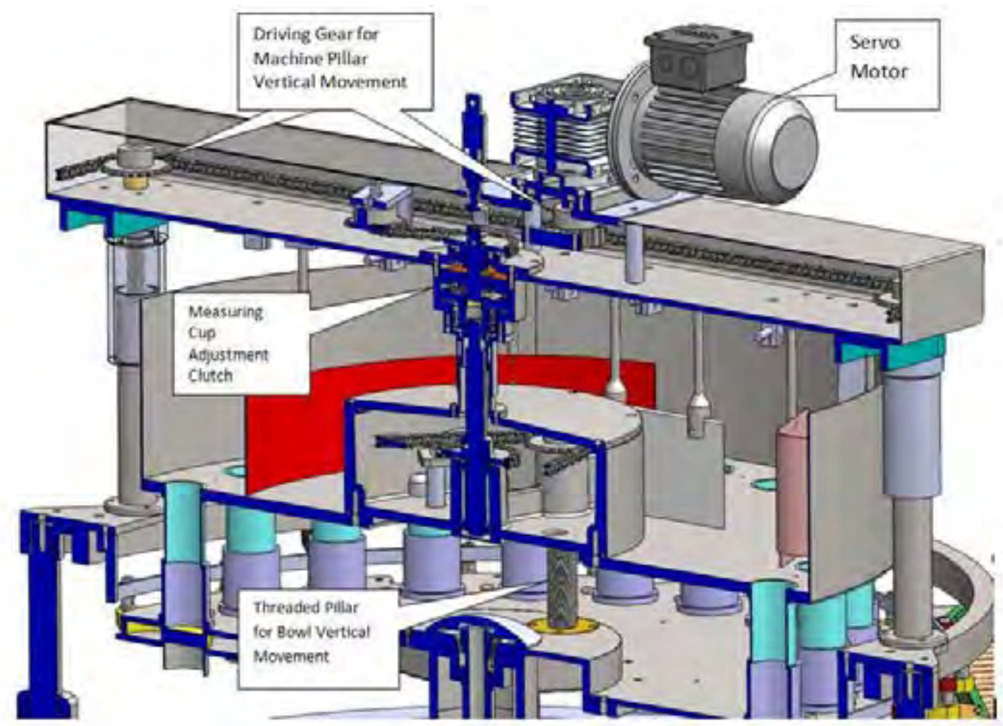


Figure 86: *Measuring Cup Volume Adjustment Mechanism in Tuna Flake Filling Prototype Machine*

7.2 Benefits

This section summarises the benefit gained from the research both from the aspects of the machine manufacturer and canned tuna flake manufacturers. The content of the section is based on the framework of technology roadmap (TRM).

According to Garcia and Bray (1997), TRM is a process used in an organisation to identify, select and develop a technology to satisfy the needs of a product to serve the market. The use of TRM has started to expand in the US both in the government and private sectors since 1990s (Laat and McKibbin, 2003). Its popularity has especially grown in the last two decades due to its ability to predict the change in market trends and technology changes giving advantage for an organisation to address problems faced by customers and improve their productivity.

A general TRM framework was introduced by Albright (2003), the roadmap includes four aspects of decision making which are know-why, know-what, know-how and know-when. The diagram explaining framework is shown in Figure 87.

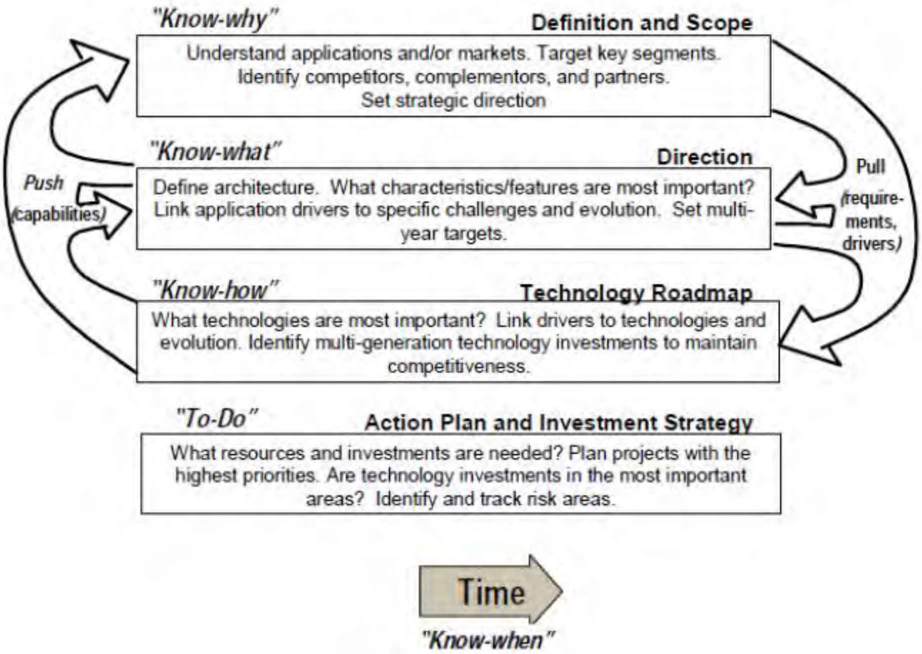


Figure 87: *TRM four-part Framework (Albright,2003)*

7.2.1 Method improvement: Know-what

In the traditional method, the tuna flake filling process is semi automatic and requires a number of workers in the filling process, especially in the weight correction due to the inaccuracy of the existing machine. With the research, it has been has been found that the number of the workers in the process can be improved along with the improvement in the incoming material investigating process and new investment in automatic filling machine.

7.2.2 Incoming material Characteristics: Know-how

In Section 5.2, the characteristics of the incoming material have been established and analysed, moreover, the contributions of those characteristics towards the net weight control of the products have been found in Section 5.4.2. The research does not only benefit the machine manufacturer in designing a functional tuna flake filling machine but also allows the tuna flake manufacturer to reflect on the characteristics of the filling material as a target weight achieving contributor.

This is such that granular shape is the main contributor towards target weight accuracy and that the current moisture control only gives a minor effect towards weight control (1.3g for 45g fill weight). Moreover, it has been found that the current bulk density control may affect the weight accuracy at a degree of 2g for 45g fill weight.

This is equivalent to the concept of value co-creation. As defined by Nenonen and Storbacka (2010), value co-creation consists of the essential 5 elements of business model which are as follows,

(1) Value for the customer: In this case, the value for the customer would be cost saving by reducing the number of workers involved in the tuna flake filling process.

(2) Profit formula: This is similar to the explanation for price strategy in Section 6.4. In the beginning, the first machine would be offered at a very low price in order to gain market insight with a particular customer, and the other elements needed as machine functions and other addition of related processes if needed. Once proven successful, the machine manufacturer can then offer the machine at a profitable price to other customers in the same field.

(3) Value network: For this particular part, it is mentioned by the author that the network should be externally oriented, and this case it is relevant especially for the beginning stage as the value is co-created with the first customer learning the machine functions and adaption of related processes which can then be applied to the next machine and other new customers.

(4) Resources and Core competencies: The resources required for the business model is the prototype machine and engineers of the machine manufacturer and customer brainstorming to improve the performance of the filling process both using the newly designed machine and other related processes. The brainstorming part of the business plan can be considered as a core competency as this activity is not something capable by the other competitors in the market.

(5) Target Customer: The target customers in this case are the canned tuna flake manufacturers which is included in the value chain as mentioned by the author.

7.2.3 Feasibility: Know-what

With the data collected in the research, the feasibility of using an automatic tuna flake filling machine can be justified. As concluded in Section 5.5, the automatic machine can be used; however, additional processes have to be introduced to the production line such as incoming material sizing and moisture content inspection.

7.2.4 MVP as a budget controller: Know-when

In the research, the MVP has been designed and used as a tool for the experiments to trail for the most beneficial methods and setting conditions to allow the most efficient condition of both machine and filling material to be found. Without the MVP, the machine manufacturer may have to build a whole fully functional machine in order to find out the similar achieved results without knowing whether the research would be a success or a failure. As explained in Section 6.4, building one whole fully functional machine, the company may have to spend up to 2.175M THB for the research in terms of testing machine only.

7.2.5 New Product Portfolio: To-do

As explained in Section 6.3, in the current product line up of the company, there is a granular filling machine; however, the machine is designed for homogenous granular media such as sweet corns and coconut sacks. The machine in the current line up does not include adjustable measuring cup function and fine material flow management due to the nature of the mentioned filling material.

The research benefits the company by confirming the feasibility of the machine, however, with limitation which will be explained in Section 7.3. Nevertheless, above all new product portfolio has been created in the process.

7.2.6 Expansion in sales and business opportunity: To-do

With the new product portfolio added to the line up, the machine manufacturer now has an opportunity to gain new sales in newly developed machine to the existing customers. The execution part of the plan is explained in Section 6.5.

7.2.7 Improvement of relationship with customer: Know-how

Throughout the research, the machine manufacturer had been working closely with the tuna flake manufacturer to form working methods and machine functions which are most suitable for the tuna filling process. This can be considered as know-how gaining in the aspect of TRM and co-creation of value in the learning process.

7.3 Research Limitations

As the study is based on the experiments done on a MVP, there are 3 major limitations on the research due to the construction of the machine and the limitation of the number of trails of the experiments.

1. Linear Single Head to Circular Multiple Heads

The experiments conducted in the research are based on the trails done on the MVP which is a single filling head machine. In contrast, the actual machine which will be made for the mass production purpose (prototype) is a multiple head machine as shown in Section 7.1. However, the number of the filling heads in the prototype is converted based on the calculation using the data from the experiments; the detail of the calculation is shown in Section 6.3. Although the calculation is logical in terms of the flow of the material in accordance to the grain sizes of the tuna flakes and the speed of the machine, the performance of the machine in mass production is to be tested with the actual prototype.

2. Wiper Dimensions

The experiments on the effectiveness of the dimensions of the wiper are based on the testing on single filling headed MVP which is wiped through the filling cup in a single step manner, however, in the prototype the 3 wipers will be stationary while the measuring cups will be rotating with the machine and the filling material will flow continuously into the cups. Although the MVP has proved the thickness (t) of the wipers is to be kept minimum with minimum clearance between wiper tip and the bottom of the bowl (δ) and maximum wiper tip angle (α), the same hypothesis is to be tested on the mass production prototype.

3. Number of Trials: Precision and Accuracy

All the major conclusions of the study which include the efficient grain size for filling precision, the number of the filling heads in the actual prototype and the wiper dimension are based on a number of experiments in Section 5. However, the number of the trails is limited to 100 for each experiment due to the limitation on the supply of the filling material provided by the tuna flake manufacturer. The result of the experiment would be more effective if the number of the trails on each experiment is greater, for examples increased to 1000 times. The number of the samples coincides with the effectiveness of the data analysis, as the number of grows larger, the effectiveness also increases (Chen et al., 2003).

7.4 Suggestions

The current research is based on testing on indirect experiments such as testing on MVP and discussions with people have experienced using the machine on the results of the weight-controlled machine available in the market. The following suggestions include the future researches which consist of various direct experiments on actual machines.

1. Cost of Prototype Study

The calculation of the cost of the machine in the study is based on the cost of the existing similar machine plus the additional functions. The detailed study of the cost of the prototype machine is to be studied to determine the actual profit of each sale.

2. Mass Production Prototype Experiment

All the experiments in the research are done using the MVP which is a single filling head machine. In order to confirm the feasibility in the mass production manner, it is suggested that the prototype is to be made and the same experiments are repeated at higher number of repetitions,

3. Performance of Weight-Controlled Filling Machine Study

The performance of the weight-controlled machine is only done through researching on the machine manufacturer website and discussion with the tuna flake manufacturer who has the experience using the machine. It is suggested that the actual performance of the machine is to be tested with proper data analysis.

4. Performance Sieving Machine Study

Similar to the weight-controlled filling machine, the performance of sieving machine is only done through researching through machine manufacturer website. It is suggested that actual experiment with data analysis are also to be performed.

5. Mixed Range of Granular Sizes Study

Similarly to the experiments with mixed nuts in various size, it is also suggested that the mixed range of granular at various percentage is to be studied for filling accuracy, for example, 50% of 7mm, 25% of 10mm and 25% of 15mm of grain sizes.

CHAPTER 8 CONCLUSION

Machine can be used for the tuna flake filling process in cans in the case that additional incoming material inspection and sizing processes are adopted.

The conclusion of the study is summed up into 2 parts. Firstly the part related to the achieving tolerance of ±3g fill weight accuracy which is demanded by the canned tuna flake manufacturer. This part includes (1) Granular Fillers Available in Market, (2) Incoming Material (3) Machine Conditions and Flowablity Enhancement (4) Cost Effectiveness and (5) Product Launching. The second part is related to the launching of product.

1. Granular Fillers Available in Market: Weight-controlled (bad flow rate) and Volume-controlled (incoming material control needed)

According to the literature review, there are 2 types of granular filler available in the market which are weight-controlled and volume-controlled filler. Both types have advantages and disadvantages.

The cost of the weight-controlled filler is considerably higher than the volume controlled due to the technology employed in the machine. Although the machine is claimed by the manufacturer to have tolerance of ±1g fill accuracy, due to the construction of the machine, it is not able to achieve the tolerance of ±3g filling accuracy target for wet product such as tuna flake.

On the other hand, although the weight accuracy is worse for volume-controlled filler, with the advantage in the construction of the machine, it has greater possibility for achieving the tolerance of ±3g filling accuracy target. Other related processes such as incoming material processing and investigation are studied in the research to find the most suitable condition for attaining the desired filling accuracy.

2. Incoming Material Related Factors (Tuna Flake)

Incoming Material factors which relate to the accuracy of filling process are grain dimensions, moisture content and bulk density. The detail of each factor is as follows.

2.1 Grain Dimension a and a/b: The smaller the better the weight control

The incoming material received from the canned tuna flake manufacturer can be categorised into 2 types according to their longest dimensions (a) which are 10-15mm and 20-30mm. According to the manufacturer, 70% of the tuna flakes are to be kept within the specified range, however, after the investigation it has been found that 46% of 10-15mm sample are kept within range, moreover, only 7% of 20-30mm are kept within range.

On the other hand, a/b is the ratio of the longest dimension (a) and the shortest (b) which is although not controlled, it has been measured as it was assumed to have relationship with the flow rate of the material. The coefficient of variance was used to determine the consistency of the incoming material 41.2% for 10-15mm sample and 36.2% for 20-30mm.

With the experiment using MVP, when filling smaller grain sizes of tuna flake (a) 6.5 mm and below and elongation a/b of 2.3 and below, the machine is able to achieve the weight at the tolerance of ±3g filling accuracy with the Cp and Cpk above 1.

2.2 Moisture Content: The lower the better the weight control

After the investigation, it has been discovered that, the tuna flake manufacturer is able to keep their incoming material at the standard moisture level of 65-70% which is within their desired range.

With the natural repose angle experiment, it was found that the lower level of moisture enhances the flow rate of tuna flake better.

2.3 Bulk Density: Higher Speed equals Lower Bulk Density

The bulk density in the 2 sample sizes received from the tuna flake manufacturer are similarly in bulk density, 10-15mm sample has bulk density of 0.445g/cm3 while 20-30mm has 0.477 g/cm3.

In the accuracy experiments, it was discovered that speed plays an important role in void percentage (ε) and hence the bulk density while filling (ρ_b') which is called specific bulk density in the research for this particular machine with 10-15mm and 20-30mm sample, ρ_b' equals 0.3511-0.0005S (g/cm3). It is therefore vital to establish ρ_b' for each filling condition to enhance the filling accuracy of each tuna flake type.

3. Machine Conditions and Flowablity Enhancement: Minimum t, δ and Maximum α

In the best condition verification experiments, it has been discovered that Wiper thickness (t) clearance between wiper and bottom of bowl (δ) are best kept minimum in order to gain minimum loss in process and hence filling precision.

While wiper tip angle (α) is needed when the thickness of the wiper is needed to be large, the effect of α becomes apparent at t of 5mm, while at the maximum level of thickness which is 15mm, the outcome of α is the most effective.

Not only has the effect on ρ_b', speed also effects the loss in process negatively when t, δ, α are not at the best condition. However since the speed of machine is inevitable, t, δ and α are to kept at the best condition discovered to maximise the accuracy and precision of the filling.

4. Cost Effectiveness: Rate of Return of 1.8 years

Since the number of workers required in the tuna flake filling is considerably high at the number of 9, 1 at the filling station and the other 8 in the weight correction station which sums up to the labour cost of 2.738 Million Baht per year.

The target price for the machine is 2.175 Million Baht which is based on the similar existing machine made by the machine manufacturer with added costs for additional functions. Considering the price of the machine and the labour cost, the machine buyer would attain their return in 1.8 years.

5. Product Launching: Initially Low Price offered to Renowned Customer followed by Word of Mouth

One of the best ways to launch the product is to offer the first machine at a considerably low price to a renowned canned tuna flake manufacturer. For example, offering the machine to Thai Union at the price of 1 Million Baht with research agreement. While the customer is using the machine, the machine manufacturer gains the knowledge on the strong and weak points of the machine and is able to collect data and make adjustments to the design to obtain the performance required.

However, once the machine is successful, the word of mouth among tuna flake manufacturers will be used as a marketing tool, not only does it cost effective, the effect of it is also efficient employing the reputation gained from a world renowned company.

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