

# System for Monitoring Progress in a Mixing and Grinding Machine Using Sound Signal Processing



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Major: Functional Control Systems

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A thesis submitted in fulfilment of the  
Requirements for the award of the degree of  
Doctor of Engineering

## **ACKNOWLEDGEMENTS**

I would first like to thank my supervisor, Professor Yoshikazu Koike, whose expertise was invaluable in formulating the research questions and methodology. Your insightful feedback pushed me to sharpen my thinking and brought my work to a higher level.

I would like to thank Masakazu Nakamura, CEO of Ishikawa Kojo Co., Ltd., Koto-ku, Tokyo, Japan, for supplying the mixing and grinding machine. This research was performed by the Environment Research and Technology Development Fund JPMEERF21356447 of the Environmental Restoration and Conservation Agency of Japan and by JSPS KAKENHI Grant Numbers JP21H01554.

In addition, I would like to thank Prof.Maeda, Prof.Chintaka, Prof.Morino, and Prof.Ishii from University of Yamanashi for their kind agreement in reviewing my dissertation.

## ABSTRACT

In this research we present a system for monitoring the progress of a mixing and grinding machine using the signal processing of sound emitted from the machine. For an improved automatic machine or for the industrial Internet of Things (IoT), we present a concept for a low-cost and low-maintenance device. Raspberry Pi and Pumpkin Pi boards are two examples of low-cost hardware devices selected for recording sounds via a microphone and analyzing sound signals. Sound data obtained in regular intervals are converted to small-size data. To estimate state changes while mixing and grinding material using the machine, we used power spectral density (PSD) estimation values processed by measuring sound signals to estimate progress remotely. We found that the PSD values were relative to the status of the material during the mixing and grinding process. As a result, progress was estimated successfully when the proposed method was applied to the mixing and grinding machine.

**Keywords:** Internet of things (IoT), mixing and grinding machine, power spectral density (PSD), short-time Fourier transform (STFT), sound signal processing.

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# CHAPTER 1 INTRODUCTION

## 1.1 Background of the study

Nowadays, the Internet of Things (IoT) is applied in wide variations in daily life. For example, traffic monitoring system [1], smart home intelligent system [2-4], smart appliances such as microwaves, refrigerators, television, washing machines, coffee machines, speakers and so on. In addition, IoT is an essential technology in business and industry. It allows companies to automate processes, save money on labor and reduce costs. Particularly, in industrial fields, IoT allows increasing productivity and high quality. Therefore, most companies used to IoT in process manufacturing.

The Ishikawa kojo company has been in business for more than 120 years or since 1987's [5]. Through the manufacture and sale of the "Ishikawa Grinding Mixer", The machine has contributed to the research and development of many industries. The first president was Heizo Ishikawa succeeded in developing the fish sausage-processing machine and he name the machine is Ishikawa grinding mixer. The mixer was a machine equipped with a mill and a tip of a wood pestle. It was suitable for manufacturing food products, such as kamaboko paste, bean jam, and soba machines. Haruo Ishikawa, the second President change the machine equipped to porcelain pestle and mortar, which have been widely used for research and development of various materials in manufacturing. The Ishikawa grinding mixer is its precision mixing and stable performance. The more uniform the size of the ground particles, and the more evenly the ingredients are blended, the higher the quality of the final product. Uniform particle size enhances the quality of products because substances demonstrate their innate performance more strongly as the surface area and the density increases.

Pestle and mortar have been used to mix and grind materials, e.g. rice powder, peanut, pottery, etc. In order to achieve high quality and high quantity of grinding material, a machine is selected for the mixing and grinding process. Particularly, in the industrial manufacturing process, the Ishikawa mixing and grinding machine is well known in manufacturing. Additionally, the machine can be used to mix and grind various types of materials such as electronic parts, chemical products, art

craftworks, and some kinds of special material such as solar batteries, fluorescent paint, and gold powder.

In this research, the machine model D18S for experiment is used. The machine mixes and grinds simultaneously and the machine consists of 4 components: mortar, pestle, a stirring bar and an electrical motor. The mortar and pestle were various types depending on what material is pounded. For example, a stone mortar and wood pestle is used for a food processor, porcelain mortar and pestle is used for hard processed items, such as in a semiconductor process. The functions machine installed inverter for setup speed motor can be changed speed between 8 to 40 rpm. by a controller and timer relay can be set up to run the machine for a maximum to 12 hours for a controlled stop the machine. The Ishikawa machine operates by two pestles rotating around the mortar and moving with gear rotation. The materials are mixed by a stirring bar and grinded by the pestles tip spinning around the bottom of mortar.

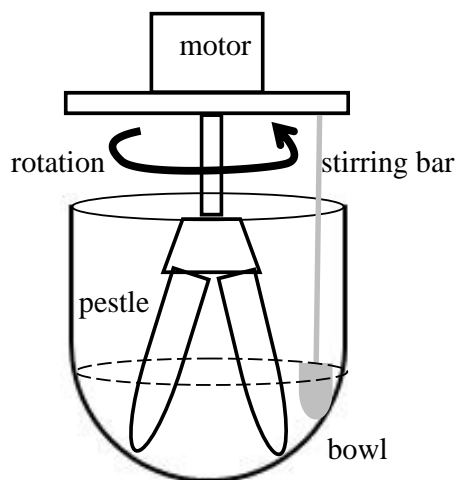


Figure 1.1 The mixing and grinding machine. (Model D18S)

### **Specification (ModelD18S)**

Rotation method: OR type

Porcelain mortar :

Inner radius: 203 mm.

Depth : 114 mm.

Volume : 1 lite

Machine size (W×L×H) : 295×450×465 mm.

Power source : 60 kW.

Number of pestle : 2

Weight : 30 kg.

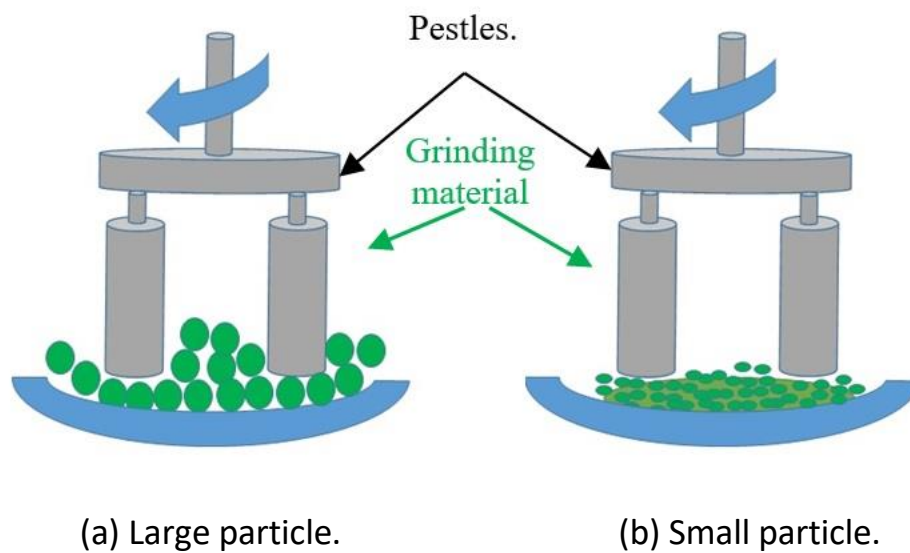


Figure 1.2 The reduction mechanism as smaller grinding particle.

Figure 1.2 shows schematic explanation of the PSD reduction mechanism. The emission sound will become smaller as the motion distance of the pestle becomes shorter due to the small particles. Since the particles are aligned, the level of light reflection and passage is uniform.

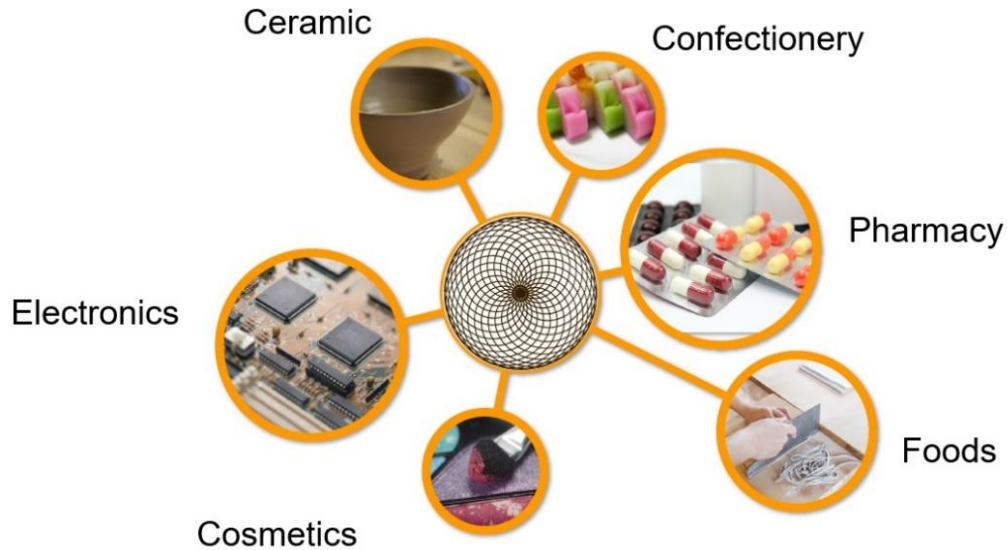


Figure 1.3 Example of the material using the machine.

The Figure 1.3 show example of the material using by the Ishikawa mixing and grinding machine. The materials are crushed by the pestle on various materials. The machine can be use liquids, hard, viscosity and powder materials.

Monitoring system of the mixing and grinding material during the operation of the machine is very important. There are several methods to check the status of the material during the process such as using microscope, or sieving analysis. However, the machine needs to be stopped for data collection in intervals. We found that this sampling method was inefficient loss of time and operated high cost. Moreover, the operator was unable to observe the progress remotely.

In this research, we propose the progress method of the Ishikawa mixing and grinding machine using sound signal processing remotely. The power spectral density (PSD) is calculated and sent data to real-time monitoring.

## 1.2 Literature Review

### Introduction

In this research applied about sound signal analysis using python program to calculated the estimate power spectrum density (PSD) for monitoring the progress of mixing and grinding machine. For studying and searching following related researches as:

#### 1.2.1 Monitoring System

The progress investigation of mixing and grinding from the remote area is preferred and having high demand in various manufacturing processes. Recently, many researchers have studied online monitoring systems with the development of the Internet of Things (IoT) technology. The architecture of the IoT system is composed of sensors that transmit the measurements to a wireless network and real-time monitor by tablet, smartphone, and computer see Figure 1.4 in the below.

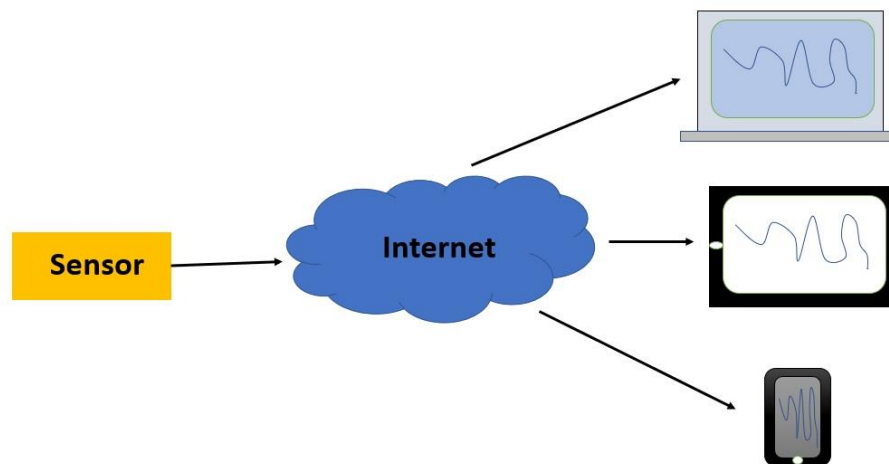


Figure 1.4 Structural monitoring system using IoT

There are many research studies about monitoring system. For example, Swati Dhingra et al. have proposed real-time monitoring using Arduino IDE with a Wi-Fi communication module. The sensor network monitored air pollution or particles and data is sent to the cloud system. Users could check pollution levels via IoT-Mobair on an android application [6]. Ascensión López-Vargas et al. proposed an online monitoring system on the website and mobile application for a solar

measurement system based on ArduinoTM [7]. Zhihan Lv et al. designed a monitoring system with IoT technology for a smart city using a Zigbee wireless network for monitoring and controlling temperature, lights, air conditioners, and various appliances [8]. Pardeep Kumar et al. presented a light weight and secure session key establishment scheme in smart home environments. They used a short authentication token and established a secure session key between GWN and smart devices [9]. Jinsoo Han et al. applied ZigBee module to monitor the energy consumption of home appliances and the power line communication (PLC) was used to monitor the energy generation of renewable energies. Their methods were proposed to optimize home energy for cost savings [10]. For industrial manufacturing, industry 4.0 is focusing on smart hardware and real time data. Qilong Han et al. have proposed the monitoring and predicting air pollution in manufacturing industry. They designed the sensors for measuring such as carbonic oxide, nitrogen dioxide, sulfur dioxide, ozone, particulate matter (PM), temperature, and humidity by using the Zigbee network to collect the data from the sensor [11]. Feng Zhang et al. proposed the investigation of IoT technologies in manufacturing to obtain an online monitoring architecture system for steel casting process [12]. Wen-Tsai Sung and Yao-Chi Hsu presented an industrial real time measurement and monitoring system using ZigBee and DAQ application. They designed and developed LVDT sensor, current sensing, CO2 sensor, and energy monitoring [13].

### **1.2.2 Sound signal processing**

The first concept of sound signal processing recognition is data acquisition. The analog signal read by sensor and convert to digital signal and analysis by software. We can show that the sound signal processing in the following:



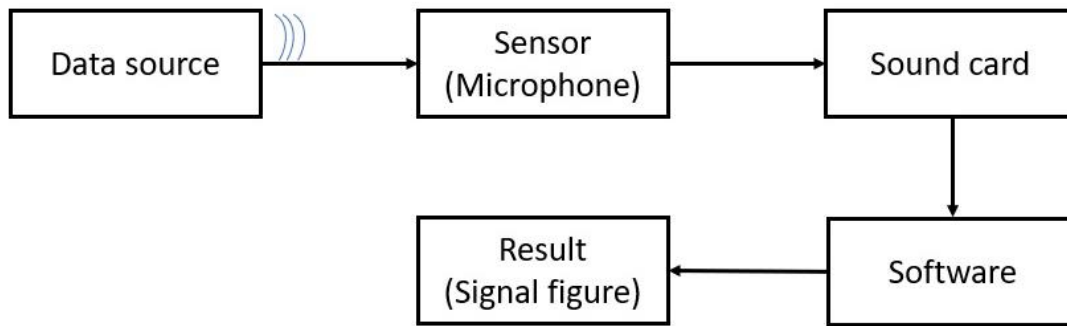


Figure 1.5 Structural of the sound signal processing

In recent years, the development of sound analysis has been widely used in various fields. For example, Takamichi et al. [14] created the CogKnife to identify the type of food using a microphone sensor to record the cutting sound and analyzed the system using a spectrogram and found that this method can be used to evaluate the type of material at high accuracy but could not be used to identify samples that produce low volume of sound. e.g. tofu or jelly. Nachanant Chitnaont et al. classified the musical sound of Thai musical instrument called Khlui [15]. The sounds produced by three types of Khlui made from different types of material, such as Bamboo wood, Pradu wood, and plastic. The sound signal was recorded by using a microphone and used spectral centroids analysis. K.A.Unnikrishna Menon et al.[16] analysis lung infections and lung diseases via lung sounds and calculate FFT and plot graph using matlab program. Quino et al. applied sound measurement to E-glass fiber bundles and monitored it in Matlab. They analyzed the sound emitted by the breakage of fibers and found that the system could detect the initiation and progression of failure [17]. De Cola et al. studied three types of sand gain shapes using sound measurement combined with microscopy [18]. Sonali Sen, Arup Kumar Bhaumik reported that the mathematical model of ball mill using sound was difficult to apply to a mixing and grinding machine due to the slight sound change [19].

### 1.2.3 Particle size analysis

Additionally, various sensor technologies have been applied to measure the particle size. For example, Alessandro Bastari et al. proposed an acoustic signal processing for measuring the particle size of coal powder. They studied the

relationship between acoustic emission signals and the powder particle size distribution [20]. Yonghui Hu et al. used an acoustic emission (AE) signal and signal analysis for measuring the particle size of the pneumatic conveyer [21], the evaluation of an electrostatic sensor and imaging sensor for the measurement of mass flow rate and size distribution of particles in a pneumatic suspension by Robert M. Carter and Yong Yan [22], or the measurement of particle size using digital image processing in a pneumatic suspension by Robert M. Carter et al. [23]. However, these methods are complicated and inconvenient to apply on the progress investigation of mixing and grinding machine.

### **1.3 Scope of research**

1.2.1 Development of a new method for real time monitoring status of the material during on the machine operation.

1.2.2 Using sound signal processing for analysis by calculating the power spectral density and show data result every 2 minutes.

1.2.3 Using the Python programing language to analyze data and processing.

### **1.4 Organization of the dissertation**

This research presents the progress investigation of mixing and grinding machine using sound signal processing. The dissertation is composed of 5 chapters as follows.

Chapter 1	Introduction
Chapter 2	Material and methodology
Chapter 3	Experiment and results
Chapter 4	Analysis and discussion
Chapter 5	Conclusion

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## CHAPTER 2 MATERIAL AND METHODOLOGY

### Introduction

This chapter presents the material and methodology to apply real time monitoring the mixing and grinding machine. There are hardware and software section which will be discussed in the following:

### 2.1 Hardware equipment

The corresponding equipment and tools with their model and specification are clarified in this section show in the table. We will focus on equipment that are quite low and high performance. The equipment is easy to set up and maintenance.

Table 2.1 Corresponding equipment

Equipment name	Model	Manufactured
Microphone	ECM-PC60	Sony company
Amplifier	AT-MA2	Audio Technica Co., Ltd.
Pumpkin Pi	-	Marutsu company
Raspberry Pi 3	Model B+	Raspberry Pi company
TTL serial converter.	TTL-232R-RPI	Future Technology Devices International, Ltd. (FTDI)
Mixing and grinding machine	D18S	Ishikawa Kojo company

### 2.2 Microphone and Amplifier

#### 2.2.1 Microphone

The microphone is a transducer device for convert sound signal to the electric signal. It can be divided two types: dynamic microphone and condenser microphone. In this research we used to electret condenser microphone (ECM-PC60) of the Sony company. A microphone that records sound signals in all directions or Omnidirectional. Figure 2.1 show the Condenser microphone of the Sony company model ECM-PC60



Figure 2.1 The Microphone (ECM-PC60) [1]

**Specification:**

Type:	Electret Condenser Microphone
Frequency Response:	50-15,000Hz
Sensitivity (0dB=1V/Pa):	-38dB±3.5dB
Connector:	Gold-Plated 3-Conductor 3.5mm Mono Mini Plug
Weight:	0.4 oz (12g)

**2.2.2 The amplifier**

An amplifier is a product of Audio-Technica company. The gain of an amplifier can adjust between 20 dB to 50 dB. It serves to amplify the signal from the microphone and sending the signal to the Pumpkin Pi and Raspberry Pi board see the Figure 2.2 as below.



Figure 2.2 The amplifier (AT-MA2) [2]

**Specification :**

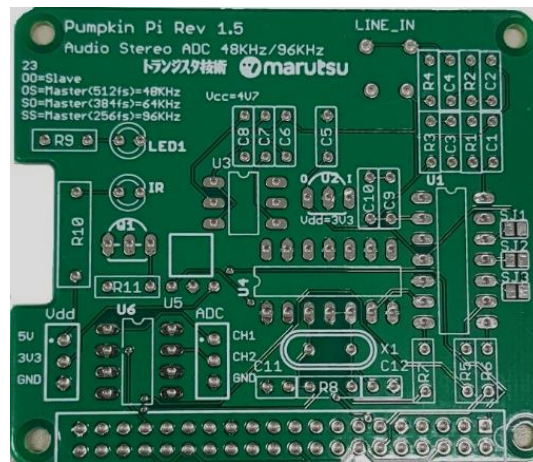
Rated output level	-10 dBV
Maximum output level	+2dBV (at 1kHz, THD 1%)
Frequency characteristic	20Hz -20,000Hz (-3dB)
Gain	+20dB (GAIN is MIN), +50dB (GAIN is MAX)
Maximum allowable input	-18dBV (GAIN is MIN)
Total harmonic distortion	0.05% (GAIN is MIN), 0.2% (GAIN is MAX)
Input conversion noise level	-110dBV ( GAIN is MIN), -120dBV (GAIN is MAX)
Power supply	DC 9V (AC adapter)
Current consumption	30mA (max)
Input terminal	Microphone input ( $\phi$ 6.3mm standard jack/ $\phi$ 3.5mm 3 pole mini jack)



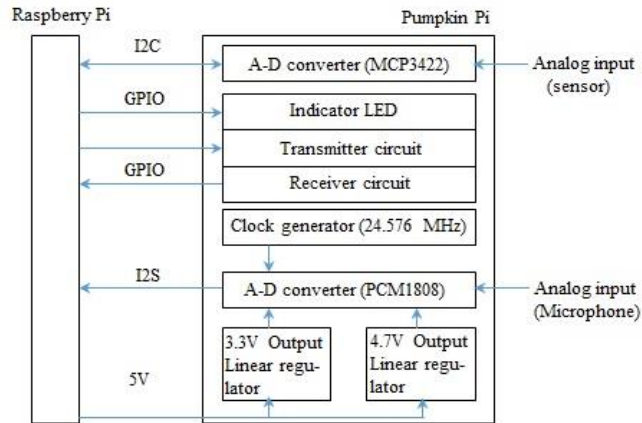
## 2.3 Pumpkin Pi and Raspberry Pi

### 2.3.1 The Pumpkin Pi

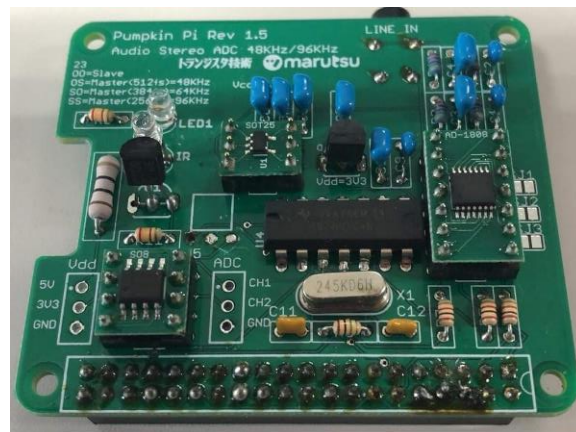
Pumpkin Pi developed by Marutsu Company in Japan, aimed to experiment and measured high-resolution audio signals [3]. Because of the Raspberry Pi does not have analog input signal function and disable used it to voice recognition and measurement. Therefore, the Pumpkin Pi board was developed to solve in this problem. The Pumpkin Pi is an expansion board for converted analog signal to digital signal (A-D Converter). The Pumpkin Pi consists of an A-D converter MCP3422 18 bit using for sensor measurement and A-D converter PCM1808 device support the analog input 24 bit and 96 kHz using for audio measurement. The audio analog input can setup bit rate maximum at 24 bit and sampling frequency at 48 kHz or 96 kHz. by pulse code modulation (PCM). Pumpkin Pi agreement structure diagram is revealed in Figure 2.3



(a) Pumpkin Pi shield



(b) Structure of the Pumpkin Pi



(c) The Pumpkin Pi board

Figure 2.3 Pumpkin Pi

### Specification :

Supported OS	Raspbian
Compatible models	Raspberry Pi Model B+/Raspberry Pi 2 Model B Raspberry Pi 3 Model B
Audio connector	φ3.5mm stereo mini jack
Audio input	Number of quantization bits = 24, sampling frequency = 48/96KHz
AD conversion for measurement	2 channels, 16 bits

Body dimensions            65(W)×56(D) mm.

Body weight                About 25 g.

### 2.3.2 The Raspberry Pi

The Raspberry Pi is a small single-board computer developed in the United Kingdom by the Raspberry Pi Foundation. To purpose for students studying computer science to try to build computers [4]. The Raspberry Pi is a very cheap and very low consumption of electricity when compared to processing performance. The Raspberry Pi 3 Model B+ is used to the experiment and show in the Figure 2.4

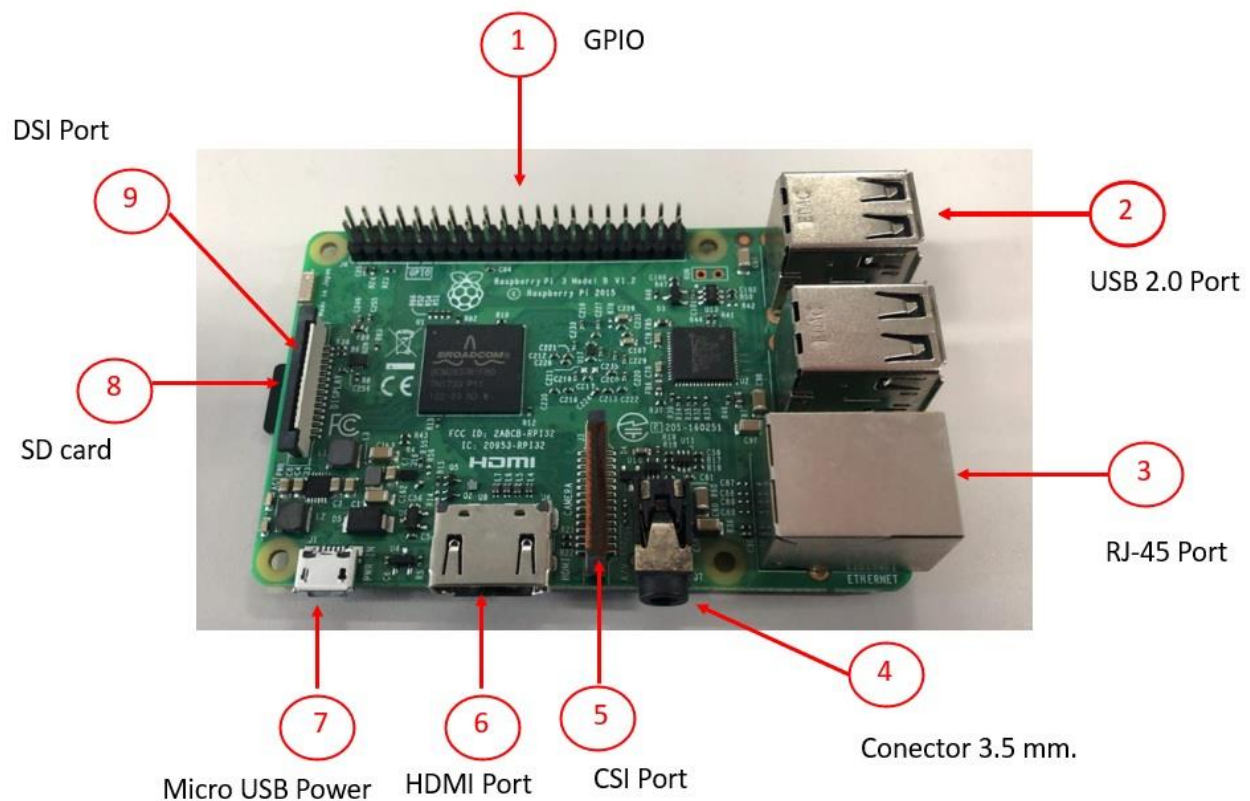


Figure 2.4 Raspberry Pi 3 Model B+ Board

1. GPIO (General Purpose Input/Output) The GPIO ports allow the Raspberry Pi to control input and output from any electronic component. GPIO have 26 pin and the pin contains various functions such as SPI, I2C, serial UART, 3.3 V and 5V power.

2. Port USB 2.0
3. Port RJ-45 Ethernet LAN 10/100Mbps.
4. The audio jack connecting headphones and speaker size 3.5 mm.
5. Port CSI (Camera Serial Interface) for connecting the camera module.
6. HDMI port for connecting video and audio signals.
7. Micro USB port to power supply the Raspberry Pi board.
8. The SD card provides the internal memory and stores the hard drive.
9. Port DSI (Display Serial Interface) is used for connecting a display such as a display.

**Specification:**

SoC:	Broadcom BCM2837
CPU:	4× ARM Cortex-A53, 1.2GHz
GPU:	Broadcom VideoCore IV
RAM:	1GB LPDDR2 (900 MHz)
Networking:	10/100 Ethernet, 2.4GHz 802.11n wireless
Bluetooth:	Bluetooth 4.1 Classic, Bluetooth Low Energy
Storage:	microSD
GPIO:	40-pin header, populated
Ports:	HDMI, 3.5mm analogue audio-video jack, 4× USB 2.0, Ethernet, Camera Serial Interface (CSI), Display Serial Interface (DSI)

Figure 2.5 show the Pumpkin Pi board combine with the Raspberry Pi board is used to in this research.

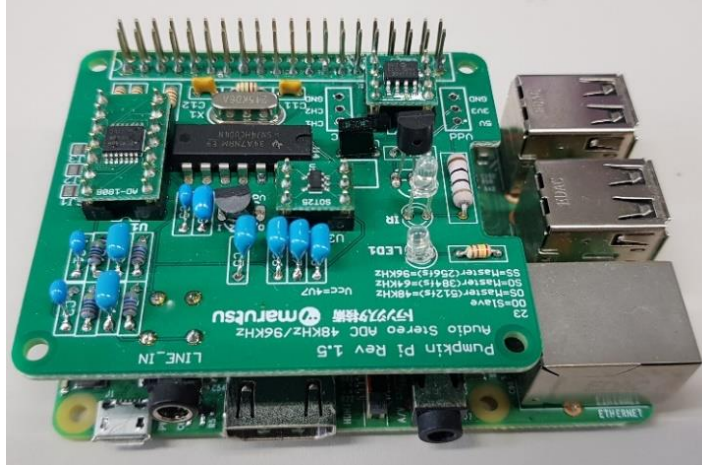


Figure 2.5 Pumpkin Pi and Raspberry Pi board

## 2.4 Methodology

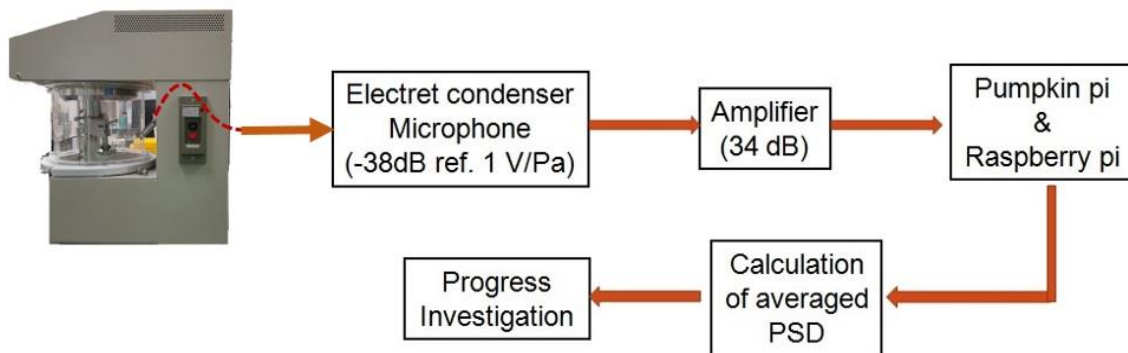


Figure 2.6 Block diagram of sound signal analysis.

We used the sound signal processing method for analysis of the progress investigation of the mixing and grinding machine. The block diagram for sound signal analysis is shown in Figure 2.6 The system consists of three sections: sound recorded data, analysis signal and results data. First, sound level occurring of mixing and grinding process recorded data by an electric condenser microphone (ECMPC60, Sony Corp.). The microphone frequency response between 50 to 15,000 Hz. It is low noise and high sensitivity ( $-38\text{dB} \pm 3.5\text{dB}$ ). The microphone set up in a cylinder for reduces adhesion of the grinding powder materials and position at the backside cover the machine. The microphone is a recorded audio data via 3.5 mm. jack conductor and connect the microphone to amplifier. An analog signal through

an amplifier (AT-MA2, Audio-Technica Corp.) by set up gain between 20 dB to 50 dB. to amplify the signal. In this research we set up gain at 35 dB. Second, we used analog to digital convertor (A-D Converter) with PCM1808 (TI incorporated) on the Pumpkin Pi board for change to digital signal at 16 bits of sample and at 48 kHz of sampling frequency. The Raspberry Pi board combines with a Pumpkin Pi board [18] for save data logger record the emitted sound at regular intervals and analysis signal. We save data to wave file and calculated data by power spectral density (PSD) using by short time Fourier transform (STFT) shown is valid with the Python programming language run on the Raspberry Pi. As a final step, we convert to small data by calculating the average PSD value and show in the real-time monitor by TTL UART serial cable (FTDI-232R).

## 2.5 Sound signal analysis

### 2.5.1 Fourier transform

The Fourier Transform is a technique that transforms a function of time,  $x(t)$ , to a function of frequency,  $X(\omega)$ . The Fourier Transform shows that any waveform can be re-written as the sum of sinusoidal functions. The results may be different either frequency or time.

$$X(f) = \int_{-\infty}^{\infty} x(t) \cdot e^{-2j\pi ft} dt \quad (2.1)$$

Form equation 2.1 can be seen that If a signal has any frequency that corresponds to the frequency of the sine wave. It will be expressed as the large amplitude in the frequency domain of the Fourier transform.

$$x(t) = \int_{-\infty}^{\infty} X(f) \cdot e^{2j\pi ft} df \quad (2.2)$$

In equation 2.2 is the inverse Fourier transform of that signal back to the original signal. The functions change according to time and is a function of varying frequency. However, we do not know the time of occurrence frequency of the signal.

### 2.5.2 Short time Fourier transform (STFT)

The Fourier transform is limited in the time analysis. Therefore, has developed a new method to analyze data both time and frequency. The short-time Fourier transform is employed by the same concept Fourier transform. As previously mentioned, the general equation for STFT is: [5]

$$x_m(f) = \sum_{n=-\infty}^{\infty} x(n)g(n-mR)e^{-j2\pi fn} \quad (2.3)$$

where  $x_m(f)$  is a STFT,  $x(n)$  is a signal,  $g(n)$  is a window function, and  $R$  is the hop size. The hop size is the difference between the window length and the overlap length. Figure 2.7 show the implementation process of STFT.

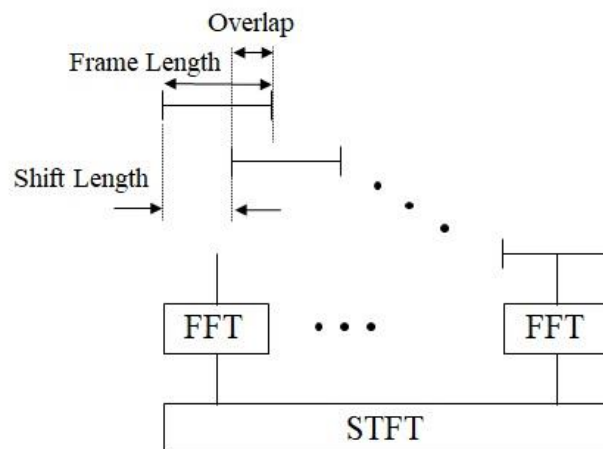


Figure 2.7 STFT implementation process.

The short-time Fourier transform (STFT) is based on the window function. The most commonly used window functions are[6]: Hanning window function, Hamming window function, Gaussian window function etc. by dividing the window function at the signal source and then perform Fourier transform calculation and advance the next window function to continue calculations until no signal at which the position of the scrolling window function.



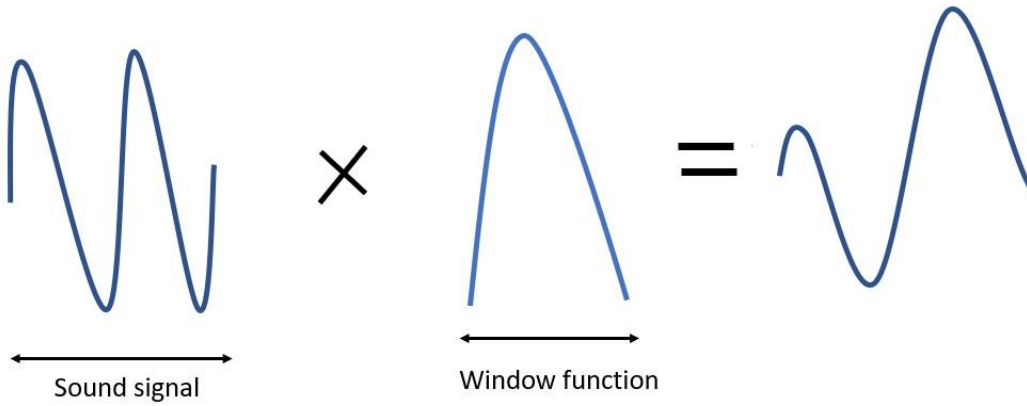


Figure 2.8 STFT with window function process.

### 2.5.3 Power Spectral Density (PSD)

The power spectral density (PSD) estimation was used for the analysis of the emitted sound from the mixing and grinding machine. The PSD is usually estimated by using Fourier transform method. There are a variety of techniques to calculate the PSD such as auto-regressive (AR) model and moving average (MA) model for parametric method; periodogram, Bartlett's method, and Welch's method for non-parametric method [20]. We calculate the PSD estimation value by spectrogram using short-time Fourier transform (STFT) to divide the analyzed signal into a particular segment such as a frame length. we can calculate the average PSD in decibel (dB) as given by,

$$average\ PSD = mean(mean10\log_{10}|x_m(f)|^2) \quad (2.4)$$

With Equation (2.4) we calculated the average frequencies and average times of the STFT. Finally, we calculated the average PSD value and got all data on one file.



## Reference

- [1] “Electret condenser microphone ECM-PC60”, Available:  
<https://www.sony.jp/microphone/products/ECM-PC60/>
- [2] “Microphone amplifier AT-MA20”, Available:  
<https://www.sony.jp/microphone/products/ECM-PC60/>
- [3] “Pumpkin Pi Introduction”, Available:  
<http://select.marutsu.co.jp/list/detail.php?id=258>
- [4] “ Raspberry Pi - Teach, Learn, and Make with Raspberry Pi”, Available:  
<http://www.raspberrypi.org/>
- [5] “Short-time Fourier transform”, Available:  
<https://www.mathworks.com/help/signal/ref/stft.html>
- [6] K. M. M. Prabhu “Window Functions and Their Applications in Signal Processing” Publisher: CRC Press; 2017, pp.96

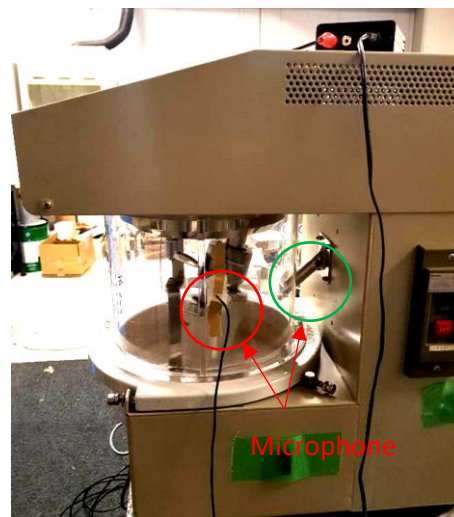
## CHAPTER 3 EXPERIMENT AND RESULTS

### Introduction

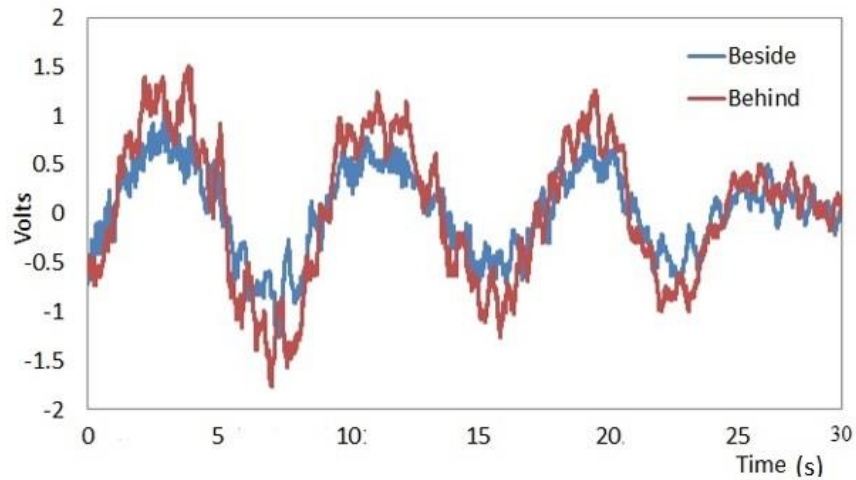
In this chapter presents all equipment setup for the experiment and example of the material including the experimental results of each material. The material has different characteristics. As the following details:

### 3.1 Setup position of the microphone

In this section, to setup a position microphone [1],[2] for the measurement signal. we measured the sound signal from microphone via oscilloscope and compared signal the position of the microphone between beside and behind of the mixing and grinding machine with empty crucible. We found that the data signals are similar. Therefore, we setup the best position of microphone at behind the cover machine shows in Figure 3.1



(a) Position microphone at beside and behind cover machine



(b) Waveform graph position microphone between beside and behind

Figure. 3.1 Positioning of the microphone.

### 3.2 Experimental setup

The mixing and grinding can be used for a various material. In this research we used three materials for the experiments: peanut butter, Japanese rice and Japanese green tea. The experiment was determined by taking the following into consideration:

1. The Ishikawa mixing and grinding machine setup motor speed at 20 rpm.
2. Sound signal recorded via microphone in 5 seconds every 2 minutes.
3. Audio recorded setup bit rate at 16 bit and sampling frequency at 48 kHz.



Figure 3.2 Setup experiment the mixing and grinding machine

### 3.3 Experiment of the materials

#### 3.3.1 Peanut butter process

In this experiment, we mixed and grinded roasted peanuts 80 grams and sugar 50 grams in the machine. To study the peanut butter begins process until became to creamy or end process. The machine run continues 200 minutes and the microphone interval time record every 2 minutes.



Figure 3.3 shows the status of peanut during the machine operation.



(a) 0 minutes.



(B) 20 minutes.



(c) 40 minutes.



(d) 180 minutes.

Figure 3.4 Peanut butter status during experiment.



### 3.3.2 Rice powder process

In this experiment, we used Japanese rice 200 grams and 500 grams and setup speed motor at 20 rpm. The mixing and grinding machine operated a long time to grind the Japanese rice into rice powder. So, the machine setup run continues 48 hours.

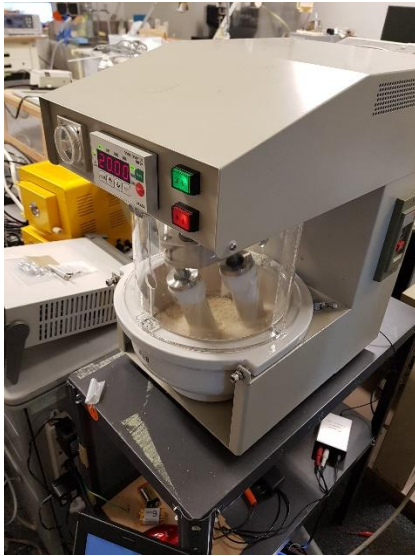


Figure 3.5 shows the status of material during the machine operation.



(a) 8 hours.



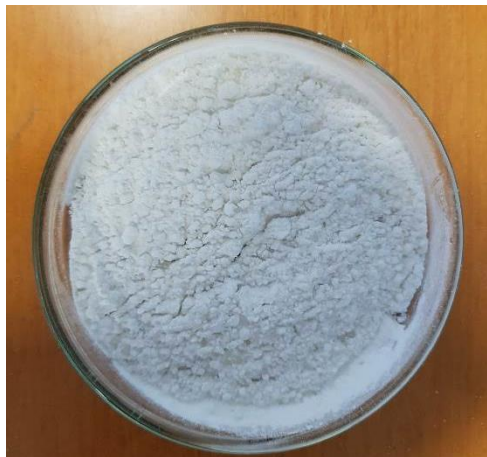
(b) 16 hours.



(c) 24 hours.



(d) 32 hours.



(e) 40 hours.



(f) 48 hours.

Figure 3.6 Japanese rice status during an experiment.

### 3.3.3 Green tea process

In this experiment, we used Japanese green tea 200 grams and setup speed motor at 20 rpm. While the mixing and grinding machine operation, the sound signal recorded in 5 seconds every 2 minutes and ran continuous for three hours.





Figure 3.7 shows the status of green tea during the machine operation.



(a) 0 hours.



(b) 1 hours.



(c) 2 hours.



(d) 3 hours.

Figure 3.8 Japanese green tea status during experiment.



## Reference

[1] “The 5 Methods of Stereo Recording”, Available:

<https://ehomerecordingstudio.com/stereo-microphone-techniques/>

[2] “Microphone Techniques for Recording”, Available:

[https://www.shure.com/damfiles/default/global/documents/publications/en/performance-production/microphone\\_techniques\\_for\\_recording\\_english.pdf-bb0469316afdb6118691d2f3f5e3ff01.pdf](https://www.shure.com/damfiles/default/global/documents/publications/en/performance-production/microphone_techniques_for_recording_english.pdf-bb0469316afdb6118691d2f3f5e3ff01.pdf)

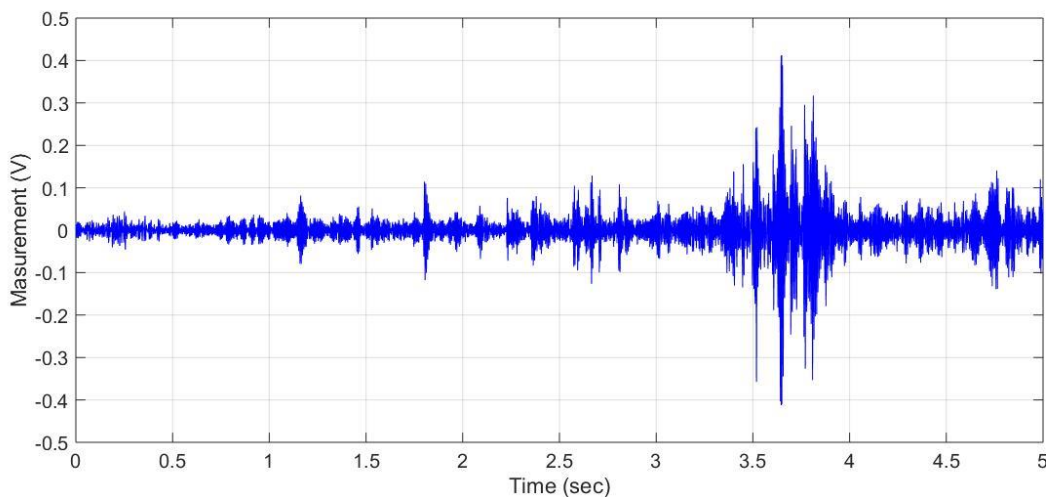
## CHAPTER 4 ANALYSIS AND DISCUSSION

### Introduction

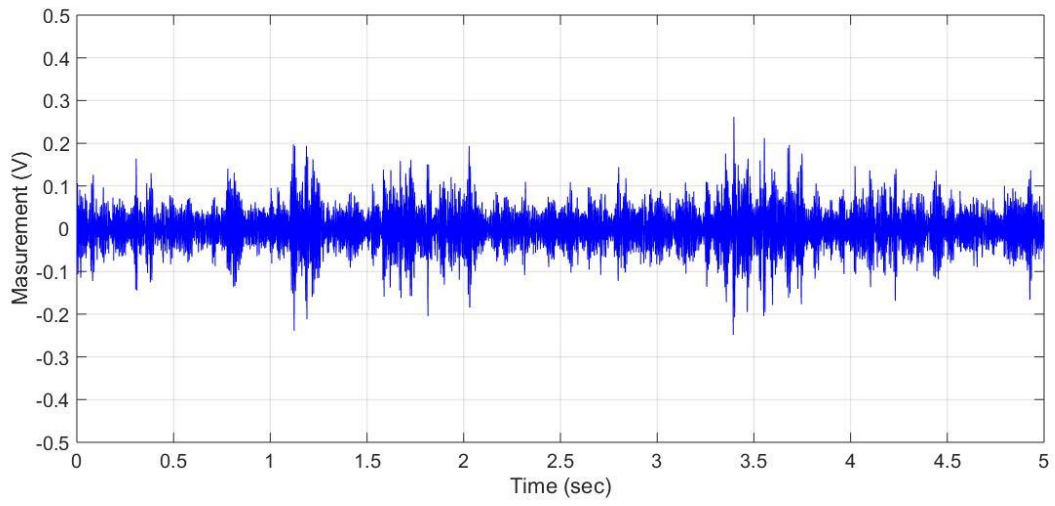
This chapter presents the material selected for experiments such as peanut, Japanese rice, and green tea leaf. The material will be crushed by a machine until the material becomes creamy or powder. The sound is recorded via a microphone while machine operation on condition that end process.

### 4.1 Waveform analysis

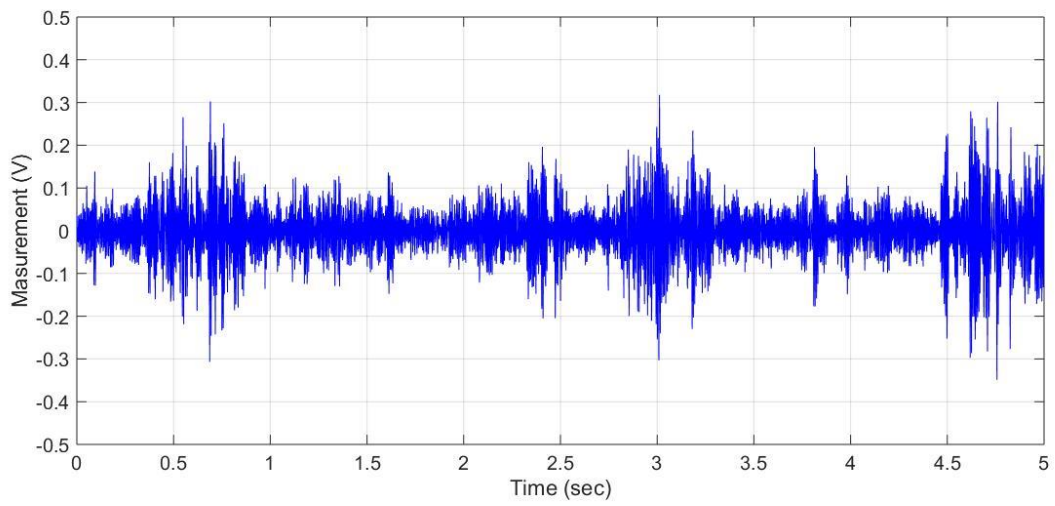
The sound recorded is a wave file that will be read the file and analyzed by python programming language on Raspberry pi. The Figure 4.1. (a)-(b) show examples wave file of the recorded waveform of peanut butter experiment at start machine, 10 minutes, 30 minutes and 60 minutes respectively. This is a record of wave files 5 seconds so that data at 120,000 data and frequency at 48 kHz. The vertical axis is converted to sound pressure and the horizontal axis converted to time in seconds. We found that the waveform graphs altered when the machine operation at different time. The graphs show that different waveform characteristics. So that it is difficult to analyze the signal difference between the recorded waveforms quantitatively. Therefore, the waveform is converted to spectrogram graph.



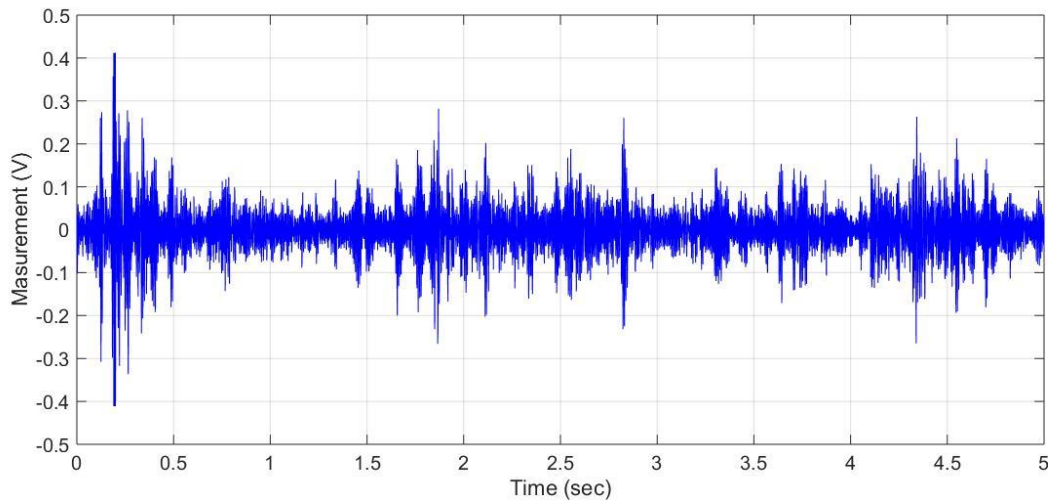
(a) At start machine



(b) At 10 minutes.



(c) At 30 minutes.

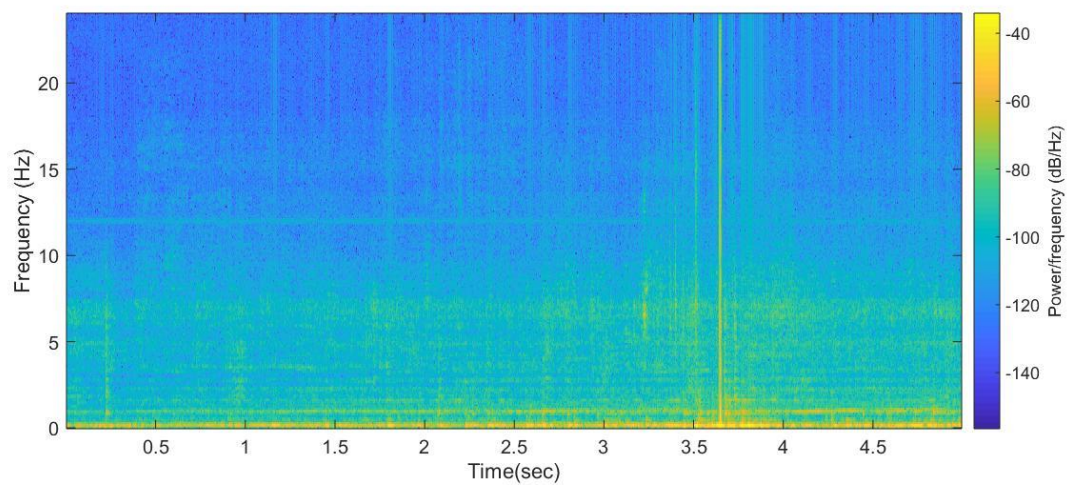


(d) At 60 minutes.

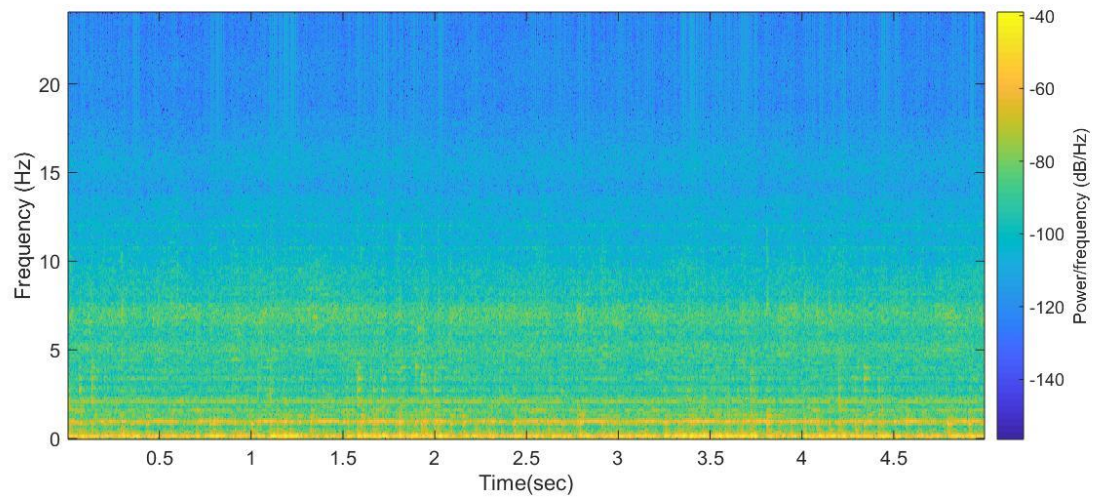
Figure 4.1 Recorded waveforms of peanut process.

## 4.2 Spectrogram Analysis

This analysis represents the relationship between frequency and magnitude of sound signal. The colors of the spectrogram graph show power level of the frequency. Yellow color indicates a high power of frequency and blue color indicates a low power of frequency. Figure 4.2. (a)-(b) show the spectrogram graph of peanut butter experiment at start machine, 10 minutes, 30 minutes and 60 minutes. The graphs show that there is a frequency between 0 and 20 kHz. The color of the power is yellow between 0 and 1 kHz. This means there is some noise while an audio is recorded by a microphone. It is complicated to observe and monitor remotely.

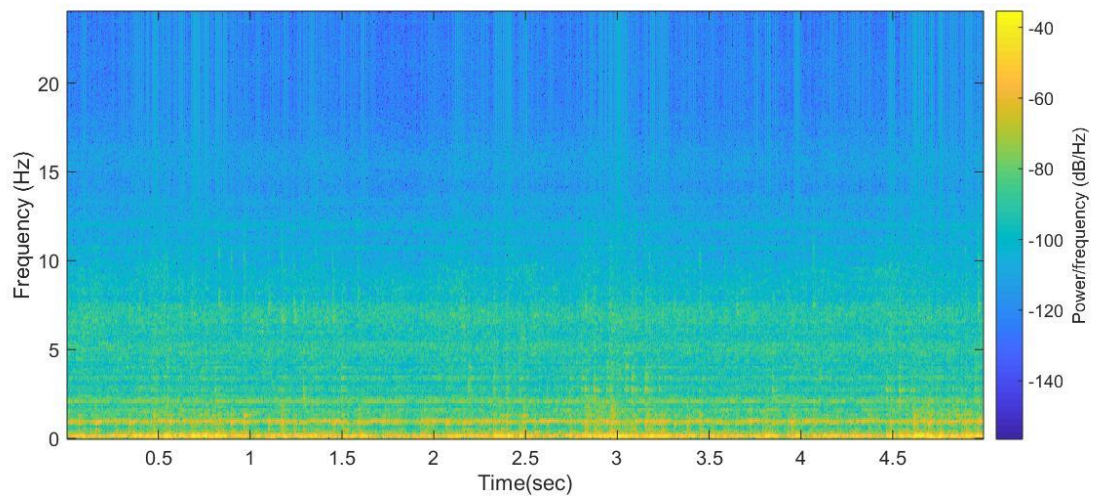


(a) At start machine

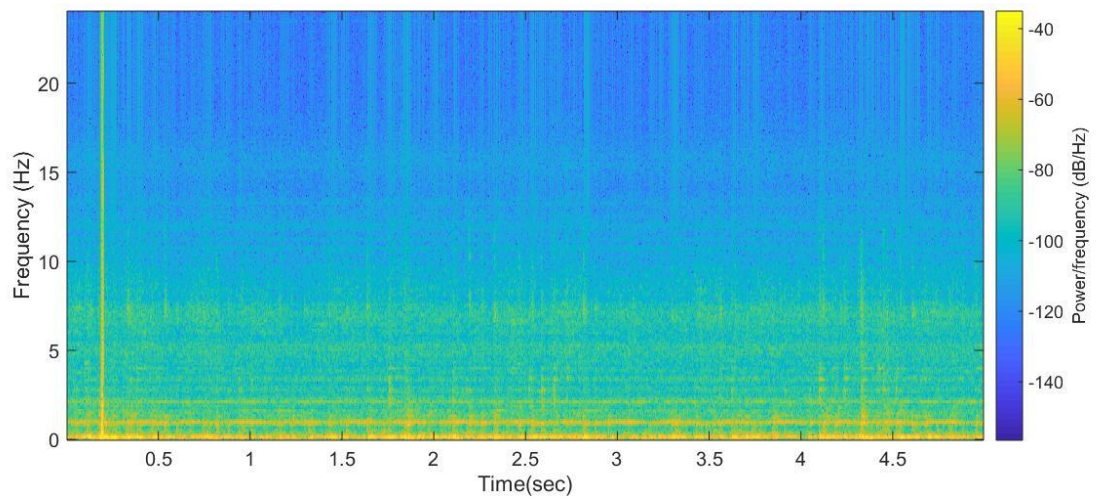


(b) At 10 minutes.





(c) At 30 minutes.



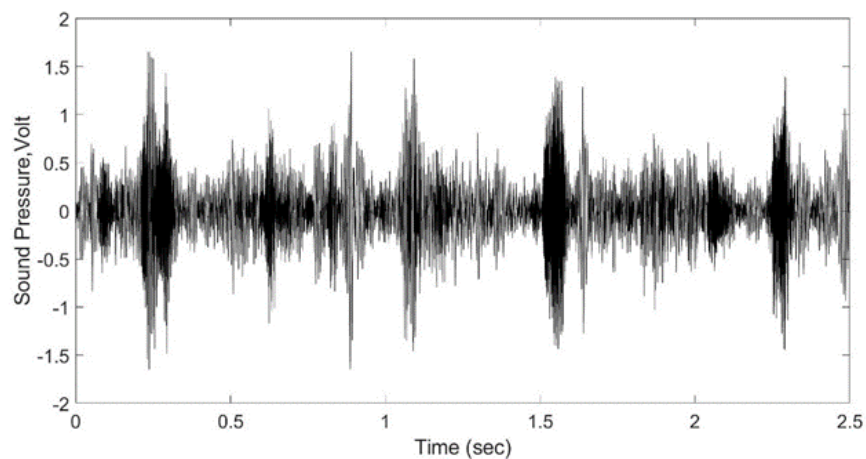
(d) At 60 minutes.

Figure 4.2. Spectrogram graphs of peanut experiment.

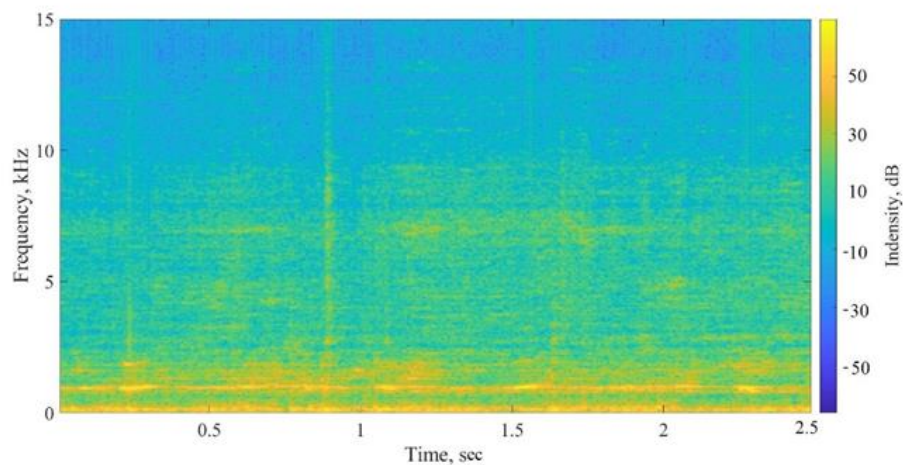
### 4.3 Power spectral density estimation

PSD estimation [1] is useful for studying the progress investigation of the material. First, we performed an experiment with the mixing and grinding machine without any material. The machine ran continuously for 40 minutes and recorded data every 2 minutes.

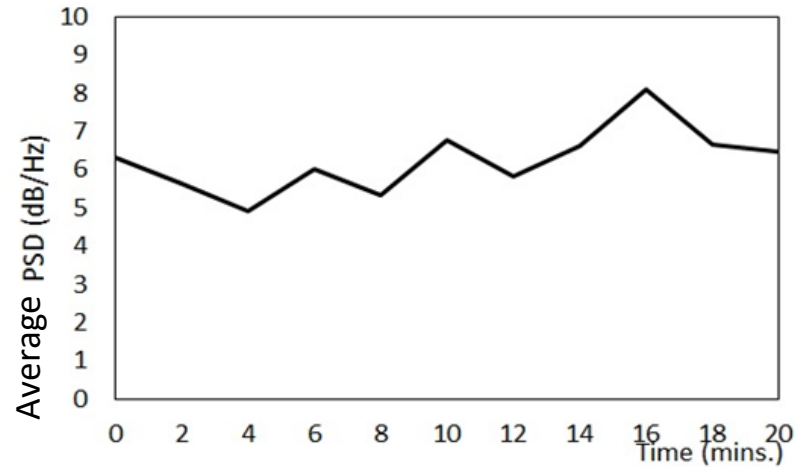
A band pass filter is used to remove low signals and high frequencies to cancel noise signals. We set the low frequency at 2 kHz and high frequency at 15 kHz. Figure 4.3 (a)- (c) show the results of the waveform graph, spectrogram graph, and PSD value, respectively.



(a) waveform graph without any material.



(b) spectrogram graph without any material.



(c) PSD variation without any material.

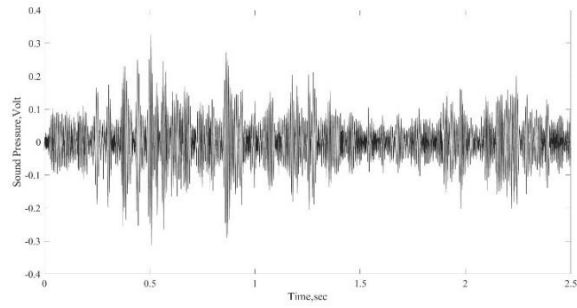
Figure 4.3. The PSD variation without material.

In this study we present average PSD values when monitoring the process of the mixing and grinding machine. The main objective was to study the characteristics of PSD values during the grinding process. In the experiment, we used 3 types of materials (peanut, Japanese rice, green tea leaf) and repeated 2 times (experiments 1 and 2) to verify accuracy and reproducibility.

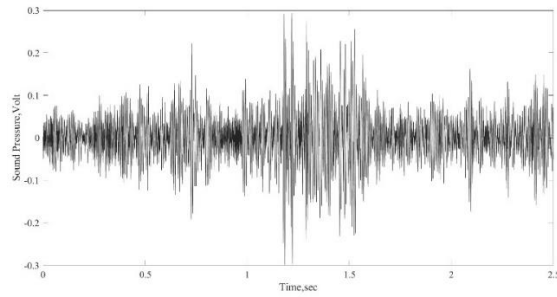
#### 4.3.1 The PSD variation of peanut.

When recorded sound of peanut in the experiment. The example a waveform graphs show in Figure 4.4 and spectrograms graphs show in 4.5. and Figure 4.6 shows the observed results of the average PSD value of grinding roasted peanuts and sugar. When the machine was in operation, in experiment 1 (Figure 4.6a), the PSD value decreased to  $-18$  dB/Hz. After that, the ground peanuts gathered and became a ball shape. The PSD value increased to a maximum of  $-10$  dB/Hz and then decreased. After 40 minutes, the ball shape bound together and became a large sticky lump. Finally, the average PSD value decreased slowly until approaching a straight line, when the peanut lump became creamy. In experiment 2 (Figure 4.6b), the PSD value decreased to  $-15$  dB/Hz at 10 minutes and increased to a maximum of  $-9$  dB/Hz, then after 40 minutes it decreased slowly to a straight line.

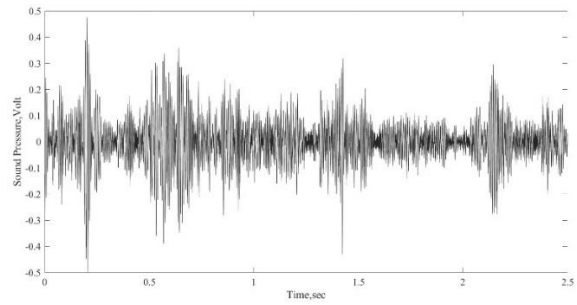




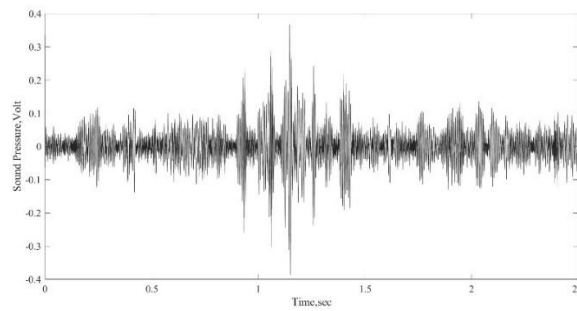
(a) at 2 mins.



(b) at 10 mins.

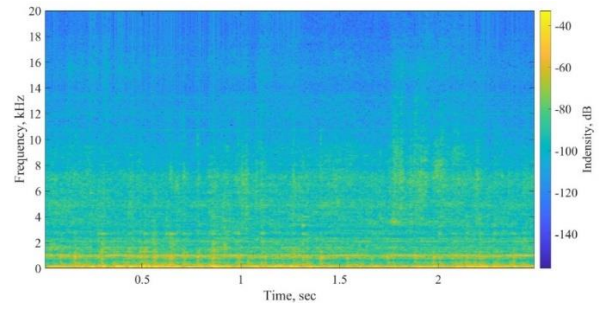


(c) at 30 mins.

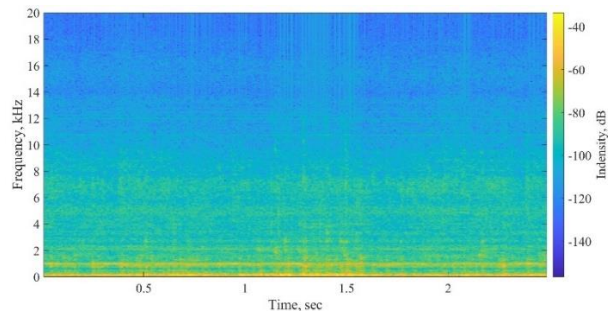


(d) at 180 mins.

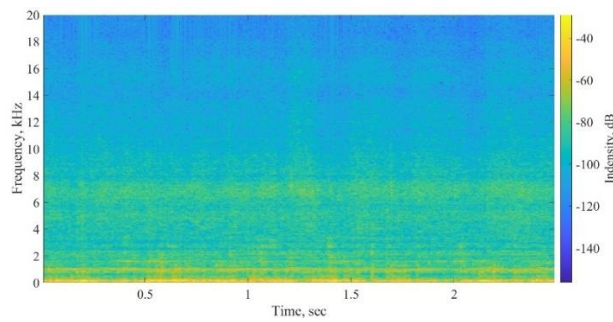
Figure 4.4 The waveform graph for peanut during the experiment



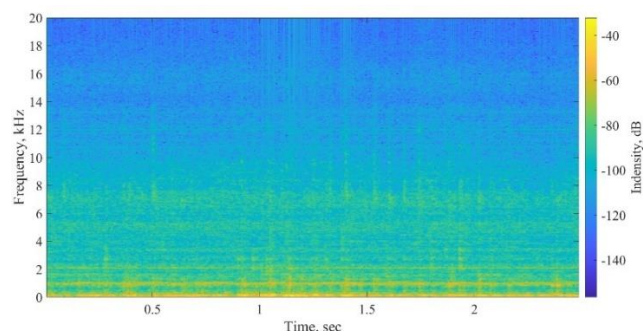
(a) at 2 mins.



(b) at 10 mins.

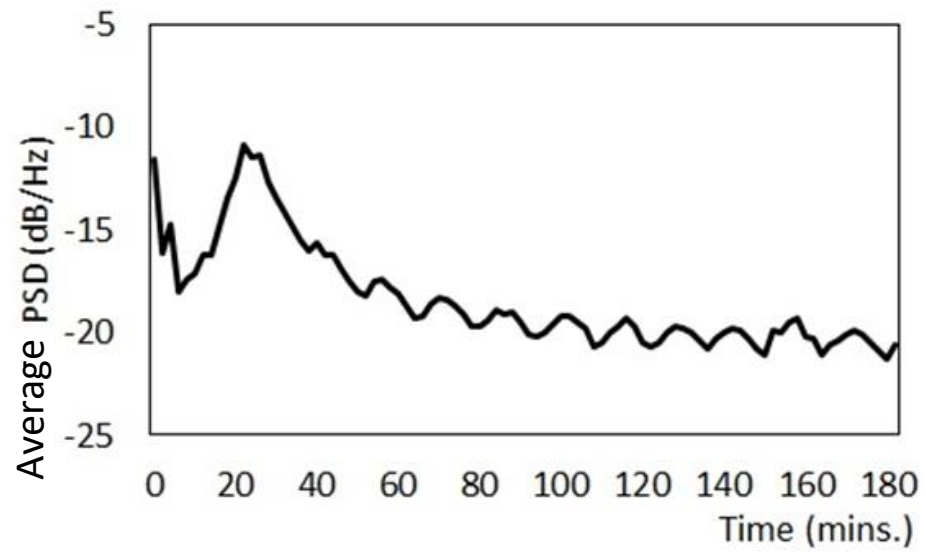


(c) at 30 mins.

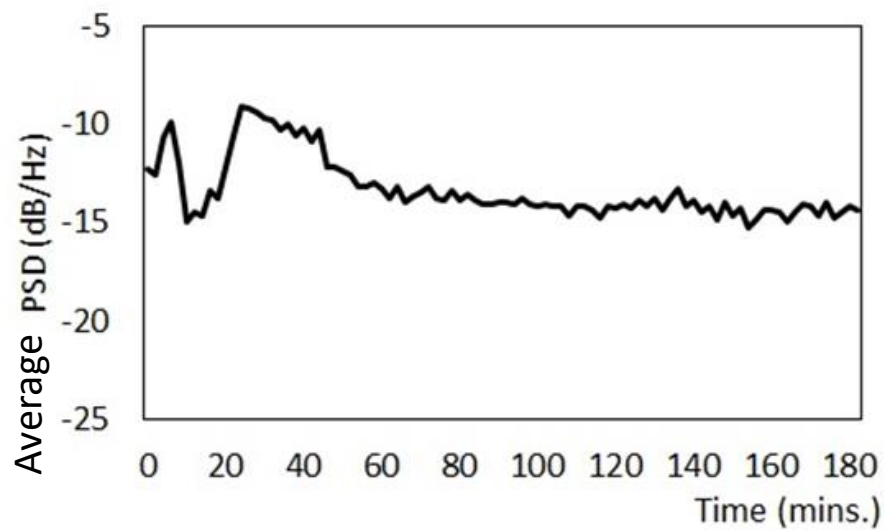


(d) at 180 mins.

Figure 4.5 The spectrogram for peanut during the experiment



(a) First Experiment peanut process

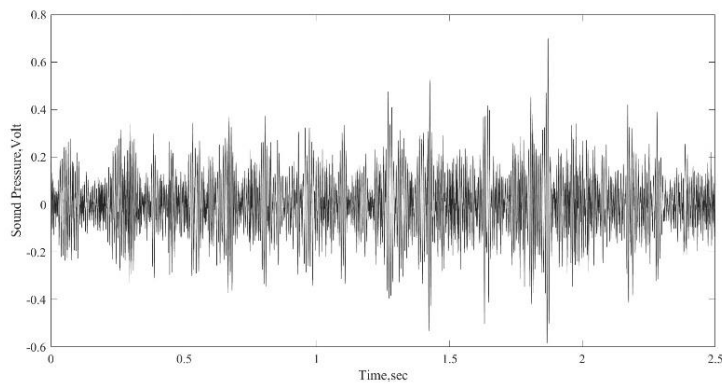


(b) Second Experiment peanut process

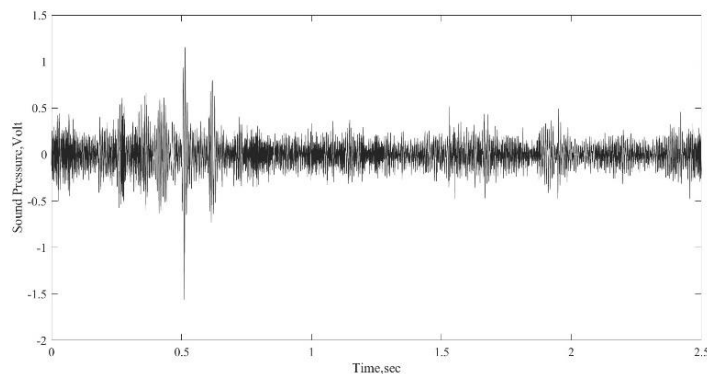
Figure 4.6 The PSD variation for peanuts

### 4.3.2 The PSD variation of Japanese rice

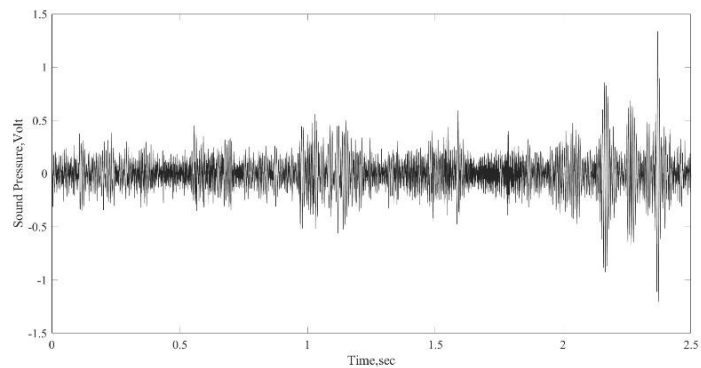
When recorded sound of Japanese rice in the experiment. The example a waveform graphs show in Figure 4.7 and spectrograms graphs show in 4.8. and Figure 4.9 shows the observed results of the average PSD value of rice powder. When the machine was operating, in experiment 1 (Figure 4.9a), the PSD value swung between 2 and 3.5 dB/Hz up to 8 h, then increased to a maximum value of 4.2 dB/Hz at 12 hours. After that, the values increased to 2.10 dB/Hz at 15 h and continued to increase. In experiment 2 (Figure 4.9b), the PSD value varied between  $-10$  and  $-15$  dB/Hz. After 32 hours, the rice was transformed to a smaller size and some of it become powder. The PSD value increased up to 40 hours, and the maximum was at 8.3 dB/Hz. At that time, the rice mostly became powder. Finally, the PSD value decreased to  $-16$  dB/Hz at 44 hours. After that, all the rice was transformed to powder.



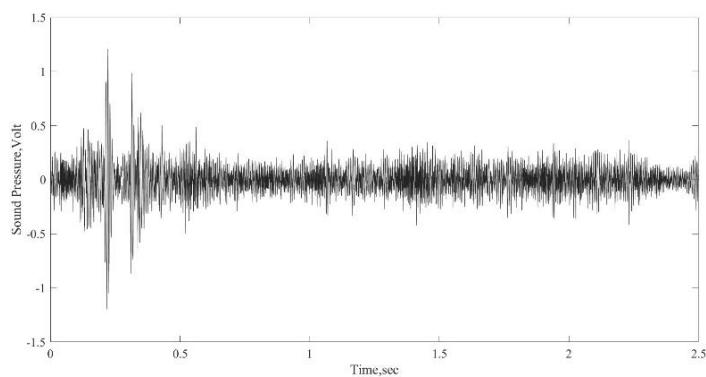
(a) at 8 hr.



(b) at 16 hr.

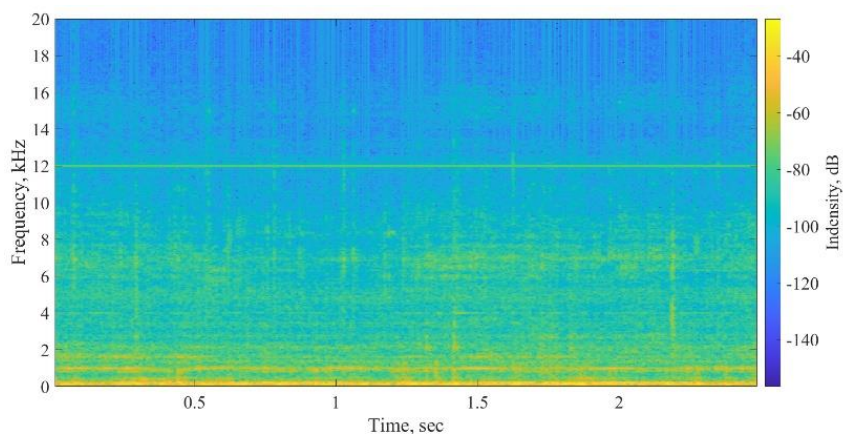


(c) at 24 hr.

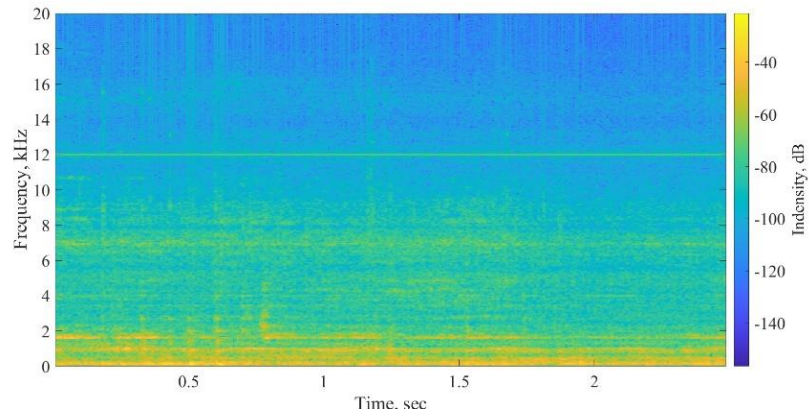


(d) at 32 hr.

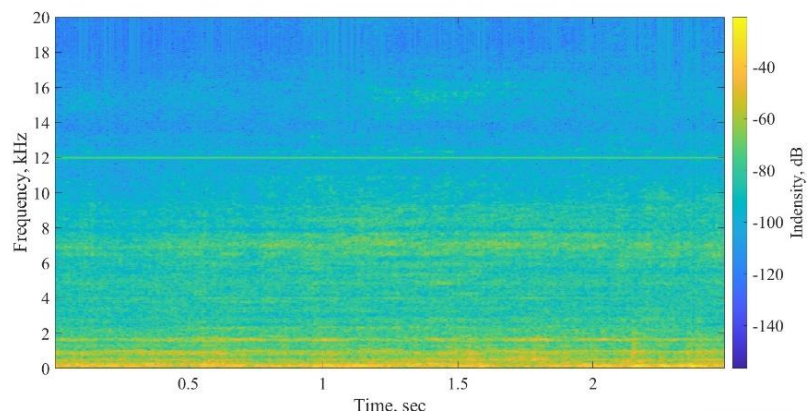
Figure 4.7 The waveform graph for rice during the experiment



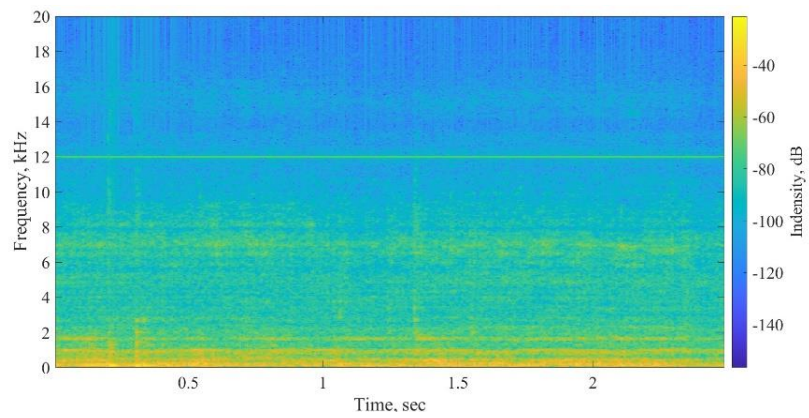
(a) at 8 hr.



(b) at 16 hr.

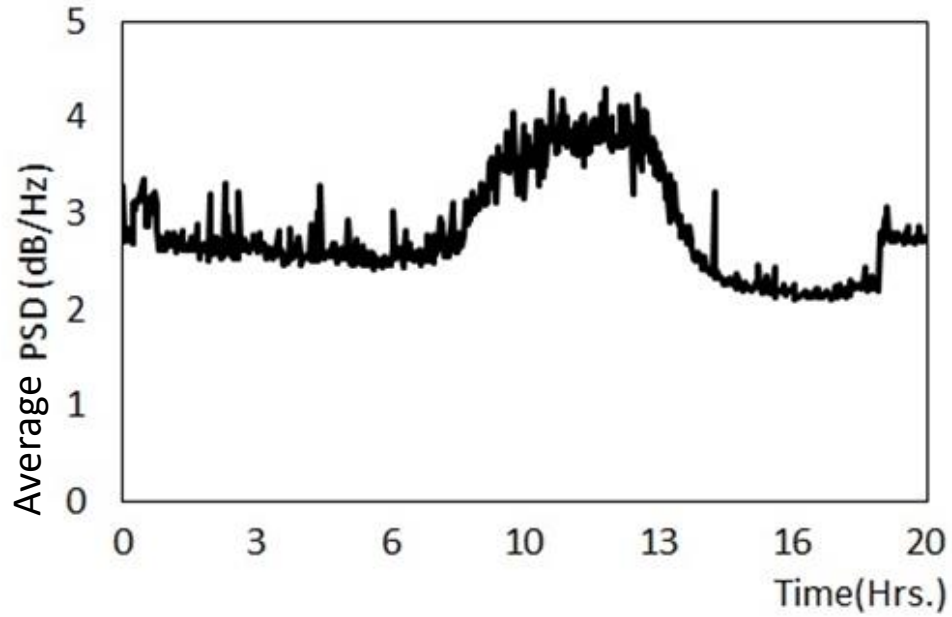


(c) at 24 hr.

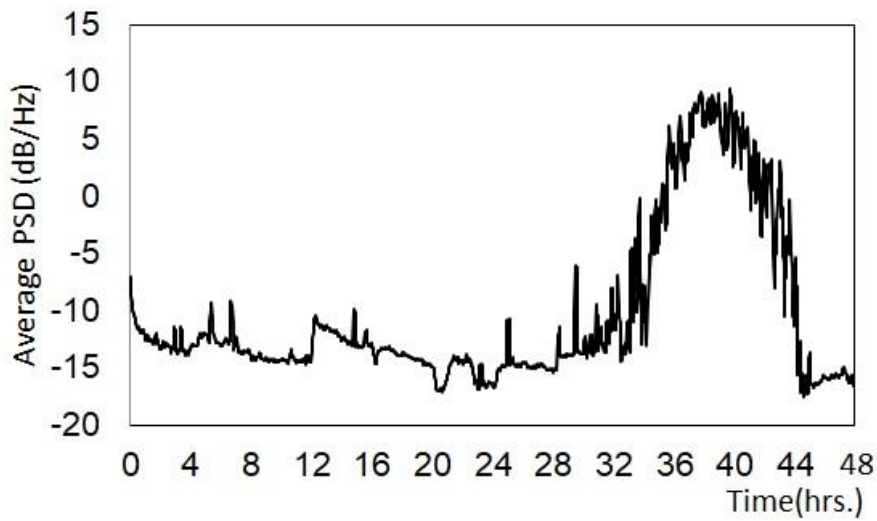


(d) at 32 hr.

Figure 4.8 The waveform graph for rice during the experiment



(a) First Experiment rice powder process 300 grams

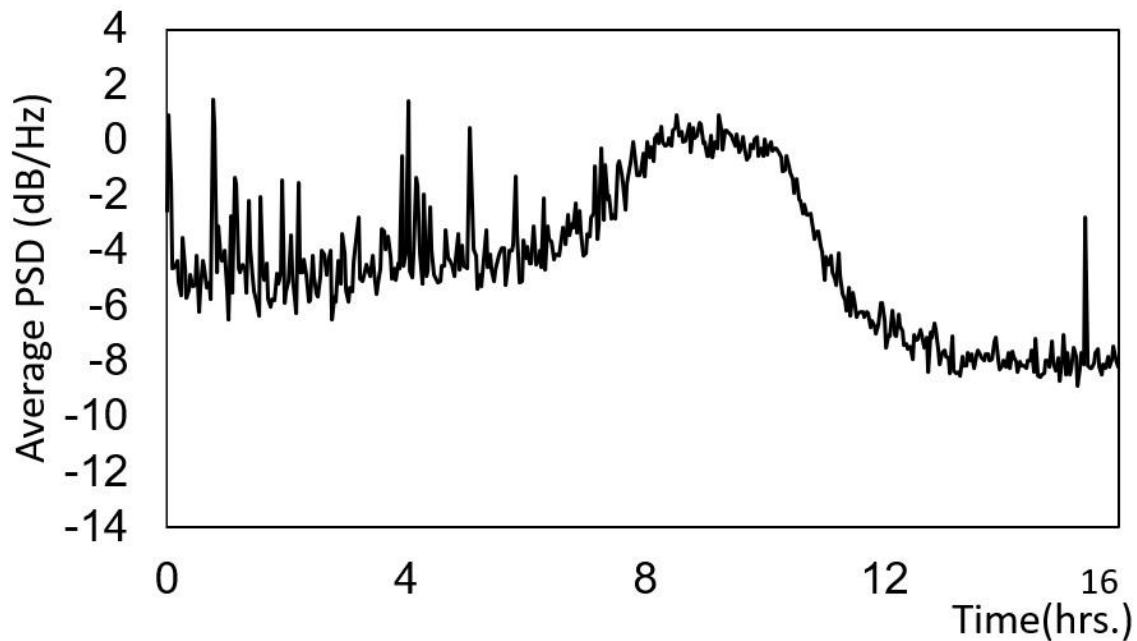


(b) Second Experiment rice powder process 500 grams

Figure 4.9 PSD variation of Japanese rice .

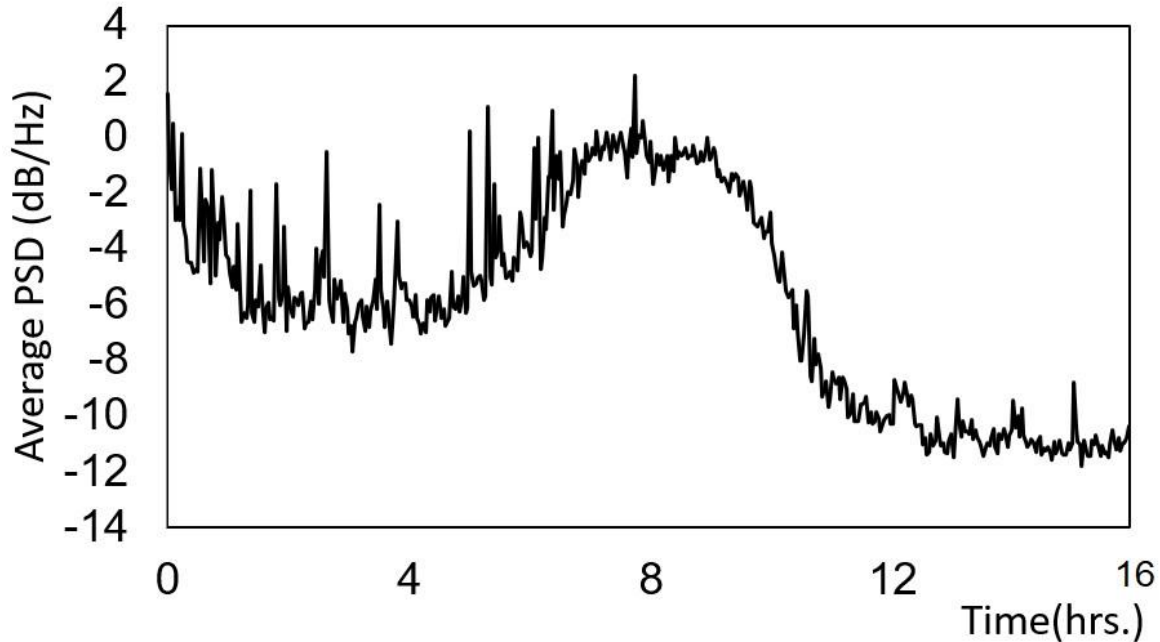
Precision is quantified by repeatability and reproducibility; thus, we performed the Japanese rice powder experiment using 200 grams of rice. Figure 4.6 shows the average PSD value for 200 g of rice powder. In experiment 1, the PSD value varied between  $-2$  and  $-5$  dB/Hz up to 8 hours, and then increased to a maximum value of 1 dB/Hz at 8 hours. The particle size of the rice decreased and some of it become powder. The PSD values decreased to  $-8$  dB/Hz at 12 hours. In

experiment 2, the PSD value varied between  $-3$  and  $-6$  dB/Hz. The PSD value increased to a maximum of  $-0.5$  dB/Hz at 8 h, at which point the rice had mainly become powder. Finally, the PSD value decreased to  $-12$  dB/Hz at 12 hours, at which point, all the rice was powder. The waveform graphs were similar in both experiments from the start until the maximum value, and subsequently, the PSD values were different because the rice powder was affected by humidity. We found that the waveform graph for 500 g of rice powder (Figure 4.9) was similar to that for 200 g of rice powder (Figure 4.10).



(a) First Experiment rice powder process



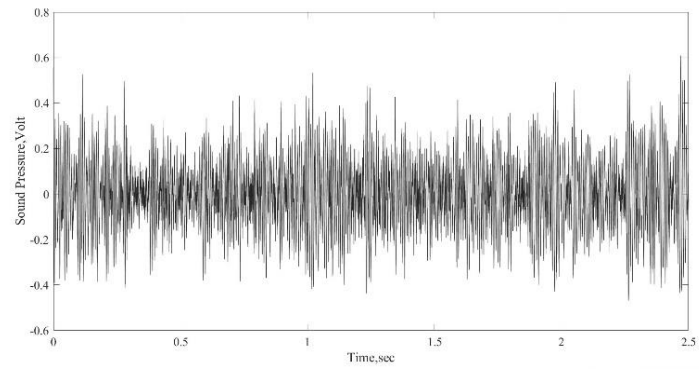


(b) Second Experiment rice powder process

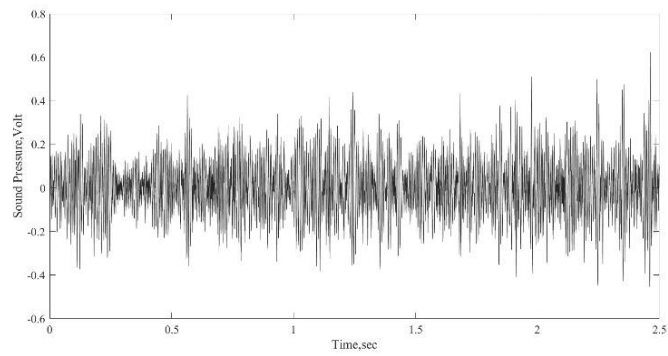
Figure 4.10 PSD variation for 200 g of rice powder

#### 4.3.3 The PSD variation of Japanese green tea

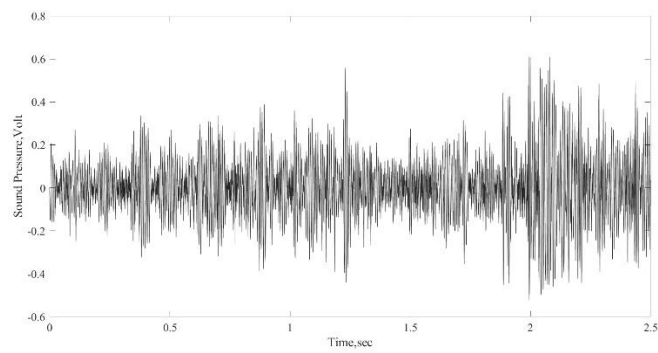
When recorded sound of green tea in the experiment. The example a waveform graphs show in Figure 4.11 and spectrograms graphs show in 4.12 and Figure 4.13 shows the observed results of average PSD values of Japanese green tea. In experiment 1 (Figure 4.13a), the estimated PSD value decreased from  $-16$  to  $-20$  dB/Hz within 1 hours. The tea leaves changed to a smaller particle size and the PSD value varied between  $-20$  and  $-21$  dB/Hz within 2 hours, and some leaves became powder. Finally, after 2 hours, the tea all changed to powder. In experiment 2 (Figure 4.13b), the PSD value decreased to between  $-15$  and  $-20$  dB/Hz within 1 hours; the value then varied between  $-20$  and  $-21$  dB/Hz within 2 hours and some tea leaves became powder. After 2 hours, the PSD value decreased to between  $-21$  and  $-21.5$  dB/Hz, observed as a low swinging graph of a trend line.



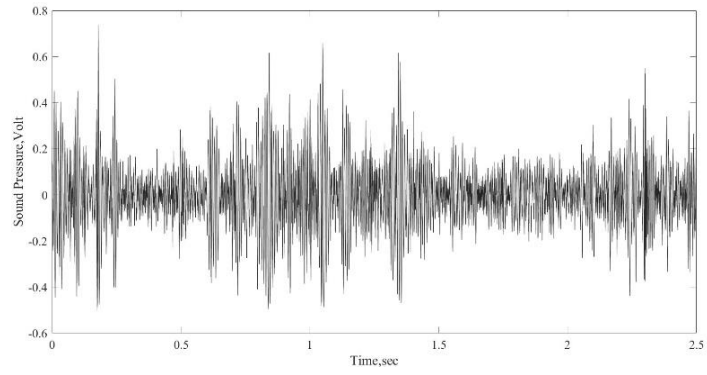
(a) at 0 hr.



(b) at 1 hr.

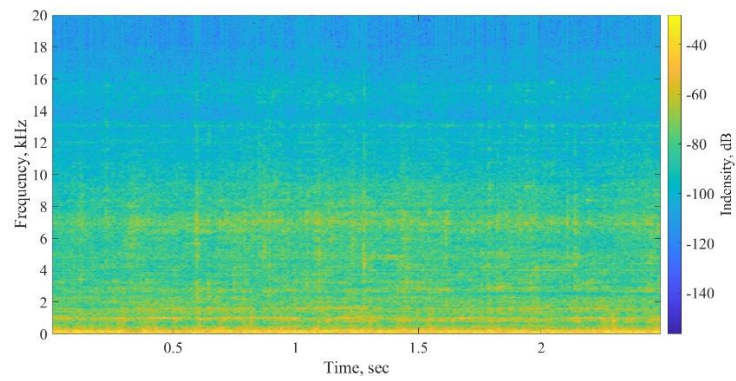


(c) at 2 hr.

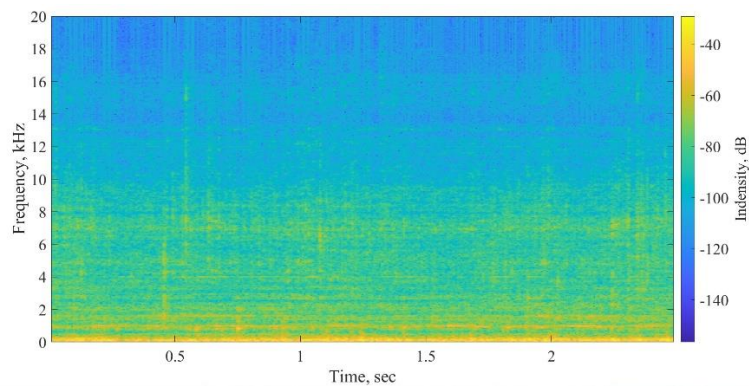


(d) at 3 hr.

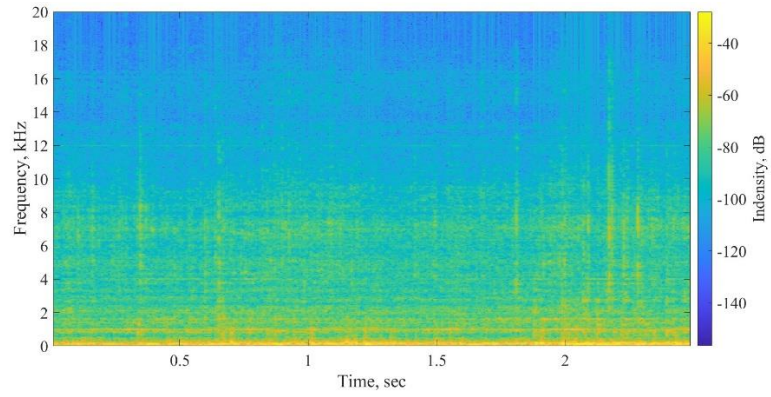
Figure 4.11 The waveform graph for green tea during the experiment



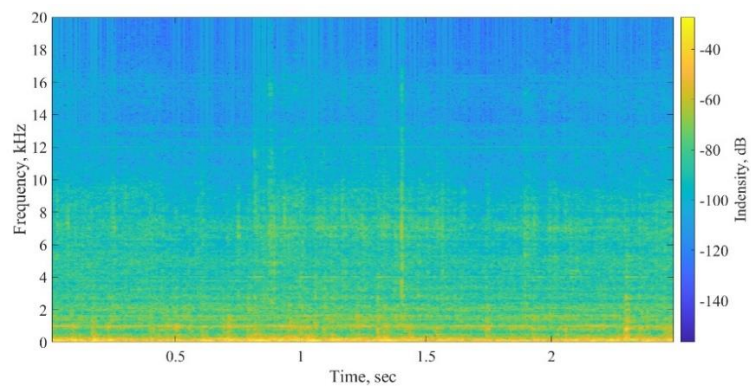
(a) at 0 hr.



(b) at 1 hr.

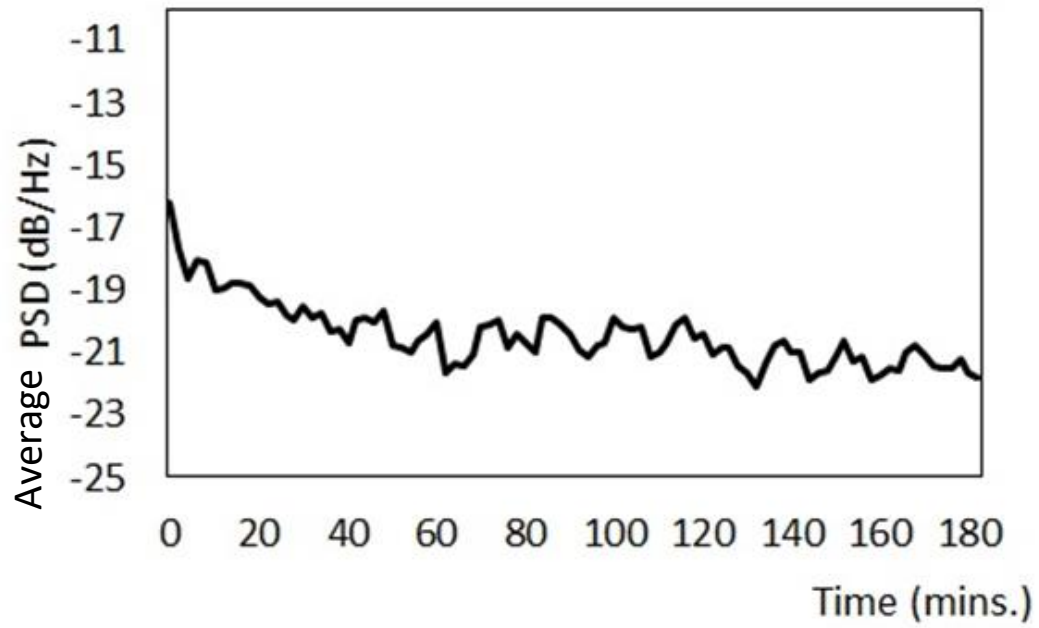


(c) at 2 hr.

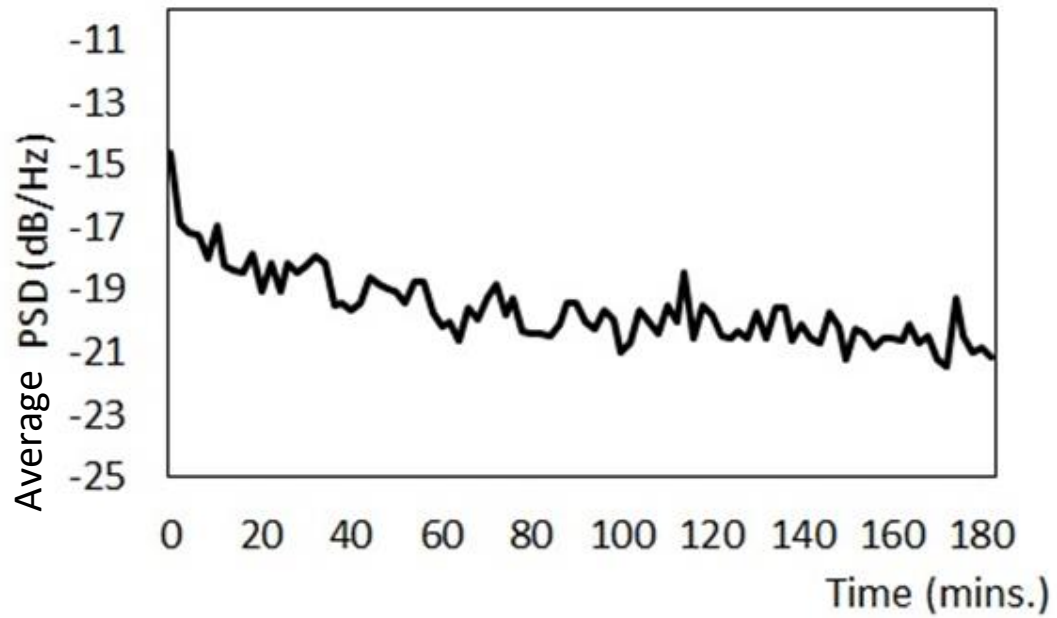


(d) at 3 hr.

Figure 4.12 The waveform graph for green tea during the experiment



(a) First Experiment green tea process



(b) Second Experiment green tea process

Figure 4.13 PSD variation of Japanese green tea.

## 4.4 Process Analyzer Program

The process analyzer program is a software operate on the computer or laptop for show graph and recorded. The graph will be displayed as soon as the communication data is connected and the data will be recorded. Data from the Raspberry Pi is transmitted wirelessly or via USB by wire. The real-time graphs are displayed as valued on the monitor. This program developed by Ishikawa Kojo company in the cooperation with our laboratory show in the Figure 4.14

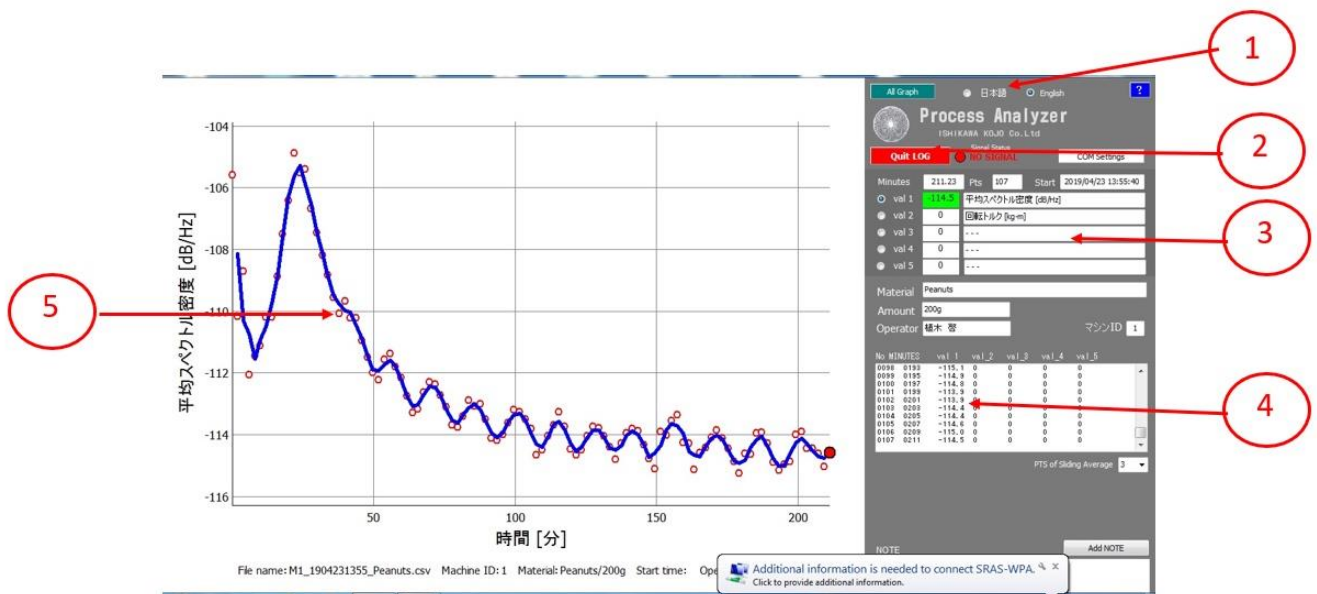


Figure 4.14 The process analyzer program

1. Select language Japanese or English
2. Start/Stop operation program
3. Up to 5 types of data can be recorded and displayed at the same time.
4. Show the details of the received data.
5. Show the graph result.

## 4.5 Correlation Analysis

### 4.5.1 Correlation between sound signal processing and particle size by sieve equipment

According to the results of Japanese rice and green tea leaves, the materials were selected to observe the particle size distribution by visually checking or observing with the microscope to acquire the valid information of the mixing and grinding process. Therefore, we applied sieve analysis to obtain the particle size distribution by using three sieve sizes[2]: 250, 180, and 75  $\mu\text{m}$ . The sample data measured by sieves and recorded weight data for each sieve size were calculated by percentage. Then, we calculated the correlation coefficient between the particle size distribution and the processed sound signal analysis by stopping the machine and collecting sample data for the measurement every 4 hours for the Japanese rice every 1 hours for the green tea leaves. The sieving equipment of experiment show in Figure 4.15



Figure 4.15 Sieving equipment

The characteristic equation of the correlation coefficient is derived as the following equation [3]:

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (4.1)$$

where  $r$  is the correlation coefficient,  $n$  is the number of pairs of data,  $x$  is the value of all sieve size, and  $y$  is the value of all average PSD. We analyze the correlation coefficient between sieve sizes of 250, 180, 75  $\mu\text{m}$ . and the average PSD values.

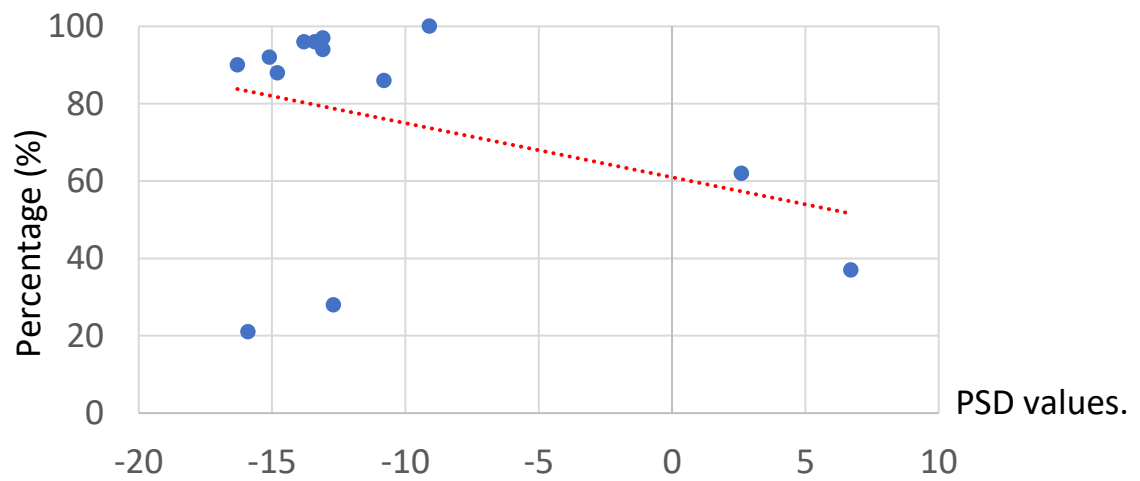
Table 4.1 show the particle size distribution compared with the average PSD values of Japanese rice. We separate 2 sections for analyzing the correlation coefficient of rice with particles. First section, we calculated the correlation coefficient between 0 h to 32 h and found that the correlation coefficient of rice with particle size greater than 250  $\mu\text{m}$  and an average PSD value of 0.68 (Figure 4.16a). This means that the variables have a positive relationship. Particle sizes between 181 and 250  $\mu\text{m}$  had an average PSD value of -0.61(Figure 4.16b). Particle sizes smaller than 180  $\mu\text{m}$  had an average PSD value of -0.58 (Figure 4.16c). Both mean that the variables have a negative relationship. For the second section, we calculated the correlation coefficient between 32 h to 48 h and found that the correlation coefficient of rice with particle size greater than 250  $\mu\text{m}$  had an average PSD value of -0.02. Particle sizes between 181 and 250  $\mu\text{m}$  had an average PSD value of -0.0006. Particle sizes smaller than 180  $\mu\text{m}$  had an average PSD value of -0.001. This means that the variables do not have a relationship.

**TABLE 4.1** Comparison of the particle size percentage and average PSD value of rice 500 grams.

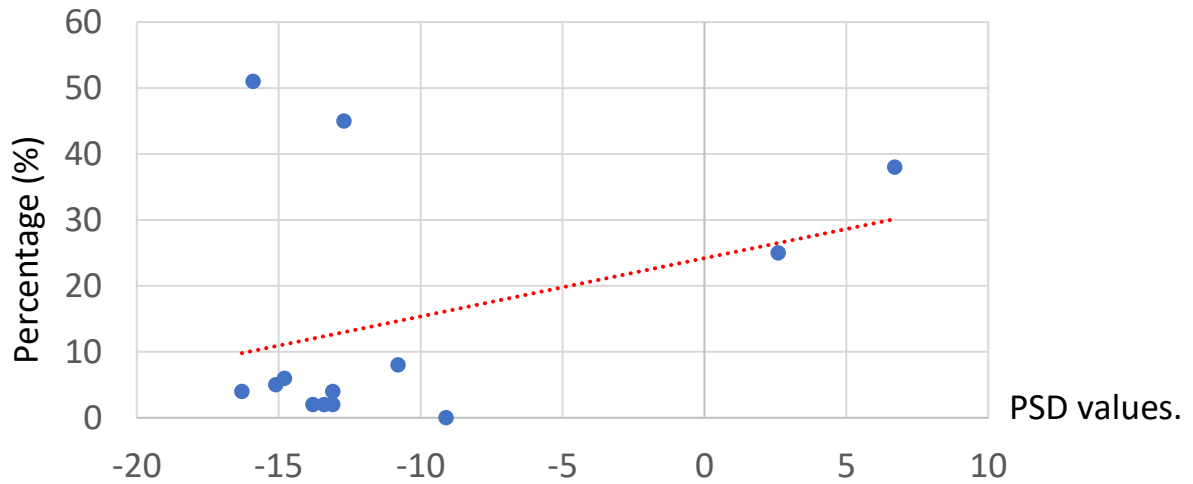
Time (Hr.)	Sieve size 250 $\mu\text{m}$ .(%)	Sieve size 180 $\mu\text{m}$ .(%)	Sieve size 75 $\mu\text{m}$ .(%)	Average PSD value (dB/Hz)
0	100	0	0	-9.1
4	97	2	0	-13.1
8	96	2	0	-13.8
12	96	2	1	-13.4



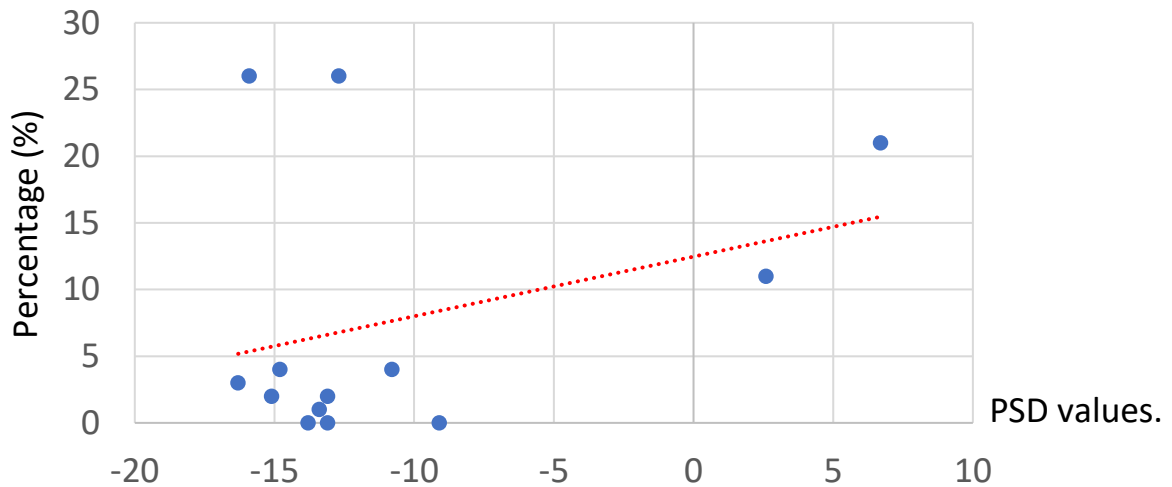
16	94	4	2	-13.1
20	92	5	2	-15.1
24	90	4	3	-16.3
28	88	6	4	-14.8
32	86	8	4	-10.8
36	62	25	11	2.6
40	37	38	21	6.7
44	28	45	26	-12.7
48	21	51	26	-15.9



(a) Correlation between sieve size 250  $\mu\text{m.}$  and PSD values.



(b) Correlation between sieve size 180  $\mu\text{m.}$  and PSD values.



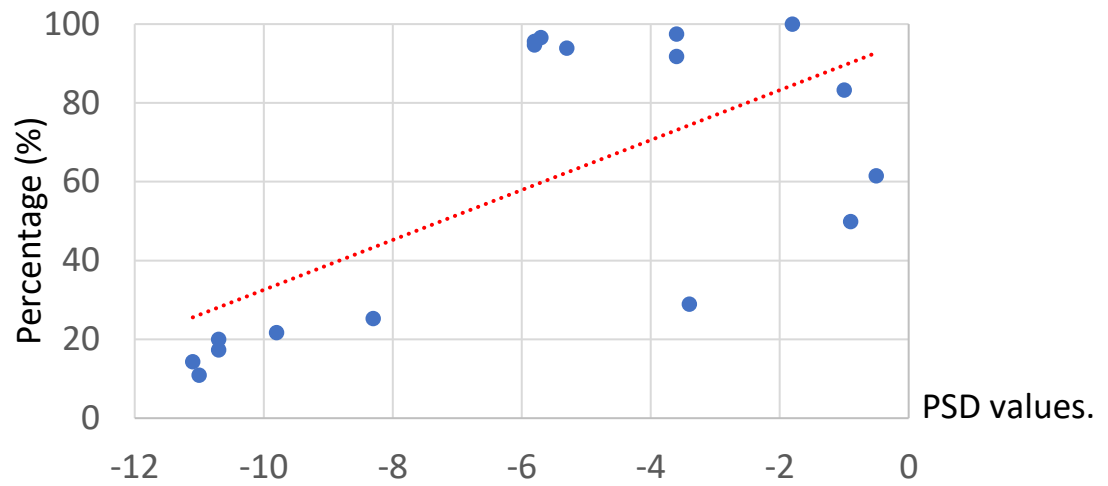
(c) Correlation between sieve size 75  $\mu\text{m.}$  and PSD values.

Figure 4.16 Correlation between particle size and PSD value of Japanese rice 500 grams.

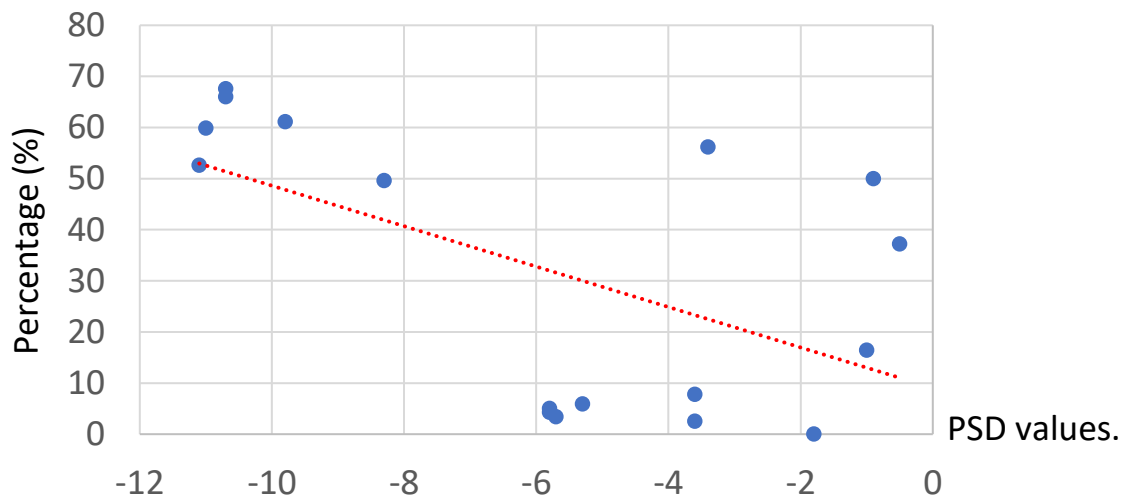
Table 4.2 shows the particle size distribution compared with the average PSD values for 200 grams of Japanese rice in Figure 4.6, experiment 2. The correlation coefficient of rice with a particle size greater than 250  $\mu\text{m}$  had an average PSD value of 0.65(Figure 4.17a); thus, the variables had a positive relationship. Particle sizes between 181 and 250  $\mu\text{m}$  had an average PSD value of  $-0.41$  (Figure 4.17b), and particle sizes smaller than 180  $\mu\text{m}$  had an average PSD value of  $-0.68$  (Figure 4.17c). The experiments with 200 and 500 grams of rice (Figures 4.9 and 4.10) had similar correlation coefficients, indicating that the method was repeatable.

**TABLE 4.2** Comparison of the particle size percentage and average PSD value of rice 200 grams.

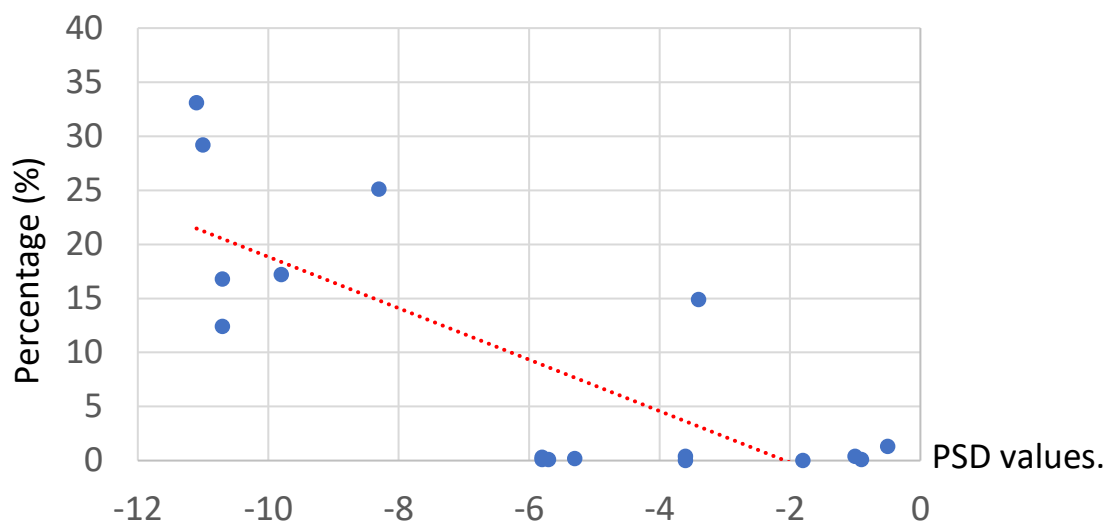
Time (Hr.)	Sieve size 250 $\mu\text{m.}(\%)$	Sieve size 180 $\mu\text{m.}(\%)$	Sieve size 75 $\mu\text{m.}(\%)$	Average PSD value (dB/Hz)
0	100	0	0	-1.8
1	97.5	2.5	0.0	-3.6
2	96.6	3.4	0.1	-5.7
3	95.6	4.3	0.1	-5.8
4	94.7	5.0	0.3	-5.8
5	93.9	5.9	0.2	-5.3
6	91.8	7.8	0.4	-3.6
7	83.3	16.4	0.4	-1.0
8	61.5	37.2	1.3	-0.5
9	49.9	50.0	0.1	-0.9
10	28.9	56.2	14.9	-3.4
11	25.3	49.6	25.1	-8.3
12	21.7	61.1	17.2	-9.8
13	20.0	67.6	12.4	-10.7
14	17.3	66.0	16.8	-10.7
15	14.3	52.6	33.1	-11.1
16	10.9	59.9	29.2	-11.0



(a) Correlation between sieve size 250  $\mu\text{m.}$  and PSD values.



(b) Correlation between sieve size 180  $\mu\text{m.}$  and PSD values.



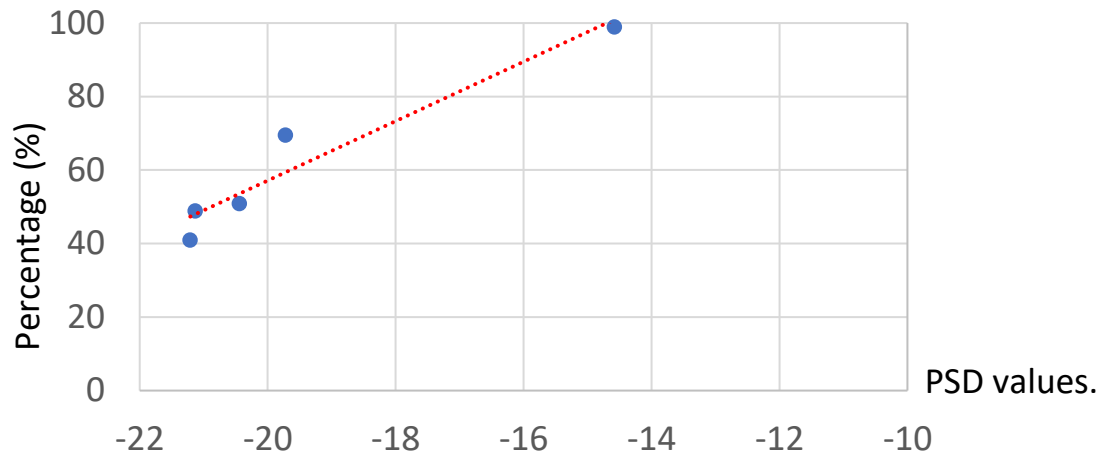
(c) Correlation between sieve size 75  $\mu\text{m.}$  and PSD values.

Figure 4.17 Correlation between particle size and PSD value of Japanese rice 200 grams.

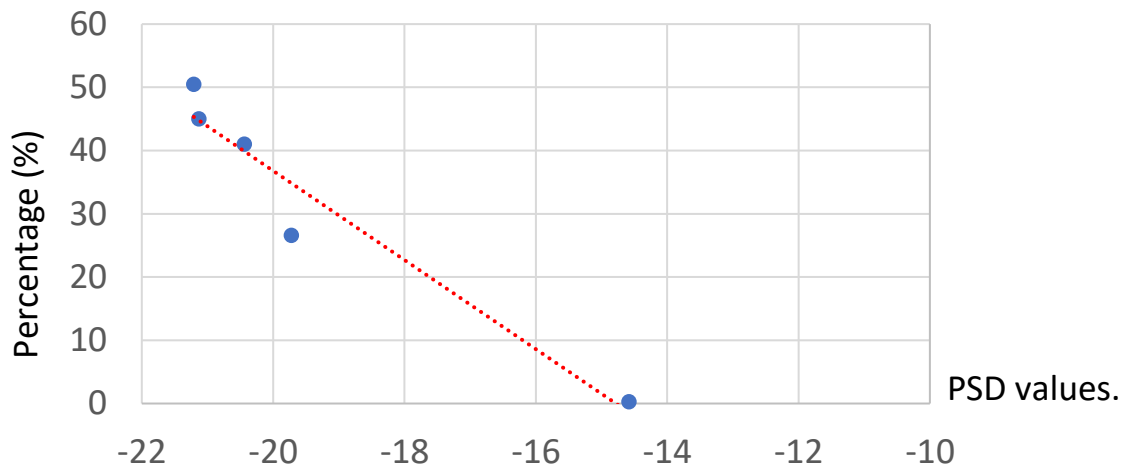
Tables 4.3 show the particle size distribution compared with the average PSD values of green tea leaves. We found that the correlation coefficient of green tea leaves for particle sizes more than 250  $\mu\text{m}$ , the average PSD value was 0.96 (Figure 4.18a). This means that the variables have a highly positive relationship. Particle sizes between 181 and 250  $\mu\text{m}$  had an average PSD value of  $-0.96$  (Figure 4.18b) and particle sizes smaller than 180  $\mu\text{m}$  had an average PSD value of  $-0.88$  (Figure 4.18c) meaning that the variables have a highly negative relationship.

**TABLE 4.3** Comparison of the particle size percentage and average PSD value of green tea.

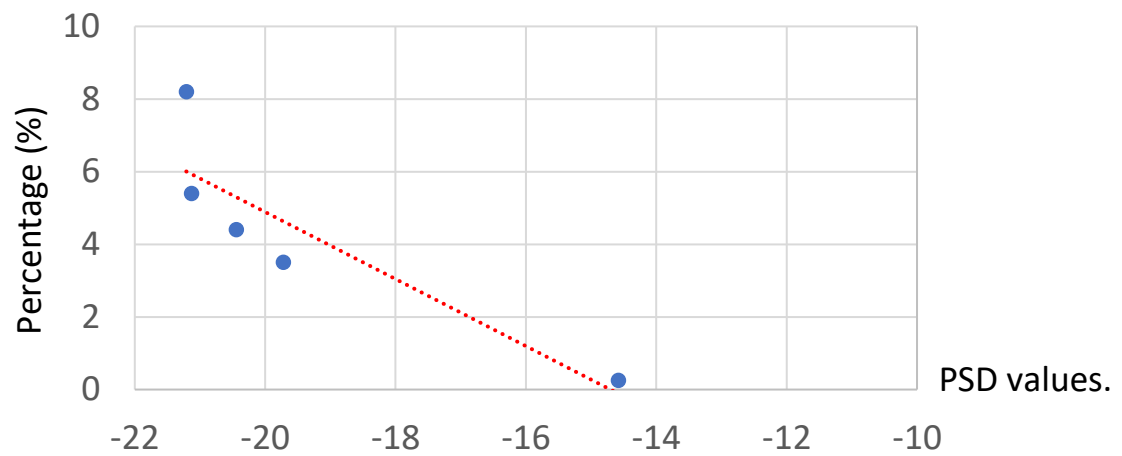
Time (Hr.)	Sieve size 250 $\mu\text{m.}$ (%)	Sieve size 180 $\mu\text{m.}$ (%)	Sieve size 75 $\mu\text{m.}$ (%)	Average PSD value (dB/Hz)
0	99	0.3	0.25	-14.58
1	69.5	26.6	3.5	-19.72
2	50.9	41	4.4	-20.44
3	48.9	45	5.4	-21.13
4	41	50.5	8.2	-21.21



(a) Correlation between sieve size 250  $\mu\text{m.}$  and PSD values.



(b) Correlation between sieve size 180  $\mu\text{m.}$  and PSD values.



(c) Correlation between sieve size 75  $\mu\text{m.}$  and PSD values.

Figure 4.18 Correlation between particle size and PSD value of green tea

#### **4.5.2 Correlation between particle size and sound signal processing by image processing**

Investigation of the particle size material is very important. In order to monitor the progress investigation of the Ishikawa mixing and grinding machine completely. In this section, we were using image processing to calculate the particle size and study of the correlation with the sound signal processing [4].

In this experiment, we use images recorded by microscope (Keyence VHX-1000) and using the ImageJ software to calculate the particle size. The procedures analyses with the ImageJ have 6 steps.

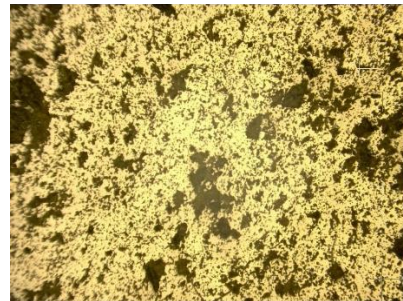
1. Open image file to be analyzed
2. Use rectangular to select the specific image and crop
3. Convert the image to 8-bit grayscale and optimized threshold
4. Set scale pixel to micrometer by click menu analyze
5. Use the menu Analyze and click on analyze particle
6. Set the display results and exclude on edges, and set up a show by outlines.

In the experiment, we used Japanese green tea leaf 200 grams were mixed and grinded by the machine and recorded sound signal via microphone in 5 seconds every 2 minutes and run machine continuously 180 minutes or 3 hours.

For the images processing, we stop machine and keep sample green tea leaf data 10 grams at every 1 hour to analyze by microscope and ImageJ software [5] see Figure 4.15 in the Figure 4.19.

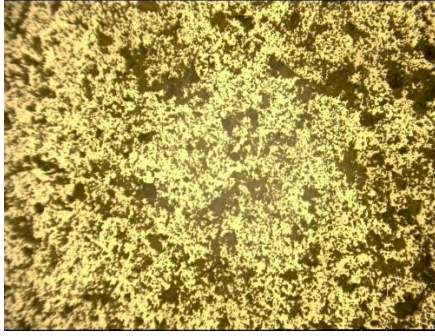


(a) At 30 mins.

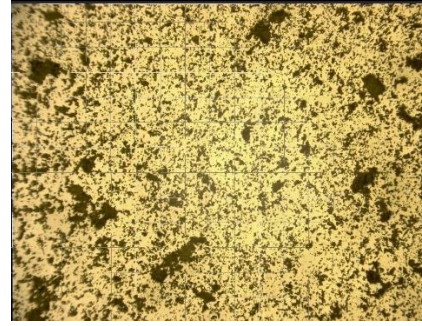


(b) At 60 mins.





(c) At 120 mins.



(d) At 180 mins.

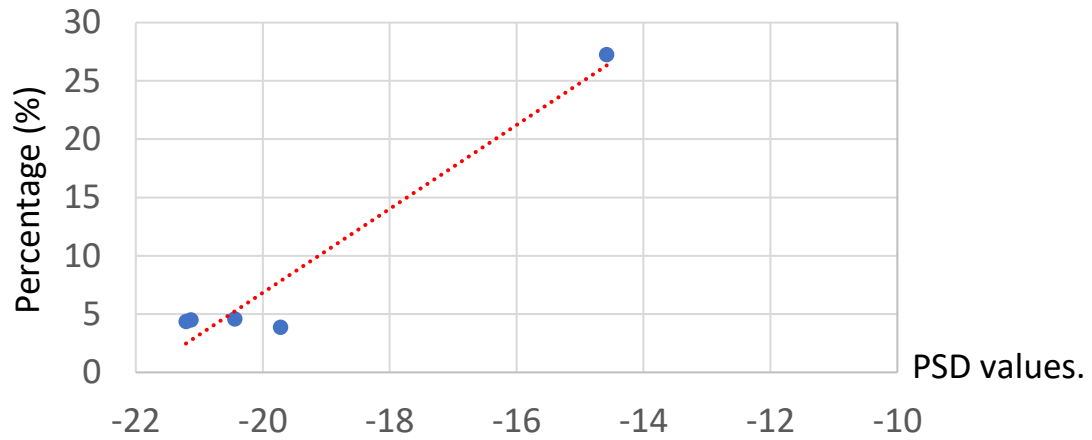
Figure 4.19 Status material from microscope in the experiment.

The calculated of average value every 1 hour and compare with the particle size, and the results are present in the Table 4.4 . The correlation coefficient between particle size and the average value of average PSD at size  $> 100 \text{ (um)}^2$  is 0.922 (Figure 4.20a), which means the variables have high positive relationship, and size between  $10\text{-}100 \text{ (um)}^2$  is -0.798 (Figure 4.20b), size  $< 10 \text{ (um)}^2$  is -0.873 (Figure 4.20c) which means the variables have high negative relationship respectively.

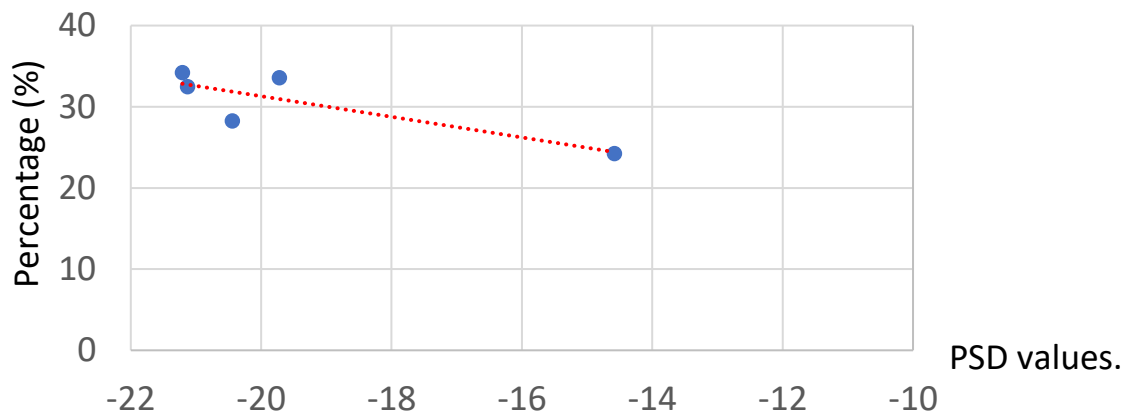
**Table 4.4** Comparison of the particle size percentage and average PSD value of green tea by image analysis

Time (Hr.)	size $>100$ ( $\text{um}$ ) <sup>2</sup>	size $10\text{-}100$ ( $\text{um}$ ) <sup>2</sup>	size $<10$ ( $\text{um}$ ) <sup>2</sup>	Average of Avg. PSD (dB/Hz)
0	27.27	24.24	47.00	-14.58
1	3.87	33.60	62.50	-19.72
2	4.59	28.26	67.05	-20.44
3	4.52	32.47	63.00	-21.13
4	4.38	34.22	61.39	-21.21

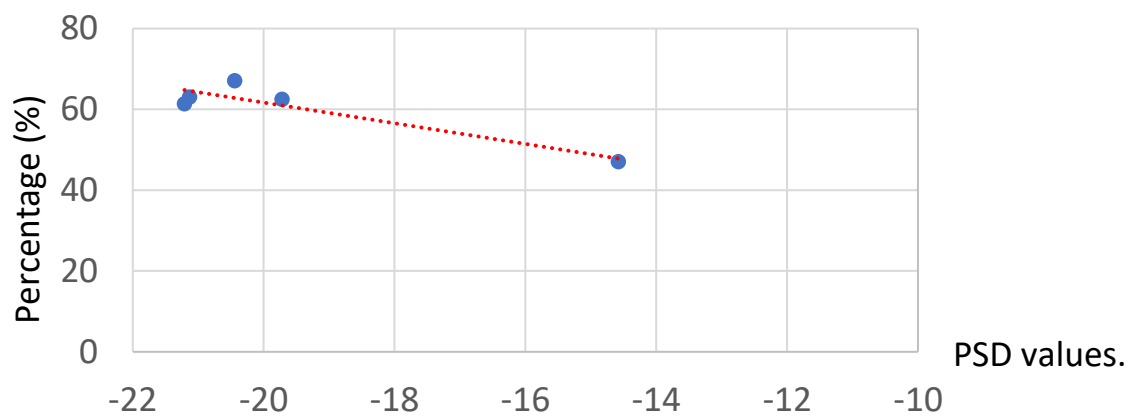
Figure 4.20 show the correlation between percentage of the particle size and the average PSD values.



(a) Correlation between particle size  $100 \mu\text{m}^2$ . and PSD values.



(b) Correlation between particle size  $10-100 \mu\text{m}^2$ . and PSD values.



(c) Correlation between particle size  $<10 \mu\text{m}^2$ . and PSD values.

Figure 4.20 The particle size distribution ratio (%).

### 4.5.3 Correlation between current measurement and sound signal processing

In the section, studying correlation between current measurement and PSD values to improvement of the process estimation. Figure 4.21 shows both example waveform of sound signal and supply current. In a short time, remarkable variation does not appear in both waveforms. Therefore, averaged PSD is effective to obtain the progress investigation of the material. Although the supply current is RMS value, the supply current waveform is not sinusoidal. It is not predicted that the RMS value is sufficient to improve the accuracy of the progress investigation.

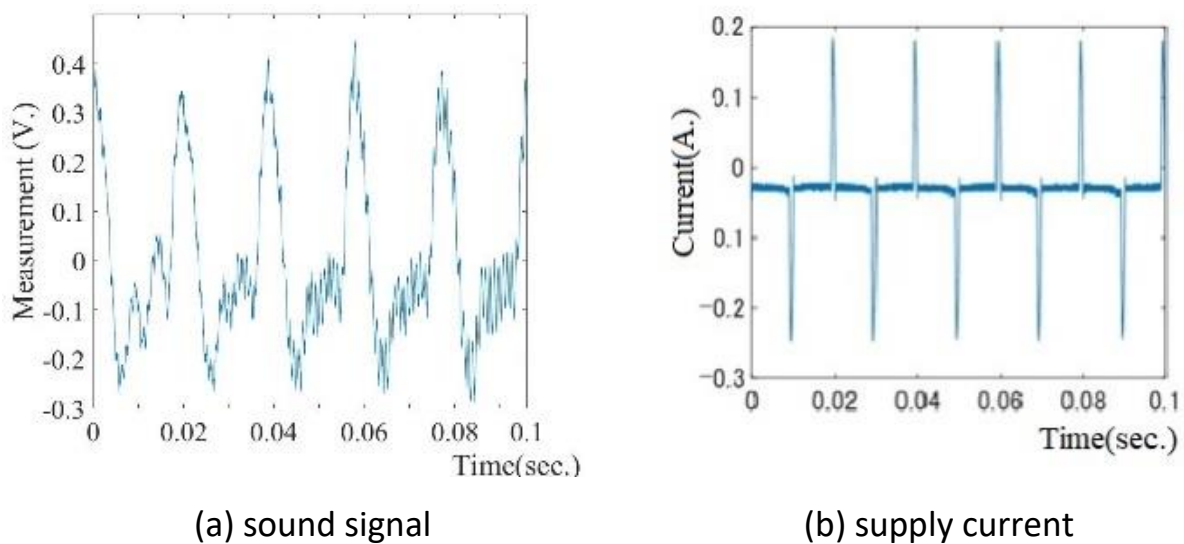


Figure 4.21 Example of recorded waveforms.

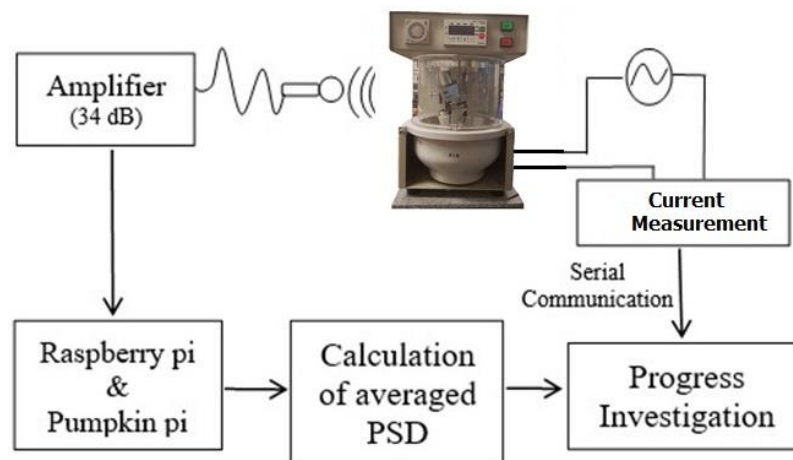


Figure 4.22 Block diagram for sound signal and current analysis.

Figure 4.22 Sound analysis data and supply current are used for the purpose of the accurate progress investigation of the mixing and grinding machine. The sound recorded via microphone set up at 5 seconds and root-mean square (RMS) value of supply current were measured every 2 minutes simultaneously.

The peanut and Japanese rice material are used to in this experiment. By setup sound recorded this same condition. That is peanut used to 80 grams and 50 grams of sugar were mixed and grinded by the machine in 200 minutes and Japanese rice 500 grams run the machine 48 hours.

The featured condition of the peanuts changes as mixing and grinding proceeds as shown in Figure 4.23 shows observation result for averaged PSD value.

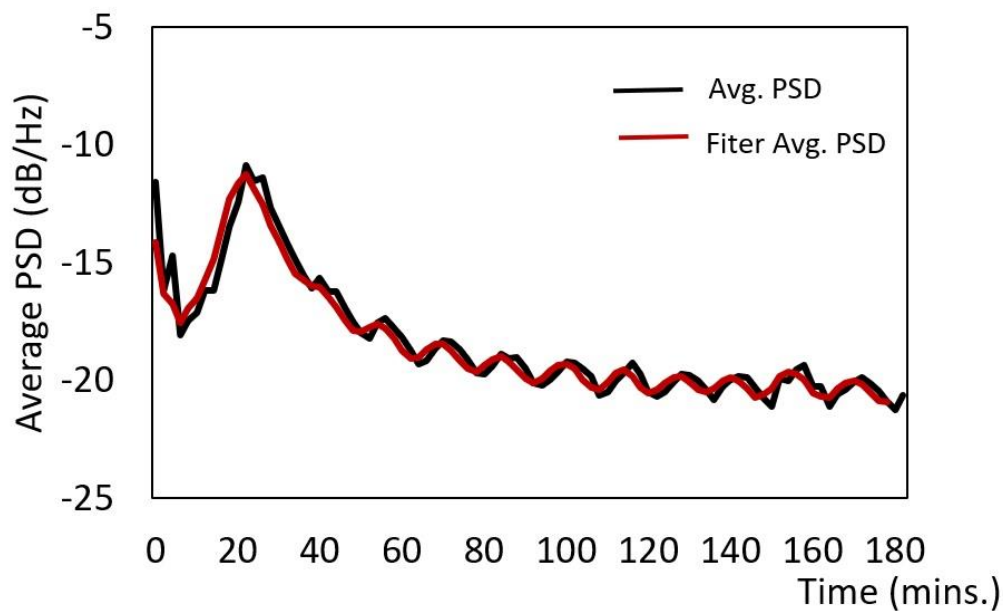


Figure 4.23 The averaged PSD variation of peanut

The featured condition of the peanuts changes as mixing and grinding proceeds as shown in Figure 4.23 After 20 minutes, the grinded peanuts gather and become into a lot of ball form. After 40 minutes, ball forms bind and become a large sticky lump. Finally, the peanuts change into cream condition.

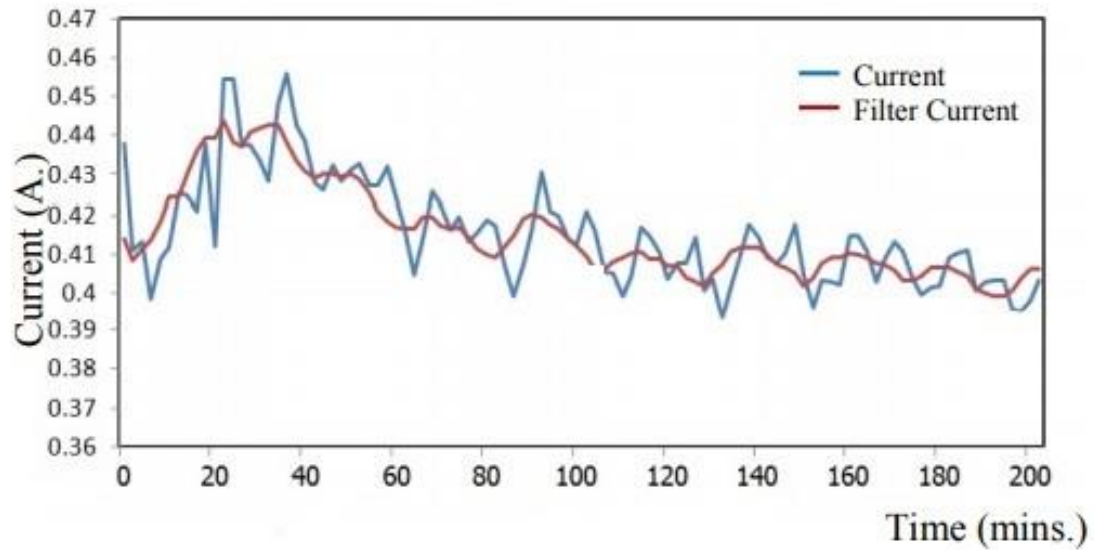


Figure 4.24 The supply current variation of peanut.

Figure 4.24 shows the variation of the supply current. According to blue lines indicated in both Figure 4.19 and Figure 4.20, a small variation during short time appears. To avoid small variations, averaging filter process is applied to both blue lines. As found by the brown line in Figure 4.19 and 4.20, the curve of the averaged PSD value and the supply current increases continuously until 25 minutes when the peanut particle become into a large sticky lump. And then the average PSD value and the supply current decreases until the lump peanut becomes into creamy.

The correlation between the averaged PSD data and the supply current is 0.869 see in the Figure 4.25. It means that the variables have high positive relationship. The maximum value of the supply current also appears around 25 minutes when the average PSD is also maximum value and the graph are similar in the 60 minutes onwards. It is considered that the supply current depends on viscosity directly.

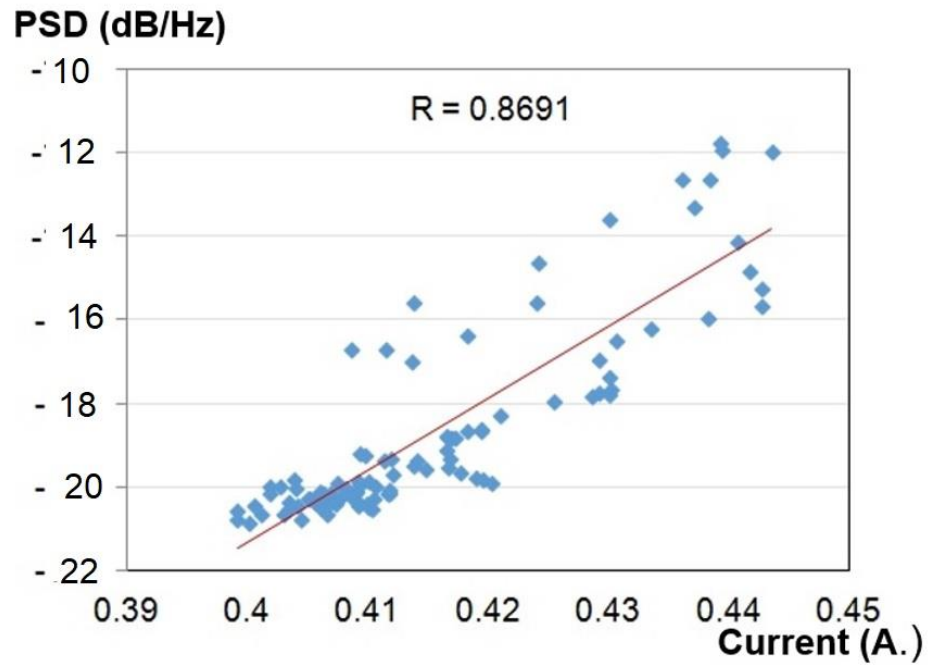


Figure 4.25 The correlation between the average PSD value and current value of peanut

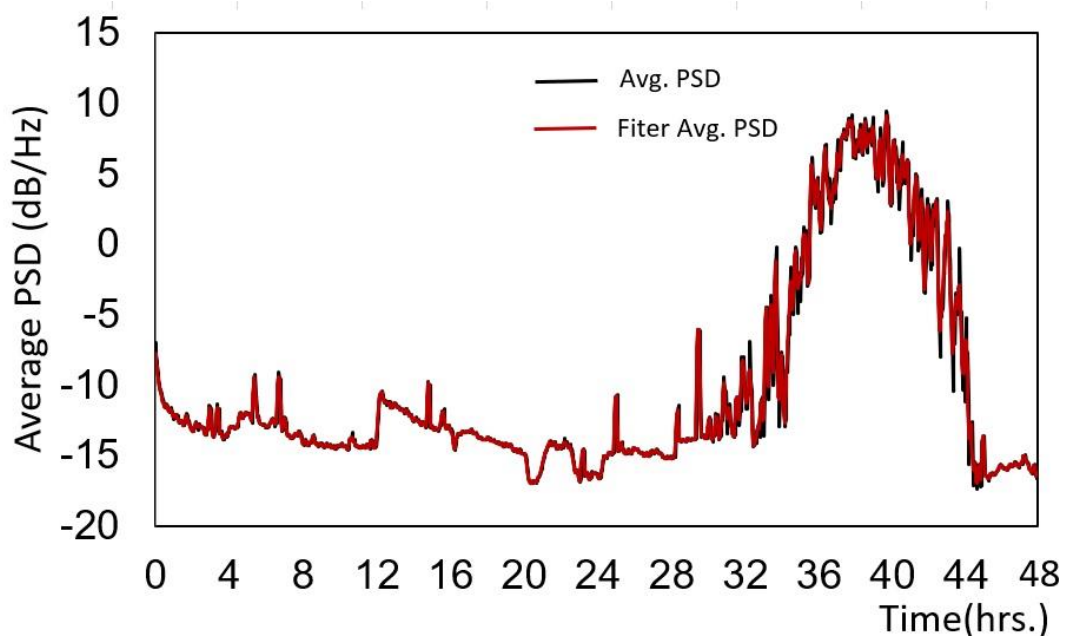


Figure 4.26 The averaged PSD variation of Japanese rice

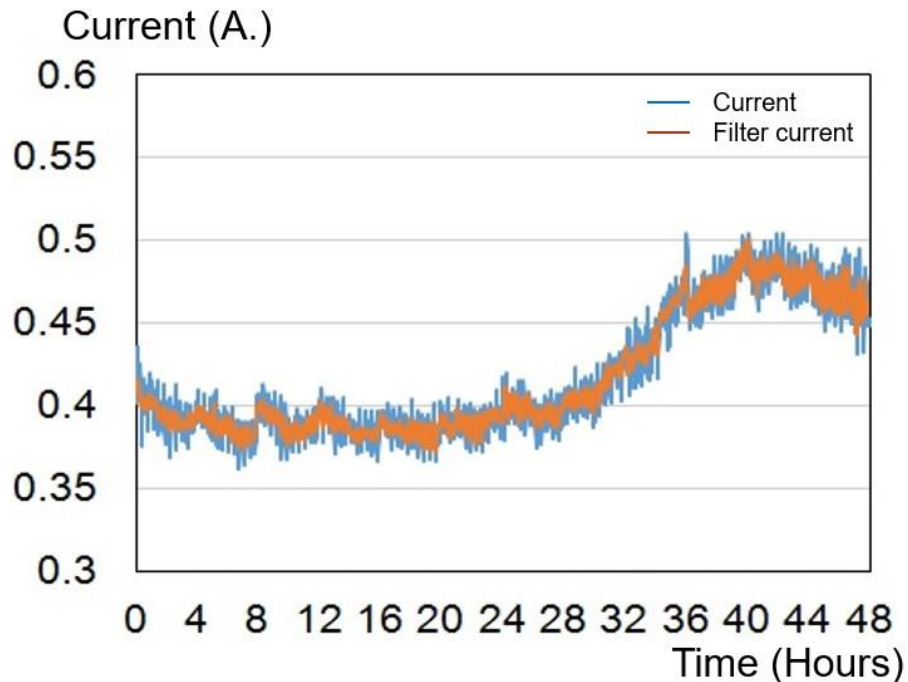


Figure 4.27 The supply current variation of Japanese rice

Figure 4.26 and Figure 4.27 shows the variation of the PSD values and shows the supply current variation of Japanese rice. The curve of the averaged PSD value and the supply current straight line or the values less change until 32 hours when the Japanese rice grain begins to crack. The average PSD value and the supply current increases until the grain become into a small size. And then the PSD decrease until the Japanese rice becomes into rice powder. But the supply current values slightly decrease when compared to the PSD values graph change into powder condition.

The correlation between the averaged PSD data and the supply current is 0.704 see in the Figure 4.28 It means that the variables have positive relationship. The maximum value of the supply current also appears around 40 hours when the average PSD is also maximum value and the graph are similarly. The current value can be investigated process until becomes rice powder until 40 hours. Therefore, the supply current is also important to investigate the mixing and grinding progress of the machine.

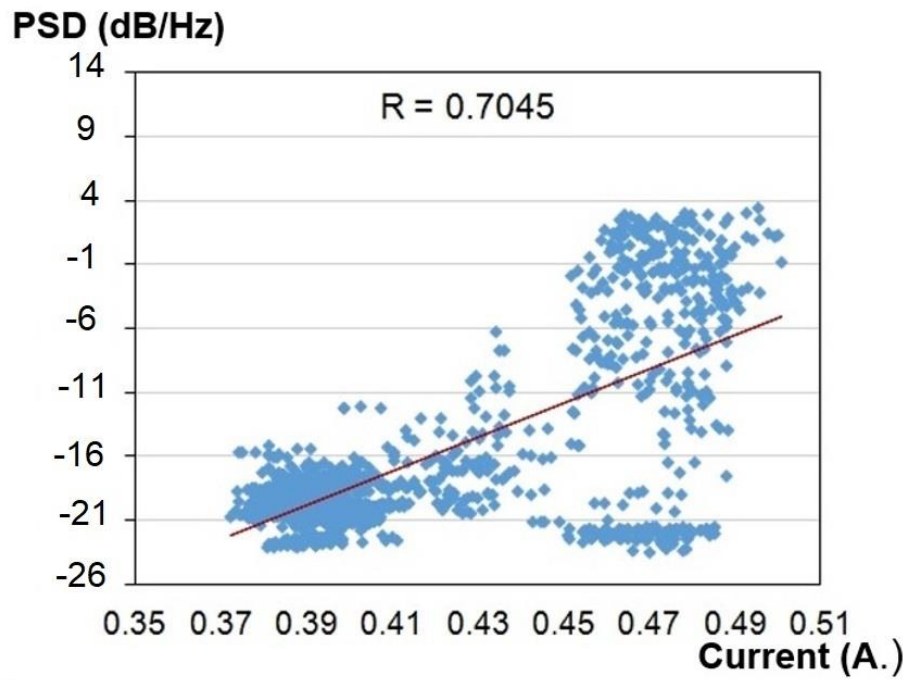


Figure 4.28 The correlation between the average PSD value and current value of Japanese rice



## Reference

- [1] “Power Spectral Density Estimates Using FFT”, Available: <https://www.mathworks.com/help/signal/ug/power-spectral-density-estimates-using-fft.html>
- [2] “Sieve analysis”, Available: [https://en.wikipedia.org/wiki/Sieve\\_analysis](https://en.wikipedia.org/wiki/Sieve_analysis)
- [3] “Correlation Coefficient Formula”, Available: <https://www.statisticshowto.com/probability-and-statistics/correlation-coefficient-formula/>
- [4] Richard G. Lyons, “Understanding Digital Signal Processing (3rd Edition)”, Boston, USA: Prentice Hall, 2010.
- [5] Tiago Ferreira, Wayne Rasband, (2012, October). ImageJ User Guide. Retrieved from: <https://imagej.nih.gov/ij/docs/guide/user-guide.pdf>

## CHAPTER 5 CONCLUSION

This chapter presents the conclusion of the new method for the progress investigation of the mixing and grinding machine. In order to monitor data remotely, we use sound analysis and calculate the PSD estimation. In this research we used three materials for the experiments: peanut, Japanese rice and Japanese green tea leaf. The obtained results in the research as follows.

1. For the peanuts, the PSD value decreases to until the grinded peanuts gather and become a ball shape. After that the PSD value increases to maximum value a ball shape binds and becomes large sticky lump. Finally, the average PSD value decreases slowly until approaching to straight line in which the lump peanut becomes creamy. The Japanese rice, PSD values a little has change in the beginning until the grain rice transforms to a smaller size and some of them become powder. The PSD value increases until maximum values. At the time, grain rice mostly becomes rice powder. Finally, the PSD value decreases until the PSD graph does not change. After that, all grain rice transforms to powder. The Japanese green tea leaf change to a smaller particle size and the PSD value decrease and some green tea leaves become powder. When the Japanese green tea all changes to green tea powder. The PSD value observed as a low swing graph of the trend line.

2. In addition, the trend line characteristics of the graph are similar. The PSD value decreases as particle size of material becomes smaller by the mixing and grinding process. When the PSD value decreases until the steady state, it will not change the material property in the mixing and grinding process. Therefore, the PSD estimation is obtained to achieve the desired result.

3. For the experiment about material process changing from large to small size or becoming powder such as Japanese rice and Japanese green tea leaf, we apply sieve measurement to obtain the particle size distribution and study the correlation between the particle distribution and the processed sound signal. The results show that the coefficient of correlation values is significant. Therefore, it can be confirmed that the progress investigation of the mixing and grinding machine using sound signal processing is successful.

4. In this research, we study the current measurement method for improvement of the accuracy in progress process of the Ishikawa mixing and grinding machine. The maximum value in both current variation and sound variation curves appeared at the similar time. The correlation between the averaged PSD data and the supply current for peanut is 0.869 and Japanese rice is 0.704. It means that the variables have positive relationship of both materials. Therefore, supply current measurement is valid to increase progress estimation accuracy of the machine.

In the future plan, examine another sensor data in order to improve the accuracy of the process progress investigation and extend the proposed method to the IoT environment.

## **APPENDIX**

At first, we created Python programs to calculate the average PSD values. The screen shot with program is shown as follows. The employed IDE is PyCharm version 2020.1.



We used the libraries in the program follow as:

1. NumPy library used for mathematical functions
2. SciPy library used for read the wav files.
3. Matplotlib library used for calculate the average PSD values and plotting graph result.

Example execute the Python script from the PyCharm program show in below:

