# EVALUATION OF SOUND ABSORPTION OF MICRO PERFORATED PANEL MADE BY PALM OIL FIBER

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# DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed………………………………………………………… (Nur Sarah binti Zainal Abidin)

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This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by giving explicit references.

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| | |
|---|---|
| MPP | Micro-perforated panel |
| SAC | Sound Absorption Coefficient |
| PLA | Polylactic acid |

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# PERNILAIAN PENYERAPAN BUNYI PANEL BERLUBANG MIKRO YANG DIPERBUAT OLEH SERAT MINYAK KELAPA SAWIT

## ABSTRAK

Pada masa kini, kawasan bandar terdedah kepada kesan negatif pencemaran bunyi akibat pembangunan pesat pengangkutan, perindustrian, dan pembandaran. Oleh itu, pengawalan bunyi adalah amat penting dan perlu dikendalikan. Panel berlubang mikro (MPP) boleh menjadi kaedah yang berkesan untuk meminimumkan pencemaran bunyi secara ketara. Oleh itu, tujuan kajian ini adalah untuk menentukan kesan penggunaan Serat Kelapa Sawit sebagai MPP dan saiz tebuk dari segi pekali serapan bunyi. Ini akan membolehkan prestasi penyerapan bunyi MPP dipertingkatkan. Pada langkah pertama proses, sampel dibuat daripada gentian kelapa sawit dan kemudian ditebuk menggunakan mesin Kawalan Berangka Komputer (CNC) dengan diameter lubang 1 mm. Selepas itu, satu eksperimen menggunakan tiub impedans dilakukan. Keputusan pengukuran menunjukkan bahawa panel serap bunyi dengan struktur MPP mencipta prestasi akustik yang lebih baik daripada panel serap bunyi tanpa struktur MPP. Menggunakan model ramalan Maa sebagai asas teori, MATLAB digunakan untuk mensimulasikan prestasi penyerapan bunyi bagi setiap senario yang mungkin. Menurut penemuan, nilai puncak pekali serapan bunyi (SAC) meningkat apabila terdapat peningkatan dalam kedua-dua ketebalan dan saiz lubang. Tambahan pula, ia menggerakkan puncak ke arah julat frekuensi yang lebih tinggi, yang seterusnya mengurangkan lebar jalur. Menurut penemuan MPP mempunyai potensi untuk digunakan dalam penyerap bunyi komersial dengan mengubah suai saiz tebuk dalam bahan. Penemuan juga menunjukkan bahawa struktur MPP mempunyai potensi dalam meningkatkan kecekapan penyerapan bunyi serat kelapa sawit dalam jalur frekuensi tertentu.

# EVALUATION OF SOUND ABSORPTION OF MICRO PERFORATED PANEL MADE BY PALM OIL FIBER

## ABSTRACT

Nowadays, the urban areas are prone to the negative effects of noise pollution as a result of rapid development of transportation, industrialisation, and urbanisation. Therefore, the regulation of noise is extremely important and needs to be handled. Micro-perforated panels (MPP) can be a promising method to minimise noise on a significant basis. Therefore, the purpose of this study is to determine the effect of using Oil Palm Fibre as MPP and the size of the perforations in terms of the sound absorption coefficient. This will allow the sound absorption performance of MPP to be improved. In the first step of the process, the samples are made from oil palm fibre and then perforated using a Computer Numerical Control (CNC) machine with a hole diameter of 1 mm. Following that, an experiment using impedance tube is performed. The results of the measurements demonstrate that the sound-absorbing panel with MPP structure creates a better acoustic performance than the sound-absorbing panel without MPP structure. Using the Maa prediction model as a theoretical basis, the MATLAB software was used to simulate the sound absorption performance of each possible scenario. According to the findings, the peak value of the sound absorption coefficient (SAC) increases when there is an increase in both the thickness and size of the perforations. Furthermore, it moves the peak towards the higher frequency range, which in turn reduces the bandwidth. According to the findings MPPs have the potential to be used in commercial sound absorbers by modifying the size of the perforations in the material. The findings also demonstrated that the MPP structure possesses the potential in improving the sound absorption efficiency of oil palm fibre within a particular frequenc

# CHAPTER 1

# INTRODUCTION

## 1.1 Background Study

Noise is best described as an environmental and social issue resulting from consumption patterns and lifestyles in the rapid economic growth, and it is produced by machines, railways, aircraft, loudspeakers, and so on[1]. Noise pollution has been defined as one of the four major environmental pollutant. Low frequency noise, in particular, has been found to cause hearing loss, headaches, sleep disturbance, inattention, and other symptoms, and thus regarded as one of the causes of degradation in people's quality of life[1]. Sound absorption materials like glass fibre and foam degrade over time and are non-renewable, making them less environmentally friendly. Small particles are dislodged and flow via ventilation ducts, polluting the air within buildings[2].

The micro-perforated panel (MPP) has evolved as a desirable sound absorption material, with greater uses in environmental acoustics, ventilation, aviation, and precision instruments[3]. MPP absorber is a common non-fibrous absorbing material that can be a good substitute for traditional fibre and porous absorbing materials. A single MPP absorber is made of a panel with submillimetre perforations and a backing cavity against the panel, allowing it to absorb sound in the one or two octave range[4].

As shown in Fig. 1(a), the original Maa MPP absorber, which is the most prevalent among numerous MPP sound-absorbing systems, is composed of a single MPP and a stiff back wall with an air-cavity in between[5]. Each hole in the MPP and volume behind it create Helmholtz resonators, resulting in a single resonance peak in absorption characteristics. The electric circuit in Fig. 1 (b) can be used to explain this system in the same way[5].

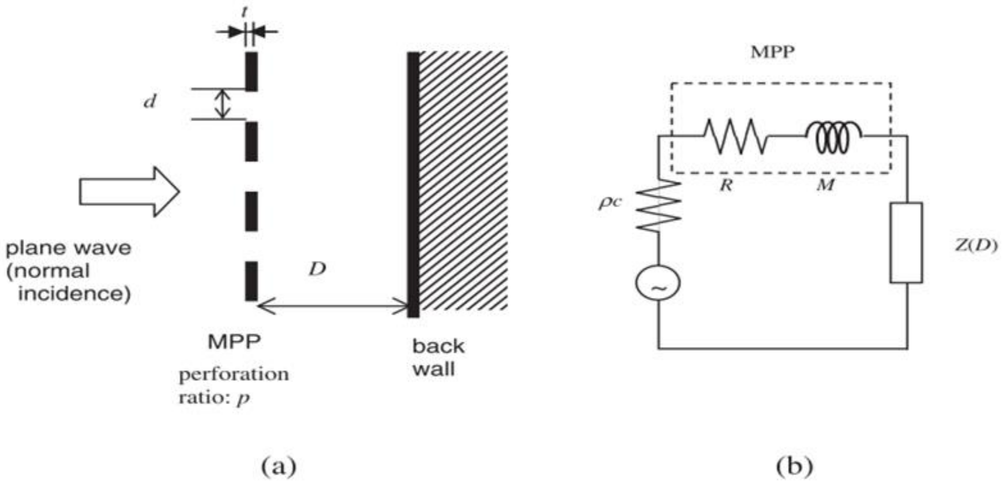


Figure 1.1 (a) single-MPP sound absorber with an air-back cavity and a rigid back-wall. (a) Geometry of the absorber and (b) its equivalent electro-acoustical circuit. The MPP has submillimetre holes of diameter d [mm], perforation ratio p [%], and thickness t [mm] (=tube length). The depth of the air-back cavity is D [mm][5]

MPP have the potential to be a commercially viable solution for noise control. MPP is a thin panel with sub-millimetre perforations that is supported by an air gap and a rigid wall. The perforations alone, according to Maa, provide the acoustic resistance and low acoustic mass reactance required for an absorber without the use of any porous material and thanks to the reduction of their diameters to the sub-millimetre scale[6]. The acoustic performance of an MPP sound absorber is determined by four primary design parameters, which are the diameter of the perforations, the depth of the air cavity, the distance between the perforations, and the thickness of the MPP.

Natural fibre is a type of material that is excellent at sound absorption and insulation. Natural fibre has been referred as an environmentally friendly material due to its biodegradable qualities[7]. Natural fibre is also abundant in Asian countries, and natural fibre processing is more cost effective and environmentally friendly than metallic material[7]. Bio composites have resulted in some of the most significant developments in green technology and material science in the twenty-first century. Several studies have demonstrated that oil palm fibre (OPF), which is recovered from empty fruit bunches, is a good raw material for bio composites. Palm Fibre is derived from the vascular bundles of the oil palm found in the Empty Fruit Bunch (EFB). The Fresh Fruit Bunch (FFB) is regarded waste once it has been processed, and the EFB is deemed waste. Palm fibre is a natural fibre that is non-hazardous, biodegradable, and environmentally beneficial in its natural state.

Recent concerns about the environmental and health implications of synthetic fibre and metallic material usage, together with the established benefits of MPP, leads to the idea of developing a sustainable MPP using oil palm fibre. Palm oil has been recognised as one of Malaysia's most important commodities. Palm oil plantation is crucial to Malaysia's economy because it is the world's second largest producer[8]. Furthermore, the significant production of oil palm fibre, one of the by-products of palm oil processing, poses an environmental concern due to the issue of disposal.

As a result, the waste material's performance as a sustainable and long-lasting sound absorber can be studied. The role of air cavity depth, perforation ratio, panel thickness, and hole diameter in determining MPP acoustic performance is also investigated. The sound absorption coefficient of the MPP sound absorber made of palm oil fiber was investigated in this experimental investigation in relation to the air cavity depth and perforation ratio.

## 1.2 Problem Statement

Sound pollution causes major issues such as emotional distress and generating disturbance to people, due to numerous reflections of the reflective wall around the room. Traditional sound-absorbing materials, such as glass fibre and foam, deteriorate and are not renewable. The acoustic quality of a building environment can be improved by using perforated panel. However, the acoustic resistance of perforated panel was not even close to becoming lower, and it was essential to attach the panel with a porous substance to increase the panel's acoustic performance. MPP absorbers feature pores are submillimetre in size and due to this, MPP absorbers provide acoustic resistance and improve sound attenuation[2]. MPP absorbers is lower cost and easily availabe. As a result, the research on the effectiveness of using oil palm fibre to manufacture MPP as an eco-friendly material for better sound attenuation should be conducted.

## 1.3 Objectives

There are three objectives to be achieved in this project as follows:

- To fabricate micro-perforated panel (MPP) samples from oil palm fibre.
- To examine the sound absorption coefficient (SAC) of MPP samples manufactured from oil palm fibre utilising an impedance tube.
- To examine the sound absorption capability of produced samples with and without the MPP structures using different parameter.

## 1.4 Scope Of Work

This study focuses on the theoretical equation, fabrication, and experimental work, which require background knowledge of MPP absorbers. To practise the modelling equation, MATLAB will be used to evaluate the theoretical sound absorption qualities of MPP samples. In addition, samples with a panel thickness of 1mm were fabricated from oil palm fibre. A CNC machine will be used to perforate MPP samples, each with a varied perforation ratio. Following that, the samples will be examined using an impedance tube with varying air cavity depths. The SAC of the sound-absorbing panel made of oil palm fibres will be compared to the SAC of the panel without the MPP structure. In both theoretical and experimental studies, MPP samples will be examined for sound absorption performance. The effect of air cavity depth and perforation ratio on MPP SAC will also be tested.

## 1.5 Thesis Outline

There are a total of five chapters presented in this project. Background research is firstly presented in chapter one, followed by the problem statements of the thesis, the objectives which need to be achieved, scope of the project, and the thesis outline.

The next chapter provides a concise review of previous research divided into five main topics, highlighting the primary focuses of this study as well as potential applications.

Aside from that, Chapter 3 discusses the methods conducted in this study. By using MPP modelling equation, a theoretical calculation made to calculate the SAC of

MPP samples. A comprehensive theory is presented, beginning with the idea of acoustic impedance and progressing all the way to the prediction of normal incidence absorption coefficients. The processes involved in the fabrication of the MPP samples are described here. After that, an experiment using an impedance tube is carried out to determine the SAC of MPP samples in an actual experiment for sample with and without MPP structure. A full theory was introduced, from the idea of acoustic impedance to the prediction of normal incidence absorption coefficients.

In Chapter 4, the results of analytical modelling and impedance tube measurements are presented, and a comparison of the results obtained from sound-absorbing panels with and without MPP structures are shown. Both types of panels are composed of oil palm fibre. In addition, the technique for improvement as well as the result are detailed in this chapter. It is also explained how the acoustic performance of MPP is affected by the air cavity depth as well as the perforation ratio.

In Chapter 5, the findings are presented to decide whether the project's objective has been accomplished or not. In addition, some suggestions have been provided for future research project within the scope of this chapter.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

This chapter contains a summary of the literature review on natural fibre as a noise-absorbing panel material. Reusable and natural acoustic material made from oil palm fibre is presented. As a noise-reduction method, a MPP is also discussed.

## 2.2 Palm Oil Fibers

The oil palm tree is a monocotyledon that grows on three different continents (Asia, Africa, and South America) on approximately 11 million hectares of land in 42 nations worldwide. The oil palm tree is the world's highest productive oil product industry, with an average lifespan of 25 to 30 years. Malaysia and Indonesia, the world's top palm-oil producers, are now struggling with waste management from both oil palm planting and processing[9].

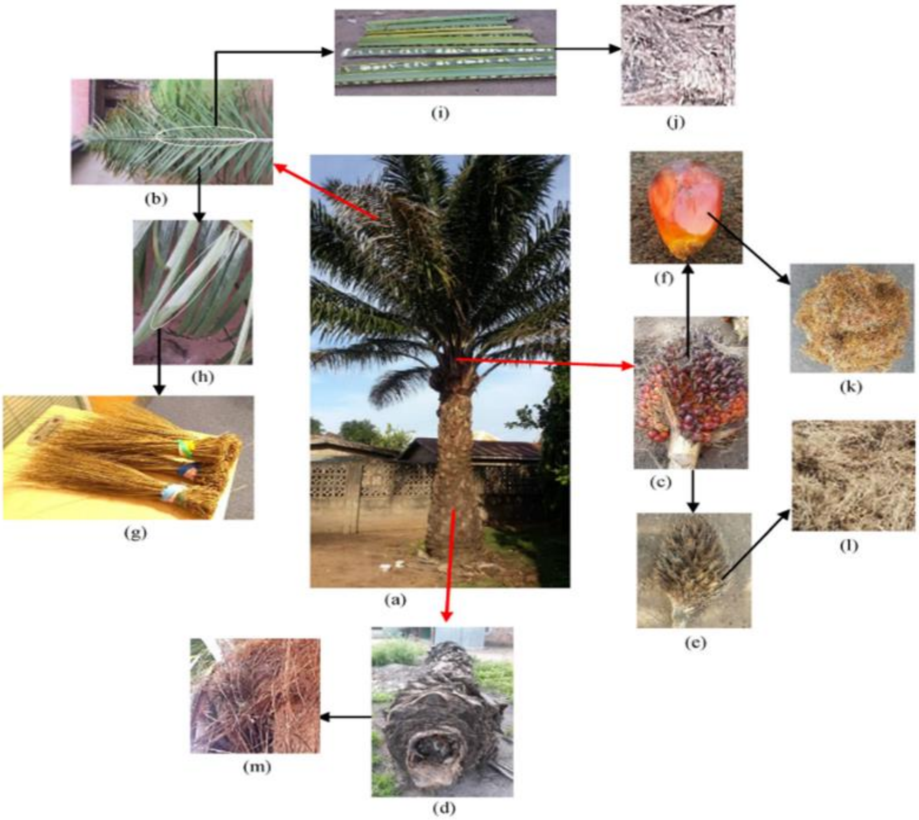


Figure 2.1 Different types of oil palm fibers (OPF): (a) oil palm tree; (b) leaf; (c) fruit; (d) trunk; (e) empty fruit bunch; (f) dissected oil palm fruit; (g) oil palm broom fibers (OPBF); (h) oil palm leaflet; (i) oil palm frond; (j) oil palm frond fibers (OPFF); (k) oil palm mesocarp fibers (OPMF); (l) empty fruit bunch fibers (EFBF); (m) oil palm trunk fibers (OPTF)[9].

Oil palm is one of the most cost-effective and high-potential perennial oil crops available today. It is a member of the Elaeis guineensis species of the Palmaceae family, and it is believed to have originated in the tropical woods of West Africa. Southeast Asian countries such as Malaysia and Indonesia are the primary producers of industrial agriculture[10]. Oil palm fibres are a form of cellulose fibre that is commonly reused or recycled. Because of the lack of research and expertise on the usage and functioning of oil palm fibres in certain sectors and products, it is often wasted in modern agriculture and industry[11]. Oil palm fibres, which are obtained as waste material after oil extraction, can be used as cordage and floor furnishing materials, as well as fibre foams and cushions in automobiles and other transportation equipment. Oil palm fibre is utilised as a reinforcement in a variety of materials such as clay, cement, and other polymers[12]. The properties of oil palm empty fruit bunch fiber are presented in Table 2.1.

Table 2.1 Characteristics of Oil Palm Empty Fruit Bunch Fiber

| Property | Percentage |
|---|---|
| Chemical constituents (%) | |
| Cellulose | 65 |
| Hemi cellulose | — |
| Lignin | 19 |
| Wax | — |
| Ash | 2 |
| Physical properties | |
| Diameter ($\mu m$) | 150-500 |
| Density (g/cc) | 0.7 |
| Tensile strength (MPa) | 248 |
| Young’s Modulus (MPa) | 6700 |
| Microfibrillar angle ( °) | 46 |
| Elongation at break (%) | 14 |

The oil palm Elaeis guineens is was widely used. These fibres were obtained from empty fruit bunches in agriculture and industry. The oil palm wastes were pressed and then shred in a decorticator. To decorate the empty fruit bunches, a decorticator was used. The shredding oil palm fibres were then dried in a drum dryer to remove 15% moisture. Finally, the oil palm fibres are sieved to remove dust and sorted into sizes. The obtained fibres were usually 1 to 10 mm long. Two sets of composite samples, untreated and treated. Untreated samples were rinsed with distilled water and dried at 60°C for 48 hours. The oil palm fibres were immersed in a 5% sodium hydroxide solution for 24 hours at room temperature[11].

Hanif Abdul Latif et al. [13] investigated the ability of oil palm mesocarp fibre to absorb sound. Mesocarp fibre is abundant in Asian countries, mainly Malaysia and Indonesia due to the rapid growth of the palm oil sector to meet international market demand. Mesocarp fibre is low density, renewable, and biodegradable. The alkali, acetylation, and silane treatments were carried out on the fibres' chemical modification. So these fibres are stronger and thus better able to reinforce[10].

Figure 2.2 Raw oil palm empty fruit bunch fibres and image of oil palm empty fruit bunch fibres under microscope[8].

## 2.3 Acoustic Absorbers from Natural Materials

The acoustic absorber is well-known for its applications in noise control in industries and, more specifically, for achieving good acoustic quality in buildings and other enclosed spaces. Most of the acoustic absorbers available on the market, such as glass wool, stone wool, and foam plastics, are still derived from synthetic materials, such as polyester. These substances not only pollute the environment and contribute to global warming, but they are also harmful to human health[2]. Since synthetic fibre produces harmful floating dust particles, which can have a serious negative impact on our health and even cause lung cancer if we are exposed for an extended period of time, we should avoid using them. Another factor contributing to the environmental damage caused by synthetic fibre production is the fact that they are manufactured using high-temperature industrial processes such as hot extrusion, and that the sources of synthetic fibre are frequently derived from petrochemical sources, resulting in significant carbon footprints[13].

The process that determines the absorption of sound may be discussed as follows: When sound travels through a porous material, it is absorbed because the sound pressure causes the air molecules trapped inside the pores of the medium to vibrate at a frequency that is proportional to the frequency of the sound. When sound goes through a porous or fibrous material, the sound waves get stuck and have to change direction many times and travel a long way before they pass all the way through the material. When sound waves change their precise position, some of the sound energy is absorbed and dissipated as heat. This happens every time the sound waves change their direction. When sound waves encounter a reflecting surface, the waves will be reflected back before proceeding through all the material in a different direction[14].

For sound absorption, materials should have a high porosity, which allows the sound to enter their matrix and dissipate while also allowing for the sound to enter their matrix. The sound absorption qualities of pores isolated from other neighbouring pores, also known as "closed" pores, are variable, but only "open" pores, which ensure a continuous channel of communication with the material's exterior surface, provide the highest levels of sound absorption [9]. Numerous studies, particularly on natural fibres, have reported on their acoustic absorption properties. Fibers derived from bamboo, tea leaves, coir, sugarcane, rice, Arenga Pinnata, orange tree pruning, date palm, and a variety of vegetable sources are among the materials used to make these acoustic absorbers. High frequency sound absorption coefficient (a > 0:5, above 1 kHz) of the fibres. Lower frequency performance can be improved by increasing panel thickness or by adding an air gap behind the panel. Adding a fabric cover to the front of the panel improves the frequency bandwidth and absorption[8]. Table 2.2 contains a comparison of the different acoustic materials' SAC, structural strength, and flammable performance, along with their respective advantages and disadvantages.

Table 2.2 Comparison of the various acoustic materials[15].

| Type of materials | SAC | Structural strength | Flame retardancy | Environmentally-friendliness | Manufacturing cost |
|---|---|---|---|---|---|
| PU Foams and sandwich panels | neat PU: poor low-frequency SAC; good high frequency SAC; modified PU: moderate low- and middle-frequency SAC; good high frequency | weak | poor | complicated processes for recycling and disposal | low to moderate |
| Textile-based sound absorbers | poor low-frequency SAC; | weak | poor | sustainable (natural fibre), can be recycled and reused | low |
| Thermoplastic foams | poor low-frequency SAC; good middle-frequency SAC | strong | moderate | sustainable, can be recycled and reused | high |
| MPPs | good low-frequency SAC generally; tailored SAC for an intended frequency range by adjusting MPP parameters | moderate to strong | moderate | environmentally friendly | moderate |

| | | | | | |
|---|---|---|---|---|---|
| Metamaterials | extraordinary low-frequency SAC | weak to strong | moderate | environmentally friendly | moderate to high |
| Metallic foam and graphene foam | metallic foam: good middle-frequency SAC; graphene foam: good SAC across the frequency band | weak | good | environmentally friendly | very high |

Natural fibres are developing as the next generation of sustainable sound-absorbing materials due to their biobased nature, biodegradability, and ability to interact well with other fibrous materials[2]. Natural fibres are competitive materials due to their low density, good mechanical qualities, ease of processing, high stability, occupational health benefits, reduced fogging behaviour, high quantity availability, low price, and reduced environmental implications for their manufacture[16]. Parikh et al created natural fibre based nonwovens for vehicle floor covering systems, using kenaf, jute, and waste cotton in mixes with polypropylene and polyethylene (PP/PET) fabrics[2].

To further improve the sound absorption coefficient of natural fibre, a variety of techniques can be used. For example, if all of the natural fibres are the same thickness, it is highly likely that kenaf fibre will outperform the rest of the natural fibres in terms of sound absorption, particularly at low frequencies[13]. Since natural fiber are waste materials which have good material properties, they can be used to test their efficacy as a biodegradable and long-lasting sound absorber due to their high production and disposal costs.

## 2.4 Applications of Micro-perforated Absorbers

The growing noise level in the car is caused by ambient sounds, engine noises, and road noise from the tyres. Vehicle manufacturers are spending heavily in soundproofing measures and innovative noise suppression technology to attenuate this noise. However, sound insulation is sometimes inadequate, particularly in older automobiles or big commercial vehicles. When a vehicle is operating, massive metal structures such as doors, roofs, and floors begin to shake and emit structure-borne sound. This is then released into the environment in the form of airborne sound and noise.

MPP absorbers may be formed of plastic or metal, although metal plates are more effective for automotive noise cancelling since they are more durable and can be easily fitted into an existing design. This is especially important in vehicle noise management, where lightweight solutions are necessary. MPP absorbers, for example, have the potential to be utilised in dissipative mufflers instead of porous materials, which not only saves weight but also provides a non-fibrous alternative. This also aids in avoiding the negative effects of certain fibrous materials on as they are harmful to one's health, particularly when used in heating, ventilation, and air conditioning (HVAC) systems[17].

Soon-Hong PARK[18] examines a method for developing an MPP absorber in launcher fairings in a high sound pressure environment. First, in his article, an empirically impedance model of an MPP absorbers is developed particularly for the launcher fairing application. The geometric features of the MPP absorber are then improved by applying this technique with a predetermined incidence sound pressure. This design strategy does not seem to deal with the issues presented by the nonlinear effect at high sound levels. Furthermore, for each specific high sound pressure noise environment, a nonlinear impedance model, whether empirical or semi-empirical, must be developed. As a direct consequence of this, pursuing this technique is always wasteful and inconvenient[19]

The sound absorption properties of acoustical materials vary greatly with frequency. Low frequency noises (those below 500 Hz) are more difficult to absorb, while high frequency sounds (those above 500 Hz) are simpler to absorb. The sound absorption coefficient, alpha, as a function of frequency may be used to represent the sound absorbing characteristics of a material. Alpha values vary from 0 (complete reflection) to 1.00 (total absorption) Not to be confused with sound insulation, which is intended to prevent sound from travelling between distinct locations over a barrier such as a wall, ceiling, or floor. Sound absorbing materials may transform part of the absorbed sound energy into heat instead of transferring it, which improves sound insulation, but it should not be considered a replacement for appropriate sound insulation.

Due to its low level of physical resistance and narrow sound absorption bandwidth, thin panels are often not suited for use as an interior finish or as room walls. Because to this limitation, the usage of MPP is limited. To make the panel sufficiently rigid for completing room walls, the panel should have a thickness that is greater than that of traditional MPP. When the panel thickness t is more than the perforation diameter d, this is when the thick MPP is deemed to have been achieved[20].

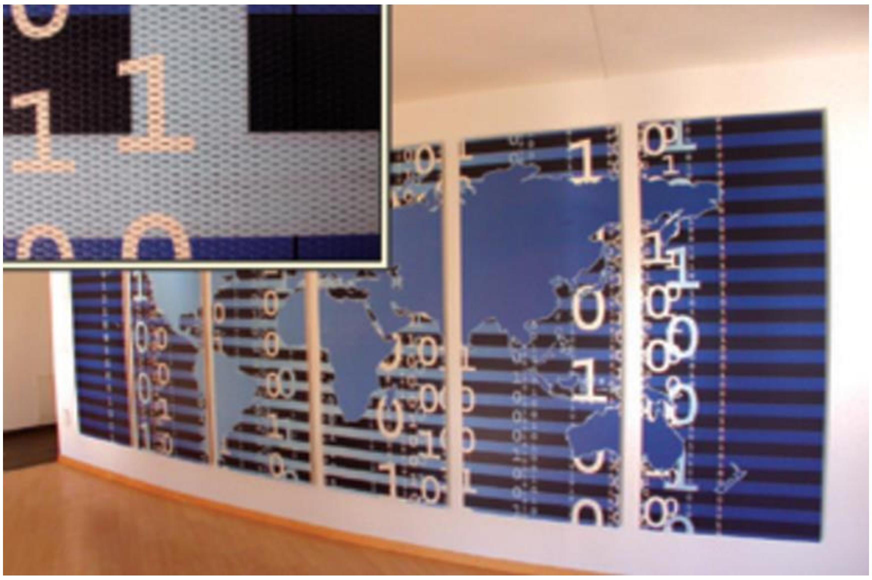


Figure 2.3 MPP used in reception area; inset shows perforations[2]

All these strategies may help to alleviate the previously noted issue of poor absorption. However, we must now evaluate which form of absorber is the best in terms of cleanliness. Because of the nature of porous and fibrous materials, they are plainly unsuitable for this purpose. Materials that are washable or readily sanitised are preferable for post-pandemic uses. As a result, sheet- or panel-like materials are useful because they can be cleaned reasonably quickly by applying (e.g., spraying) disinfectants. As a result, perforated (including microperforated) panels or panel- or membrane-type resonance absorbers are likely to be suitable candidates[21].

Chiu et al. applied spectral analysis and computer-aided numerical analysis to create single-layer micro-perforated sound absorbers[22]. The absorber was constructed using a micro-perforated plate, a glass fibre layer, and an air gap. The noise absorber was created for a specific noise control application inside a small production system where noise at 500 Hz dominates the overall noise. To determine the absorption parameters of the micro-perforated sound absorber, the matrix transfer technique is applied. The absorption coefficient is divided by the thickness of glass wool, with a minimum thickness of 20 cm, to compute the optimization objective function. The goal function is altered to attain a high absorption value at 500 Hz while utilising the least amount of fibre. Because of this effort, a better absorber is generated.

Steel or aluminium are the most common materials used in MPP. Liu also tested the sound absorption of a 3D printed MPP with an air gap and attached porous material[23]. The results showed an overall SAC of 0.8 above the frequency of 2000 Hz. Low-frequency acoustic absorption is increased significantly by the porous sound-absorbing material layer and the air gap. Metal processing, on the other hand, emits a large quantity of carbon into the atmosphere, and the materials required to make the MPP are not recyclable. In addition, the technique of designing sub-millimetre-sized holes using etching, jetting, or laser technology makes the creation of MPP from metallic material difficult and potentially expensive[24].

### 2.5 Micro-perforated Panel (MPP)

Microperforated panel is considered an ideal absorber for noise reduction due to its good sound absorption capability, high strength, excellent washability, elegant design, remarkable machinability, and inexpensive manufacturing cost[25]. Since a standard perforated panel is typically comprised of bigger holes with centimetres as a common unit of measurement, the panel has a minimal amount of acoustic resistance for the purpose of sound absorption. MPP was introduced by Maa to enhance the infirmity of standard perforated panels by lowering the size of the perforation hole to submillimetre size, allowing the width of the absorption peak to be improved[7]. Maa's first conceptual framework was only applicable to MPP with circular holes and a low perforation ratio. However, the interaction between neighbouring perforated holes may affect the acoustic properties of MPP due to the disturbance on the viscous boundary layer surrounding the edges of the perforated hole[26].

To begin, Maa recommended that efficient sound absorbers be constructed by lowering hole widths to submillimetre sizes. Perforated absorbers with submillimetre holes, it is believed, may provide an effective and broad panel absorber covers 5 to 6 octave range. Maa's study predicts normal incidence absorption coefficients of micro-perforated absorbers by beginning with the impedance of a single hole and utilising electro-acoustic similarities. The predicted absorption coefficient values and experimental findings have been found to be in theoretical values. Maa also offered an approach for designing these kinds of absorbers. Absorbers may be constructed for desired absorption bandwidth and resonance frequency using this approach, which involves using charts and simplified equations to modify design parameters[6].

Figure 2.4 Micro-perforated plate[27]

A sound absorber made of MPP operates on the Helmholtz resonator principle, and the effectiveness of such a sound absorber is dependent on the parameters that make it up, such as its perforation diameter, its air cavity depth, its pitch of perforations, and its thickness (in millimetres per square inch)[28]. Because of its simple structure and precisely predictable absorption capabilities, the MPP absorbers offer a wide range of applications. Any material, from cardboard to plastic to plywood to sheet metal, can be used to construct the panel, and it can be finished or decorated in any way that is appropriate for the function[6].

Based on the study of Wong[29], due to a very high acoustic resistance at the neck of the perforated holes, a thick MPP was found to have poor acoustic performance. He discovered that increasing the thickness of the panel without changing the hole diameter lowers the SAC and changes the peak frequency to a lower frequency range.

According to the findings of Sekar's research, a thick MPP's acoustic performance was determined to be low due to the presence of a very high acoustic resistance at the neck of the perforated holes. He discovered that increasing the thickness of the panel without changing the hole diameter decreases the SAC and shifts the peak frequency to a lower frequency range, resulting in a lower frequency range[29]. As the density of the material increases for the same thickness, an improvement in sound absorption can be observed. A good sound absorption coefficient was found at a density of 468 kg/m3 (4 g), with a > 0:5 above 2 kHz, which is a typical frequency range for a fibrous type of absorber. The rise in density adds to the increase in tortuosity, which allows for more sound waves to be trapped or absorbed as a result of the density increase[13] . The introduction of air gap shifts the peak to a lower frequency. The reduction in absorption coefficient above the peak frequency is due to standing waves in the air cavity gap behind the sample causing frequency dips (and peaks)[8].

Furthermore, it has been discovered that the use of kenaf fibre and coconut fibre in the production of MPP demonstrated superior sound absorption performance when compared to the use of synthetic fibre. As MPP porosity increased, so did the sound absorption performance of the MPP. In the case of an MPP that is backed by spaces between it and a hard back wall, the primary mechanism responsible for the absorption of sound that occurs is the resonant of the system. When MPPs are employed without a back wall, such as in the form of a double-leaf structure with an air layer in between but no back wall (a double-leaf MPP: DLMPP), the flow resistances of the leaves produce sound absorption at low frequencies. If this is the true, then the influence of the mass has a more significant effect, particularly at low frequencies: a light-weight DLMPP represents a wide decrease in absorptivity when measured at low frequencies[5].

However, using more fibre makes mixing the fibre and binder more difficult, especially when using oil palm fibre, which is harder than kenaf fibre. This study used a 30:70 composition percentage for oil palm fibre and PLA[30]. Because coconut fibre composition % increases with increasing coconut fibre composition percentage, the porosity value measured increases with increasing percentage of coconut fibre composition and hence increases the sound absorption capacity of the MPP specimen[30].

## 2.6 Summary

As a conclusion from the available research:

- The sound-absorbing panel made out of natural fibres is the best solution for MPP because natural fibres are competitive materials due to their low density, good mechanical qualities, ease of fabrication, high stability, occupational health benefits, reduced fogging behaviour, increased quantity availability, low price, and reduced environmental implications for their manufacture.
- When kenaf fibre or coconut fibre were used in the manufacturing of MPP, the resulting product had a higher level of porosity, which improved its capability of absorbing sound.
- The purpose of combining PLA with a compabilizer is to lower the interfacial tension and, as a result, improve the mechanical and physical properties of the composite.
- For the purposes of this investigation, the composition proportion of oil palm fibre and PLA should be maintained at 30:70, respectively.
- The sound absorption performance of the MPP might be affected by the variety of characteristics including the panel thickness of MPP, the hole diameter, the perforation ratio, and the air cavity depth.

# CHAPTER 3

# METHODOLOGY

## 3.1 Overview

This project focused on the modelling equation, fabrication, and experimental work, which all require a solid understanding of MPP absorbers. The MPP modelling equation will be used to forecast the theoretical sound absorption performance of the sampled materials. Also, 1 mm and of oil palm fibre will be examined. Various MPP samples will be perforated using an automated CNC machine. The samples will next be tested using impedance tube with varying air cavity depths. The SAC of the sound-absorbing panel composed of oil palm fibre will be compared to that of the panel created without the MPP structure. Also the sound absorption performance of MPP samples will be compared in both theoretical and experimental studies. The influence of air cavity depth and perforation ratio on SAC of MPP samples will be investigated.

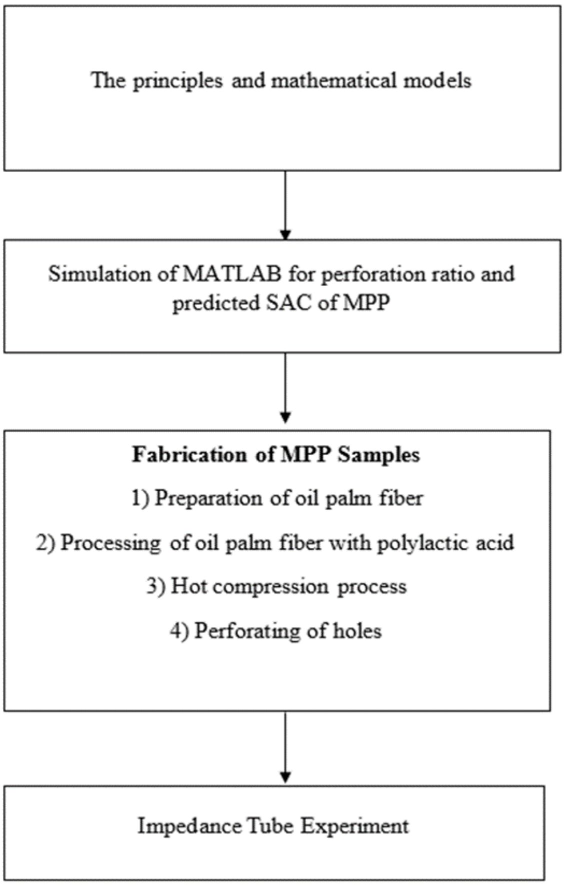


Figure 3.1 Flowchart of the project process

## 3.2 Single Layer Microperforated Panels

A MPP or MSP with a single layer consists of a plate with a thickness of t and perforations with a hydraulic diameter of d. This plate is placed in front of an impervious wall, leaving a cavity with a thickness of D that is empty. These perforations may be of any shape, such as circular holes or rectangular slits. The proportion of plate open surface is known as the perforation ratio, or porosity, and is indicated by $\phi$. An input impedance denoted by $Z_1$ is one of the defining characteristics of such a system. When a plane wave that is travelling through air and has a typical impedance of $Z_0$ reaches the MPP or MSP, the difference in impedance between $Z_1$ and $Z_0$ produces a reflection, and as a result, an absorption takes place. The reflection coefficient, R, and the absorption coefficient, $\alpha_0$, at normal incidence are as follows:

$$R = \frac{Z_1 - Z_0}{Z_1 + Z_0} \tag{3.1}$$

$$\alpha_0 = 1 - |R|^2 \tag{3.2}$$

There are four effects caused by the input impedance, $Z_1$.

- viscous–thermal dissipation within the perforations, which is characterised by the impedance $Z_{hole}$ for an MPP;
- flow distortion in the perforation edges, which is characterised by the impedance $Z_{edge}$;
- resonances in the air cavity, which are characterised by the impedance $Z_D$;
- structural vibrations of the panel impacted negatively by the incident acoustic field, which are characterised by the impedance $Z_{vib}$.

$$Z_D = -iZ_0 cot(kD) \tag{3.3}$$

$$Z_1 = \frac{Z_{MPP} Z_{vib}}{Z_{MPP} + Z_{vib}} + Z_D \tag{3.4}$$

$$Z_1 = Z_{MPP} + Z_D \tag{3.5}$$

## 3.3 Theory of MPP

An MPP is made up of numerous tiny holes, and each of these perforations functions as its own individual Helmholtz resonator. Sound energy is lost in an MPP mostly as a result of resonance and viscous loss in the neck of the perforation. The acoustic mass of an MPP is embodied by the perforations, while the acoustic spring is represented by the air gap. This configuration is analogous to that of a mass-spring system. Because of the sound waves that are incident on the perforations from a particular source, the air molecules inside the perforations are caused to oscillate back and forth, which results in a loss of energy or acoustic absorption.

This may be seen in action whenever the sound energy that is reflected is of a lesser magnitude than the sound energy that is incident. An MPP's acoustic impedance is responsible for the absorption that it provides. This impedance is made up of resistance (actual) and reactance (imaginary) components. The acoustic impedance of a perforation may be characterised as follows when the incident sound wavelength is larger than both the perforation diameter and the perforation distance:

$$Z = j\omega\rho t\left[1-\left(\frac{z}{\xi\sqrt{-j}}\right)\left(\frac{J_1(\xi\sqrt{-j})}{J_0(\xi\sqrt{-j})}\right)\right]^{-1} \tag{3.6}$$

$$\xi = r\sqrt{\frac{\rho\omega}{\eta}} \tag{3.7}$$

Where Z represents the acoustic impedance of the perforation, $\omega$ represents the angular frequency of the sound, $\rho$ represents the density of air, t represents the thickness of the panel, r represents the perforation radius, $\eta$ represents the air dynamic viscosity, and $J_1$ and $J_0$ represent the zeroth and first order for Bessel functions.

To calculate the acoustic impedance of the MPP model, we divide Equation (3.6) by the perforation ratio, which is the ratio of the perforated area to the surface area of the MPP. This gives us the acoustic impedance of the MPP system. However, the formula for acoustic impedance that is found in Equation (3.6) cannot be used in actual practise. Maa proposed a superior approach that is efficient for smaller perforation ratios and has an error rate of just around 5 %[29]. Therefore, a better way to represent acoustic impedance is as follows:

$$Z_N = R + jM \tag{3.8}$$

$$R = \frac{C_1 t \times 10^{-5}}{pd^2}\left(\sqrt{1+\frac{x^2}{32}}+\frac{xd\sqrt{2}}{8t}\right) \tag{3.9}$$

$$\mathrm{M} = 0.0185\frac{tf}{p}\left(1+\frac{1}{\sqrt{9+\frac{x^2}{2}}}+\frac{0.85d}{t}\right) \tag{3.10}$$

$$\mathrm{x} = \mathrm{C}_2 \times 10^{-3} d\sqrt{f} \tag{3.11}$$

$$p = \frac{\pi}{4}\left(\frac{d}{b}\right)^2 \tag{3.12}$$

Where $Z_N$ is the normalised acoustic impedance, R and M are the resistance and reactance components, $\mathrm{C}_1$and $\mathrm{C}_2$ are constants for non-metallic MPP, f is the sound frequency, d is the perforation diameter, $p$ is the perforation ratio, and b is the perforation distance. The sound absorption coefficient (SAC) of an MPP backed by an air gap can then be obtained by[7] :

$$\alpha = \frac{4R}{(1+R)^2 + \left[\omega M - \cot\left(\frac{\omega D}{c_0}\right)\right]^2} \tag{3.13}$$

Where $\alpha$ is the SAC, D is the air gap distance and $c_0$ is the speed of the sound.

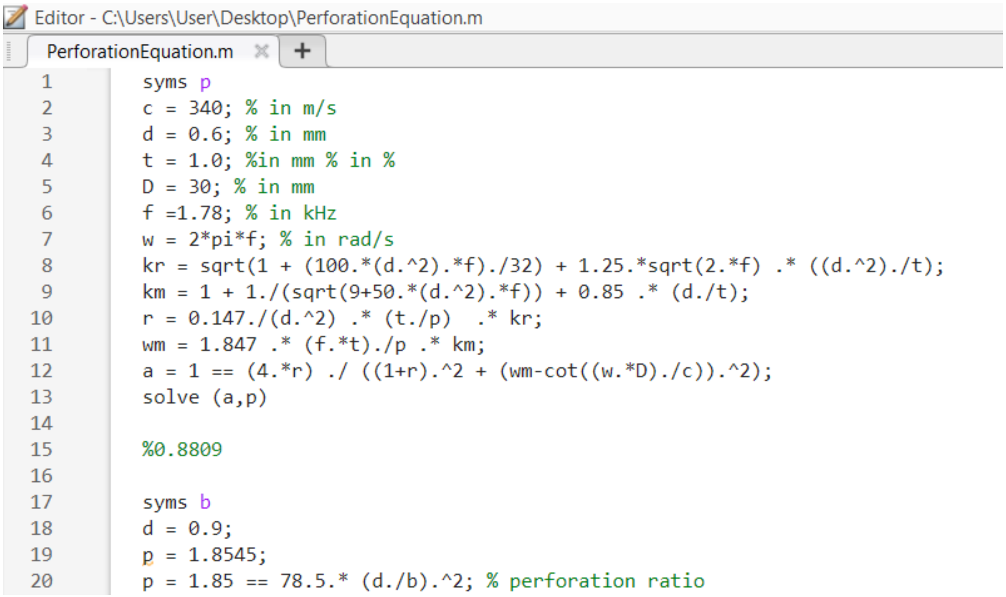
## 3.4 MATLAB Analysis

MATLAB is used to do the first step of the study, which involves calculating the perforation ratio while simultaneously coding the perforation equation in the MATLAB editor.

To investigate how the thickness of an MPP and the amount of its perforations affect its ability to absorb sound, a MATLAB modelling exercise was carried out. Equation (3.13) was converted into MATLAB, and the SAC of the MPPs was determined. To simulate the usual frequency range of a speaker that would be utilised in an impedance tube test [20] [21], the frequency range was configured to go from 0 Hz all the way up to 6000 Hz. It was determined that the speed of sound was 340 m / sec, and the spacing between the air gaps was kept constant at 1 millimetre.

Considered were three cases:

(i) variable perforation size with constant thickness,
(ii) variable diameter with constant perforation size,
(iii) variable perforation size and thickness concurrently.

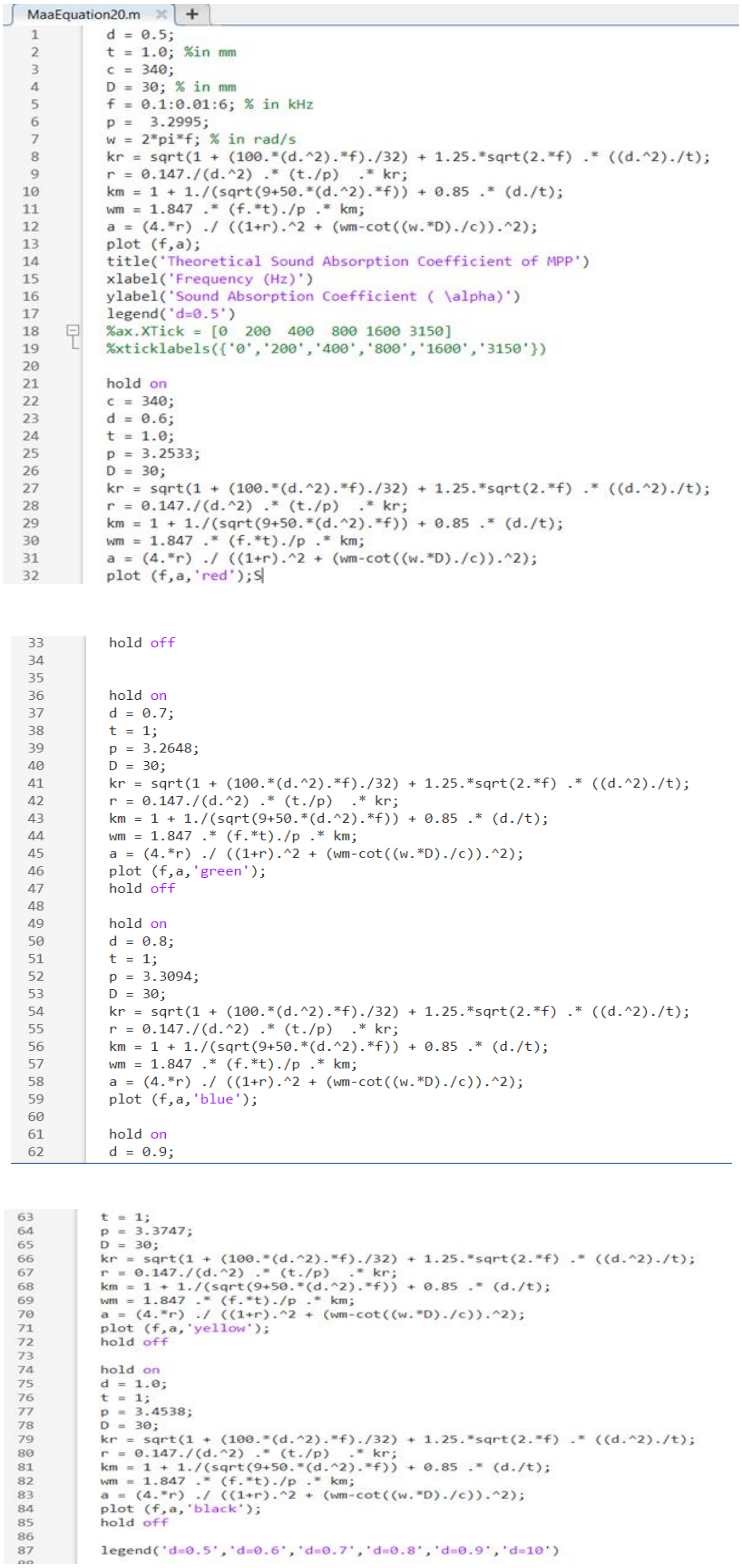


```
syms p
c = 340; % in m/s
d = 0.6; % in mm
t = 1.0; %in mm % in %
D = 30; % in mm
f =1.78; % in kHz
w = 2*pi*f; % in rad/s
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
wm = 1.847 .* (f.*t)./p .* km;
a = 1 == (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
solve (a,p)

%0.8809

syms b
d = 0.9;
p = 1.8545;
p = 1.85 == 78.5.* (d./b).^2; % perforation ratio
```

Figure 3.2 Perforation Equation In MATLAB



```
d = 0.5;
t = 1.0; %in mm
c = 340;
D = 30; % in mm
f = 0.1:0.01:6; % in kHz
p =  3.2995;
w = 2*pi*f; % in rad/s
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
wm = 1.847 .* (f.*t)./p .* km;
a = (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
plot (f,a);
title('Theoretical Sound Absorption Coefficient of MPP')
xlabel('Frequency (Hz)')
ylabel('Sound Absorption Coefficient ( \alpha)')
legend('d=0.5')
%ax.XTick = [0  200  400  800 1600 3150]
%xticklabels({'0','200','400','800','1600','3150'})

hold on
c = 340;
d = 0.6;
t = 1.0;
p = 3.2533;
D = 30;
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
wm = 1.847 .* (f.*t)./p .* km;
a = (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
plot (f,a,'red');S
hold off


hold on
d = 0.7;
t = 1;
p = 3.2648;
D = 30;
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
wm = 1.847 .* (f.*t)./p .* km;
a = (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
plot (f,a,'green');
hold off

hold on
d = 0.8;
t = 1;
p = 3.3094;
D = 30;
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
wm = 1.847 .* (f.*t)./p .* km;
a = (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
plot (f,a,'blue');

hold on
d = 0.9;
t = 1;
p = 3.3747;
D = 30;
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
wm = 1.847 .* (f.*t)./p .* km;
a = (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
plot (f,a,'yellow');
hold off

hold on
d = 1.0;
t = 1;
p = 3.4538;
D = 30;
kr = sqrt(1 + (100.*(d.^2).*f)./32) + 1.25.*sqrt(2.*f) .* ((d.^2)./t);
r = 0.147./(d.^2) .* (t./p)  .* kr;
km = 1 + 1./(sqrt(9+50.*(d.^2).*f)) + 0.85 .* (d./t);
wm = 1.847 .* (f.*t)./p .* km;
a = (4.*r) ./ ((1+r).^2 + (wm-cot((w.*D)./c)).^2);
plot (f,a,'black');
hold off

legend('d=0.5','d=0.6','d=0.7','d=0.8','d=0.9','d=10')
```

Figure 3.3 Maa’ Equation in MATLAB

## 3.5 Fabrication Process of MPP

### 3.5.1 Preparation of Oil Palm Fibre

First and foremost, oil palm fibre must be prepared. To eliminate soil particles from the oil palm fibre, it was washed with tap water. To get clean palm oil fiber, the process of separating the rough fibers needs to be done before soaking it in tap water as in Figure 3.4. It is required to soak palm oil fibre in water for several times before it can be used. The water exchange process must be repeated numerous times to ensure that soil particles are removed, and that clean and high-quality fibre is obtained.

Figure 3.4 Process cleaning of palm oil fiber with tap water

Oil palm fibre was soaked in deionized water using a deionizer, as portrayed in Figure 3.5 and Figure 3.6, to remove excess wax and other impurities from the fibres before being dried. For approximately 24 hours, the oil palm fibre was immersed in deionized water to dissolve it.