INVESTIGATION OF THERMAL CONDUCTIVITY AND WATER ABSORPTION TEST ON THERMAL INSULATION BOARD MADE FROM RICE HUSK

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Faculty of Mechanical Technology and Engineering

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DEDICATION

I would like to dedicate the success of this research to my late father, Allahyarham Mohd Thalib bin Md Jai and my mother, Rohani binti Latip. This report is dedicated to them because I want to express my gratitude for all the sacrifices they made for me throughout my time at this university. Second, this dedication is made to my friends, who assisted me in completing this report through counsel, financial assistance, and encouragement. Following that, I would want to express my deepest thanks to my supervisor, Ts. Dr. Amir Abdullah Muhamad Damanhuri. one of the important person that always advised and support me and my friends in finishing this Final Year Project.

ABSTRACT

Traditional insulating materials such as fiberglass and foam plastics are inefficient and environmentally harmful which release hazardous compounds and consuming large amounts of energy during production. These materials also rely on non-renewable resources, worsening resource depletion and environmental degradation. Sustainable alternatives are needed, but many current options are either ineffective, lack durability, or are too costly, limiting their widespread adoption. The growing demand for energy-efficient buildings and industrial processes highlights the urgency for innovative thermal insulation solutions. Addressing these issues requires interdisciplinary research to develop new materials and techniques that balance performance with sustainability. This research focuses on the investigation of thermal conductivity and water absorption tests on thermal insulation boards made from rice husk. By utilizing corn starch, citric acid, and borax as natural binders, this project fabricated thermal insulation boards using rice husk as an alternative material for the insulation industry through the factorial design method. In this study two level factorial design was employed to identify significant effect on the 2 outputs which are thermal conductivity and water absorption based on three factors (a) borax (6-13 gram), (b) citric acid (15-30 ml) and (c) hot press temperature (120 -150˚C). The insulation boards with dimensions 177.8 mm × 177.8 mm × 5 mm, were fabricated for 20 minutes under a pressure of 145 psi for 8 samples. Thermal conductivity and water absorption tests were conducted following ASTM C518 and ASTM C203 to evaluate material absorption. The experimental results showed that sample 8 shows the lowest thermal conductivity (0.40 W/m·K) and water absorption (23.08%), demonstrating its superior insulation and moisture resistance properties. Analysis revealed that the interaction between (a) borax, (b) citric acid, and (c) hot press temperature (ABC) was the most influential factor, contributing 42.41% to thermal conductivity variability. Additionally, factor (b) citric acid was identified as a critical factor affecting water absorption, contributing 55.64% of the variability. These findings highlight the potential of rice husk-based insulation in enhancing energy efficiency and supporting eco-friendly construction methodologies. Further investigations will focus on optimizing the material's properties and scalability for broader commercial applications.

ABSTRAK

Bahan penebat tradisional seperti gentian kaca dan plastik buih kurang cekap dan berbahaya kepada alam sekitar kerana melepaskan sebatian berbahaya serta menggunakan jumlah tenaga yang besar semasa pengeluaran. Bahan-bahan ini juga bergantung pada sumber yang tidak boleh diperbaharui, yang memperburuk pengurangan sumber dan kemerosotan alam sekitar. Alternatif yang mampan diperlukan, tetapi banyak pilihan semasa sama ada tidak berkesan, kurang ketahanan, atau terlalu mahal, yang mengehadkan penerimaan secara meluas. Permintaan yang semakin meningkat untuk bangunan dan proses industri yang cekap tenaga menonjolkan keperluan mendesak untuk penyelesaian penebatan haba yang inovatif. Menangani isu-isu ini memerlukan penyelidikan pelbagai disiplin untuk membangunkan bahan dan teknik baharu yang mengimbangi prestasi dengan kelestarian. Penyelidikan ini memberi tumpuan kepada penyiasatan ujian kekonduksian haba dan penyerapan air pada papan penebat haba yang diperbuat daripada sekam padi. Dengan menggunakan pati jagung, asid sitrik, dan boraks sebagai pengikat semula jadi, projek ini telah menghasilkan papan penebat haba menggunakan sekam padi sebagai bahan alternatif untuk industri penebat melalui kaedah reka bentuk faktorial. Dalam kajian ini, reka bentuk faktorial dua peringkat digunakan untuk mengenal pasti kesan signifikan terhadap dua output, iaitu kekonduksian haba dan penyerapan air berdasarkan tiga factor iaitu (a) boraks (6-13 gram), (b) asid sitrik (15-30 ml) dan (c) suhu penekan panas (120-150˚C). Papan penebat dengan dimensi 177.8 mm × 177.8 mm × 5 mm telah dihasilkan selama 20 minit di bawah tekanan 145 psi untuk 8 sampel. Ujian kekonduksian haba dan penyerapan air dijalankan mengikut ASTM C518 dan ASTM C203 untuk menilai sifat bahan. Hasil eksperimen menunjukkan bahawa sampel 8 mencatatkan kekonduksian haba terendah (0.40 W/m·K) dan penyerapan air (23.08%), menunjukkan sifat penebatan dan ketahanan kelembapan yang unggul. Analisis menunjukkan bahawa interaksi antara (a) boraks, (b) asid sitrik, dan (c) suhu penekan panas (ABC) adalah faktor paling berpengaruh, menyumbang 42.41% kepada variabiliti kekonduksian haba. Selain itu, faktor (b) asid sitrik dikenal pasti sebagai faktor kritikal yang mempengaruhi penyerapan air, menyumbang 55.64% kepada variabiliti. Penemuan ini menonjolkan potensi penebat berasaskan sekam padi dalam meningkatkan kecekapan tenaga dan menyokong metodologi pembinaan mesra alam. Kajian lanjut akan memberi tumpuan kepada pengoptimuman sifat bahan dan skalabiliti untuk aplikasi komersial yang lebih luas.

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LIST OF SYMBOLS AND ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
DoE	-	Design of Experiment
HVAC	-	Heating, Ventilation and Air Conditioning
EPS	-	Expanded Polystyrene
XPS	-	Extruded Polystyrene
SPF	-	Spray Polystyrene Foam
ΔT	-	Temperature difference
Q	-	Heat flux
k	-	Thermal conductivity
A	-	Area
d	-	Thickness
°C	-	Degree Celcius
Wwet	-	Wet weight
Wdry	-	Dry weight
g	-	Gram
Mm	-	Millimeter
Psi	-	Pounds per square inch
T	-	Temperature
%	-	Percent

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CHAPTER 1

INTRODUCTION

1.1 Background

Thermal insulation is the process of reducing heat transfer between objects or spaces with different temperatures in order to improve energy efficiency and maintain temperature control. Generally, it is used to prevent unwanted heat gain or loss, ensuring thermal comfort, while reducing energy consumption and hence promoting sustainability (Tay et al., 2022). There are three fundamental modes of heat transfer: conduction, convection, and radiation. Conduction is heat transfer by direct contact; hence, materials with low thermal conductivity, like fiberglass or foam, make good insulators (Hung Anh & Pásztory, 2021a). Convection is a transfer of heat through fluids can be reduced by the entrapment of air or gas in minute pockets of the insulation materials. Radiation is heat transferred through electromagnetic waves and can be reduced by the use of reflective surfaces such as aluminum foil, which reflects heat back to its source (GreenSpec, 2024).

Applications in the field of thermal insulation are wide, from construction, where it is used in walls, roofs, and windows to maintain indoor temperatures and reduce heating and cooling requirements, to improving efficiency and safety by maintaining process temperatures in pipes, boilers, and storage tanks in industrial settings. It is also very important in transportation to control cabin temperatures and improve energy efficiency in vehicles (Okokpujie et al., 2022). Household appliances such as refrigerators, ovens, and water heaters depend on insulation for improved performance and lower energy usage, but more specialized applications, such as cryogenics, require maintaining very low temperatures to store and transport liquefied gases (Yang et al., 2021).

Its performance is based on characteristics such as low thermal conductivity, light weight, moisture resistance, long-term durability, and fire safety. The conventional types of insulation materials include the fibrous kind, such as fiberglass and mineral wool; the foam kind, including polyurethane and polystyrene; and the reflective kind with aluminum foil facing (Hung Anh & Pásztory, 2021b). Natural materials such as wool and cork are environmentally friendly, yet modern materials such as aerogels provide excellent insulation for high-performance applications (Varamesh et al., 2024).

Thermal insulation is critical for conserving energy, cutting carbon emissions, and encouraging sustainability (Paraschiv et al., 2021a). It helps to reduce costs, improve comfort, and comply with environmental requirements defined by the International Energy Agency (IEA). Research continues to focus on creating breakthrough materials that combine efficiency, durability, and environmental friendliness to meet the growing need for energy-efficient solutions in a variety of sectors.

1.2 Problem Statement

The inefficiency and negative environmental effects of traditional materials are the root of the thermal insulation problem. Conventional insulating materials, such fibreglass and foam plastics, may release hazardous compounds over their whole lives and frequently need large energy inputs during manufacture. Furthermore, the non-renewable resources used to create these products contribute to resource lack and degradation of the environment.

Another challenge is the lack of sustainable alternatives that offer both effective thermal insulation properties and low environmental impact. While there is growing awareness of the need for eco-friendly solutions, many existing alternatives fall short in terms of performance, durability, or cost-effectiveness. This limits adoption on a large scale and restricts the development of more environmentally friendly manufacturing and construction processes.

Furthermore, the increasing demand for energy-efficient buildings and industrial processes underscores the urgency of finding innovative solutions to improve thermal insulation. Inefficient insulation not only leads to higher energy consumption and costs but also exacerbates greenhouse gas emissions and climate change. Addressing these challenges requires interdisciplinary research and development efforts to explore novel materials, manufacturing techniques, and insulation systems that prioritize both performance and sustainability.

On the other hand, identifying the optimal composition of rice husk insulation boards based on factors such as borax and citric acid concentrations, as well as hot press temperatures, would traditionally require numerous experiments using a one-factor-at-a-time (OFAT) approach or trial-and-error method. However, these methods have limitations in efficiency and accuracy. Given this, the study adopts the Design of Experiment (DoE) technique known as Response Surface Methodology (RSM). By applying RSM, the number of experiments required can be minimized while accurately predicting the effects of these factors on the thermal conductivity and water absorption properties of the insulation boards.

1.3 Research Objective

The main aim of this research is to create a sustainable alternative that effectively impact. By leveraging the unique properties of rice husk, such as its high silica content and fibrous structure, the goal is to :

a) To develop thermal insulation board from rice husk for use as alternative material in the insulation industry using factorial design method.

b) To investigate interaction between factor (a) borax, (b) citric acid and hot press temperature to the thermal conductivity and water absorption of the developed rice husk insulation board.

1.4 Scope of Research

The scope of this research are as follows:

a) Rice husk for insulation board fabrication was collected from North Malaysia from local supplier.

b) Insulation board fabrication is made within the dimensions of 177.8mm x 177.8mm x 5mm.

c) The range temperature for the hot press process are varies between 120°C and 150°C.

d) Thermal conductivity and water absorption test are following ASTM C518 and ASTM C272 standards.

e) Design Expert version 13 software is used to analyze factorial design method of DoE.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Thermal insulation refers to materials or technologies that decrease heat transmission between objects with different temperatures, saving energy and improving comfort in buildings and other structures. This is accomplished by using materials with low thermal conductivity, which block the transmission of heat. Fibreglass, mineral wool, cellulose, and foam boards are common thermal insulation materials, each with various degrees of heat resistance. The efficacy of an insulating material is frequently measured by its R-value, which evaluates its resistance to heat flow the higher the R-value, the better the insulating effectiveness. Proper thermal insulation is essential for energy efficiency since it helps maintain desirable indoor temperatures, lowers energy consumption for heating and cooling, and contributes to environmental sustainability (Tian et al., 2024).

Nowadays, DOE software is frequently utilised as an alternative for sample data collecting. It was chosen for its methodical approach to finding the link between the elements influencing a process and the process's output. Furthermore, it is highly significant since it aids in the input management process and optimises the output (Jankovic et al., 2021a) The DOE input methodology approach is separated into six factors: hypothesis testing, interaction, controlled and uncontrolled, replication, reaction, and blocking. The DOE input methodology idea is broken into six factors: controlled and uncontrolled, response, hypothesis testing, blocking, replication, and interaction (Antony & St, 2022).

For design and analysis, there are two ways i.e., first and foremost, comparing two or more levels in a factor allows us to analyse the variation between the methods of various factor levels to individual variance. The second method has two levels or stages, which are determined by the size of the experiment in comparison to other designs and the interplay of factor efficacy. The latter technique is more often employed in studies since it may incorporate numerous elements. It is easy and adaptable (Isuwa et al., 2023).

2.2 Thermal Insulation

Thermal insulation is a critical component in modern construction, designed to reduce the transfer of heat between different environments, thereby improving energy efficiency and indoor comfort (Paraschiv et al., 2021). Thermal insulation reduces heat flow through building envelopes, including walls, roofs, and floors, thereby reducing energy consumption for heating and cooling systems (Fawaier & Bokor, 2022). Insulation reduces energy costs and significantly contributes to environmental sustainability by lowering greenhouse gas emissions (Hafez et al., 2023).

Over the past few years, there has been an increasing emphasis on the development of sustainable and eco-friendly insulation materials (Erkmen et al., 2020). While fiberglass and foam insulation are effective, they pose environmental and health concerns. Consequently, interest in natural and renewable alternatives, like rice husk, is growing (Chen et al., 2021).

There are plenty of common insulation materials available on market today such as fiberglass, mineral wool, cellulose, polystyrene and polyurethane foam. Each of these insulation material have their own ups and downs. The most material that is commonly used in construction industry is fiberglass. It is made from fine glass fibers and commonly used in residential and commercial buildings, especially in walls, attics, and ceilings.

2.3 Application of Thermal Insulation

Thermal insulation plays a vital role in enhancing energy efficiency and maintaining indoor comfort by minimizing heat transfer between the interior and exterior environments of a building. It is a key component in both residential and commercial construction, designed to stabilize indoor temperatures and create a more comfortable living or working environment. By reducing heat loss during winter and limiting heat gain in summer, insulation minimizes the dependence on heating and cooling systems, leading to significant energy savings and reduced utility costs (Paraschiv et al., 2021b). This contributes not only to cost efficiency but also to environmental sustainability by lowering energy consumption and associated greenhouse gas emissions.

In addition to its role in maintaining building envelopes, thermal insulation is extensively used in heating, ventilation, and air conditioning (HVAC) systems. Insulation materials are applied to ducts, pipes, and other HVAC components to prevent energy losses and ensure that conditioned air or fluids retain their desired temperature as they travel through the system. This improves the overall energy efficiency of HVAC systems, reducing operational costs and enhancing system performance.

Furthermore, modern insulation materials are designed to meet specific thermal resistance (R-value) requirements, providing tailored solutions for different climatic conditions and building types. Insulation can also contribute to soundproofing, fire resistance, and moisture control, making it a multifunctional component of sustainable building practices. Advances in material science continue to produce innovative and eco-friendly insulation options, addressing the growing demand for energy-efficient and environmentally responsible construction.

2.4 Material for Thermal Insulation

Materials for thermal insulation include fiberglass, mineral wool, polystyrene, and polyurethane foam, all chosen for their ability to reduce heat transfer and enhance energy efficiency in buildings. Fiberglass, made from fine glass fibers, is highly effective in reducing heat flow and is widely used due to its affordability and non-combustible properties (Zhao et al., 2022).

Mineral wool, derived from volcanic rock or industrial slag, offers fire resistance and sound insulation, while polystyrene provides lightweight, moisture-resistant insulation for walls, roofs, and foundations (Johnson & Brown, 2019). Polystyrene, a lightweight, moisture-resistant material, is ideal for various construction applications like wall, roof, and foundation insulation, available in expanded and extruded forms (Williams et al., 2020).

Polyurethane foam, available as rigid boards or spray foam, offers a high R-value per inch, ideal for sealing gaps and insulating thin spaces (Kumar & Yadav, 2020). Eco-friendly materials like cellulose, sheep wool, and cork are popular for their sustainability and low environmental impact (Sharma & Bhardwaj, 2019). These materials enhance thermal performance, reduce energy consumption, and improve comfort in buildings.

2.5 Adhesives for Thermal Insulation Board

Thermal insulation board adhesives are essential for attaching insulation materials, such as fiberglass or foam boards, to a variety of surfaces, including floors, walls, and roofs. There are many different kinds of adhesives, such as solvent-based adhesives that are known for their strong bonding, water-based adhesives that are environmentally friendly and simple to clean, polyurethane adhesives that provide flexibility and durability, and contact adhesives that form an instant connection when they come into contact (Cárdenas-Oscanoa et al., 2024). When selecting an adhesive, it's essential to consider the type of insulation material, the environmental conditions where it will be used, and any specific building code requirements (Ezema, 2019). In addition to guaranteeing a solid connection, using the proper adhesive improves the thermal insulation system's lifetime and efficiency, which helps buildings use less energy (Tu et al., 2024).

2.6 Previous Study

A previous study refers to research conducted by other scholars or organizations on a specific topic before the current investigation. These studies are typically reviewed as part of a literature review in research papers or projects to provide a foundation for new work. By examining previous studies, researchers can gain a deeper understanding of the existing knowledge in the field, identify gaps or unanswered questions, and build on the findings of earlier research. This process not only ensures that the current study is informed by past work but also prevents duplication of efforts and highlights areas that require further exploration.

Additionally, previous studies guide researchers in choosing appropriate methodologies, tools, and techniques while establishing credibility by demonstrating familiarity with established research. For instance, in the context of thermal insulation boards, previous studies may explore materials like fiberglass, mineral wool, and adhesives such as citric acid and borax, providing insights into their properties and applications. Such reviews form the basis for advancing knowledge and developing innovative solutions in the field.

Fiberglass, a widely used thermal insulation material, provides high effectiveness, affordability, and ease of installation. It works by trapping air within its fibers, significantly reducing heat transfer (Smith et al., 2018). Available in various forms such as batts, rolls, and loose-fill, fiberglass is versatile, non-combustible, and durable, making it an ideal choice for residential and commercial buildings (Johnson & Brown, 2019). Recent advancements in fiberglass production have incorporated recycled glass to reduce environmental impact, though skin and respiratory irritation risks remain (Williams et al., 2020). Despite these challenges, fiberglass continues to be a staple in energy-efficient building practices due to its long-standing market presence and ongoing innovations (Kumar & Yadav, 2020).

Mineral wool, including rock wool and slag wool, is another effective thermal insulation material, known for its excellent fire resistance, sound absorption, and thermal performance (Miskinis et al., 2018). This material, made from volcanic rock or recycled slag, can withstand high temperatures without melting, making it ideal for fire safety applications in walls, ceilings, and industrial settings (Smith et al., 2018). The dense, fibrous structure of mineral wool traps air, enhancing its thermal insulation properties, while its sound-absorbing capabilities improve acoustic insulation in buildings (Williams et al., 2020).

Polystyrene, available in expanded (EPS) and extruded (XPS) forms, is favored for its lightweight, moisture-resistant, and thermal properties (Tan et al., 2023). XPS, produced through an extrusion process, has a denser structure than EPS, resulting in higher thermal resistance and greater mechanical strength (Johnson & Brown, 2019). Both forms are used widely in construction for wall, roof, and foundation insulation due to their durability and ease of installation (Raza et al., 2023). The closed-cell structure of polystyrene prevents moisture absorption, ensuring its insulating properties remain intact over time (Williams et al., 2020).

Polyurethane foam, a versatile high-performance thermal insulation material, is available in rigid boards and spray foam forms (Alsuhaibani et al., 2023). Spray polyurethane foam (SPF) expands and hardens into a solid foam, filling gaps and enhancing insulation and air sealing in buildings (Johnson & Brown, 2019). With a high R-value of R-6-7 per inch, polyurethane foam is an effective material for reducing heat transfer and improving energy efficiency (Williams et al., 2020). Its moisture resistance and adhesive properties make it suitable for complex architectural designs and retrofitting projects, improving both indoor air quality and building longevity (Kumar et al., 2022).

In addition to the insulation materials, the adhesives used to bind and enhance their properties are crucial. Natural adhesives, including those derived from agricultural resources, have been utilized since the 1930s and are biodegradable, making them more environmentally friendly compared to synthetic alternatives (Anbu, 2009). Plant-based proteins, such as those from soy, wheat, and peas, are also used to create eco-friendly adhesives. These protein-based adhesives exhibit high viscosity and resistance to water, although further modifications are needed to improve their bonding strength and water resistance (Nordqvist et al., 2013).

Starch, a widely available and inexpensive natural polymer extracted from plants like corn, rice, and potatoes, is used in the production of insulation boards, particularly rice husk insulation (Apriyanto et al., 2022; Jhonson & Yunus, 2009). Starch serves as a paste for bonding materials like paper and is also effective in producing environmentally friendly insulation products. Similarly, citric acid, found in citrus fruits, acts as a natural cross-linking agent that, when combined with starch, enhances the performance and longevity of insulation materials (Hosseini et al., 2019; Gao et al., 2018). Citric acid also improves fire resistance by promoting the formation of a carbonaceous layer during combustion, providing a barrier against heat and flames (Liu et al., 2017).

Sodium borate (borax) is another essential additive in natural adhesives and insulation materials. It reacts with starch to form borate ester bonds, improving mechanical strength, elasticity, and water resistance, making it an effective cross-linking agent for insulation boards (Y. Chen et al., 2024). Borax also serves as a fire retardant, protecting natural fiber composites from fire and microbial attacks, which enhances the durability of bio-based insulation products (Ahmadi et al., 2024). The use of borax is particularly appealing due to its low cost, accessibility, and environmental benefits, supporting sustainable material development in the construction and manufacturing industries (Reotutar et al., 2024).

2.7 Overview of Design of Experiment

The Design of Experiment (DoE) is a systematic and statistical approach used to plan, conduct, analyze, and interpret experiments to optimize processes and improve product quality. DOE allows researchers and engineers to evaluate the effects of multiple variables and their interactions simultaneously, making it a powerful tool for process optimization and decision-making. By providing a structured methodology, DoE ensures that experiments are conducted efficiently, minimizing the resources, time, and costs required to achieve reliable results. It is particularly useful in identifying critical factors that influence a process or product and determining optimal settings to achieve desired outcomes (Jankovic et al., 2021b).

Traditionally, DoE has been most widely applied in engineering and manufacturing to enhance the quality and performance of products. It has proven invaluable in the optimization of production processes, the development of new products, and the improvement of existing products. By identifying important factors and their interactions, DoE allows manufacturers to achieve better efficiency, reduced defects, and consistency in production. For example, the automotive and aerospace industries use DoE to optimize materials, processes, and designs for reliability and safety. The usage has also been applied broadly in industry to help with decisions while developing new products made, the overall manufacturing process of the product as well as product improvement. Moreover, it is not just used in engineering but also medicine in the form of pharmaceuticals and hospitals, chromatography, administration, architecture, marketing, energy, and food industries (Javaid et al., 2022).

This flexibility makes DoE an extremely useful tool in a large variety of fields, enabling organizations to make decisions based on data toward their objectives effectively. It analyzes experimental data systematically to identify optimal conditions and reduce uncertainties, driving innovation and continuous improvement. Its potential has been heightened with its integration into modern technologies such as artificial intelligence and machine learning, allowing more sophisticated experimental designs and analyses (Alghamdi & Agag, 2024).

2.8 Summary

The significance of thermal insulation in reducing heat transfer and enhancing energy efficiency in buildings. It highlights various common insulation materials, such as fiberglass, mineral wool, cellulose, and polyurethane foam, each with unique properties and applications. The effectiveness of insulation is measured by its R-value, which indicates its resistance to heat flow, contributing to energy conservation and environmental sustainability. Additionally, the use of Design of Experiments (DoE) in research and product development is emphasized, showcasing its systematic approach to optimizing processes by evaluating multiple variables and interactions. Furthermore, the role of adhesives in thermal insulation systems is addressed, detailing types used and their importance in enhancing the overall effectiveness and longevity of insulation materials. Recent interest in sustainable materials, including natural and eco-friendly alternatives like rice husk, is also noted, signifying a shift towards environmentally responsible construction practices. Overall, the integration of advanced methodologies and sustainable materials stands to improve energy efficiency and support innovative solutions in the construction industry.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The purpose of this methodology chapter is to achieve the objectives of the study that have been set. This study began with a literature review, then followed sample design by the use of factrorial design method using Design of Experiments (DoE) concepts. Next, sample preparation, mixing and compounding, moulding and shaping, hot press, thermal conductivity test, water absorption test and last but not least, the results, discussions and conclusions.

3.2 Research Flowchart

Figure 3.1 below shows the flowchart of the project. The process that will be involved are sample preparation, mixture for the product moulding and shaping, hot press process and analysis. The data was collected based on the physical and mechanical properties of the insulation board. Finally, the rice husk insulation board were produced with compositions of corn starch, citric acid and borax.

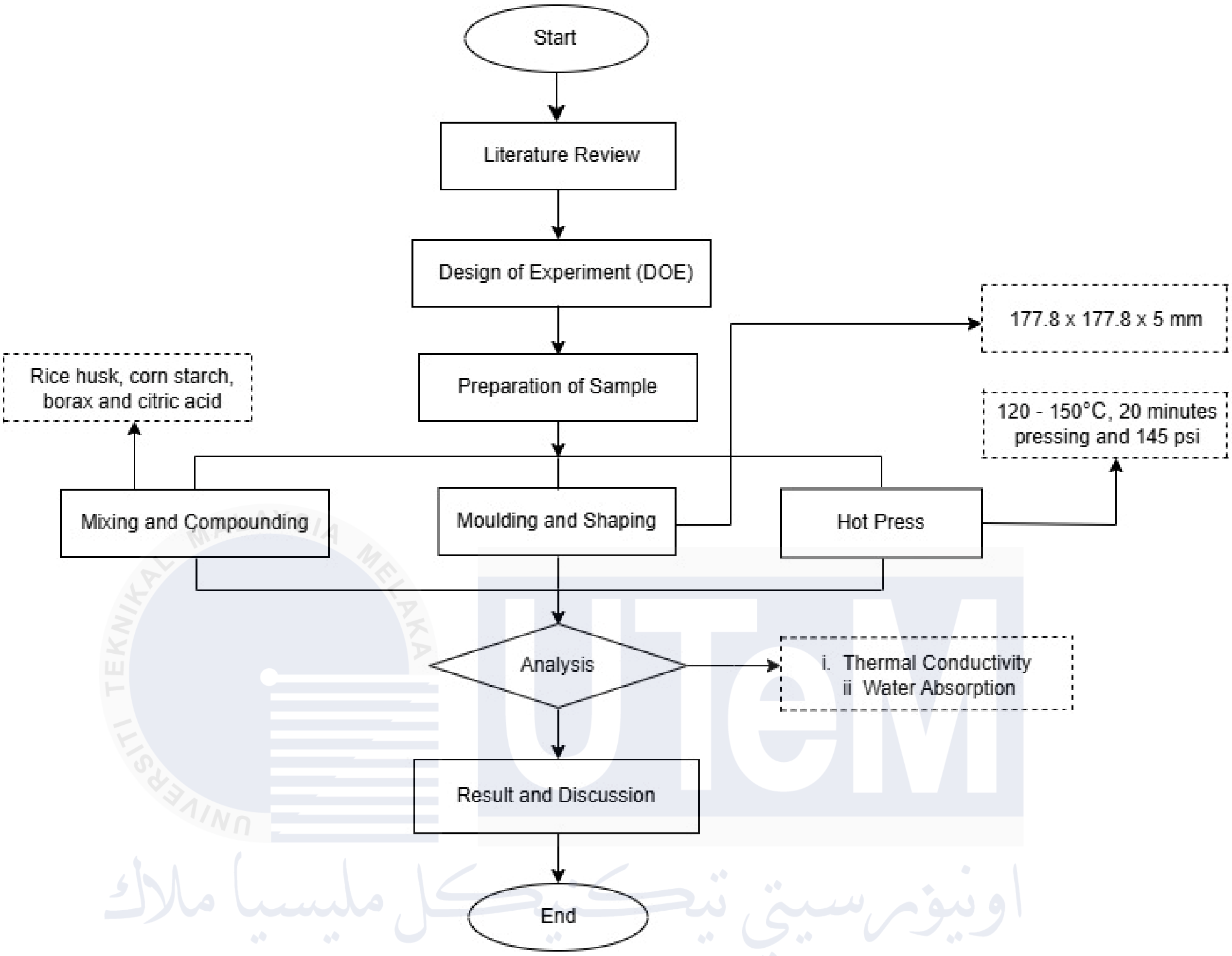

Figure 3.1 : Flowchart of Project

3.3 Design of Experiment (DOE)

Design of Experiment (DoE) is a data analysis technique that aids in the planning, execution, analysis, and interpretation of controlled experiments to identify factors impacting product quality, stability, or other essential process features. Rather than testing with one parameter at a time, DoE can assist speed up the process and find relevant relationships by tweaking numerous variables simultaneously. In DoE, replication runs and repeated runs refer to several response readings done at the same factor level. The DoE also contains a function that determines how to handle the case (Özcan et al., 2023). The decision to replicate or repeat runs can have a substantial influence on experimental data processing. In the instance of replicas, demonstrating an interaction between the two elements had a considerable impact on the experimental sample. In the instance of repetition, neither the components nor the interactions were significant. When employing numerous observations for all experimental treatments, all runs must be randomly generated (Gómez et al., 2010).

In this study, the use of repetition and replication was applied to 8 experimental runs. Repetition was conducted on samples with identical conditions, such as Std 7 and Std 8, where the concentrations of rice husk, cornstarch, citric acid, and borax, as well as the hot press temperature, were kept constant. Meanwhile, replication was applied to ensure consistency across different experimental runs, particularly for conditions with a citric acid concentration of 15 g and borax concentration of 13 g. Additionally, for the constant parameters such as rice husk and cornstarch, these were fixed at 120 g and 135 g, respectively. For the varying factors such as hot press temperature, the levels were set between 120°C and 150°C, while for citric acid and borax concentrations, the levels ranged from 15 g to 30 g and 6 g to 13 g, respectively. Table 3.1 below shows the sample data that have been generalized by the DoE.

Table 3.1 : Sample data generated by DoE

Std	Run	Factor 1 : Borax (g)	Factor 2 : Citric Acid (g)	Factor 3 : Hot Press Temperature (°C)
7	1	6	30	150
4	2	13	30	120
1	3	6	15	120
2	4	13	15	120
3	5	6	30	120
5	6	6	15	150
8	7	13	30	150
6	8	13	15	150

3.4. Sample Preparation

In the process of development of rice husk-based thermal insulation board, the first step involves the collection and preparation of rice husk. Rice husk, an abundant byproduct of rice milling, was sourced from local rice mills to ensure a steady and reliable supply. Care was taken to select rice husk with consistent quality and minimal impurities (Shamsollahi & Partovinia, 2019).

The rice husk was cleaned to remove dust, dirt, and rice grains through sieving and washing, ensuring it was free from contaminants. It was then dried to an optimal moisture level using natural sunlight (Deivaseeno Dorairaj et al., 2022).

Following the drying process, the rice husk underwent size reduction through grinding or milling. This step ensures a uniform particle size for better mixing and binding in later stages. The prepared rice husk is stored in airtight containers to prevent moisture uptake and contamination (Nandiyanto et al., 2020).

Rice husk is combined with binders and additives to create a homogeneous mixture for thermal insulation. Corn starch, chosen for its natural adhesive properties and environmental friendliness, serves as the primary binder. Citric acid and borax is added to enhance cross-linking between starch molecules and rice husk fibers to improving the strength and durability of the insulation material (Silva et al., 2023). Figure 3.2 shows the process for sample preparation.

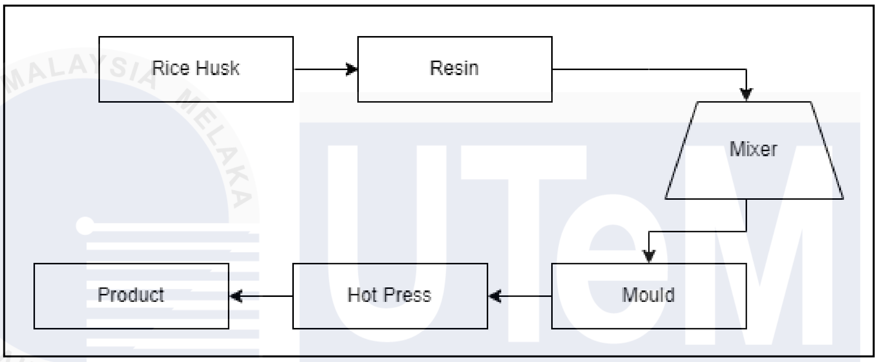

Figure 3.2 : Process for sample preparation

3.4.1 Formulation of Binder

In the formulation development phase, rice husk was combined with binders, additives, and borax to create a homogeneous mixture suitable for thermal insulation. Corn starch was selected as the primary binder due to its natural adhesive properties and environmental friendliness. Citric acid was incorporated to enhance the cross-linking between the starch molecules and the rice husk fibers, improving the overall strength and durability of the insulation material (Hazim et al., 2020). Borax was added as a flame retardant and preservative, contributing to improved fire resistance and fungal protection of the insulation material.

The treated and dried rice husk was gradually mixed with a corn starch solution prepared by dissolving the starch in water. Citric acid was then added to the mixture in controlled amounts, facilitating the formation of a robust biopolymer matrix. Borax was introduced at this stage to ensure its uniform integration into the mixture, enhancing the material's thermal and mechanical performance. This combination ensured strong bonding between the rice husk particles and provided added functionality such as fire resistance, resulting in a cohesive and stable insulation material (Wu et al., 2017).

The mixing process was carried out using a mechanical mixer to ensure even distribution of the binder, additive, and borax throughout the rice husk. The mixture was continuously stirred until a uniform consistency was achieved, indicating that the rice husk particles were adequately coated with the corn starch, citric acid and borax blend. The formulated mixture was then ready for molding and shaping into desired insulation forms (Amran et al., 2021).

3.4.2 Mixing and Compounding

In the mixing and compounding phase, the prepared rice husk and the binder-additive solution were thoroughly combined to create a uniform insulation material. The rice husk, pre-treated and dried, was gradually introduced into a mechanical mixer. The binder solution, prepared by dissolving corn starch in water, adding citric acid, and incorporating borax, was then slowly poured into the mixer containing the rice husk.

The mixing process was conducted at a controlled speed to ensure even distribution of the binder and additives among the rice husk particles. This step was crucial for achieving a homogeneous mixture, essential for the insulation material's consistency and quality. The mechanical mixer was operated until the rice husk particles were fully coated with the corn starch, citric acid and borax resulting in a uniform composite.

To further improve bonding and mechanical properties, the material was kneaded and blended thoroughly. This additional step ensured that the corn starch, citric acid, borax, and rice husk particles were well integrated into a cohesive matrix. The final mixture was then prepared for molding into insulation board and ready for curing and testing (Silva et al., 2023). Figure 3.3 below shows the mixture of insulation board.

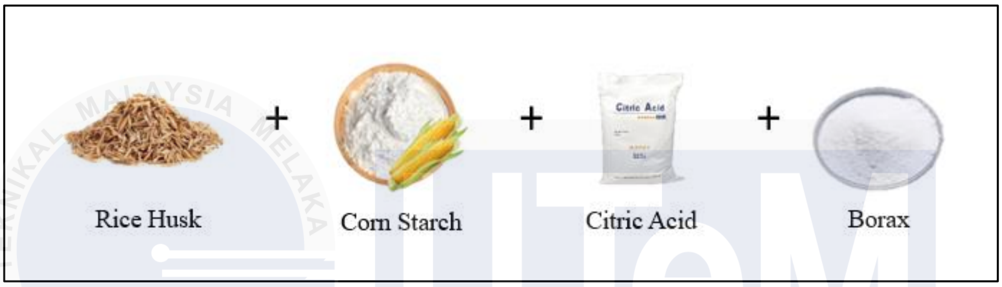

Figure 3.3 : The mixture of insulation board

3.4.3 Moulding and Shaping

In the molding and shaping phase, the compounded rice husk mixture was formed into insulation boards using specially designed molds. The molds, with dimensions of 177.8 mm x 177.8 mm x 5 mm, were selected to produce rectangular board (Dhand, 2018). The homogeneous rice husk mixture was carefully poured into the molds, ensuring an even distribution to avoid air pockets and inconsistencies. The mixture was then compacted within the mold using a mechanical hot press machine, applying uniform pressure to achieve the desired density and structural integrity.

This compaction process was critical for enhancing the thermal insulation properties and mechanical strength of the final product. After compaction, the molded boards were allowed to set and cure under controlled conditions. The curing process involved maintaining specific temperature and humidity levels to facilitate the proper bonding of the binder and rice husk particles. This step ensured that the boards achieved optimal hardness and stability.Once cured, the boards were removed from the molds. Designed for easy installation, the standardized boards offer an efficient and sustainable alternative to traditional insulation. They were then tested to ensure they met performance standards (Marín-Calvo et al., 2023). Figure 3.4 shows the molds of insulation board.

Figure 3.4 : The molds of insulation board

3.4.4 Hot Press Process

The hot press is a crucial tool in fabricating rice husk insulation boards, serving to compact the mixture of rice husk and binders such as corn starch, citric acid, and borax under controlled heat and pressure. In this study, a Motorized Hydraulic Molding Test Press Machine (GOTECH) was utilized to ensure precise and consistent pressing conditions. Hot pressing, using a mold measuring 177.8 x 177.8 x 5 mm, allows the material to be compressed with minimal voids, resulting in increased density.

The heat involved in the process activates the binders and initiates various thermal reactions, such as gelatinization and esterification, which enhance the adhesion between rice husk particles and solidify the board. Additionally, the application of heat promotes moisture evaporation, preventing defects like bubbling or swelling.

In this project, eight samples were prepared and subjected to two pressing temperatures, 120°C and 150°C, to investigate the effect of temperature on the board's properties. Higher temperatures can improve binder activation, resulting in stronger and more cohesive boards but, excessive heat may cause material breakdown. The hot press process is of paramount importance for the board to achieve desired thermal and mechanical properties, such as improved water resistance, structural integrity, and optimized thermal insulation performance. Figure 3.5 and 3.6 below shows the Motorized Hydraulic Molding Test Press Machine (GOTECH) and pressing of insulation board.

Figure 3.5 : Motorized Hydraulic Molding Test Press Machine (GOTECH)

Figure 3.6 : Pressing of insulation board

3.5 Thermal Conductivity Test

Thermal conductivity testing is crucial for determining the efficiency of rice husk-based insulation in limiting heat transfer, impacting its effectiveness in building applications. This test was conducted with specification of ASTM C518 (Marín-Calvo et al., 2023). To measure thermal conductivity, standardized methods such as the hot plate technique are commonly employed.

In this method, samples of the insulation material was prepared with 177.8 x 177.8 x 5 mm dimensions to ensure they fit the testing apparatus accurately. The sample is placed between a heated plate and another side was maintained at a constant temperature. During the thermal conductivity tests, the temperature difference (ΔT) between the hot and cold sides of the insulation board was recorded using Digital Thermometer (FLUKE–54IIB), while the heat flux (Q) was recorded using Heat Flow Meter (HFM-201). Figure 3.7 and 3.8 shows the Digital Thermometer (FLUKE–54IIB) and Heat Flow Meter (HFM-201). Thermal conductivity (k) is then calculated using the formula in equation 3.1:

$$k = \frac{Qd}{A\Delta T} \tag{3.1}$$

Where (k) is the thermal conductivity, (Q) represents the heat flow rate, (d) is the thickness of the sample, (A) is the cross-sectional area, and (ΔT) is the temperature difference across the sample. This formula provides a precise measurement of the material's ability to conduct heat.

Figure 3.7 : Digital Thermometer (FLUKE-54IIB)

Figure 3.8 : Heat Flow Meter (HFM-201)

3.6 Water Absorption Test

This test is carried out to ensure the rice husk insulation board for its resistance to wet conditions by moisture. It determines the material's absorption of water during submersion in water over a known period of time. In this process, drying of the sample in the Laboratory Drying Oven (Nabertherm) with temperature 105°C should be carried out until all moisture has gone and the dry weight was recorded. Figure 3.9 shows the Laboratory Drying Oven (Nabertherm).

Figure 3.9 : Laboratory Drying Oven (Nabertherm)

Then the samples is submerged in water at room temperature for 24 hours to allow imbibing of water into the material. The sample is then removed from the water and blotted lightly to remove the water on its surface and is weighed in the wet condition. Water absorption is computed from the difference in wet and dry weights. The test is important for establishing the durability and performance of insulation board in humid environments since too much water absorption may lower thermal efficiency and even compromise the structural integrity of the material. Equation 3.2 shows the formula for calculating water absorption.

$$\text{Water Absorption (\%)} = \frac{(\text{Wwet} - \text{Wdry})}{\text{Wdry}} \times 100 \qquad (3.2)$$

Where, Wwet is the weight of the sample after immersion in water (g) and Wdry is the initial weight of the dry sample before immersion (g).

3.7 Summary

This chapter presented the proposed methodology in order to development of thermal insulation board using rice husk on various method and process that are already discussed in Chapter 2. The primary focus of the proposed methodology is to ensure the product will work properly as expected.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The preliminary results of this project include the successful development of a cost-effective thermal insulation board using rice husk, with optimized concentrations of 120 grams of rice husk, 135 grams of corn starch, 15 and 30 grams of citric acid and 6 and 13 grams of borax. The resulting insulation material is anticipated to exhibit excellent thermal performance, comparable to conventional insulation materials, while also providing sufficient mechanical strength and durability. Additionally, the rice husk-based insulation board should demonstrate environmental benefits by utilizing agricultural waste, thus promoting sustainability. This innovative insulation solution is expected to be a viable alternative for use in the construction and insulation industry, offering both economic and ecological advantages.

4.2 Samples of Insulation Board

The preparation of samples is a critical step in ensuring the quality and consistency of rice husk-based insulation boards. The rice husk, collected from local rice mills, was cleaned, dried, and ground to achieve a uniform particle size. This process ensures minimal impurities and optimal bonding in the subsequent mixing phase.

A binder solution was prepared using corn starch, citric acid, and borax. The rice husk was gradually mixed with the binder solution to form a homogeneous mixture. Using molds of dimensions 177.8 mm × 177.8 mm × 5 mm, the mixture was compressed under a hydraulic hot press at specific temperatures (120°C and 150°C) and a pressure of 145 psi for 20 minutes. These steps ensure consistency and uniformity across all samples, with eight samples prepared under varying conditions for detailed analysis. Figure 4.1 shows eight samples of the insulation board.

Figure 4.1 : Eight samples of the insulation board

4.3 Thermal Conductivity Testing Analysis

In this study, thermal conductivity testing was carried out using a Digital Thermometer (FLUKE 54IIB) and a Heat Flow Meter (HFM-201) to evaluate the performance of rice husk-based insulation boards. The samples were tested with a diameter of 5 mm and a surface area of 0.003025 m². The Heat Flow Meter (HFM-201) applied a controlled heat flux (Q) across the sample, while the Digital Thermometer (FLUKE 54IIB) measured the temperatures on both sides of the board to calculate the temperature difference (ΔT). These precise instruments ensured accurate measurements, providing reliable data for assessing the insulating properties of the material.

The thermal conductivity (k) of the 8 samples was determined using Fourier's Law of Heat Conduction, which relates heat flux (Q), board thickness (d), cross-sectional area (A), and temperature difference (ΔT). This setup allowed for systematic and consistent testing of the samples, ensuring that any variations in thermal conductivity could be attributed to changes in experimental factors, such as resin composition or manufacturing conditions. By using this method, the study was able to obtain reliable results to evaluate and optimize the thermal insulation performance of the rice husk insulation boards. Figure 4.2 below shows the thermal conductivity testing.

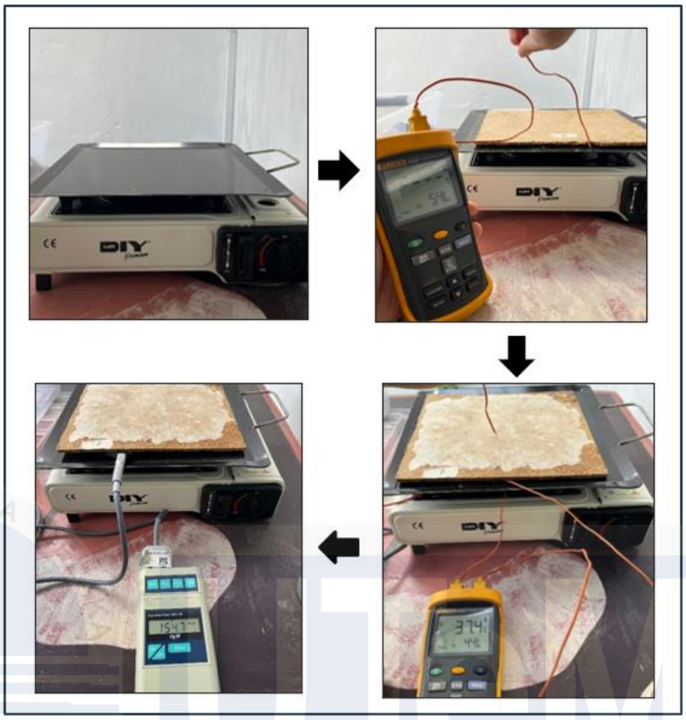

Figure 4.2 : Thermal conductivity testing process

The table presents experimental data related to the thermal conductivity (k) of various samples, highlighting their thermal performance under specific conditions. The heat flux (Q), which represents the rate of heat transfer through the material, varies significantly among the samples, ranging from 0.8 W/m² sample 8 to 172.7 W/m² sample 7. The cross-sectional area (A) of the material remains constant at 0.003025 m² for all samples, while the thickness (d) is fixed at 5 mm. Temperature readings on the warmer side (T1) and cooler side (T2) of the materials show variations in the temperature difference (ΔT), which is a driving factor for heat transfer. ΔT values range from 3.3 °C in sample 8 to 18.5 °C in sample 6.

The calculated thermal conductivity (k) values, which indicate the material's ability to conduct heat, display a wide range. Sample 8 exhibits the lowest k value (0.40 W/m·K), signifying excellent thermal insulation, while sample 7 shows the highest k value 36.13 W/m·K, indicating higher heat conduction. This variation suggests that different materials or conditions were tested, each impacting the heat transfer characteristics. Overall, the data underscores the effectiveness of certain samples, such as sample 8, in providing superior insulation, while others, like sample 7, are less efficient at resisting heat transfer. These findings are essential for assessing and optimizing materials for thermal insulation applications. Table 4.1 below shows the result of thermal conductivity testing.

Table 4.1 : The result of thermal conductivity testing

Sample	**Heat Flux, Q (W/m^2)**	**Area, A (m^2)**	**Thickness, d (mm)**	**T1 (°C)**	**T2 (°C)**	**ΔT (°C)**	***k* (W/m·K)**
1	17.3	0.003025	5	37.1	42.4	5.3	5.40
2	23.3	0.003025	5	37.5	42.8	5.3	7.27
3	11.5	0.003025	5	38.0	43.1	5.1	3.73
4	98.4	0.003025	5	36.0	42.1	6.1	26.66
5	22.3	0.003025	5	38.1	48.8	10.7	3.44
6	142.8	0.003025	5	39.5	58.0	18.5	12.76
7	172.7	0.003025	5	35.9	43.8	7.9	36.13
8	0.8	0.003025	5	37.0	40.3	3.3	0.40

The table presents the statistical analysis of factors influencing thermal conductivity, focusing on individual factors A - Borax, B - Citric Acid, and C - Hot Press Temperature and their interactions AB, AC, BC, and ABC. Each factor is evaluated based on its standardized effect, sum of squares, and percentage contribution to the overall variability in thermal conductivity.

Among the individual factors, Borax (A) exhibits the highest standardized effect which is 11.2825 and contributes significantly 22.33% to the overall variability. Hot Press Temperature (C) has a moderate impact, with a standardized effect of 3.3975 and a contribution of 2.03%. However, Citric Acid (B) shows a relatively small standardized effect 2.1725 and contributes only 0.83%.

The interactions between factors play a critical role, with the BC interaction Citric Acid and Hot Press Temperature contributing 25.32% to the overall variability, demonstrating a strong combined effect. The three-way interaction ABC - Borax, Citric Acid, and Hot Press Temperature has the highest impact, with a standardized effect of 15.5475 and a dominant contribution of 42.41%. The AB interaction Borax and Citric Acid also shows notable significance, contributing 6.31%. The AC interaction Borax and Hot Press Temperature has the least impact, with a negative standardized effect -2.0975 and a minimal contribution 0.77%.

In summary, the three-way interaction ABC and the BC interaction are the most influential contributors to thermal conductivity, while Borax (A) is the most impactful individual factor. These findings emphasize the importance of both individual components and their interactions in optimizing material performance. Table 4.2 below shows the statistical analysis of factors influencing thermal conductivity.

Table 4.2 : The statistical analysis of factors influencing thermal conductivity

Term	**Standardized Effect**	**Sum of Square**	**% Contribution**
A - Borax	11.2825	254.59	22.3343
B – Citric Acid	2.1725	9.43951	0.828097
C – Hot Press Temperature	3.3975	23.086	2.02526
AB	5.9975	71.94	6.31106
AC	-2.0975	8.79901	0.771908
BC	12.0125	288.6	25.3179
ABC	15.5475	483.45	42.4114

The normal probability plot presented is used to analyze the factors and interactions affecting thermal conductivity. The plot evaluates the significance of individual factors (A) borax, (B) citric acid, and (C) Hot Press Temperature as well as their interactions, such as BC and ABC. The red line on the graph represents the baseline of no significant effect, and deviations from this line indicate the impact of the factors. Points farther to the right of the line have a significant positive effect, while points on the left indicate negative effects. Figure 4.3 below shows the factors and interactions affecting thermal conductivity testing.

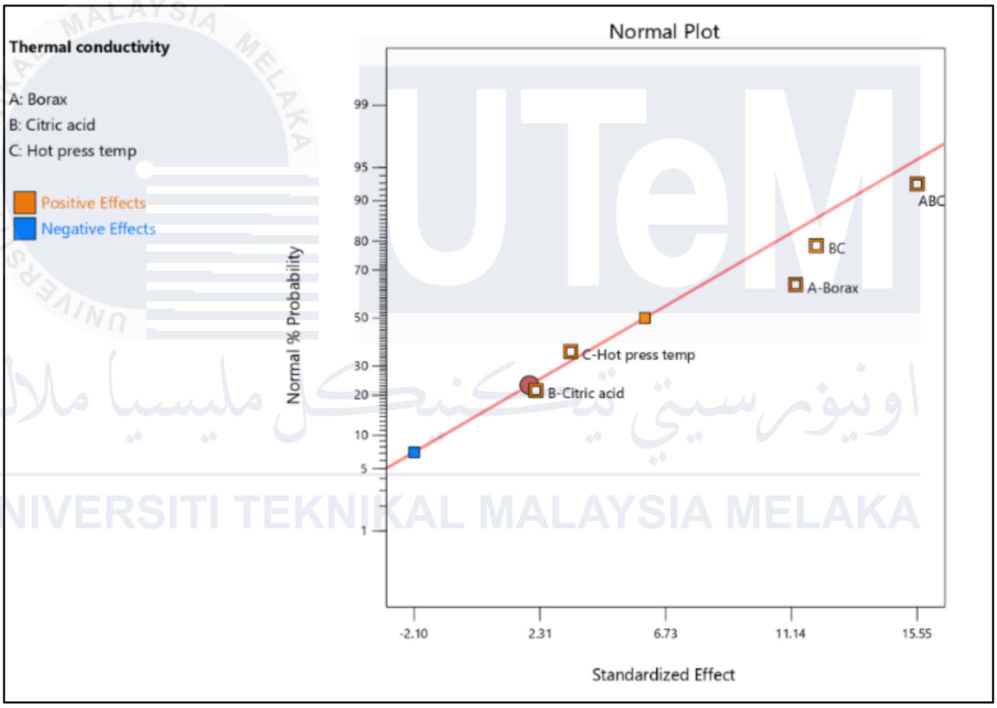

Figure 4.3 : The factors and interactions affecting thermal conductivity testing

In this plot, the interaction between borax, citric acid, and hot press temperature (ABC) shows the largest positive effect on thermal conductivity, as it is farthest to the right of the red line. Borax (A) also demonstrates a strong positive impact, followed by the interaction between citric acid and hot press temperature (BC). Citric acid (B) and hot press temperature (C) have minor positive effects, as their points are closer to the red line. A single blue point indicates a factor or interaction with a negative effect on thermal conductivity, but its impact is relatively small compared to the positive effects.

This analysis highlights that the combined effect of borax, citric acid, and hot press temperature (ABC) plays a significant role in enhancing thermal conductivity, making it a critical factor for optimizing the formulation of thermal insulation boards. Figure 4.4, 4.5 and 4.6 shows the interaction between AB, AC and BC

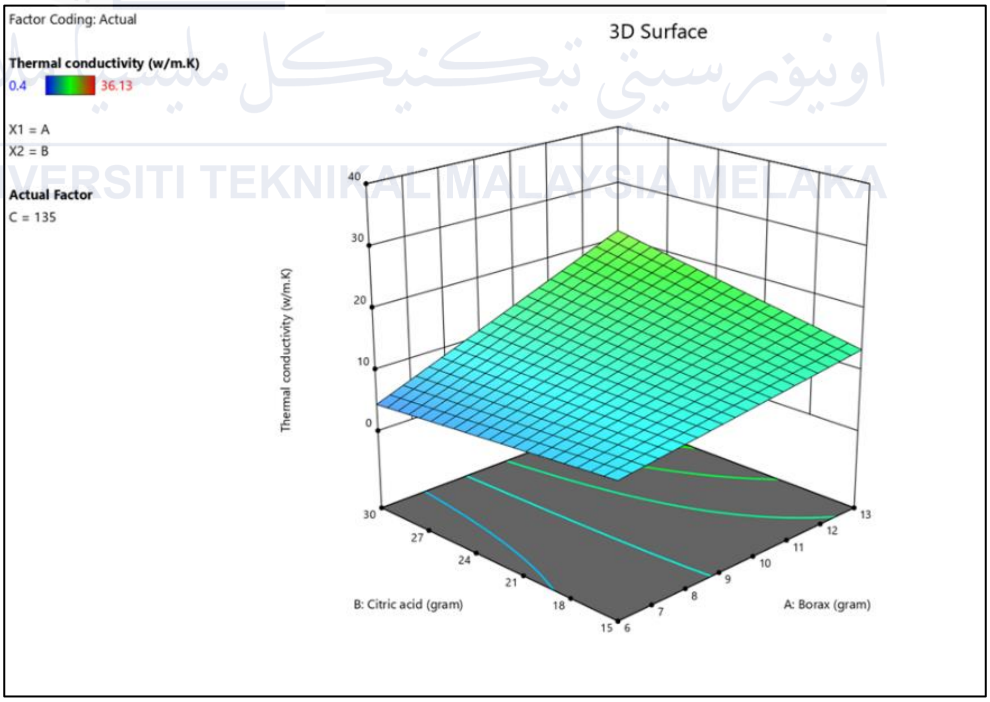

Figure 4.4 : The interaction between A and B

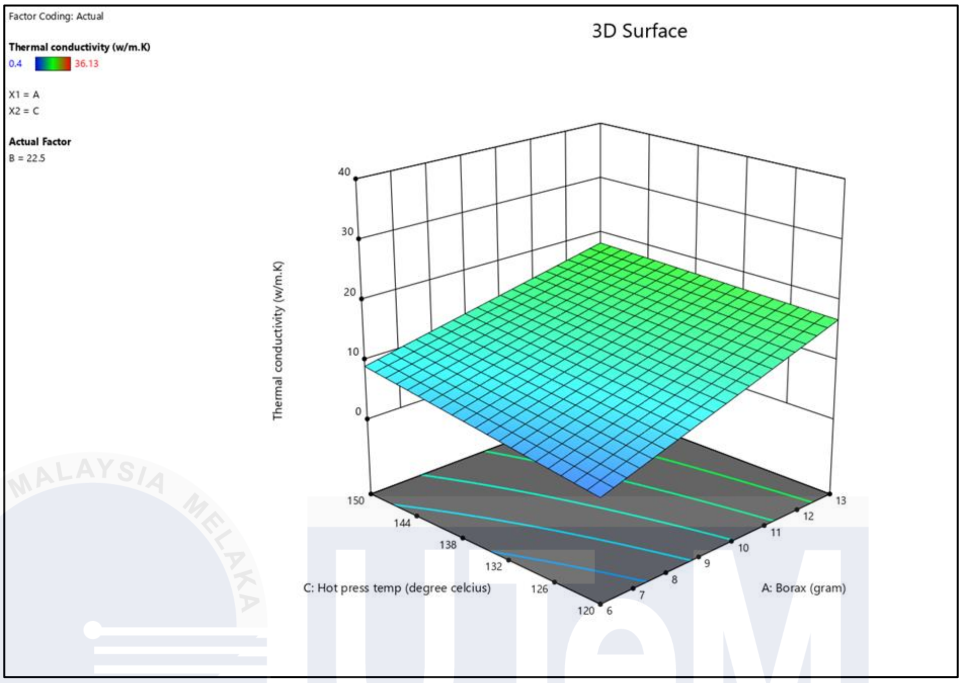

Figure 4.5 : The interaction between A and C

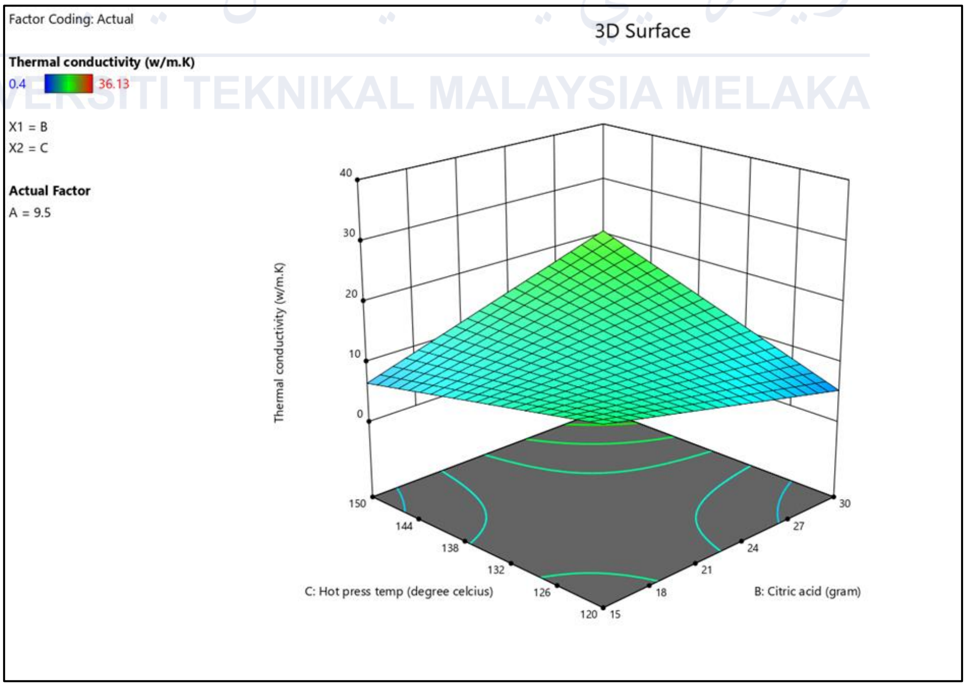

Figure 4.6 : The interaction between B and C

4.4 Water Absorption Testing Analysis

In this study, the water absorption test was conducted on 8 rice husk-based insulation board samples to evaluate their ability to absorb and retain moisture. The test involved drying the samples using a drying oven to remove all moisture, and the initial dry weights (Wdry) were recorded for each sample. The samples were then submerged in water for 24 hours ensuring they were fully saturated, after which the wet weights (Wwet) were measured. The dry weights of the samples ranged from 9 g to 15 g, while the wet weights ranged from 13 g to 19 g, reflecting the variation in water absorption capacity across the samples.

This test helps determine the ability of the material to resist moisture penetration, which is crucial for insulation boards exposed to humid conditions. By analyzing the water absorption results, the study aimed to assess how well the boards maintain their structural integrity and insulating properties after exposure to water. This information is essential for optimizing the material's formulation to improve its durability and performance in practical applications. Figure 4.7 shows the water absorption process.

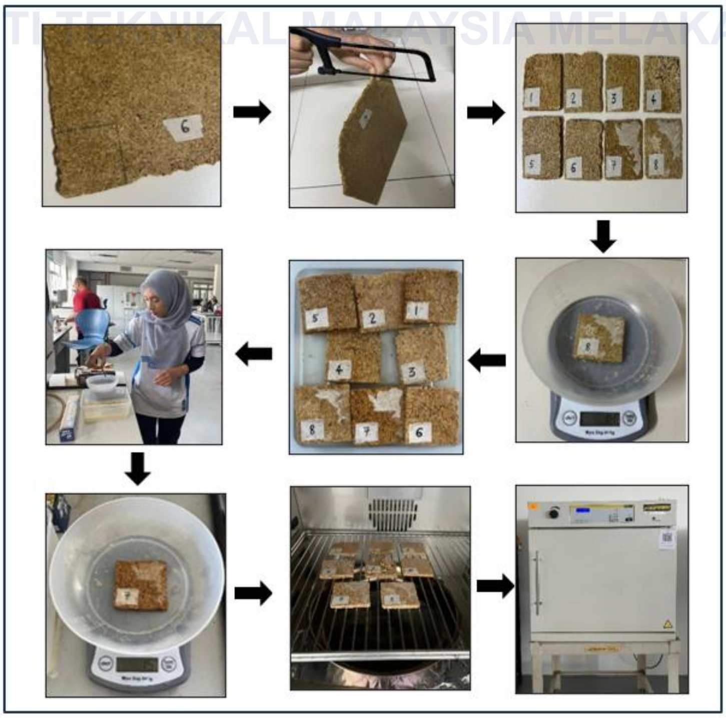

Figure 4.7 : The water absorption process

The water absorption properties of eight samples was evaluated based on their dry weight (Wdry), wet weight (Wwet), and percentage of water absorption. Water absorption percentage is a critical parameter for determining the suitability of materials in applications where moisture resistance is essential, such as insulation.

Among the samples, sample 8 exhibited the lowest water absorption at 23.08%, indicating its superior resistance to moisture compared to the other samples. This low absorption rate highlights sample 8 as the most moisture-resistant material, making it potentially ideal for environments with high humidity. On the other hand, sample 5 demonstrated the highest water absorption at 63.64%, absorbing a significant amount of water relative to its dry weight. This high absorption rate suggests that sample 5 may be less effective in applications requiring moisture resistance, as excessive water retention can degrade thermal insulation performance and compromise material integrity over time.

Overall, the results demonstrate a range of water absorption capacities, with most samples falling between 30% and 55%, while sample 8 and sample 4 was 26.67% stand out for their lower moisture uptake. These findings provide valuable information for selecting materials based on their water resistance in specific applications. Table 4.3 below shows the results for water absorption test.

Table 4.3 **:** The results for water absorption test

Sample	Wdry (g)	Wwet (g)	Water Absorption (%)
1	10	14	40.00
2	9	15	55.67
3	10	16	37.50
4	15	19	26.67
5	11	18	63.64
6	10	13	30.00
7	11	15	36.36
8	13	16	23.08

The factors influencing water absorption are analyzed with a focus on key variables such as borax content, citric acid concentration, and hot press temperature. Each factor is evaluated comprehensively using three metrics which is standardized effect, sum of squares, and percentage contribution.

The first column lists the factors under investigation, including interactions between them, such as AB (Borax and Citric Acid) and AC (Borax and Hot Press Temperature). The standardized effect measures how much influence each factor has on water absorption. For instance, Citric Acid (B) has a positive effect of 19.605, suggesting it significantly increases water absorption, while Borax (A) and Hot Press Temperature (C) have negative effects, indicating they may decrease water absorption.

The sum of square column indicates the total variation attributed to each factor. Citric acid again stands out with the highest value of 768.712, highlighting its substantial impact compared to others. In terms of percentage contribution, citric acid accounts for 55.639% of the influence on water absorption, followed by hot press temperature at 26.421% and borax at 7.799%. The interactions, such as AB and AC, contribute minimally, illustrating that the primary factors driving water absorption are the individual components rather than their combinations.

Overall, the table underscores that citric acid has the most significant positive influence on water absorption, while borax and hot press temperature may act to reduce it, providing valuable insights for further research or practical applications in material selection. Table 4.4 below shows the statistical analysis of factors influencing water absorption.

Table 4.4 : The statistical analysis of factors influencing water absorption

Term	**Standardized Effect**	**Sum of Square**	**% Contribution**
A - Borax	-7.34	107.751	7.79897
B – Citric Acid	19.605	768.712	55.639
C – Hot Press Temperature	-13.51	365.04	26.4214
AB	1.535	4.71245	0.341085
AC	2.06	8.4872	0.614299
BC	-7.965	126.882	9.18368
ABC	0.105	0.02205	0.00159597

The normal probability plot illustrates the impact of various factors, including Borax (A), Citric Acid (B), Hot press temperature (C), and their interactions (AB, AC, BC, and ABC), on water absorption. Positive effects, represented in orange, indicate factors or interactions that increase water absorption, while negative effects, shown in blue, represent those that reduce it. Among these, Citric Acid (B) exhibits the most significant positive effect on water absorption, as evidenced by its position farthest to the right of the red diagonal line. On the other hand, Hot press temperature (C) demonstrates a notable negative effect, suggesting its ability to reduce water absorption. Figure 4.8 below shows the factors and interactions affecting water absorption testing.

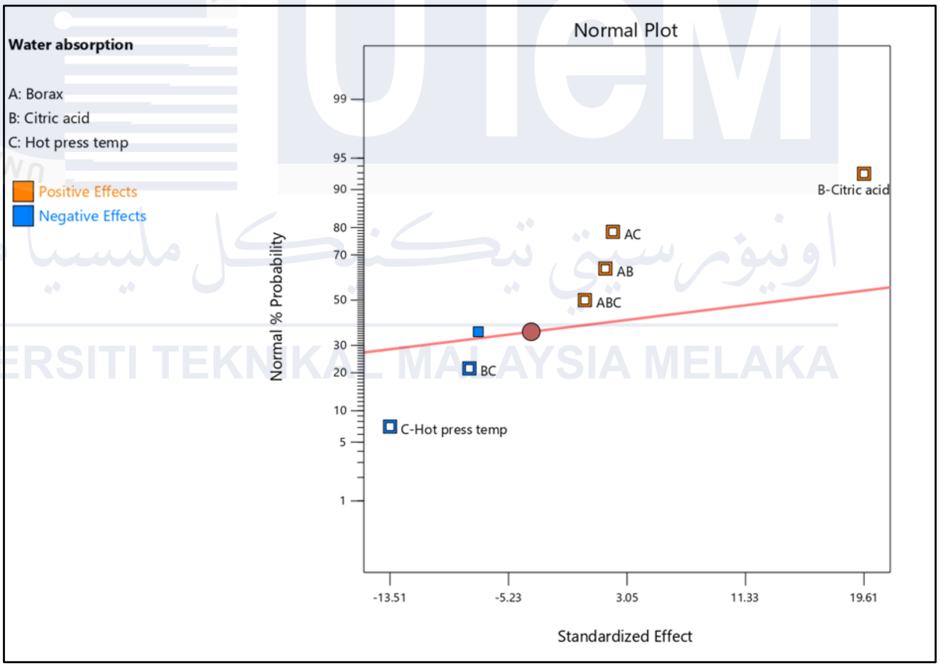

Figure 4.8 : The factors and interactions affecting water absorption testing

Interactions such as Borax × Hot press temperature (AC), Borax × Citric Acid (AB), and the combined interaction of Borax, Citric Acid, and Hot press temperature (ABC) also show substantial positive effects, with the ABC interaction being the most significant among them. The standardized effect on the horizontal axis quantifies the strength of each factor or interaction, while the vertical axis represents the normal probability distribution. Factors and interactions further from the diagonal line deviate significantly from the norm, highlighting their critical role in influencing water absorption. Overall, citric acid and the interactions involving all three factors emerge as the dominant contributors, while hot press temperature plays a key role in enhancing water resistance by reducing absorption. Figure 4.9, 4.10 and 4.11 shows the interaction between AB, AC and BC.

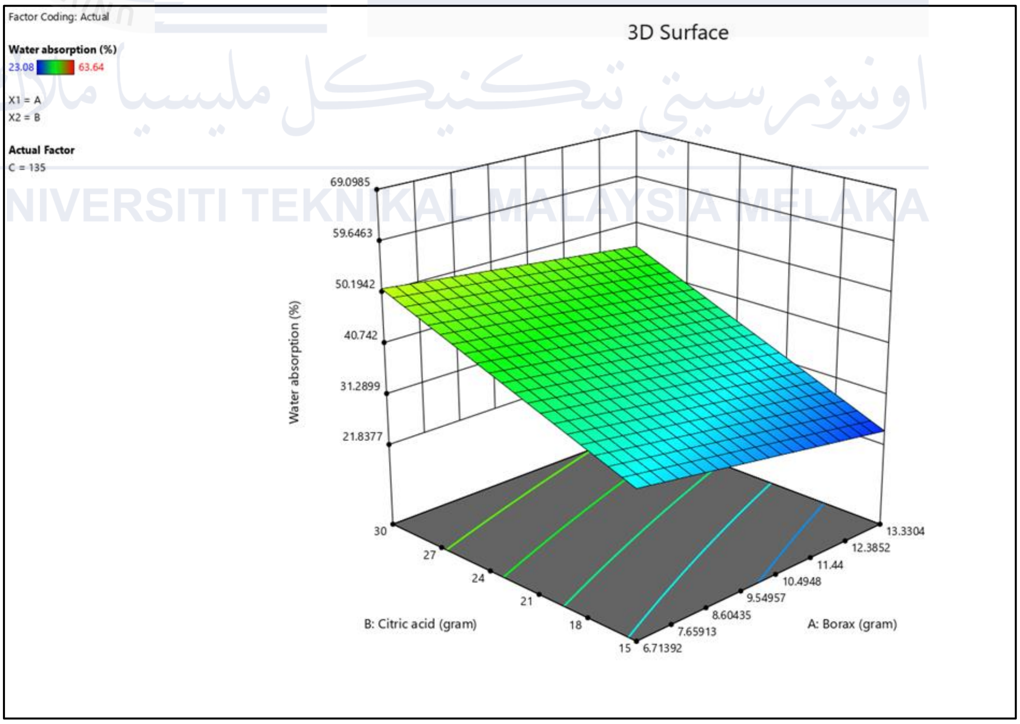

Figure 4.9 : The interaction between A and B

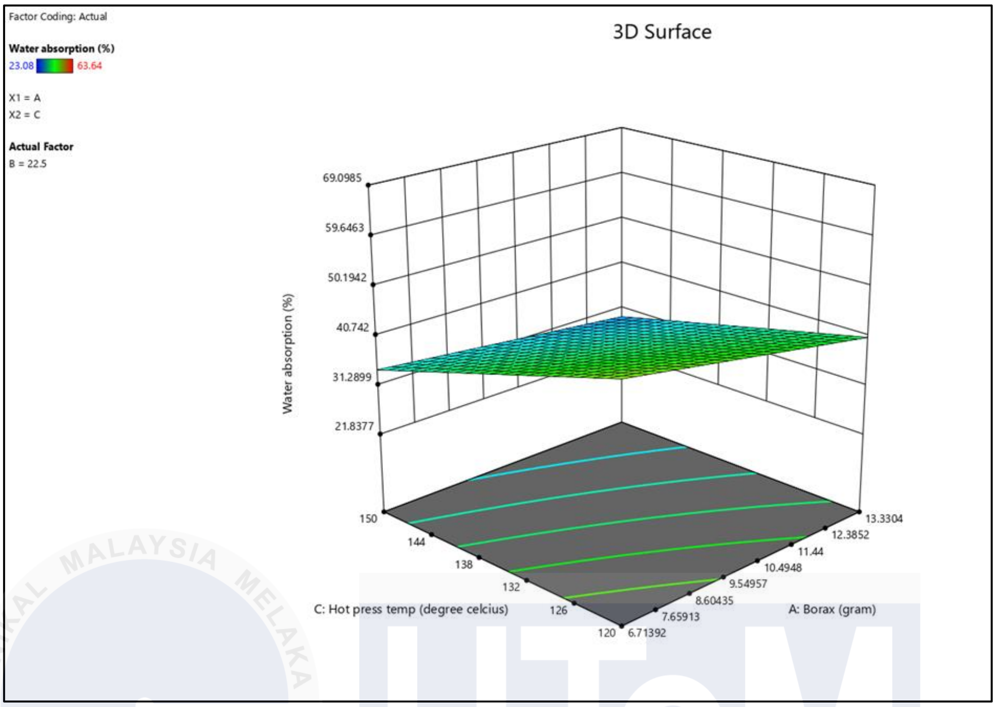

Figure 4.10 : The interaction between A and C

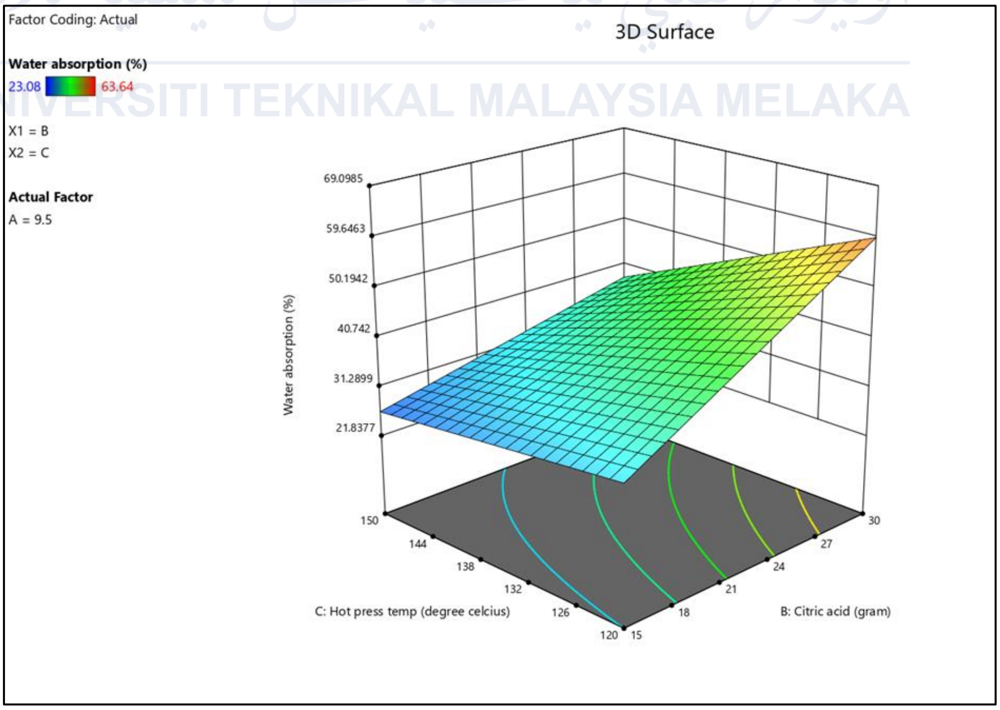

Figure 4.11 : The interaction between B and C

4.5 Summary

It can be summarized here in chapter 4 that data optimization results, which have been released by the DoE software, are good data. Besides, it also can generate product production data for industry. The study found that sample 8 exhibited the best thermal conductivity (0.40 W/m·K) and lowest water absorption (23.08%), showcasing excellent insulation and moisture resistance. Statistical analysis revealed the interaction of Borax, Citric Acid, and Hot press temperature (ABC) as the key factor for thermal performance, while citric acid had the most significant effect on water absorption. These results highlight the potential of rice husk-based boards as sustainable insulation materials.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study successfully developed a thermal insulation board utilizing rice husk, showcasing its potential as a sustainable and eco-friendly alternative to traditional insulation materials. By integrating natural binders such as borax, citric acid, and corn starch, the research aimed to address the environmental and efficiency drawbacks of conventional options like fiberglass and foam plastics. The experimental findings identified sample 8 (13g borax, 15g citric acid, and 150 hot press temperature) as the best-performing formulation, achieving the lowest thermal conductivity (0.40 W/m·K) and water absorption (23.08%), demonstrating its exceptional insulating and moisture-resistant properties.

The statistical analysis further emphasized the importance of key factors and their interactions in determining material performance. The interaction between borax, citric acid, and hot press temperature (ABC) was identified as the most influential factor affecting thermal conductivity, contributing 42.41% to the variability. Similarly, citric acid emerged as the primary factor influencing water absorption, accounting for 55.64% of the observed variation, while borax and hot press temperature contributed to reducing water uptake, enhancing the material's durability in humid conditions.

These results highlight the effectiveness of rice husk-based insulation boards in meeting the dual demands of thermal efficiency and sustainability. The study demonstrates that carefully selected formulations and controlled processing conditions can produce high-performance insulation materials, suitable for applications in energy-efficient buildings and eco-friendly construction practices.

5.2 Recommendation

Based on the findings, the following recommendations are proposed:

i. Further research should focus on optimizing the proportions of borax, citric acid, and hot press temperature to enhance the thermal and moisture resistance properties of the insulation board.

ii. Conducting a comprehensive environmental impact assessment to quantify the benefits of using rice husk-based insulation over traditional materials.

iii. Implement field testing in various climatic conditions to evaluate the long-term durability and performance of the insulation boards in real-world applications.

5.3 Project Potential

The project has significant potential to revolutionize the insulation industry by providing a cost-effective, sustainable alternative to traditional materials. The use of rice husk, an agricultural byproduct, not only addresses waste management issues but also promotes the utilization of renewable resources. The developed insulation boards can contribute to energy-efficient building practices, reducing carbon footprints and supporting green construction initiatives. With further optimization and commercialization, rice husk-based insulation has the potential to become a mainstream solution in the construction industry, offering both economic and environmental benefits.

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APPENDICES

APPENDIX A - Gantt Chart

		PSM 1														PSM 2															
NO.	ACTIVITY	WEEKS																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1.	Title Selection																														
2.	Planning and Research																														
3.	Background, Problem Statement																														
4.	Objective, Scope																														
5.	Literature Review (Find Journal)																														
6.	Research Gap																														
7.	Flowchart																														
8.	Survey Binders																														
9.	Finalized Binders																														
10.	Survey Rice Husk																														
11.	Purchasing Rice Husk																														
12.	Preparation of Sample																														
13.	Mixing and Compounding																														
14.	Moulding and Shaping																														
15.	Hot Press																														
16.	Product Testing																														
17.	Report Preparation																														
18.	Presentation																														
19.	Weekly E-Logbook																														
20.	Final Report Submission																														