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The Efficacy of Using Thermal Insulator Powder in the Production of Cellulose Acetate Aerogel Foam

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Abstract

This study presents a comprehensive evaluation of the efficacy of infusing thermal insulator powder into cellulose acetate aerogel foam to enhance both the production process and its thermal insulation performance, with a focus on the impact of varying concentrations of thermal insulator powder on the structural and mechanical properties of CAAF, compared to commercially available aerogel foams. The researchers used true experimental quantitative design that allowed them to have precise control over variables, particularly the amount of thermal insulator powder. This method helped establish causal relationships and assessed the impact of the powder on foam properties, particularly thermal insulation. Findings indicate that there is a significant difference in the commercial aerogel foam, cellulose acetate aerogel foam, and cellulose acetate aerogel foam infused with different concentrations of thermal insulator powder in terms of their thermal conductivity and time longevity. However, the results indicated that the infusion of thermal insulator powder did not significantly enhance the physical stability property of the samples.

Keywords: Thermal Insulation Powder, Cellulose Acetate Aerogel Foam, Cellulose Acetate, Physical Stability, Thermal Insulation, Thermal Conductivity, Longevity

INTRODUCTION

Background of the Study. According to an estimate by the United States Department of Agriculture, more than 5.5 trillion cigarettes were produced worldwide in 2004 and the value of cigarettes produced corresponds to 1.2 million cigarette butts waste per year. Cigarette butts cause a buildup of CBs in the environment, releasing hazardous compounds as it deteriorates; moreover, it leaves a significant impact in the marine ecosystem (Kadir & Sarani, 2015). Cigarette butts are often discarded; hence, recycling it will adhere to its causing issues in the environment. Furthermore, these cigarette wastes are used in the recycling of cellulose acetate aerogel which possess characteristics suitable for oil spill treatment and thermal insulation (Ngoc et al., 2020). Additionally, for Kadir and Sarani (2015), only few studies have explored the effects of cigarette butts on the aquatic ecosystem. However, these studies have proven its biohazard to organisms found in freshwater illustrating it as a serious issue.
Cigarette butts, a product with a mixed synthetic arrangement, are notable for their widespread distribution and large quantities. In 2016, the globe consumed 5505 trillion units of cigarettes, according to Santos (2017). Nine trillion cigarettes will be smoked worldwide by 2025. According to Curtis (2017), Novotny and Slaughter (2014), cigarette butts are the most prevalent type of personal litter worldwide. Despite being tiny, these residues are produced in significant quantities. Furthermore, the cigarette butt issue has been brought up by the studies of Mindell (2001), Santos (2005), and Martinez-Ribes (2007) several years ago. The Surfrider Foundation reports that during the organization's sponsored beach clean-ups, cigarette butts are the most often collected item. A report from the Ocean Conservancy (2011) states that over 27 years, 52 million cigarettes were retrieved from coastal areas. A total of 13,806,887 trash pieces, including 2,127,565 cigarette butts, were collected by volunteers working on beaches in more than 100 countries throughout the 2015 campaign (Ocean Conservancy, 2016). As a result, this kind of litter was the most prevalent.

The pursuit of sustainable and high-performing materials in the field of advanced energy storage has sparked significant enthusiasm for the exploration of cellulose-based composite foams and aerogels. Cellulose, which originates from renewable biomass sources, emerges as an environmentally friendly substitute for traditional materials in energy storage devices. Its adaptability has captivated researchers in their quest for innovative approaches to enhance energy density, safety, and the overall sustainability of such systems. Composite foams and aerogels, in particular, have gained prominence due to their exceptional structural properties. Aerogels, characterized by their ultra-lightweight, high surface area, and porous structures, have garnered attention for their potential to enhance the performance of batteries and supercapacitors. Several approaches have been explored, including the incorporation of conductive additives, carbon nanotubes, graphene, or conducting polymers, to improve charge transport within the materials. (Liu et al., 2021). A reference review thus challenges persistence in achieving high electrical conductivity, scaling up production, ensuring durability and compatibility with existing technologies, addressing environmental concerns, meeting safety regulations, and achieving cost-effectiveness.

Moreover, as cellulose gave rise to the alternative variations of commercial aerogel foams, a newly developed cellulose acetate aerogel foam has surfaced. Cellulose acetate aerogel foam is an aerogel foam made from cellulose acetate filters retrieved from cigarette butts, a litter that is commonly found in urban places like Metro Manila. The process of cellulose acetate into aerogel foam has shown results of a present thermal insulation in its components. Thus, the study intends to utilize cellulose acetate aerogel foam by means of implementing a cost-effective study that is also beneficial to waste management upon the area of interest. Thermal insulation powders will also be used in order to enhance the thermal insulation of the already processed cellulose acetate aerogel foams.

Zhang et al. (2022) and Liu et al. (2021) have provided data and information about the components and properties of cellulose acetate aerogel foam in diverse aspects, but the infusion of thermal insulator powder in cellulose acetate aerogel foam is seldom reviewed. Consequently, this study will be exploring and analyzing the efficacy of utilizing thermal insulator powder in the cellulose acetate aerogel foam retrieved from cellulose acetate derived from cigarette butts. It was stated in the study of Chau et al. (2020) that CA aerogels must have a strong thermal stability in order to maintain their mechanical properties which the researchers also aim to aid. Furthermore, the data that will be collected will serve a purpose as a basis of whether thermal insulator powder should be included or to not be included in the production of cellulose acetate aerogel foam.

This paper comprehensively evaluates the efficacy of utilizing thermal insulator powder in cellulose acetate aerogel foam in order to enhance the production and thermal insulation performance of the product. Specifically, the study will investigate the influence of different concentrations of thermal insulator powder on the structural integrity and the mechanical properties of the cellulose acetate aerogel foam compared to commercially available aerogel foams. In such manner, the researchers will have the opportunity to assess the potential for improved thermal performance of the CAAF. The study will also provide valuable insights into the feasibility of using thermal insulator powder-infused cellulose acetate aerogel foam in various industrial applications requiring superior thermal insulation materials.

By addressing these objectives, this study aims to contribute to the advancement of cellulose acetate aerogel foam, offering potential solutions for enhancing its thermal insulation properties and broadening its range of applications in industries.

Statement of the Problem. This study will be investigating the thermal properties of the cellulose acetate aerogel foam infused with thermal insulator powder in pursuit of enhancing its performance and production through the following questions:

1. What is the time longevity of temperature conservation in terms of:
   1.1. Commercial Aerogel Foam

1.2. Cellulose Acetate Aerogel Foam
1.3. Cellulose Acetate Aerogel Foam infused with the following concentration:
   1.3.1. 5 grams of thermal insulator powder
   1.3.2. 10 grams of thermal insulator powder
   1.3.3. 15 grams of thermal insulator powder

2. What are the thermal conductivity and physical stability results in various amounts of thermal insulator powder in the solution corresponding to:
   2.1. Commercial Aerogel Foam
   2.2. Cellulose Acetate Aerogel Foam
   2.3. Cellulose Acetate Aerogel Foam infused with the following concentrations:
      2.3.1. 5 grams of thermal insulator powder
      2.3.2. 10 grams of thermal insulator powder
      2.3.3. 15 grams of thermal insulator powder

3. Is there a significant difference in the commercial aerogel foam, cellulose acetate aerogel foam and cellulose acetate aerogel foam infused with insulator powder in terms of their thermal insulation.

Hypotheses. Based on the problems enumerated, the following are the hypotheses of the study:

H_0: There is no significant difference in the commercial aerogel foam, cellulose acetate aerogel foam and cellulose acetate aerogel foam infused with insulator powder in terms of their thermal insulation.

H_A: There is a significant difference in the commercial aerogel foam, cellulose acetate aerogel foam and cellulose acetate aerogel foam infused with insulator powder in terms of their thermal insulation.

Literature Review

The different applications of thermal insulator powder. Thermal insulation materials play a pivotal role in various ways, as evidenced by a diverse body of literature exploring their significance. These materials are indispensable in cryogenic systems, where precise temperature maintenance is imperative to prevent heat leakage. While conventional high thermal insulators have proven effective, powder insulating materials have garnered attention due to their cost-effectiveness and lightweight properties. For instance, Jin et al. (2014) assessed the thermal conductivity of powder insulation materials like expanded perlite, glass microspheres, and EPS beads, yielding promising outcomes.

Emphasizing the critical importance of thermal insulation, Deshmukh et al. (2017) underscored their relevance across various industries, including the dairy and food sectors. These insulating materials operate by curbing heat transfer, resulting in energy conservation and substantial reductions in energy consumption. Their utility extends to the convenience of mitigating heat gain or loss, maintaining process temperatures, and preventing deterioration. The increased deployment of insulator products within industries enhances their functionality and contributes to significant energy cost reductions.

In a comprehensive study, Villasmil et al. (2019) delved into various thermal insulation materials, including powders, highlighting their advantages, especially in applications like Thermal Energy Storage (TES) at elevated temperatures. Notably, these powders excel in subterranean usage, optimizing residential living spaces, a stark contrast to traditional materials prone to moisture absorption and subsequent increases in thermal conductivity. Similarly, Karthikeyan et al. (2018) conducted an exhaustive investigation into the thermal conductivity properties of diverse insulating powders such as encompassing silica-fumed, sodium silicate, mica, foundry sand, wood, cement, white cement, red soil, coal, cement + foundry sand, silica fumed + sodium silicate, and silica-fumed + sodium silicate + mica. Some takeaways from their study include sodium silicate as an exemplary choice for crafting high-temperature and pipe insulation boards due to its notably low thermal conductivity. Furthermore, coal, despite its insulation limitations, found unique applications outside the insulation realm, including dental hygiene.

The significance and versatility of thermal insulation materials render them crucial in various industrial and residential applications. These studies offer invaluable guidance in selecting and applying them to achieve superior thermal performance, enhanced insulation effectiveness, and energy efficiency. Therefore, the prudent selection and application of thermal insulation materials are critical in ensuring optimal performance and resource efficiency in industrial and residential contexts.

Components of Commercial Aerogel Foam. As the thermal insulations manufactures lean on to a period of utilizing thermal conductive foams, commercial aerogel foams have been a protruding, yet infamous component of production in thermal insulation materials. Silica aerogels are inorganic fillers and can be used in physical and chemical cross-linking. Implication of silica aerogel particles enhances the firmness of the organic foam's thermal conductivity. Containing an evident remarkable thermic performance, the silica aerogel blocks quick distribution of heat and restricts degradation (Zhao et al., 2015).

Aerogels are remarkable thermal insulators and when compared to ceramic foams, they have a lower skeletal density. Despite the low levels of skeletal density, C-aerogels impose a bulkier density both in preceramic and ceramic foam. On the other hand, N-aerogels and A-aerogels have lower bulk density (Zambotti, et al. 2022). The most popular kind of aerogel is silica aerogel. According to Ślosarczyk (2022) due to its open pore structure with nanoscale dimensions, silica aerogel (SA) is regarded as one of the most promising thermal insulation materials. In this study, SA was used as a filler to create a one-part room-temperature vulcanized silicone rubber (RTV-SiR) composite with better thermal performance. The extraordinarily low thermal conductivity of SA, which is among the lowest ever recorded for solid materials, is one of its most fascinating characteristics. Stephan Kistler developed silica aerogel in the 1930s, but it hasn't garnered much attention until the past twenty years. Meanwhile, in 2019, Hai et al. conducted a study wherein silica aerogel and sodium alginate were deposited on the skeleton of flexible polyurethane foams (FPUFs). The structure created by the silica gel's strong protection barrier inhibits the FPUP base from further burning from transferring into heat and smoke gases. Consequently, the combination of these two main components enhanced the thermal flame- retardant and smoke suppression properties of the said foam. Thus, utilization of silica aerogel in the production of thermal insulator foams has been made prominent due to the remarkable components of the aerogel's thermal properties.

The studies beforehand induce an analytical context of the primary components that commercial aerogel foams contain. The thermal properties of the commercial aerogel foams indicates that these aerogel foams bear thermal insulating properties capable of aiding the study's objective. Aerogels have been renowned for their exceptional thermal insulating capabilities. Aerogels such as Silica Aerogels have gained widespread popularity due to its remarkable properties and structure that makes it the standard of commercial aerogel foams. The analysis of the studies regarding commercial aerogel components could provide assistance to the study to easier distinguish the difference of commercial aerogel foams to cellulose acetate aerogel foams.

Components of Cellulose Acetate Aerogel Foam. According to Long et al. (2018), cellulose aerogel (CA) is a porous material and can be used in heat insulation, biomedical, and metal oxide carriers. They are characterized by high porosity and low density, rendering them remarkably lightweight. Their extensive surface area stemming from intricate porous structures are advantageous for applications demanding substantial surface area (Lavoine and Bergström, 2017). Furthermore, chemical cross-linkers can create covalent bonds between polymer chains, which is efficient in the expansion of cellulose gels. Their extensive surface area stemming from intricate porous structures are advantageous for applications demanding substantial surface area.

The production of CA is divided into three parts: dissolving the cellulose acetate, forming the cellulose gel, and drying the cellulose gel while its porous structure remains. The structure of a cellulose aerogel is dependent on its preparation method, according to Long et al. (2018). In the study of Liu et al. (2021), it provides insights into the manufacturing techniques for cellulose-based composite foams and aerogels, combined with diverse active components, cellulose materials, serving as the foundational building blocks, are integral to the foams and aerogels' composition. Furthermore, the concentration of the cellulose acetate fibers affects the shape and density of the cellulose acetate aerogel foam (Chua et al., 2020). Active materials, often on the nanoscale, like carbon nanotubes, graphene, or metal nanoparticles, are incorporated to enhance electrical conductivity. The materials used for cellulose acetate aerogel have characteristics that are considered valuable for oil spill treatment and thermal isolation.

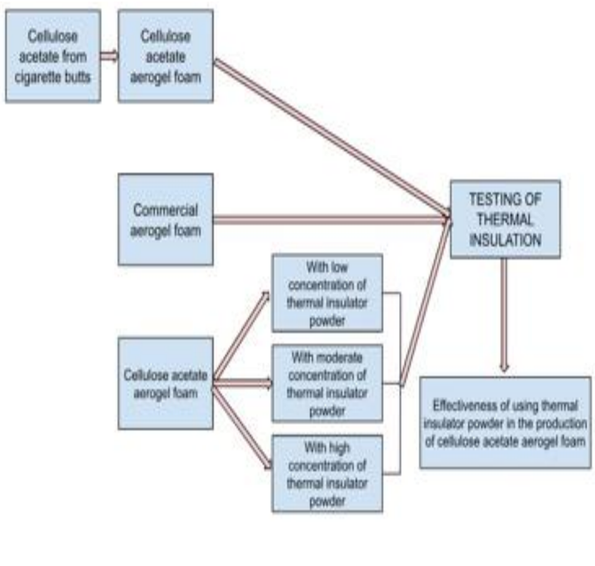
The existing studies offer a broader perspective on the prospective roles of cellulose-based aerogels, it clarifies the composition, processing techniques, properties, and applications of cellulose-based foams and aerogels, offering a foundational framework for evaluating and comprehending the distinctive attributes of cellulose acetate aerogel foam. Thus, situating cellulose acetate aerogel foam within the context of aerogel materials and their utility in energy storage applications. In addition, cellulose acetate aerogels are ideal for heat isolation and insulation. The methods and precautions can be adapted, modified, and applied. Furthermore, the data found in the studies can give credibility to the study and be used for drawing conclusions and suggestions.

Theoretical Framework. Hao et al. (2015) founded the theoretical underpinning of this study using the variational principle with the entransy concept. The theory further explains the possibility of distributing the porosity in a porous insulator under conditions like fixed mass and thickness of the substance. The best insulating performance of a porous material is achieved with the lowest effective thermal conductivity at the extremum of entropy dissipation rate. Moreover, in 2010, Chen and Guo proposed the entransy theory as a physical measure that defines the porous medium's capacity for heat transmission when compared between heat and electrical conduction. The entransy dissipation during heat transfer operations, measuring how irreversible the heat transfer is, corresponds to the concepts of entransy, a new indication of efficient thermal conductivity for complex heat transmission problems. Consequently, the entransy dissipation based effective thermal conductivity is suited not just exclusively for assessing heat transfer capacity in its physical essence, but also for imperial performances in developing material systems with needed thermal conductivity.

Furthermore, the study is anchored on the theory of Hodgson in 1970. The cellulose acetate membranes are considered as porous materials, or a barrier that allows water to pass through by diffusion. In a study done by Wen et al. (2015), a theoretical model was presented to predict the efficiency of cellulose acetate cigarette filters. The study used the porosity of a cellulose acetate filter in examining the calculations needed; hence, it was stated that the porosity ratio of a cellulose acetate filter is 90%. Thus, in 2010, Lauwerier proposed the concept of transient heat transport in porous media. This produced significant relevance to entransy theory and offered valuable insights with applications in various fields, including geothermal energy extraction, groundwater flow modeling, and the design of effective heat exchangers for porous media, making it a noteworthy contribution to the study of heat transfer in porous environments.

Conceptual Framework

Figure 1
Research Paradigm



Scope and Limitations. Thermal insulation has emerged as a component in the construction and manufacturing of modern products such as Aquaflask, blackout curtains, and modern lunch boxes. One of the main products used in the production of these known products is aerogel foam. Hence, the study will focus on the addition of thermal insulator powder to determine the improvements in the thermal insulation of a specific aerogel foam made from treated cellulose acetate filters from cigarette butts: Cellulose Acetate Aerogel Foam (CAAF).

The study will be conducted within Metro Manila; hence, it will be enclosed in the adjoining areas. The researchers will also focus on the difference between the efficiency of commercial aerogel foam, cellulose acetate aerogel foam, and cellulose acetate aerogel foam infused with different amounts and concentrations of the thermal insulator powder which will be discerned.

The study is subject to limitations as the effectiveness of thermal insulator powder is determined with the method used in the production of cellulose acetate aerogel foam. Hence, different thermal insulation will be overlooked. Moreover, other leading wastes are discarded as the study only distinguishes the environmental impacts of cigarette butts. Surface area, density, and porosity as factors of the end-product will not be taken into consideration as the study only focuses on thermal insulation, physical stability, and other mechanical properties. Furthermore, the run of the test is only limited to four set-ups in identifying the efficacy of thermal insulator powder infused. Future researchers may use the methodologies, results, and discussion with issues related in the study with these research gaps in providing answers and solutions in the future.

Significance of the Study. This study is deemed significant as it provides a comprehensive investigation about the efficacy of thermal insulator powder in the enhancement of its properties and production. Hence, this study is significant to the following:

1. *To the waste collectors*. Waste collectors are responsible for collecting and disposing of various types of waste, including littered cigarette butts. It would be beneficial for waste collectors to decrease the amount of cigarette butt waste, as it would result in less time and energy required for collecting and disposing of this particular form of litter.

2. *To the households*. This study is beneficial to the residents of the community for it can help mitigate environmental pollution and waste accumulation. The results of this study can help improve waste management practices which would reduce health hazards and a healthier environment ultimately leading to a better quality of life.

3. *To the Local Government Units (LGUs) and Policymakers*. Policymakers can use this report as a resource when creating rules, regulations, and policies for waste management and environmental protection. Policymakers may contribute to more sustainable and environmentally responsible practices, ensuring a healthier future for our planet and its inhabitants, by implementing the learnings from this research into their decision-making processes.

4. *To sustainable companies*. With the rise of sustainable businesses, investors and entrepreneurs interested in green and sustainable technologies, such as Aspen Aerogels Inc. and ABIS Aerogel Co., will benefit in this study. Through this, they may find opportunities in supporting or developing businesses related to the production or application of cellulose acetate aerogel foam that is not just cost-effective but sustainable and more eco-friendly.

5. *To the future researchers*. The results of this study can also serve to enhance one's understanding of the efficacy of thermal insulation powder in the production of cellulose acetate aerogel foam to reduce cigarette butt waste, insulation materials, and their potential impacts on thermal

performance and cost-effectiveness. They may also use this as a valuable reference for their future research.

METHODOLOGY

Research Design. This study will utilize a true experimental quantitative research design to investigate the efficacy of infusing thermal insulator powder in cellulose acetate aerogel foam. This research design will enable the researchers to have precise control over key variables, including the quantity of thermal insulator powder, facilitating a meticulous assessment of its impact on foam properties. By establishing causal relationships, it enables the researchers to determine whether the infusion of thermal insulator powder directly influences foam characteristics, such as thermal insulation. According to Gribbons and Herman (1997), true-experimental design is described where subjects are randomly designated to program and comparison groups. The design may illustrate an effective differentiation as it can satisfy real comparison between objects and further observe new outcomes with the differences.

After gathering the results from the thermal conductivity longevity test of the commercial aerogel foam groups and the cellulose acetate aerogel foam groups that were infused with thermal insulation powder, the collected data will be interpreted by means of detecting a significant difference between the thermal insulation of commercial aerogel foams and cellulose acetate aerogel foam infused with different concentrations of thermal insulation powder.

Sampling Method. This study will utilize non-probability quota sampling method to study the thermal properties of different aerogel foams, specifically focusing on commercial aerogel foam and cellulose acetate aerogel foam, compared to cellulose acetate aerogel foam infused with thermal insulator powder. Quota sampling will enable the researchers to ensure proportional representation of each foam type, providing a thorough analysis of their thermal properties. Quota sampling was defined by Iliyasu and Etikan (2021) as a process that defines the characteristics of the entire population, establishes specific criteria for the composition of the sample, and selects samples who match these predetermined criteria. This approach allows researchers to select participants from each subgroup in a non-random manner to accurately reflect the population in terms of their attributes.

Out of clusters of different types of commercial aerogel foams, those who meet the criteria of being a thermal insulation foam will be chosen. Additionally, the samples that will be used must also be manufactured only from the Philippines, specifically, in Metropolitan Manila. The aim is to collect samples in a ratio that reflects the actual distribution of these foams in the market and for each quota to meet the criteria for the specific foam type ensuring their representation in the study. The thermal properties of the collected commercial aerogel foam and cellulose acetate aerogel foam samples will be assessed through standard longevity, thermal conductivity, and physical stability to determine their thermal insulation properties.

Research Instrument. In the evaluation of the foam's thermal insulation properties, the researchers incorporated a comprehensive range of factors encompassing durability, energy efficiency, environmental implications and safety considerations. These assessments include testing for:

1. *Longevity.* To ensure the reliability and effectiveness of insulation materials throughout their anticipated lifespan, testing the longevity of thermal insulation foam was deemed necessary. Beyond ensuring compliance with legal requirements, this testing contributed to the development of more enduring and environmentally friendly insulation alternatives, aligning with broader objectives of energy efficiency and environmental responsibility.

2. *Thermal Conductivity.* To evaluate the thermal conductivity of the samples, the researchers heated one end of a metal

using a heat source. They then measured the time it took for the heat to travel through the foam to reach the non-metal material at the other end. The sample that allowed the heat to propagate more quickly was identified as having lower insulation properties compared to the other samples.

3. *Physical Stability.* The evaluation of insulation foams' physical stability involved assessing their capacity to maintain structural and chemical integrity under elevated temperatures. Conversely, testing for thermal conductivity examined the heat-conducting characteristics of the material. In the context of insulation foams, lower thermal conductivity was preferable, indicating superior insulating properties and heightened resistance to heat transfer. Consequently, the researchers assessed the physical stability and thermal conductivity of commercial aerogel foam, cellulose acetate aerogel foam, and cellulose acetate aerogel foam infused with various concentrations of thermal insulation powder to ascertain their thermal insulation properties.

RESULTS

In this research analysis, the researchers delved into the intricacies of the findings, exploring key patterns and insights that have emerged from a comprehensive data collection. The findings show:

Table 1

The result of different foams tested in terms of time longevity. As ascribed with the P-Value being lesser than 0.05, the model is proven to be significant. Therefore, there is a significant difference in the commercial aerogel foam, cellulose acetate aerogel foam, cellulose acetate aerogel foam infused with thermal insulator powder in terms of their time longevity.

Source	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	F-Stat	P-Value
Between Groups	4	24645.6	6161.4	4.498	0.025
Within Groups	10	13698	1369.8		
Total	**14**	**38343.6**			

Table 1. Longevity Test

Table 2

The result of different foams tested in terms of physical stability. As ascribed with the P-Value being greater than 0.05, the model is proven to be not significant with physical stability. Therefore, there is no significant difference in the commercial aerogel foam, cellulose acetate aerogel foam, cellulose acetate aerogel foam infused with thermal insulator powder in terms of their physical stability.

Source	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	F-Stat	P-Value
Between Groups	4	366268	91567	3.5502	0.0986
Within Groups	5	128960.5	25792.1		
Total	9	495228.5			

Table 2. Physical Stability Test

Table 3

The result of different foams tested in terms of thermal conductivity. As ascribed with the P-Value being lesser than 0.05, the model is proven to be significant. Therefore, there is a significant difference in the commercial aerogel foam, cellulose acetate aerogel foam, cellulose acetate aerogel foam infused with thermal insulator powder in terms of their thermal conductivity.

Source	Degrees of Freedom (DF)	Sum of Squares (SS)	Mean Square (MS)	F-Stat	P-Value
Between Groups	4	554.4	138.6	47.7931	0.0.0004
Within Groups	5	14.5	2.9		
Total	9	568.9			

Table 3. Thermal Conductivity Test

DISCUSSION

In a study by Chau et al. (2020), it was stated that CA aerogels must have a strong physical stability in order to maintain their mechanical properties. With the results at hand, it was proven that CA aerogels have a strong physical stability which aided them in maintaining their mechanical properties. In this study, it was found that infusing CA aerogels with insulator powder had no effect on their physical stability. As shown in Table 2, the performance of the samples was not enhanced through the infusion of thermal insulator powder, instead, the performance levels of the samples decreased and their mechanical properties downgraded.

Cited in Zhang et al. (2017), Caps et al. (1997) studied the thermal conductivity of polyimide foams in the temperature range from -100°C to 50°C for different gas types at different gas pressure and established a quantitative model to predict the thermal conductivity as a function of density, gas pressure and temperature. Meanwhile, the experiment studied the thermal conductivity of commercial aerogel foams in the temperature range from 100°C to 150°C. The results have shown that cellulose acetate aerogel foam has the highest thermal conductivity among the samples with an average of 42.5 seconds. Moreover, it is stated in a study that having to achieve high conductivity of the cellulose acetate aerogel foam will speed its production in the market as it is compatible with many technologies in different industries (Liu et al., 2021). Hence, this will help address environmental concerns in achievement of cost-effectiveness. In this study, the collected cigarette butts that were used in the production of CAAF is proven to be successful with its thermal conductivity.

Furthermore, cited in Liu et al. (2021), it was stated that the incorporation of conductive additives, carbon nanotubes, graphene, or conducting polymers, to improve charge transport within the materials. Meanwhile, the experiment that was conducted studied if the infusion of thermal insulator powder in the cellulose acetate aerogel foams improved its properties. It was revealed in the results that the thermal insulator powder was able to improve its thermal conductivity and time longevity.

In conclusion, the study by Chau et al. (2020) emphasized the importance of strong physical stability for cellulose acetate (CA) aerogels to maintain their mechanical properties. Infusing these aerogels with insulator powder, however, was found to have a detrimental effect, reducing both physical stability and mechanical performance. Contrastingly, Caps et al. (1997) explored thermal conductivity in polyimide foams, while Liu et al. (2021) highlighted the potential of cellulose acetate aerogel foam for its high thermal conductivity. The incorporation of conductive additives, as suggested by Liu et al. (2021), showed promise in enhancing charge transport.

Ultimately, Liu et al. (2021) have demonstrated that the effective utilization of collected cigarette butts for the production of cellulose acetate aerogel foam not only addresses environmental concerns but also enhances cost-effectiveness in the market. In the end, Chau et al. (2020) pointed out that although insulator powder infusion improved thermal conductivity and endurance in cellulose acetate aerogel foams, care should be taken when evaluating its effects on mechanical characteristics and physical stability.

To sum it up, the study found that implementation of insulator powder infusion into the samples does not significantly enhance the physical stability of the samples. Additionally, the results showed that the infusion of insulator powder had a negative effect on the physical stability of the samples and reduced the performance of their mechanical properties.

Conclusions. Based from the results of the study, the following are conclusions:

1. Commercial aerogel foam stands out as possessing the lengthiest average lifespan without any external intervention.

2. Between Cellulose Acetate Aerogel Foam (CAAF) and Commercial Aerogel Foam (CAF), accentuated by substantial differentials in time longevity. This temporal extension correlates with an augmented quantity of thermal insulator powder.

3. The comparative analysis between Commercial Aerogel Foam (CAF) and Cellulose Acetate Aerogel Foam (CAAF) reveals a marked dissimilarity, with the former exhibiting a superior physical stability average in contrast to the latter. The fortification of physical stability is attributed to the introduction of thermal insulator powder, wherein

varying quantities yield incremental enhancements.

4. Concerning thermal conductivity, Cellulose Acetate Aerogel Foam surpasses Commercial Aerogel Foam in seconds, indicating prolonged efficacy. The introduction of thermal insulator powder demonstrates a decreasing trend in the thermal conductivity of Cellulose Acetate Foam. Amongst the concentrations tested, the addition of 5 grams proves the most effective, succeeded by 10 grams and 15 grams, with presenting the lowest average.

5. There is a significant difference in the commercial aerogel foam (CAF), cellulose acetate aerogel foam and cellulose acetate aerogel foam infused with insulator power in terms of their thermal insulation. Commercial aerogel foam is often considered a benchmark for high thermal insulation, while cellulose acetate aerogel foam, although more sustainable, may have lower thermal performance. Infusing insulator powder into cellulose acetate aerogel aims to improve its insulation capabilities.

Recommendations. From the drawn conclusions, the following are the recommendations:

1. *Laboratory Testing.* In order to achieve better results, future researchers must test the Cellulose Acetate Aerogel Foam in a laboratory since different variables may affect the outcome of testing when it is conducted at home. Consequently, laboratory testing also provides a controlled environment where researchers can manipulate variables, conduct precise experiments, and gather reliable data. This controlled setting allows for a more systematic exploration of, enhancing the reproducibility and reliability of the test results. The controlled conditions in laboratories enable researchers to isolate specific factors, leading to a deeper and precise understanding.

2. *Physical Stability.* Investigating physical stability in foams infused with thermal insulation powder is crucial given the current lack of literature on the subject. This unexplored territory presents an opportunity to enhance our understanding of how these materials perform under varying temperature conditions. Such studies could deliver insights into optimizing thermal insulation efficiency, potentially impacting industries reliant on thermal management.

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