FINAL PROJECT - TL234839

EFFECT OF MEMBRANE COMPOSITION TOWARDS THE MECHANICAL PROPERTIES AND THERMAL PROPERTIES OF PAN/$CsPbBr_3$ NANOFIBER TO CAPTURE CO_2/GREEN HOUSE GASES IN SEVERAL INDUSTRIES

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TUGAS AKHIR – TL234839

EFEK KOMPOSISI MEMBRAN TERHADAP SIFAT MEKANIK DAN SIFAT *THERMAL* PAN/$CsPbBr_3$ *NANOFIBER* UNTUK APLIKASI PENANGKAPAN GAS EFEK RUMAHKACA/CO_2 DI BEBERAPA INDUSTRI

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LEMBAR PENGESAHAN

EFEK KOMPOSISI MEMBRAN TERHADAP SIFAT MEKANIK DAN SIFAT THERMAL PAN/CsPbBr$_3$ NANOFIBER UNTUK APLIKASI PENANGKAPAN GAS EFEK RUMAH KACA/CO$_2$ DI BEBERAPA INDUSTRI

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EFFECT OF MEMBRANE COMPOSITION TOWARDS THE MECHANICAL PROPERTIES AND THERMAL PROPERTIES OF PAN/CsPbBr3 NANOFIBER TO CAPTURE CO2/GREEN HOUSE GASES IN SEVERAL INDUSTRIES

FINAL PROJECT
Submitted to fulfill one of the academic requirements
for obtaining a degree Bachelor of Engineering at
Undergraduate Study Program of Materials Engineering
Department of Materials and Metallurgical Engineering
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dengan ini menyatakan bahwa Tugas Akhir dengan judul "EFFECT OF MEMBRANE COMPOSITION TOWARDS THE MECHANICAL PROPERTIES AND THERMAL PROPERTIES OF PAN/$CsPbBr_3$ NANOFIBER TO CAPTURE CO_2/GREEN HOUSE GASES IN SEVERAL INDUSTRIES" adalah hasil karya sendiri, bersifat orisinal, dan ditulis dengan mengikuti kaidah penulisan ilmiah.

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ABSTRAK

EFEK KOMPOSISI MEMBRAN TERHADAP SIFAT MEKANIK DAN SIFAT *THERMAL* PAN/$CsPbBr_3$ NANOFIBER UNTUK APLIKASI PENANGKAPAN GAS EFEK RUMAH KACA/CO_2 DI BEBERAPA INDUSTRI

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Abstrak

CO2 yang dipancarkan ke lingkungan yang dapat mengakibatkan peningkatan jumlah gas rumah kaca (GRK) dapat dikurangi lebih lanjut dengan menggunakan direct air capture (DAC), yang merupakan metode pengurangan CO2 dalam program CCUS. Tujuan dari penelitian ini adalah untuk menganalisis pengaruh variabel komponen matriks polimer PAN terhadap membran dalam hal sifat termal dan sifat mekaniknya, sementara juga memperhatikan morfologi nanofiber itu sendiri. Proses pembuatan membran nanofiber PAN/CsPbBr3, dimulai dengan mensintesis larutan perovskit CsPbBr3. Setelah itu, sintesis polimer PAN dilakukan, diakhiri dengan mencampur bahan keramik perovskit dan polimer PAN bersama-sama dan mulai mencampurnya. Proses pembuatan membran PAN/CsPbBr3 memerlukan pemanfaatan electrospinning, karena kami ingin mencapai produk akhir dari membran/nanofiber yang halus. Dengan fokus utama pada analisis sifat mekanik dan analisis resistansi termal, penelitian ini memerlukan beberapa prosedur pengujian seperti: Pemetaan SEM/EDX, DTA/TGA, dan FTIR. Dalam penelitian ini kami juga memecah resistansi termal berdasarkan data dari DTA/TGA, di mana kami mengambil rata-rata dari setiap puncak suhu yang ditunjukkan pada data. Karena penelitian difokuskan juga untuk memasukkan pengujian mekanis dari uji tarik ultimit, dapat diperoleh perpanjangan tercatat sebesar 26,18% untuk membran nanofiber PAN saja, yang seperti yang diharapkan bahwa sebelum perlakuan panas, membran nanofiber PAN dan PAN/CsPbBr3 akan lebih ulet. Pengujian mekanis juga dilakukan dengan perlakuan panas yang diterapkan pada membran nanofiber, dan itu menunjukkan bahwa perpanjangan pada membran nanofiber PAN saja hanya 21,77. Oleh karena itu dapat disimpulkan bahwa nanofiber lebih getas dibandingkan dengan yang sebelum perlakuan panas. Suhu termal yang ditetapkan untuk penelitian membran nanofiber PAN/CsPbBr3 ini adalah 250°C – 260°C, sebelum nanofiber mengalami kerusakan. Hal ini diharapkan agar material komposit nanofiber ini memiliki toleransi termal yang lebih tinggi dibandingkan dengan nanofiber lain yang terbuat dari material komposit film lainnya.

Kata kunci: Membran, CO_2, Properti Mekanik, dan Properti *Thermal*

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ABSTRACT

EFFECT OF MEMBRANE COMPOSITION TOWARDS THE MECHANICAL AND THERMAL PROPERTIES OF PAN/$CsPbBr_3$ NANOFIBER TO CAPTURE CO_2/GREEN HAUSE GASES IN SEVERAL INDUSTRIES

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Abstract

CO_2 emitted in to the environment that can results in the increase amount of green house gases (GHG) can be further mitigated by using direct air capture (DAC), which is a method of CO_2 reduction in CCUS program. The purpose of this research is to analyze the effect of PAN polymer matrix component variable towards the membrane in term of their thermal properties and mechanical properties, while also concerning about the morphologies of the nanofiber itself. The process of manufactured the PAN/$CsPbBr_3$ nanofiber membrane, starts by synthesizing the $CsPbBr_3$ perovskite solution. Afterwards the synthesizing of the polymer PAN is conducted, finished by mixing bothh the perovskite ceramic materials and the PAN polymer together and start mixing it. The manufacturing process of PAN/$CsPbBr_3$ membrane required the utilization of electrospinning, because we wanted to achieve the final product of a fine membrane/nanofiber. With the main focus of mehcanical properties analysis and thermal resistance analysis, this research required several testing procedure such as : SEM/EDX Mapping, DTA/TGA, and FTIR. In this research we also breakdown the thermal resistance based on the data from DTA/TGA, where we took the average from each temperature peak shown on the data. Because of the research focused in also including the mechanical testing of ultimate tensile test, it can be obtained the elongation is recorded at 26.18 % for the PAN only nanofiber membrane, which is as expected that in before heat tretamnet the PAN and PAN/$CsPbBr_3$ nanofiber membrane would be more ductile. Mechanical testing are also conducted with heat treatment applied to the to the nanofiber membrane, and it shows that the elongation in PAN only nanofiber membrane was only 21.77. Therefore it can be conclude that the nanofiber was more brittle compare to the one in before heat treatment. The thermal temperature set for this research of PAN/$CsPbBr_3$ nanofiber membrane are set to 250°C – 260°C, before the nanofiber gets deteriorate. This was expected for this composite materials nanofiber to have a higher thermal tolerance compare to other nanfiber made from other film composite materials.

Keywords: ***CO_2, Mechanical Properties, Membrane, and Thermal Properties***

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CHAPTER I
INTRODUCTION

1.1 Background

A global phenomenon of “global warming” have become the main problem for many industry worldwide. This phenomena had done many negative occurrence for science development and mainly energy industry. Tracing back to the source of CO_2, these are the main cause of this I: Industrial activities of steel making, mining industry, and fossil fuel combustion activity. Reported as average flows of CO_2 in billions of metric tons of CO_2 per-year ($GtCO_2$/yr) for the time period of 2006-2015. The concentration of CO_2 in the atmosphere keep increasing, the data from 2016 shows that the concentartion peaked in 400ppm with the rate of atmosphere CO_2 per-year are approximately reaching the amount of 2ppm per-year. In order to managed CO_2 emission as the main aspect for the cause of GHG, many governments set some new objectives related to the policy of CO_2 emission. In Asia, the Asian Development Bank has adopted a new policy in the transportation industry that measures CO_2 emission based on the vehicle travelled distance, fuel consumption, vehicle speed, and the types of vehicle, this policy was also supported by the USA. While in the mining industry sector the policy are recommended based on their high CO_2 emission output, where they required to improve energy efficiency to decreased energy intensity and CO_2 emissions (JAW Elliot, 2021).

CO_2 that lingers in the environment that results in the increase amount of GHG can be mitigated by utilizing direct air capture (DAC), in this method a certain specification of membrane are used. To develop and implement the membrane materials for industrial utilization and global scale production, properties and standardization are an essentials aspect to be considered. Important properties to needed for the materials are : high CO_2 selectivity and permeability, good thermal resistance, greater mechanical ability to withstand external pressure, and cost effectiveness aspect. In the other hand standardization to ensure global implementation are also needed, where guidelines for this aspect are as follows : performance metrics of ISO 1147 for (gas permeability measurements), ASTM D1434 for (plastics characteristic used for PAN based membranes). Environmental standards such as ISO 14040 for (life cycle assesment (LCA)) is also essentials for global implementation (JL Dufresne et al.,2013).

Material development as the adsorbent media to capture the CO_2 are developed, where this material aren’t just vilify CO_2 emissions as a valueless combustion by-products, but instead providing a way for them to be further utilized as a potential feedstock. Membrane technology used for gas seperation are commonly used in CCUS, where the goals are to adbsorb the CO_2 onto the surface of the membrane. Combine with the perovskite as catalyst, this material can influence their reactive to CO_2 when Implemented in various industrial environments. Perovskite based catalyst are considered as promising candidates for practical applications, given their unique abilities of catalytic activity, stability, and flexibility. Gas seperation membrane used in this research are consist out of polyacrylonitril (PAN) as the matrix of the membrane and perovskite ($CsPbBr_3$) as the reactive adbsorpbent component that attracts the CO_2.

This research will provide a study to find how each membrane with different composition and heat treatment can perform in various industrial application. On the previous study it has been proven that PAN/$CsPbBr_3$ can adsorps CO_2 theoritically, however this study is not yet provided us with an explanation regarding the morphologies of membrane. With the research gap from previous study of (De Yonarosa et al.,2023) that lack a thorough analysis in mechanical and thermal properties of PAN/$CsPbBr_3$ membrane itself, in this study we dealt into analyzing those aspect of properties. With the main purpose of providing a recommendation to several industries based on the specification of membrane suitable to their liking. Therefore net-zero emission goals in global scale can be achieved.

Another previous research data shown of this similar material of PAN-based membrane, material of (PAN-C) polyacrylonitrile dopes carbon and the surface area of this material is then determined by using BET equation to fit experimental data of nitrogen adsorption at 77K and carbon dioxide adsorption at 273 K. Therefore after we manufactured our PAN/$CsPBBr_3$ membrane the output will be several recommendation of where we can apply the membrane in several industry (L Dominguez et al, 2022).

Carbon capture, utilization, and storage (CCUS), came as a promising concept to hinder carbon dioxide (CO_2) problem. Focusing on capture and utilization stage have been the main priorities for this research. CO_2 utilization have exist to further managed and reduced GHG emission, and they have a high feasibility. In previous utilization of CO_2, various ways have been implmented such as converting CO_2 into chemical, energy products, and direct utilization via microalgae. The basic mechanism of CCUS it self basically capturing CO_2 through direct air capture process, then transporting it to a storage or utilization site/plant, then storing it in the subsurface or using it directly as a feedstock. Additionally in the aspect of economical business the implementation of using CCUS have lower estimated cost than those industry without CCUS implementation.

1.2 Problem Formulation

Based on the given background of this research, these are the following problem formulation that needs to be solved :

1. What is the effect of PAN/$CsPbBr_3$ material towards the membrane on thermal properties and mechanical properties ?
2. What is the effect of PAN/$CsPbBr_3$ material in term of CO_2 adsorption ?

1.3 Research Limitation

The research limitation of this topic are related to the manufacturing process, where limitation such as : room temperature, humidity, solvent, and the $CsPbBr_3$ material are considered to be in a perfect state while conducting the synthesizing process are not able to be controlled, therefore those factors are to be ignored in the process.

1.4 Research Purpose

These are the following research purpose based on the given problems that need to be solved and studied further :

1. To analyze the effect of PAN/$CsPbBr_3$ variable towards the membrane on mechanical and thermal properties aspect.
2. To analyze the effect of PAN/$CsPbBr_3$ variable towards the membrane CO_2 adsorption.

1.5 Research Benefit

The benefit from this study is to achieved the best PAN and Perovskite membrane composition for capturing CO_2 emission. Therefore peak performance and highest level of efficiency can be benefited by many industries from implementing CCUS method in their system, in order to cut down the CO_2 emission gradually.

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CHAPTER II
LITERATURE STUDY

2.1 Previous Studies for Perovskite

Perovskite based materials are commonly known of their utilization for advanced functional materials including photocatalysis, electrocatalysis, and many fuel cell components. Many recent technologies development are using perovskite based materials, because they have a promising prospects in developing mass-production technologies and practical applications in many sector of industries. The most recent study in perovskite have been presented in suggestion of for perovskite photovoltaics presented solely by hybrid lead halides, with application for solar cell. Where the researchers represented a new generation of solar cell materials with an outstanding optimal morphologies of the material it self. Some factor that made this materials stand out among the others are their chemical element features composing the phases, where different metal, non-metal bonds resulting in different variants of physical properties.

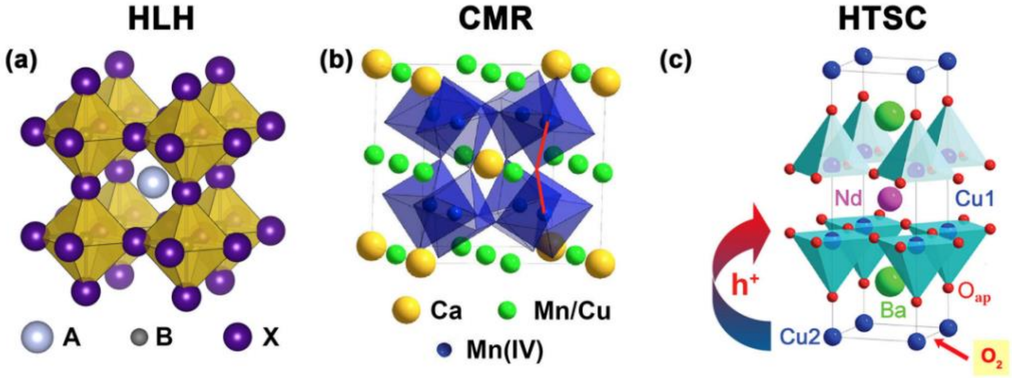


Figure 2.1 Crystal structures of HLH perovskite.

The presented crystal structures shown in the figure are a typical morphologies from a top view of films or coatings solution-derived HLH perovskites. The halide perovskites are composed from a soft acid pb^{2+} and a soft base I^{-} from the p-block of PTE.

Table 2.1 Previous nanofiber researchs.

Materials	**Method**	**Application**	**References**
PAN-TEPA	Electrospinning	CO_2 Adsorption	(J Zhang et al, 2023)
Carbon Nanofibers	Electrospinning	CO_2 Adsorption	(L Zhang et al, 2014)
PAN N-doped Carbon	Carbonization, Activation, and HCL Washed	Gases Separation	(L Dominguez et al, 2022).
PAN/$CsPbBr_3$/Culns $_2$ Qds	Electrospinning	CO_2 Adsorption	(De Yonarosa et al.,2023)
PAN/PCL	Electrospinning	Antibacterial Nanofiber Composite	(Hutomo et al, 2024)
PAN/PU/GMA	Electrospinning and Grafting	CO_2 Adsorption	(Tourzani et al, 2024)
MoS/$CsPbBr_3$	Density Functional Theory Simulation Method	Adsorption and Reduction of CO_2 to form CO and CH_4	(Q M. Li et al, 2024)
Bi/$CsPbBr_3$	In-Situ growth Method	Adsorption and reduction of Photocatalytic CO_2	(Y. Wu et al,2023)
$CsPbBr_3$/Cu-RGO	Mechanochemical and Solvothermal	Selective Photocatalystic Reduction of CO_2	(Kumar et al,2020)
PAN/ZIF-8 and PAN/HKUST-1	Electrospinning Method	Adsorption and Selectivity of CO_2/and N_2	(Choi et al, 2020)

2.2 $CsPbBr_3$ (Cesium Lead Bromide) Perovskite

This are perovskite material with a distinct properties that made a noble difference in the field of scientific research, many recent development of technologies have utilized this materials to help them maximize the potential of green energy in many sector of industry, especially in energy and environmental applications. The reason behind their popularity in recent times are caused by their outstanding and unique electronic optical, and structural characteristics that make it ideal for many applications. The crystal structure of $CsPbBr_3$ are typically found in the form of ABX3 type of perovskite structure. When we analyze the crystal structure, their form can shapeshift, when the temperature rises above room temperature it turns from orthorombic phase (pbnm, below 88^oC) to tetragonal phase (p4/mbm, 88C) and cubic phase (Pm-3m, 130 C).

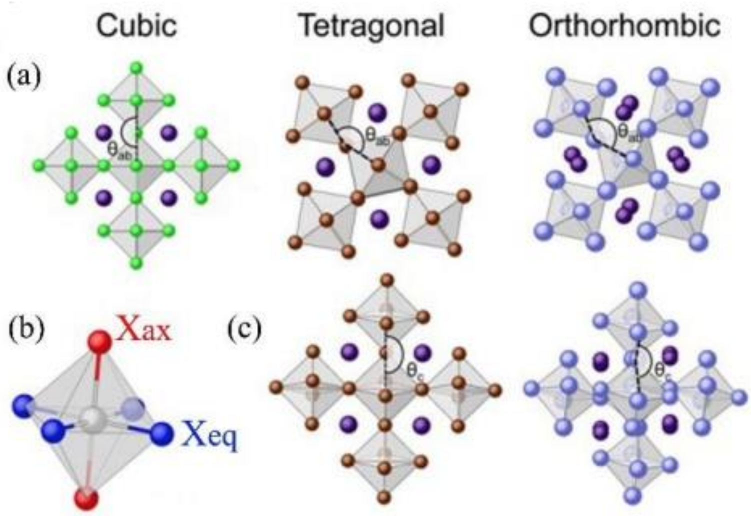


Figure 2.2 PbX6 Octahedra in CsPbBr3

These are the following explanantion from the provided crystal illustration above, where the lattice structure will eventually distorted and a large amount of stress will be generated inside the crystal. From this occurrence of stress, it leads to higher concentration of vacancies and substitution defects, which will have a greater imoact on the material properties.

Perovskite has a special characteristic called photoreduction, which refers to their light induced reduction process, where in the stage of redox reactions are combined with the electrons that leaves during the process. When we analyze an orthohombric phase of $CsPbBr_3$, which consist of PbBr6 octahedrons combined with Cs^+ cations that able to occupies the interstitial site to stabilize the crystal structure. Halide perovskite type with a general formula of AMX3, are an emerging class of semiconductors with extraordinary optoelectronic properties (Y Zhou et al,2021). In term of the sophistication and efficiencies of CO_2 photoreduction, lead halide perovskite (LHP) have shown outstanding efficiencies for that matters. Some of the supporting factor that cause this efficient CO_2 photoreduction was due to their narrow band gaps and adequate band structure that suitable for carrying out the photocatalytic CO_2. Additionally these materials have good charge transport properties, which allows charge electrons to be efficiently seperated and transferred within LHP band structure. Perovskite $CsPbBr_3$ are long to be known to have a particularly high photocatalytic performances for CO_2 photoreduction (E Luevano et al, 2022).

$CsPbBr_3$ perovskite have an outstanding bandgap compare to the other types of perovskite such as $CsPbl_3$, where only 1.73 eV band gap is obtained, while for the $CsPbBr_3$ perovskite with the band gap of 2.3 eV and appropriate light harvesting characteristics and superior stability in ambient conditions. Halide of $CsPbBr_3$ perovskite single crystal, also shows ultra high electron mobility of 1000 cm^2 V s^{-1} and an electron lifetime of 2.5 µs, which is relatively higher compare to full cesium based perovskite, therefore making it a huge potential as a promising material for photovoltaic applications (S Ullah et al, 2020).

2.3 Polyacrylonitril (PAN)

Polyacrilonitril (PAN) is a polymer with linear dielectric characteristic which turns into a semiconductor material under pyrolisis without changing it's basic structure. PAN can be transformed into a polymer with a cyclic structure, semiconducting of PAN polymers are provided by conjugated double bonds in their internal structure. In the manufacturing industry, PAN have been utilized in a various products such as PAN based carbon nanofibers and PAN based perovskite, this was due to PAN high carbon yield and superior mechanical properties. PAN are manufactured commonly by using electrospinning and conventional spinning, they mostly done by wet spinning and dry jet wet spinning although it is also achieveable by using melt spinning (Tatiana S, et al,2015).

Polyacrylonitrile is a common polymer materials that has been extensively used in electrospinning method. The reason behind the utilization of this material for membrane fabrication was because polyacrylonitril has a high mechanical strength due to its molecular structure, while also posessed a high chemical resistance and heat/sun resistance and low sensitivity of moisture, making it great for carbon capture application in many environments. PAN application for carbon capture has been thoroughly developed in the recent years, hence of its unique features of high adsorption capacity, rapid adsorptionrate, and good dynamic performance (H Shaki ,2023).

On the previous research where they utilize polyacrylonitrile (PAN)-TEPA hollow fiber has been analyze in the field of CO_2 adsorption, where amino group reacting with CO_2 molecule is an exothermic reaction, therefore in direct air capture (DAC), ambient has been observed to have an effect on PAN-TEPA hollow fiber. The effect towards PAN based membrane was studied under a simulation environment, where the air content is (0.3% CO_2-N_2) which is an average CO_2 concentration in confined space, with the ambient temperature at 5°C, 15°C, 25°C, 35°C, and 45°C. The equilibrium adsorption capacities were 2.28 mmol g^{-1} , 2.33 mmol g^{-1} , 2.62 mmol g^{-1} , 2.89 mmol g^{-1}, and 3.02 mmol g^{-1} respectively (J Zhang, et al,2023).

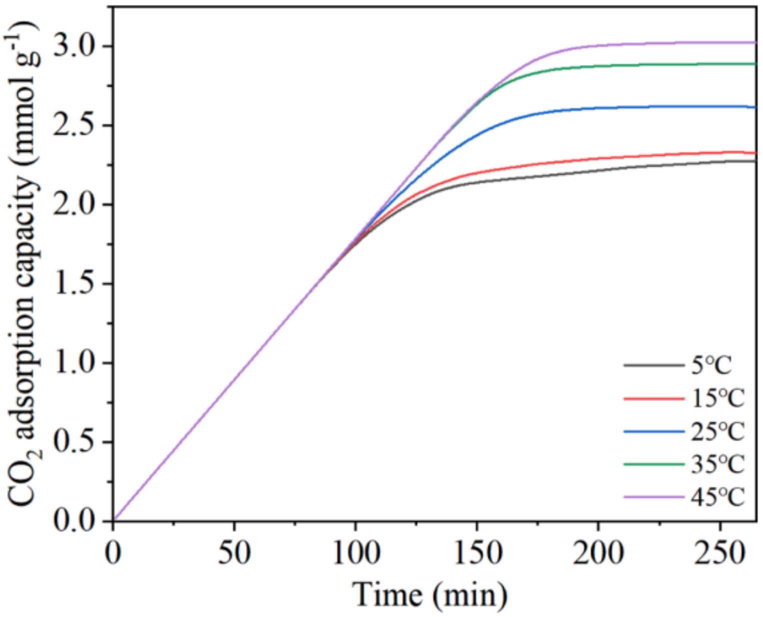


Figure 2.3 Effects of temperature on CO_2 adsorption capacity on PAN based material (J Zhang, et al,2023)

The CO_2 adsorption capacity increases with with the temperature, which indicates under ambient temperature, temperature has a positive effect towards PAN-TEPA hollow fiber material. It can be seen from the temperature range, the CO_2 capture process is determined by kinetics, high temperature, CO_2 molecules would be more active from this activity, therefore those molecules can diffuse to the deep layer to react with amino groups. Then the amino on TEPA will be more active with the increasing temperature, hence the membrane capability to capture CO_2 will increase (J Zhang, et al,2023).

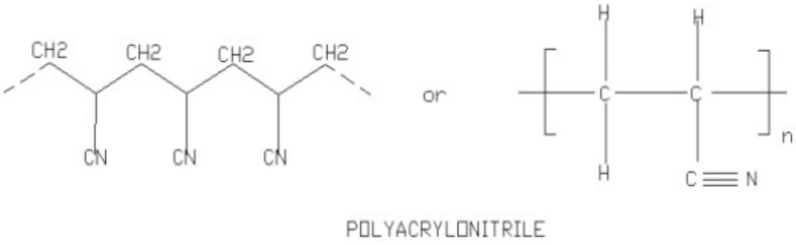


Figure 2.4 Polyacrylonitrile (PAN) molecular structure (Saufi&Ismail et al,2002)

Chemical group of (PAN) polyacrylonitril that contributes to the selectivity of CO_2 are the nitrile parts. It has been shown that the prepared materials that exhibit high adsorption capacity and fast adsorption rates for CO_2 as a result of possesing a high content of nitrogen-containing groups (W Shen, et al,2011). Carbon precusors that are able to incoorporate nitrogen atoms in the structure were polyacrylonitrile (PAN) (L Dominguez et al,2022). However there's a specific requirement of a membrane that'll be used for CO_2 adsorption, where they need to have a good permeability of CO_2, while also posessed a good CO_2/N_2 selectivity (Brunetti et al,2010).

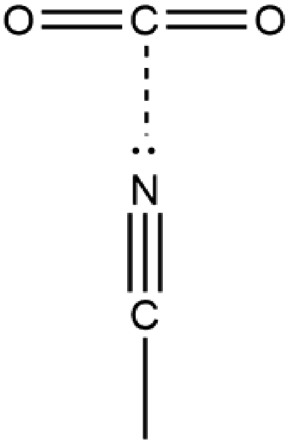


Figure 2.5 Nitril unit depiction of PIM-1 (JK Moore et al.,2018)

Physisorption interactions have been observed to occur with CO_2 by (PIM) polymer intrinsic microporosity and by using solid state NMR spectroscopy, it can be use to studied a series of PIM adsorption materials. PIM membrane has an electron rich nitrile group that adsorbs CO_2 by interaction with the carbon in carbon dioxide, which is considered to be electron deficient (JK Moore et al.,2018).

2.4 Nanofiber

When conducting nanofiber manufacturing process, there are a few aspects that need to be studied starting from the synthesizing process of the polymer it self. Polymer solutions for nanofiber manufacturing procedure, were prepared by mixing some types of polymers with their respective solvents at room temperature under cosntant stirring for a few minutes up until 1 hour before to electrospinning (RA Revia et al.,2019). Nanofiber production based from electrospinning method has been long utilized for centuries, it is a method that are usually used for manufacturing continous nano scale fibers. Product of electrospun nanofibers present promising applications, as for repairment of bone or muscle, and many other tissues with a grouping of engineered biomaterails. Recently nanofiber inclusion allow a new production of highly developed air filter media that increases filtration efficiency. CCUS is a field of scientific research that utilize membrane/nanofibers to capture CO_2 by adsorption process, which then the captured CO_2 can be benefitted for many utilization (M LF Nascimento, et al,2015).

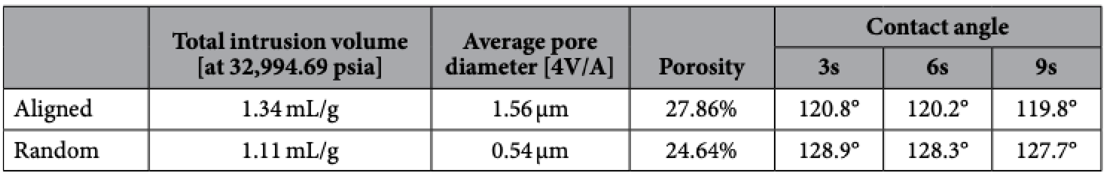
Nanomaterials are also widely recognized for their excellent prospects in the development of advanced sensing technologies. When manufacturing nanofibers, the optimization of electrospinning is very important because of its correlation with unique structures, morphologies, and fucntions of the nanofibers. Nanofibers produced via electrospinning generally exhibit a large specific surface area with their atoms normally located on the surface or within the interfacial regions. With the focused in mechanical properties polymer section, concentration moduling, and optimization of composition is very important, because the mechanical strength, hydrophilic/hydrophobic, electrical conductivity, and flexibility of nanomaterials can be adjust to the desired specification through those process (J Song, et al,2023)

Electrospun polymeric nanofibers currently have a high demands to be an ideal materials for carbon capture and storage (CCS), moreover because electrospun nanofibers are easily modified by adding a certain substances such as amines, in order to maximize the CCS capacity and selectivity. These amines can essentially applied by impregnating porous substrate in polymeric amine solutions (G Zainab et al, 2018).

The average diameters of a carbon fibers that are produced from wet/dry jet wet spinning typically have diameters ranging from a few to a couple tens of micrometers. For examples in wet spinning a spinneret with 40-80 um diameter that are immersed in a coagulation bath and a spin dope (PAN solution) is ectruded directly into the coagulation of bath forms filaments. With high length/diameter, the improvement of electrochemical performance is affecting mainly on the synergictic effect of Ni nanoparticles and carbon matrix as well as the unique 1D nanofiber structure. Nanofiber it self are cosnidered to be a 1 dimesional materials, because of their size which values only about 1μm (Lv et al.,2018).

Electrospinning based nanofiber membrane procedure is more widely used due to its superior adjustability in diameter, alignment, and signal encapsulation of the nanofibers. For example a highly aligned nanofibers play a crucial role in neurite outgrowth of the neural cell when compared to randomly distributed nanofibers. By observing the response of aligned nanofibers, where cell migration and the extracellular matrix deposition of the neural cells, aligned nanofibers tend to stretch in a parallel direction along the alignment of the nanofibers. An electrospun, aligned nanofibers matrix has a transparency that is different from that of randomly aligned nanofiber matrix, and this property plays a vital role in further reconstructive purpose nanofiber utilization An aligned nanofibers where the manufacturing process are constant, they created an increase bending stability and shorter path length for the polymer solution creating thicker nanofier diameter. Based on the intrusion volume of susbtances for the aligned nanofiber is larger than that for the randomly oriented nanofibers, which results in the volume of this nanofiber is larger than the volume of the pores In the ran”omly’oriented nanofibers can be seen on table 2.1 (JI Kim et al., 2016).

Table 2.2 Average pore diameter and porosity and contact angle measurements of random and aligned nanofibers (JI Kim et al., 2016



	Total intrusion volume [at 32,994.69 psia]	Average pore diameter [4V/A]	Porosity	Contact angle		
				3s	6s	9s
Aligned	1.34 mL/g	1.56 μm	27.86%	120.8°	120.2°	119.8°
Random	1.11 mL/g	0.54 μm	24.64%	128.9°	128.3°	127.7°

Related to the discusion regarding the dimension, the porosity, and the characteristic of membrane adsorption of CO_2, permeability is always in discussion in term of membrane utilization for CCUS. The permeability of a membrane dependance on a certain perovskite substance such as $CsPbBr_3$, where the concentartion, membrane thickness, fiber diameter, and pore size was investigated in detail. Therefore PAN/$CsPbBr_3$ based membrane with a promising permeability would have a huge potential applications in air filtartion (A Ince et al.,2022). The air permeability of PAN/$CsPbBr_3$ nanofiber was evaluated under 100pa as shown in the figure below, it is shown that the air permeability presented a good breathability with 38 mL/s, which was higher than PDM’s film with 0 mL/s (Y Yang., 2024).

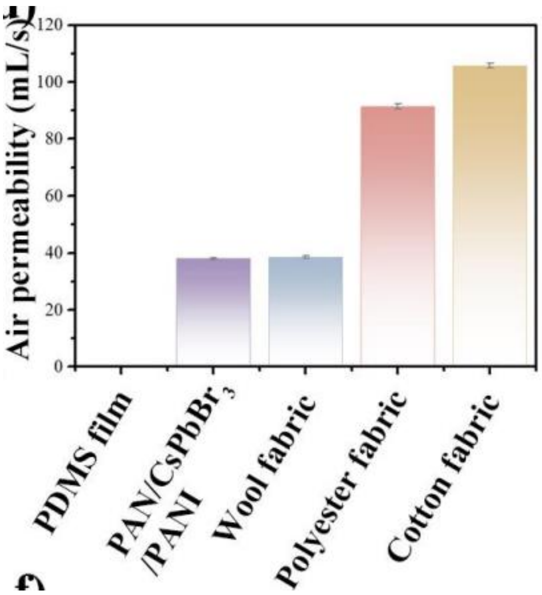


Figure 2.6 The air permeability of PAN/CsPbBr3/PANI nanofiber membrane as compared to other different fabric (Y Yang., 2024).

2.5 Electrospinning Process

Manufacturing of nanostructured materials undergoes a significant use in the industrial sector and daily lives, considered to be the most versatile fundamental materials with lots of potential to be developed. Electrospinning has emerged as a direct technology that can produce nanofiber membranes with simple and efficient operation. In our application of membrane manufacturing process, electrospinning involves the application of strong electric fields on a polymer blend of ($CsPbBr_3$) solution, that generates nanofibers which then deposited on the collector, where in our case is the alumunium foil area.

Electrospinning have three main components that plays a key role in term of creating the desired nanofiber specification : the voltage power supply ranging from 0 to 40 kV, the syringe to store polymer solution, and the grounded collector that came in a different configuration design such as alumunium foil. The process of manufacturing nanofiber goes by feeding the polymer solution into the syringe, and connecting the high voltage power supply to the metallic needle tip. As the polymer solution being pushed constantly by a syringe pump, the applied electric field from the DC power supply prevail over the surface tension of the polymer solution, which then forming a cone shaped droplet. Afterwards ultrathine fiber can be seen emitted flying through the space between the needle tip and grounded collector (LD Tijing, et.al,2017).

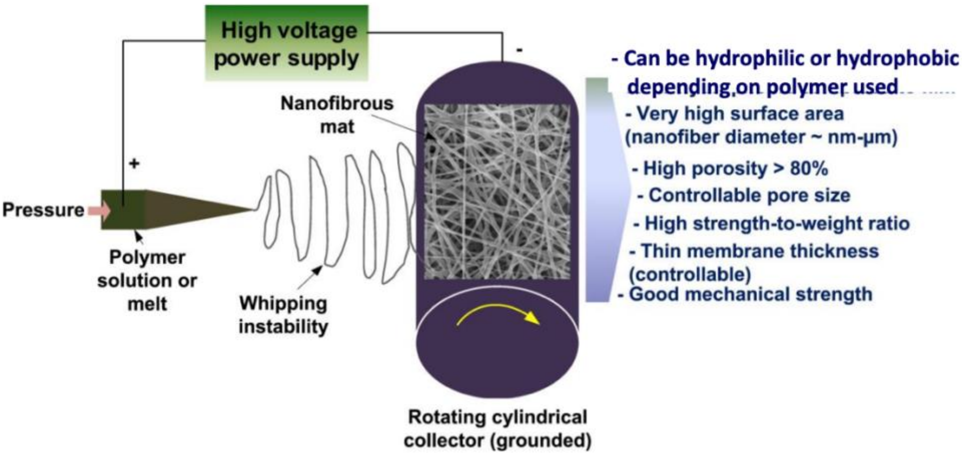


Figure 2.7 Electrospinning set-up (LD Tijing, et.al,2017)

Some important aspects that affect the electrospinning process for membrane manufacturing can be designed accordingly. Several aspects such as operational parameters, material, environment, and post-processing parameters are considered to hold the key role. Operational parameters that should came into attentions are voltage, polymer solution, distance of tip to collector, collector design, and the flowrate. While for the material aspects such as : solvent additives, viscosity, and molecular weight can affect the final result of the nanofiber itself. The environmental aspects, where it can also be the research limitation for our research are also a thing to be considered. Ambient temperature and humidity are some of the examples of envionmental aspects (LD Tijing, et.al,2017). By manipulating these following parameters, we can adjust the surface morphology, microstructure, and composition of the nanofibers (F Zhu et.al,2021).

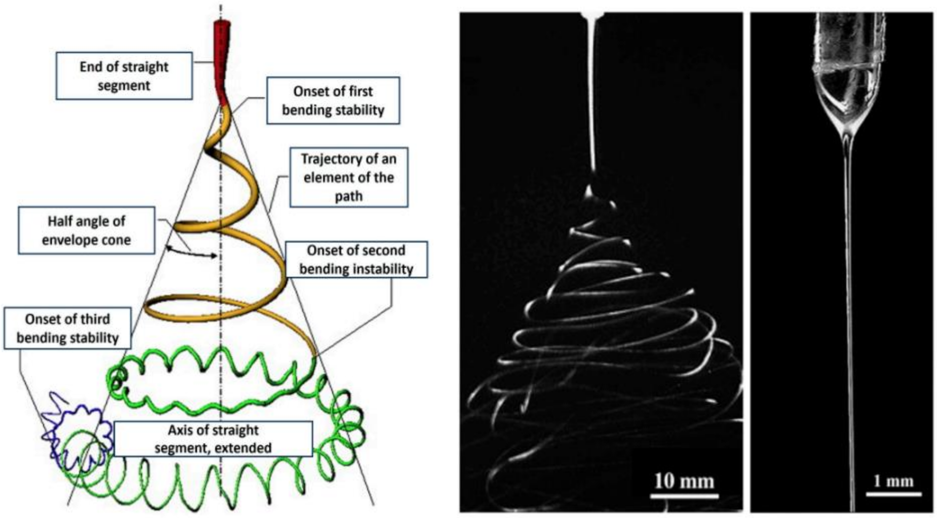


Figure 2.8 Scheme of electrospinning jet trajectory (M Ahmadi, et al,2024)

Electrospinning is a versatile technique for producing nanofibers from various different materials such as ; polymers and sol gels. This materials are supported with many great characteristics for example in polymetric nanofibers they have a suitable high molecular weight and with a lot of solvent option to dissolve the polymer, this characteristic is very important because polymer molecular weight controls the solution rheology. When producing nanofibers, solvent volatility affects the evaporation and jet solidifications rate when the polymer exits the metallic syringe tip. Several polymers, both natural and synthetic have been proven to be succesfull in electrospinning based manufacturing process, these includes natural bipolimers of (chitosan, alginate, and collagen) and synthetic polymers of (polysterene and polivinyl chloride (PVC)) (Ahmadi Bonakdar, et al,2024).

Additionally electrospinning technology enables the continous preparation of nanomaterials with different structures and morphologies and that includes, nanofibers, nanowires (nanorods), nanoribbons, hollow nanofibers, core-shell structures, hollow nanotubes, and nanodendrites. Electrospinning method is facile and the derived materials are highly reproducible and easily scalablefor further industrial scale prodution. Therefore with these charactersitcs electrospinning base materials can provide a great selection towards environmental sensing (Jialing S, et al,2022).

2.6 CO_2 Adsorption Process

Considering the application of membrane for CO_2 adsorption through direct air capture, things such as the particular requirements for such adsorpbents will be different with each different applications. The following are the general necessities for a proper CO_2 adsorption : high selectivity for CO_2 adsorption over the other components present in the gas mixture, the capacity of of CO_2 working adsorption between the conditions of regeneration and adsorption, high stability and resistance against impurities and moisture, also with their fast adsorption kinetics.

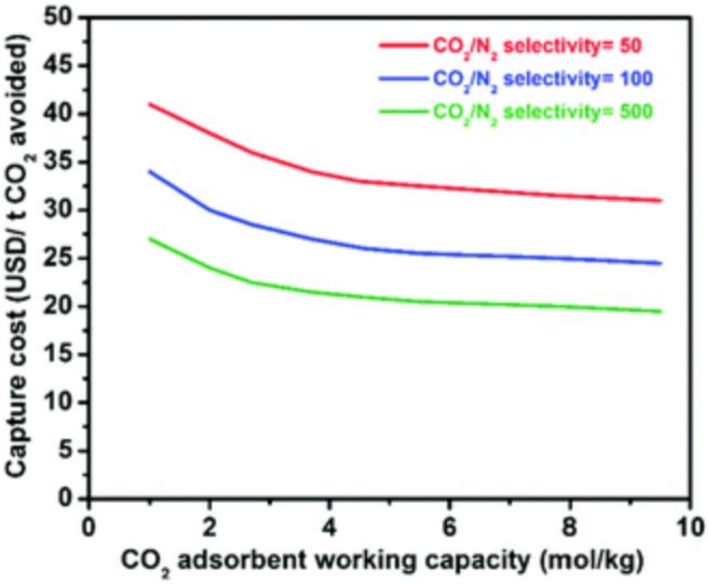


Figure 2.9 Relationship between captured CO_2 cost and working capacity/selectivity of CO_2 of solid adsorpbent (M Oschatz, et al,2018).

In our case of maximizing the potential of CCUS, the scenario of capturing CO_2 are by utilizing direct air capture (DAC). The reason behind utilizing this method is because DAC can contribute to a slower increase or even a decrease of the atmospheric CO_2 concentration, especially it can be more effective if applied in closed spaces or thermally well insulated environment. However there's seem to be a little downside of this method, where it is correlated with our membrane materials that are made out of perovskite ($CsPbBr_3$), because this material aren't considered to be a rich amine material while DAC works best with strong adsorption (chemisorption). This was because $CsPbBr_3$ is an inorganic perovskite that doesn't have any oranic amine, which are typically present in hybrid organic-inorganic perovskites (M Oschatz, et al,2018).

In order to further improve the CO_2 adsorption capacity we can connect to the aspects of solvent that use, where several solvent are proven to either increase the capability of CO_2 adsorption and decrease it. Dimethylformamide is an organic compound used in our research because of it's organic compound with the chemical formula of $HCON(CH_3)_2$, by utilizing this solvent the nanofiber ability to adsorp the CO_2 can be improved. In the other hand several groups have explored the chemical activation of activated carbon materials that contained a large amount of of additional micropores, where it mostly favourable for CO_2 adsorption (D Qian, et al,2014).

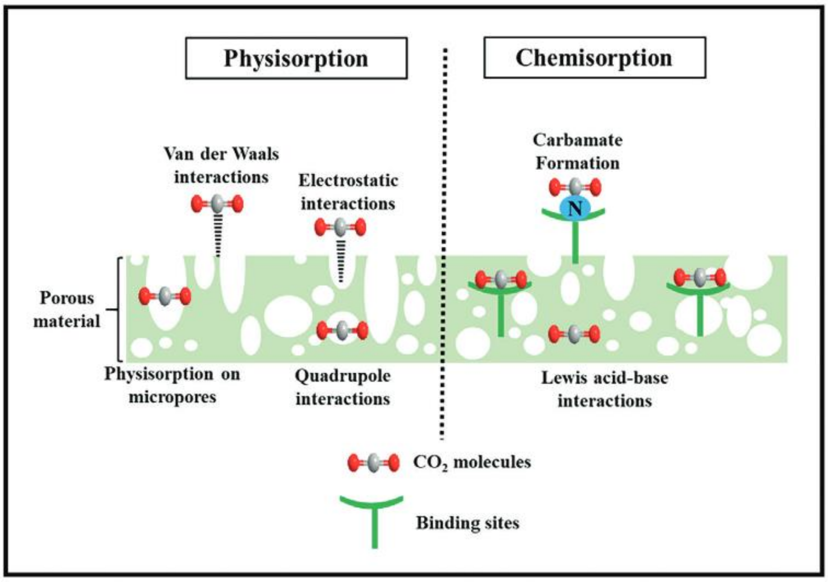


Figure 2.10 Schematic of CO_2 physical and chemical adsorption by porous material (Made Ganesh et al, 2024)

It can be classified that CO_2 capture have three major processes : precombustion capture, oxyfuel combustion capture, and postcombustion capture, this postcombution capture refers to the CO_2 capture from flue gases generated by fossil fuel and biomass in air combution. Where in this method instead of flue gas being released which contains nearly 5%-15% CO_2 directly into the atmosphere level, it is directed through a system which seperates the majority content of CO_2. This CO_2 is then tarnsferred to a storage reservoir and some of the residual gas is emitted into the atmosphere. Adsorption is concidered to be a postcombustion capture of CO_2 seperation methods. This startegy can be utilized into a lot of industrial existing plants through retrofitting and thus sustainability can be achieved in full scale commercial facilities. Therefore this concept is became the key aspect's of (CCUS) carbon capture, utilization, and storage (Made Ganesh et al, 2024).

The definition of Adsorption process of CO_2 is that they removes CO_2 from a mixture of other gases using a solid surface. Several types of surfaces can be used such as activated carbon, zeolites alumina, and metallic oxides. They're typically considered as efficient options for small-scale capture system such as direct air capture (DAC). An explanation regarding the CO_2 adsorptio by utilizing membrane based materials, has the same concept that applies in the stripper for the chemical adsorption, where the H_2O partial pressure decrease and as a result the bottom temperature dercreases since the temperature aspects is mainly controlled by the boiling point of the solution (Mourrad et al, 2025).

For CCS applications, one class of physical adsorpbents that has shown huge potentials is activated carbons, where carbon dioxide is adsorbed onto the high surface area pore walls within the activated carbon sorbent ranges from -25 to -40 kJ/mole. It has been observed under the low heat of adsorption reduces the amount of energy needed to desorb a given quantity of carbon dioxide.

Modification of membrane can be done either by using solvent (usually applied for inorganic materials like $CsPbBr_3$) and the addition of aerogels to modify materials and it's characterisation. Modification to increase CO_2 adsorption can be analize by using (thermal gravimetric analysis) TGA, where they study the reaction mechanism during the formation and determination of the thermal properties and stability based on the solvent/substances used in the modification (Leila Keshavarz et al,2021). Selecting an appropriate adsoprtive is also critical for surface area calculations. Because of having a sole focused in CO_2 adsorption, the cross sectional area of the adsorbate is an important paarmeter for the accuracy of the surface area calculation (Katie A, et.al,2018). Therefore a structural characterization such as BRT surface area, pore size, volume, and connectivity are utilized. In the other hand gas sorption can be used to directly assess the storage capacity of pororus materials at the pressure and temperature of the application for gases of interest such as CO_2 (Katie A, et.al,2018).

CHAPTER III
METHODOLOGY

3.1 Research Flowchart

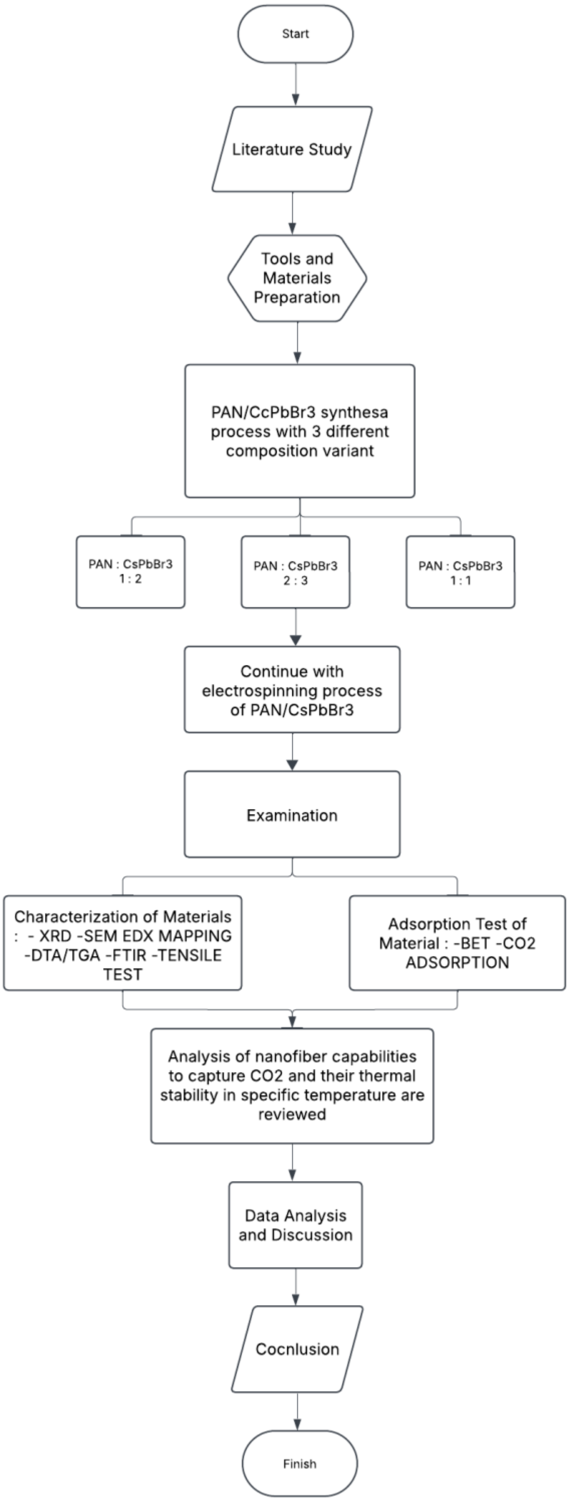


Figure 3.1 Flowchart

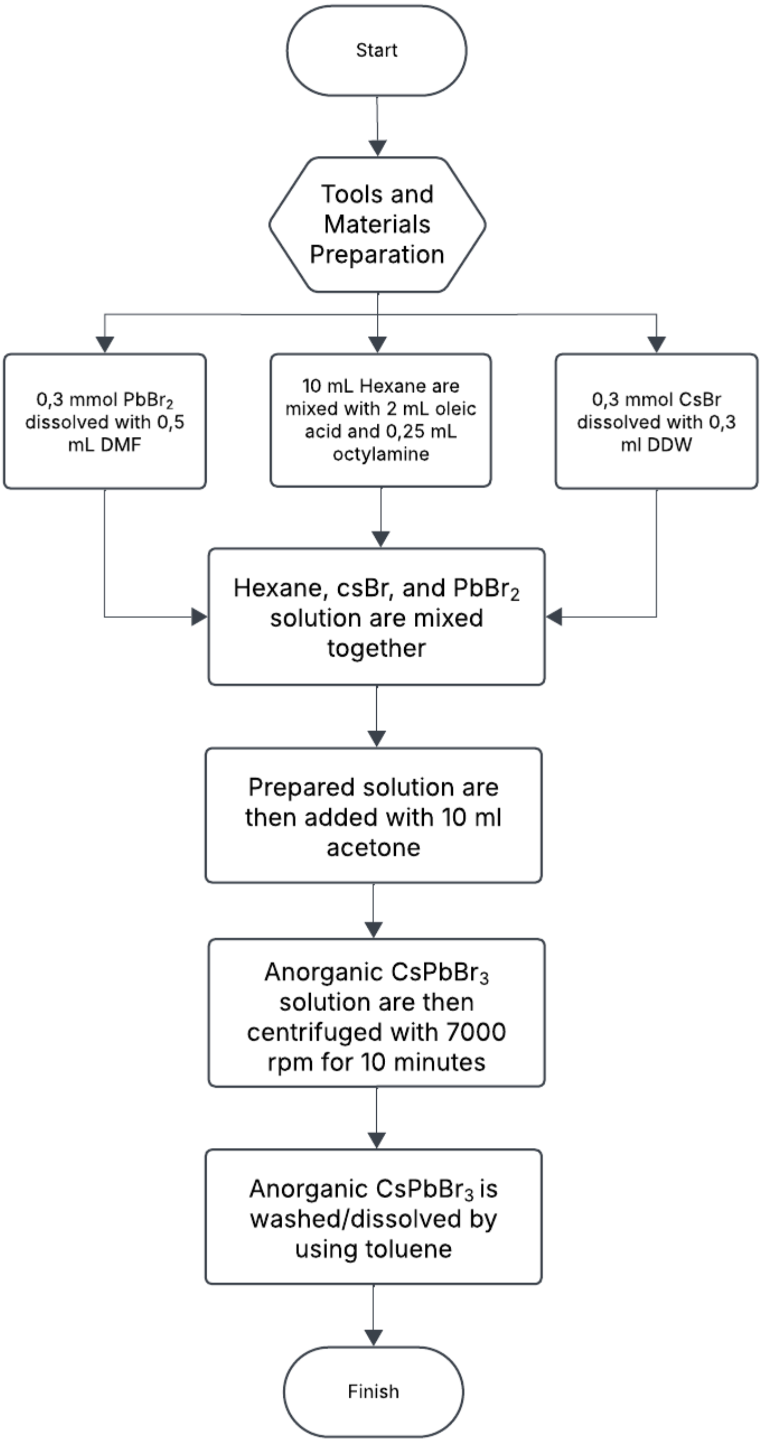


Figure 3.2 $CsPbBr_3$ Synthesizing Process

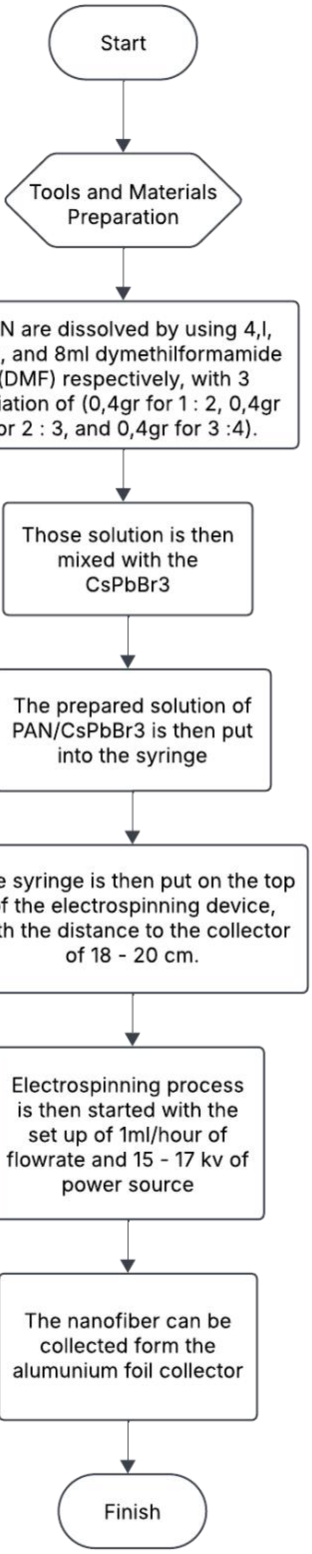


Figure 3.3 PAN/$CsPbBr_3$ diagram

3.2 Tools and Materials

In order to conduct our research experiment of manufacturing PAN/$CsPbBr_3$ membrane we required the following tools and materials to support the procedure accordingly.

3.2.1 Tools

These are the following tools used for making the PAN/$CsPbBr_3$ membrane, as follows :

1. Measurement Glass
   Use to measure chemical substance volume.
2. Beaker Glass
   Use to mix various chemical substances.
3. Hot Plate
   Use to mix various substances until it reached homogenous state.
4. Micropipette
   Use to picked chemical solution with high precision.
5. Centrifuge
   This equipment is specifically used to spin sample with high velocity, so that the chemical particle can be seperated and gets collected in the bottom of the tube.
6. Digital Scale
   Use to measures the weight of our chemical substances.
7. Electrospinning
   This equipment is used to make the PANF membrane.

3.2.2 Materials

These are the following materials used for making PAN/$CsPbBr_3$ membrane, as follows :

1. Cesium Bromide
   CsBr 99% trace metal base, used to synthesize for $CsPbBr_3$, this material has the form of a powder

Figure 3.4 Sigma Aldrich Cesium Bromide

2. Lead (II) Bromide
   PbBr2 98% used to synthesize $CsPbBr_3$, this materials is in a form of powder.

Figure 3.5 Sigma Aldrich Lead (II) Bromide

3. Oleic acid technical grade 90%

Use as a ligand for anorganic synthesa process

Figure 3.6 Sigma Aldrich Oleic Acid

4. Octylamine

Use as a ligan for synthesa of inorganic perovskite $CsPbBr_3$.

Figure 3.7 Sigma Aldrich Octylamine

5. Hexane, (n-hexane) for analysis

This material are use as ligand solvent, that are used in inorganic synthesa of $CsPbBr_3$ perovskite.

Figure 3.8 Sigma Aldrich Hexane

6. Distilled Water

   This material are use as organic solvent to dissolve CsBr.

Figure 3.9 Aquadest/Distilled Water

7. N-Dimethylformammide (DMF)

   This material are use as organic solvent to dissolve PAN and PbBr2.

Figure 3.10 Sigma Aldrich Dimethylformamide (DMF)

8. Acetone

   This material are use as a solvent to dissolve $CsPbBr_3$ dengan PAN.

Figure 3.11 Sigma Aldrich Acetone

9. Polyacrylonitrile (PAN)

   This material are use as a matrix of composite polymer of the nanofiber.

Figure 3.12 Polyacrylonitrile (PAN)

10. Toluene

    This material are use to rinse the $CsPbBr_3$ layer that has been formed, form centrifuge process.

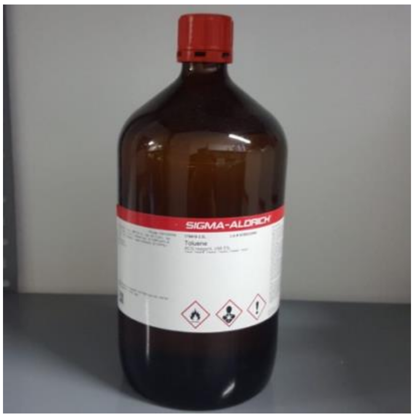


Figure 3.13 Sigma Aldrich Toluene

3.3 Research Variable

These are research variables that are provided to support the research. Where the dependent variable are as follows :

1. Synthesizing Composition
2. Thermal Properties
3. Mechanical Porperties
4. Morphologies

While for the free variables are as follows :

1. The ratio of (PAN) polyacrylonitrile content

For the controlled variable will be shown as follows :

1. The voltage used in electrospinning

3.4 Research Procedure

These are the following research procedure of $CsPbBr_3$ perovskite synthesa, electrospinning of the nanofiber, and the measurement procedure of CO_2 adsorption performance potential.

3.4.1 Synthesizing procedure of $CsPbBr_3$ Perovskite.

The following are synthesizing process of $CsPbBr_3$:

1) 0,3 mmol CsBr are stirred with 0,3 ml distilled water (Aquadest) in a beaker glass by using magnetic bar with rpm setting of 700 rpm and 60°C heating.
2) 0,3 mmol $PbBr_2$ are stirred by mixing 0,5 mL DMF in a beaker glass by using magnetic bar with 700 rpm and heating of 60° until it reach homogenous state.
3) In the stirring process an Hexane-N substances are prepared and combining by 2 mL oleic acid and 0,25 octylamine by using micropipette, then mixed those three substances into CsBr and $PbBr_2$ that are already being dissolve.
4) The prepared solution is then stirre for as long as 3 minutes, with 50°C heating until it gets dissolved.
5) After the $CsPbBr_3$ is ready, then it gets put into centrifuge tube.
6) Inorganic $CsPbBr_3$ solution is then undergoes centrifuge process with the speed of 7000 rpm for as long as 10 minutes.
7) After the centrifuge process has been done, the sedimentation of perovskite and the solvent will be seperated.
8) Poured out the remaining solvent, then the sediment will be washed by using acetone(0,2 mL) and toluene(o,8 mL) with the ratio of 1:4.

3.4.2 Nanofiber manufacturing process by using Electrospinning

The following steps are the procedure of $CsPbBr_3$/PAN nanofiber accordingly :

1) Polyacrylonitirle (PAN) are dissolve with 4 mL DMF with ratio variation of 0,2 gr for 1:2, 0,4 gr for 2:3, and 0,4gr for 2:4, which then mixed by using stirrer with 800 rpm and heating of 90°C for 30 minutes.
2) Afterwards the substance are added with 1 mL $CsPbBr_3$, and then mixed again by utilizing stirrer with 800 rpm and 90°C heating process.
3) The prepared substance is then put into syringe.
4) The syringe is then put on to the top of electrospinning device, 15 cm from the colletor.

5) Before starting the electrospinning process, the syringr pump is set with flowrate of 1 mL/hour – 2 mL/hour and the power supply are set 17 kV with DC current.
6) Electrospinning process are conducted with the time period of 180 – 240 minutes.
7) The PAN/$CsPbBr_3$ are picked up from the collector.

3.4.3 Measurement Procedure of CO_2 Adsorption Performance Potential

Procedure that are utilized for this CO_2 adsorption performance potential accordingly for this research are as follows :

1) Specimen preparation.
2) Specimen are placed in a beaker glass.
3) KOH 0,05M electrolite are added into the beaker glass.
4) Substances in a beaker glass are then connected with potensiotat by using 3 electhrode.
5) The beaker glass are lighted with UV light.
6) The reaction result are shown in electronic application that are already installed Cs Studio
7) Lastly the chamber are cleanse.

3.4.4 FTIR Characterization

FTIR abalysis are conducted with a wavelength of 4000 – 400 cm^{-1}. Next step is to compare between the provided peak based from FTIR analysis result and the IR table. The results can be seen in a form of adsorption ribbon of organic chain based on the chemical structure from our material. FTIR characterization is conducted with the sole purpose of detecting the existence of interaction from hidroksil group, carbonil group, and perovskite in the material. The speciifc equipment type used for the FTIR are the Thermoscientific (Nicolet Summit Lite).

3.4.5 XRD Characterization

The working principle of XRD testing is based on the difference in X-ray intensity between the material exposed to X-rays and the intensity of the transmitted X-rays. The transmitted X-rays have a lower intensity than the incoming X-rays due to absorption by the material. The scattered X-ray beams may either cancel each other out due to phase differences or reinforce each other if they are in phase. The X-ray beams that reinforce each other are known as diffraction beams. The data obtained from XRD testing consist of diffraction peaks that provide complete information about the crystal structure of a sample, including atomic positions, crystal size, and more. The grain size analysis in XRD results is based on the width of each diffraction peak. The XRD equipment utilized on the This analysis is performed using the Debye-Scherrer equation, as expressed in the formula.

$$D = \frac{k\lambda}{B \times cos\theta}$$

Where :
D = Grain Size (nm)

K = Konstanta = 0,9
Λ = Light Wavelength
B = Full Width Half Maximum

The XRD analysis was conducted at the bioenergy lab at UPN (Universitas Pembangunan Nasional) of East Java.

3.4.6 SEM-EDX Mapping

SEM-EDX Mapping analysis is conducted to determine the morphology of the sample or the resulting product, this testing procedure was conducted at the Bioenergy lab of UPN (Universitas Pembangunan Nasional) of East Java. The composition of the produced product can also be identified through EDX mapping, with different color distributions representing the precursors used. The magnification used to analyze the morphology of a product ranges from 1,000x to 100,000x, depending on the type of product being examined. However, it should be noted that higher magnification may affect the visual clarity of the product. The composition selection can be digitally adjusted based on the elements present in the precursor. This allows for the determination of the distribution and percentage of chemical molecules within the sample or product. The data obtained includes images at the desired magnification along with the chemical composition of the sample.

3.4.7 DTA/TGA Charactrization

DTA/TGA analysis is conducted to identify the thermal properties of the obtained product, its thermal stability, composition identification, and characterization of phase changes or material degradation at specific temperatures. This allows for the observation of structural or compositional changes occurring at various temperatures. The test is performed at temperatures below 1000°C with a 5°C interval. The specific type of equipment used in the thermal testing of DTA/TGA is (DTG-60/Shimadzu), at Brawijaya University.

3.4.8 Tensile Test

Tensile test analysis is conducted to determine the mechanical characteristics of the produced product, specifically its ability to withstand tensile forces before failure. This test is crucial for understanding how strong, elastic, and tough the product is when subjected to pulling or stretching forces. The tetsing was conducted at the Material Innovation lab of Materials and Metallurgical Engineering ITS.

3.4.9 Brunnauer-Emmet-teller (BET)

BET analysis is conducted to determine the specific surface area, pore volume, and pore size distribution of $CsPbBr_3$/PAN/ZrO_2 nanofibers based on nitrogen adsorption isotherm measurements at a temperature of 150°C. The relative pressure range used in the measurement is approximately 0.05–0.3. This test are conducted by utilizing the specific type of BET equipment (BET-NOVA).

3.5 Research Design Experiment

These are the ratio composition of PAN/$CsPbBr_3$ that were conducted to make a comparison of membrane performance and morphologies based on their composition.

Table 3.1 Composition Ratio of PAN/$CsPbBr_3$

PAN-CsPbBr3	**DTA/TGA**	**Before Heat Treatment**					
		XRD	**FTIR**	**BET**	**CO2**	**UTS**	**SEM-EDX**
1 to 0	✓	✓	✓	✓	✓	✓	✓
1 to 1	✓	✓	✓	✓	✓	✓	✓
1 to 2	✓	✓	✓	✓	✓	✓	✓
2 to 3	✓	✓	✓	✓	✓	✓	✓
PAN-CsPbBr3	**DTA/TGA**	**After Heat Treatment**					
		XRD	**FTIR**	**BET**	**CO_2**	**UTS**	**SEM-EDX**
1 to 0	×	✓	✓		✓	✓	✓
1 to 1	×	✓	✓		✓	✓	✓
1 to 2	×	✓	✓		✓	✓	✓
2 to 3	×	✓	✓		✓	✓	✓

3.6 Design of Composite Material Composition

These are the following illustration of how $CsPbBr_3$ Perovskite are attached to the polymeric skeleton og Polyacrylonitrile.

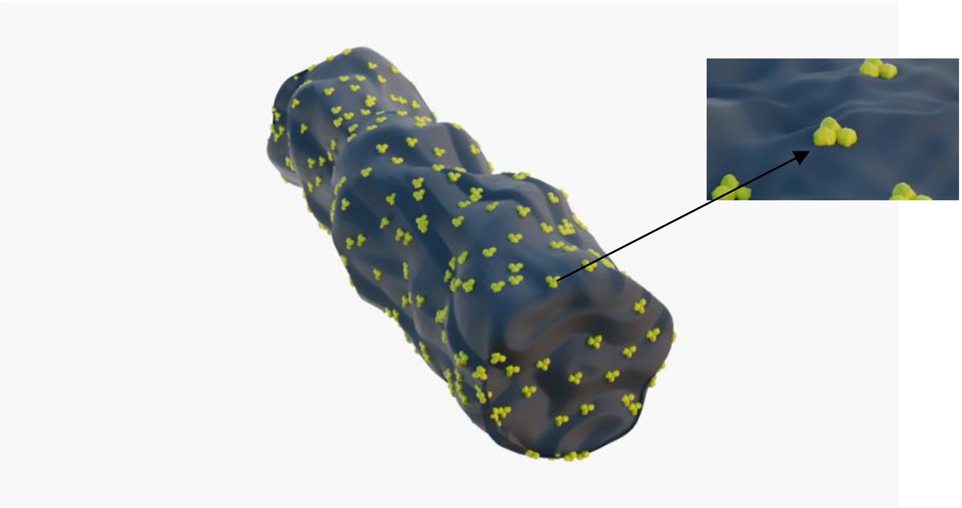


Figure 3.14 Scheme of the composite nanofiber

In this illustartion the visilble red dots that are attached to the polymeric struture of polyacrylonitrile. Where the polymer materials act as the main supporting structure of the whole nanofiber/membrane body. Therefore the importance of finding the perfect ratio between the polymer and ceramic of perovskite are very important. From three of my variable ratio, the amount of polymer are always less than the ceramic perovskite in order to prevent clotting in the synthesizing process.

3.7 Research Schedule

These are the following research schedule timeline sohon on the table below.

Table 3.2 Research Schedule

Research Process	Month's															
	1 and 2				3 and 4				5 and 6				7 and 8			
Literature Study	■	■	■	■	■	■	■	■	■	■	■	■	■			
Tools & Materials Preparation	■	■	■	■	■	■	■	■	■	■	■	■				
Synthesizing of Membrane	■	■	■	■	■	■	■	■	■	■	■	■				
Characterization of Sample					■	■	■	■	■	■	■	■				
Data Analysis					■	■	■	■	■	■	■	■	■			
Compiling the Report		■	■	■	■	■	■	■	■	■	■	■	■			
Final Presentation														■		

CHAPTER IV

DATA ANALYSIS AND DISCUSSION

4.1 Visual Data Analysis

Photoluminescence phenomenon can be visually observed on the $CsPbBr_3$ where it also considered to be a semiconductor material. When the ceramic material of $CsPbBr_3$ adsorp light wave in a certain wavelength, the electron on their crystal structure can obtained enough energy to jump on to a higher energy level. However in the case of electron that came back into a lower energy level the adsorp energy can then be relaeased in the form of a photon, which then results in a light emission. This light emission are happen in a certain light spectrum, where it can be seen in to a different color of light depends on how much photon energy are emitted. The mixture of CsBr and $PbBr_2$ in a certain composition can be made in to composite materials like $CsPbBr_3$ and other products such as Cs4PbBr6. However only the $CsPbBr_3$ can emitted a light spectrum in the color of green flourescent under the UV light spectrum of 365 nm (Zhang et al., 2023). Therefore a proper testing procedure are necessary to be conducted to make sure that the synthesizing proces of $CsPbBr_3$ are successful.

4.1.1 Visual Testing of $CsPbBr_3$

Visual testing are conducted on the $CsPbBr_3$ solution that are used as the main addition to the nanofiber membrane. Here we can see the difference in term of appearance of the $CsPbBr_3$ solution, where one is exposed with UV light illumination.

Figure 4.1 Visual testing $CsPbBr_3$ illumination (a) Regular condition (b) Under UV light

This testing procedure are also conducted to make sure that the dispersion of $CsPbBr_3$ are evenly disoersed in PAN, after the synthesizing process of CsBr and $PbBr_2$ are synthesized. From the testing procedure we can decide if the synthesizing of PAN and $CsPbBr_3$ are mixed evenly by observing wether they emitted lights or not, if they are observed that they can emitted lights it means the perovskite of $CsPbBr_3$ are evely distribute in the whole are of nanofiber.

4.1.2 Visual Testing on PAN/$CsPbBr_3$ Solution

The visual testing are also necessary to be conducted on PAN/$CsPbBr_3$ solution, where this mixture of solution will be the main material composition to manufactured the nanofiber membrane by electrospinning. The visual testing report shows a difference when the solution of PAN/$CsPbBr_3$ are exposed to the UV light, where they emitted a light pink color.

Figure 4.2 Visual testing of PAN/$CsPbBr_3$ (a) Regular condition (b) Under UV light

4.1.3 Visual Testing of PAN/$CsPbBr_3$ (Nanofiber Membrane)

Visual testing procedure are then continue to be conducted on the final nanofiber membrane product, where all three of my composition each are illuminated by UV light to see the photoluminescence phenomenon that occurred under UV light emmitance.

Figure 4.3 Visual testing of PAN/$CsPbBr_3$ nanofiber membrane under UV light condition in all three composition (a) 1:2 (b) 2:3 (c) 1:1.

4.2 Morphology Analysis

4.2.1 XRD Testing Procedure

X-Ray Difraction procedure are conducted to obtained the peak of difraction of each nanofiber composition with $CsPbBr_3$ and PAN. The XRD were employed to characterize the morphology and structure of the materials. Therefore the analysis were performed by a specific equipment at ITS Research Center, by using the XRD equipment of Rigaku MiniFlex

600. The testing of XRD are done at the Energy Lab of ITS Research Center. The obtained results are then processed by using Highscore Software to tackle the diffraction peak in each of the sample variation of $CsPbBr_3$ and PAN. In this research XRD are used to quantify the percentages of the major minerals that are contined in the specimen. The method of X-ray diffraction (XRD) can also be utilized to characterize crystalline materials. XRD is a non destructive test procedure and it requires minimal sample preparation, hence also minimize the errors in analysis. XRD is also a rapid technique for identification and quantification with straightforward data interpretation. Despite a simple sample preparation, the technique requires homogenous and crystalized structure of samples, besides it has the limitation of peak overlay (Abubakar et al., 2019).

When the analysis of XRD are conducted, the important initial step that needs to be done is to match the database with our own XRD data results, referring to the ICDD data base the peak that are presented in our raw data were suitable in term of the materials that are presented on each peaks are actually visisble. Matching the existing XRD data graph to the reference of previous data analysis of PAN/$CsPbBr_3$ nanofiber membrane, the data indicates that the difractogram of the prepared materials matched to ICDD 00-054-0752 as the $CsPbBr_3$ standard (Yonarosa et.al., 2024).

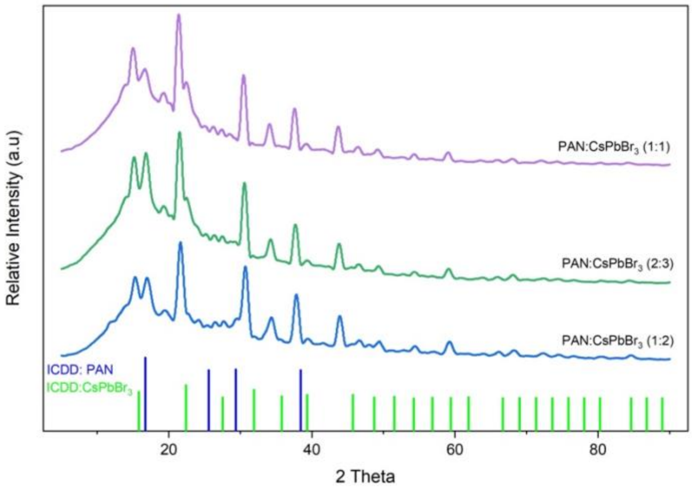


Figure 4.4 XRD Graph of PAN/$CsPbBr_3$

In the next stage of this analysis we need to focus on the comparison of the sample composition, therefore it is necessary to understand wether the addition of $CsPbBr_3$ perovskite component have a significant effect on the PAN nanofiber membrane. Continue by analyzing the shift of peak change in the XRD analysis it self . In our XRD data graph that are presented in **Figure 4.1** PAN can be seen ranging from 17° and 29°, as this peaks serve as the refrence of ICDD : PAN), this interpretation was for the PAN only baseline. Continuing to the effect of what the $CsPbBr_3$ gives to the XRD peaks, it can be seen that with the addition of perovskite to the polymer nanofiber membrane, the peaks get a distinct sharp/high intensity peaks that emerge at 2theta ranging from (15°, 21°, 30°, and 38°). These peaks are the interpretation of a dominant $CsPbBr_3$ effect, this could indicates that the perovskite froms a distinct crystalline domains within the fiber. Therefore, we can elaborate that the addition of $CsPbBr_3$ perovskite to the PAN polymer nanofiber membrane results in a different peak length, compare with the one only made out of pure PAN polymer. The peaks shows in several 2theta points that was mentioned before, means that the content of $CsPbBr_3$ made the overall peaks higher. Hence it can be expected that each sample with a higher content of $CsPbBr_3$ perovskite embedded to the PAN polymer nanofiber membrane should results in a higher intensity in term of the amount/length of peaks. Correlated with addition of $CsPbBr_3$ and the heat treatment that would be conducted, the crystallinity would also be more intense in the composition with higher content of the perovskite it self. For example the sample of (2:3) that has a perovskite composition three times higher compare to the other sample, should have the highest crystallinity, hence the XRD peaks would be sharper. As also mentioned in other research that XRD could reveals that $CsPbBr_3$ embedded in polymer maintains its distinct crystallinity with sharp peaks, even when electrospun with PMMA or PAN (Hua et al., 2023).

Table 4.1 PAN/$CsPbBr^3$ Crystal Size.

Crystal size PAN 1:2					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.138	0.013	29.196	0.125	657
Crystal size PAN 2:3					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.787	0.013	16.787	0.774	104
Crystal size PAN 1:1					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.945	0.013	16.557	0.932	86
Crystal size $CsPbBr_3$ 1:2					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.787	0.013	22.414	0.774	105
2	0.63	0.013	15.003	0.617	130
3	0.236	0.013	27.627	0.223	367
4	0.945	0.013	59.149	0.932	98
Crystal size $CsPbBr_3$ 2:3					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.945	0.013	22.441	0.932	87
2	0.472	0.013	27.561	0.459	178
3	0.945	0.013	59.196	0.932	98
Crystal size $CsPbBr_3$ 1:1					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.472	0.013	22.339	0.459	176
2	0.63	0.013	49.227	0.617	142
3	0.945	0.013	67.908	0.932	103

After the process analyzing the morphology through XRD, it can be seen that the defect tolerance here means that though the optical and electronic properties of perovskite often appear as though there are no excessive doping present, structural and other morphology testing method methods to point to a large density of various structural defects. In term of crystal size aspect X-ray diffraction (XRD) analysis of a nanocrystal can confirm the crystallinity of the sample, which shows different peaks related to different reflection panes (Nath D et.al., 2020). The corresponding PAN polymer that acts as the main skeleton structure of the nanofiber membrane and CsPbBr$_3$ perovskite shows a distinctive crystalline peaks. When concerning about crystallinity of nanofiber membranes, heat treatment process that are conducted in this research becomes the main focus of discussion. The heat treatment is conducted in the temperature range of 250ºC – 260ºC, in a common occurrence PAN undergoes cyclization and dehydrogenation that could further enhance its thermal stability. Heat treatment at this range improves polymer crystallinity and enables embedded nanocrystals like CsPbBr$_3$ to recognize into more ordered domains (Duan et al., 2012).

The difference in term of crystal size value can affect the overall morphology of the nanofiber, hence we can make a recommendation of how the nanofiber membrane can be further utilized. When discussing regarding thermal analysis, the overtime degradation of a material needs to be further studied. Because of the focus of creating good mechanical properties of the nanofuber membrane, stabilization is the main step to determine the structures and properties of PAN/CsPbBr$_3$ nanofiber membrane. Factors in the stabilization that became the main concern in our discussion is the temperature, because it can have a large impacts on the crystalinity of the nanofiber membrane. When the fiber diameter decrease from micron to nano-scale level, the heat treatment process should be carefully adjusted to control the defects in the nanofibers. It has been examined about the effects of temperature on electrospinning PAN nanofibers, where the conclusion was that at the pre-oxidation temperature of 250ºC, cyclization and dehydrogenation reactions of the fibers occurred (Duan et al., 2012).

Table 4.2 PAN/CsPbBr^3 Crystal Size.

Crystal size 1:2 PAN					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.551	0.013	16.997	0.538	149
Crystal size 2:3 PAN					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.433	0.013	16.792	0.42	191

Crystal size 1:1 PAN					
No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.63	0.013	16.685	0.617	130
Crystal size 1:2 CsPbBr$_3$					

No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.472	0.013	27.702	0.459	178
2	0.472	0.013	39.524	0.459	184
3	0.472	0.013	59.262	0.459	199
4	0.551	0.013	68.469	0.538	179

Crystal size 2:3 CsPbBr$_3$

No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.433	0.013	16.792	0.42	191
2	0.315	0.013	27.603	0.302	271
3	0.472	0.013	39.391	0.459	184
4	0.472	0.013	59.086	0.459	199

Crystal size 1:1 CsPbBr$_3$

No.	B obs. [°2Th]	B std. [°2Th]	Peak pos. [°2Th]	B struct. [°2Th]	Crystallite size [Å]
1	0.63	0.013	22.491	0.617	131
2	0.472	0.013	27.438	0.459	178
3	0.472	0.013	39.218	0.459	184
4	0.315	0.013	48.855	0.302	289

Based on all three of the PAN/CsPbBr$_3$ composition after the heat treating process, the crystallinity shows the highest amount at the specimen with the highest CsPbBr$_3$ perovskite. Which means that with higher CsPbBr$_3$ content, the perovskite has more mass and surface area to make the crystallization happen, therefore it can be seen that the XRD peaks went sharper. In the other hand, when the CsPbBr$_3$ perovskite content are lower, the PAN would dominate and restricts crystal formation. This can be further validate through a previous research where the PAN with other addition material of itaconic acid showed a higher capability of stabilization processing and the diameters of the nanofibers shows a decreased by about 20% as the result of stabilization at 250°C (Duan et al., 2012). This can be seen on the composition of (1:2) when the PAN dominates the phase and the perovskite weren't able to help the stabilization process enough. From a thorough analysis of the XRD we can further elaborate the mechanical properties of the nanofiber membrane specimen. Nanofibers that are treated at the highest temperature had the largest amount of crystallinity and strength. The mehcanism of how crystallinity could be improved by heating can be explained as follows, by providing sufficient time for polymeric chains, because of the motion of molecular chains in amorphous regains, some smaller crystals might be disturbed while other larger crystals were formed so that the crystallinity of fibers could be further improved (Abdolkarim et.al., 2011). In conclusion the dgree of crystallinity of nanofiber membrane could be observed from the XRD of PAN/CsPbBr$_3$ specimen, with some specimen has been enhanced with heat treatment. From this morphology analysis then it can be correlated to further reaching the analysis of mechanical testing, in order to test the durability of the nanofiber membrane material.

4.2.2 FTIR

The specimen of PAN/$CsPbBr_3$ (perovskite) are then continue to undergoes a Fourier Transform Infrared Spectroscopy (FTIR), by utilizing the equipment of thermoscientific (SummitLite). This procedure are conducted in order to detected that the specimen have the intercation between the functional groups and chemical bonds that are presented in the material, while also ensuring that CO_2 are thoroughly difused into the PAN/$CsPbBr_3$ nanofiber.

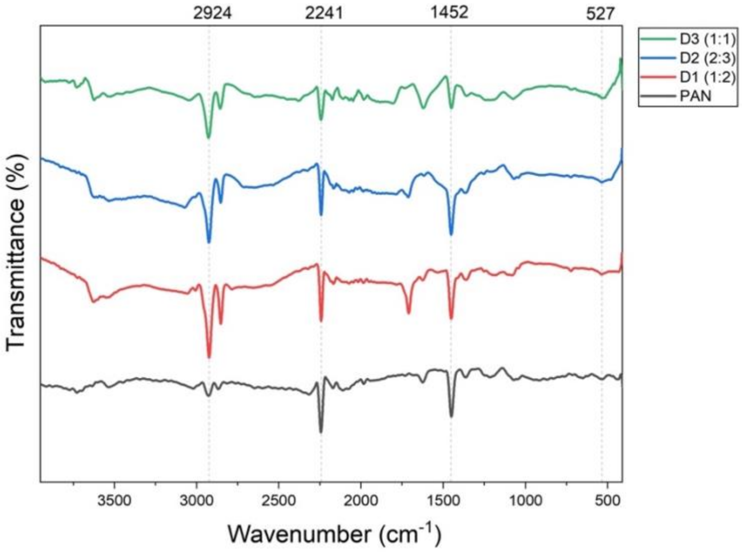


Figure 4.5 FTIR data of PAN and PAN/$CsPbBr_3$ nanofiber before CO_2 adsorption (a) PAN (b) 1:2 (c) 2:3 (d) 1:1

Based on the graph figure above it can be confirm that on (a) PAN specimen the spectrum confirms the integrity of PAN, the furthest peak that can be seen on the first graph of the specimen are shown that there’s a content of PAN’s nitrile group therefore it resembles a strong sharp peak of (2242). Therefore to further analyze the the influence of thermal treatment on a chemical structure of CE samples Fourier transform infrared spectroscopy (FTIR), the brand model of are utilized using transmission mode. The study aims to examine the function group and chemical bonds in a material by measures the infrared light that are applied to the nanofiber membrane. The explanation of strong interaction between PAN and $CsPbBr_3$ can be further interpreted throught FTIR spectroscopy.

On the composition variant of pure PAN, the peak wavenumber could reach the length of 2242 cm^{-1}. This can be a sign of a $-C\equiv N$ intact bond. The PAN (Black line) $-C\equiv N$ (nitrile stretch can be observed in those specific wavelength. It can be seen that sharp PAN graph indicates the interaction with $CsPbBr_3$ ceramic materials, to be specific the Pb^{2+} would be the materials that interact with $-C\equiv N$ in that wavelength. This type of bonding can inidcates several things such as inonic bonds and hydrogen bonds, because the FTIR is relively sensitive to bond vibrations the hydrogen bonds can easily shifts the wavenumber. Hydrogen bonds could occured by the effect of air moisture that applied in the nanofiber membrane.

Tabel 4.3 Wavenumber of PAN/$CsPbBr_3$ Nanofiber Membrane Before Heat Treatment

Wavenumber				**Interpretation**	**Reference**
D-PAN	**D-1 (1:2)**	**D-2 (2:3)**	**D-3 (1:1)**		
2914	3000	-	-	C-H	(Jawad and Mahmood, 2019) & (Yang Bo et.al., 2022)
2241	-	-	-	C≡N	(Jawad and Mahmood, 2019)
1079	-	-	2924	C=O stretching and C-H bending	(Jawad and Mahmood, 2019) & (Yang Bo et.al., 2022)
1452	-	-	-	N-H bending	(Jawad and Mahmood, 2019)
	-	1452	-	C=C stretching	(Yang Bo et.al., 2022)

The FTIR for PAN are shown in the table above, the stretching of C-H bond appeared at around 2914 and 3000, The bands appeared at 2241 are related to the C≡N stretching of acrylonitrile unit in the polimer chain (Acrylonitrile is an organic compound with the formula CH_2 CHCN). Howeve a weak adsorption appeared at 1079 for PAN may attribute to the C=O in carbonyl group and C=C vibrations respectively(Jawad and Mahmood). In the wavelngth of 2924, it can be seen that it indicates a stretching vibartion behaviour of C-H from CH_2 where the appeared elements are PAN polymer (De Yonarosa et.al., 2024).

4.2.3 SEM-EDX Testing

The SEM-EDX tetsing procedure are conducted to analyze the morphology, sample size, and the main spread of the $CsPbBr_3$ filler type towards the PAN nanofiber. The SEM analysis towards PAN/$CsPbBr_3$, are further processed by analyzing the individual nanofibers size to see wether the spread of elements is already proper or not, this tetsing procedure was conducted at Universitas Pembangunan Nasional (UPN) Veteran Jawa Timur. The actual morphology of the specimen will be provided as follows in **Figure 4.6**

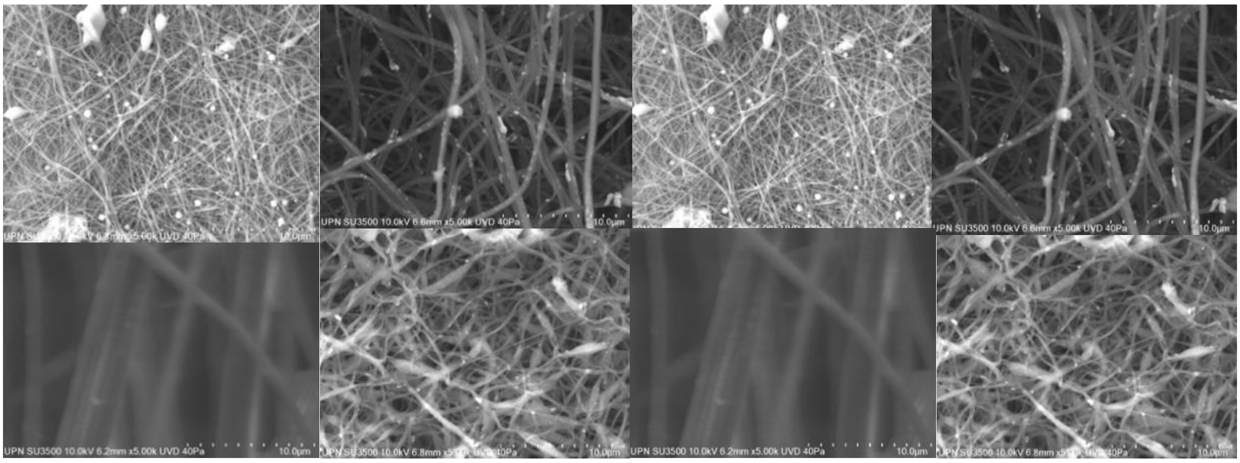
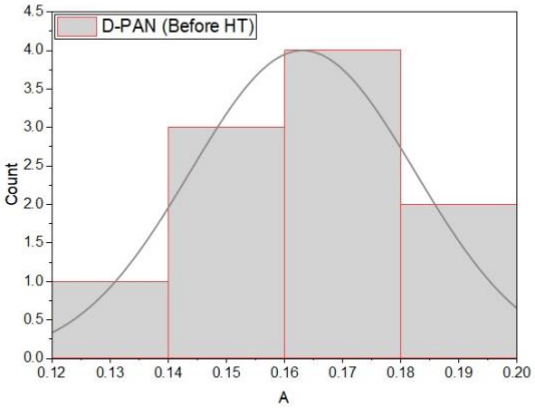
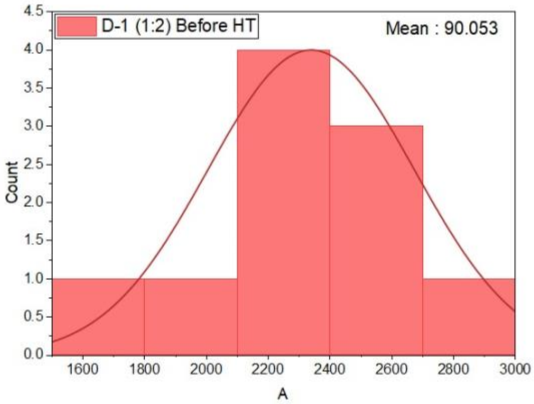


Figure 4.6 SEM testing results of PAN/$CsPbBr_3$ Nanofiber Membran with 5000x Magnification.

Scanning electron microscopy (SEM) has been designed to demonstrate various properties related to surface topography while if it gets combined with the energy dispersive X-ray spectroscopy (EDX) has been designed to examine chemical composition. SEM-EDX are a non destructive test and rapid measurements in a wide range of matrices (Abubakr et.al., 2019). Through this testing procedure, the nanofiber can be observed in term of their diameter of each variation and the synthesize nanofiber morphology. The obtained data is then can be utilized to decide which variation/composition of nanofiber have the most suitable morphologies for their intended application, which is their photochemical performance for CO_2 capture. In this graphic scheme the interaction between PAN as the adsorbbant with the CO_2 as the adsorbate aren't yet to be presented, because the fiber is yet to be tested for CO_2 adsorbtion process. However if the CO_2 adsortion process is already to be conducted, the peak on the graph will be shrinking because of the CO_2 adsorption phenomenon that occur.





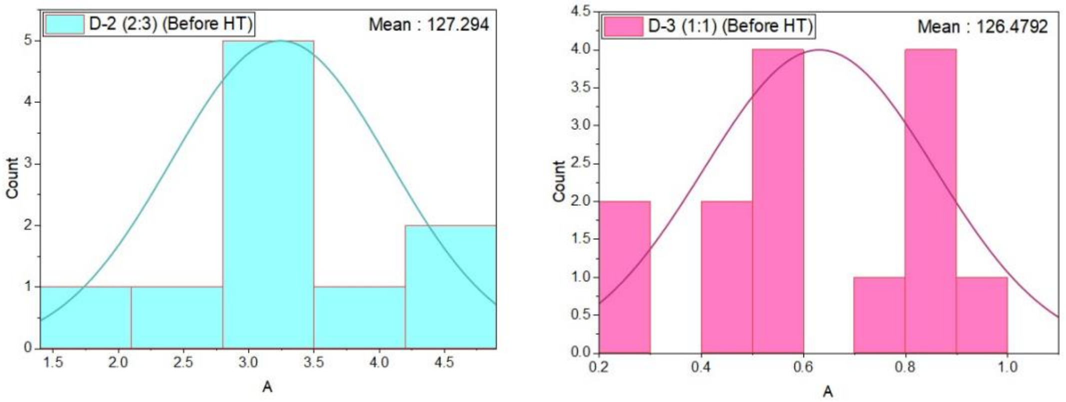


Figure 4.7 Nanofiber spread data of PAN/CsPbBr3 Before Heat Treatment.

Based on the SEM analysis it can be obtained the spread diameter of fibers that are presented on the specimen, however the fiber boundaries at fiber to fiber corss over area are more difficult to be identified from just the raw binary image. Therefore to seperated each fiber boundary at the fiber cross over areas plotting by using single fiber detection to measures the diameter of the fiber, the diameter measurement needs to be conducted at least 10 fiber diameter throughout the whole specimen area. Fiber individualization is the next step that should be considered when making the perimeter, when fibers are located in the supposed area such as the part that we wanted (Eun Ho Shin et.al, 2008).

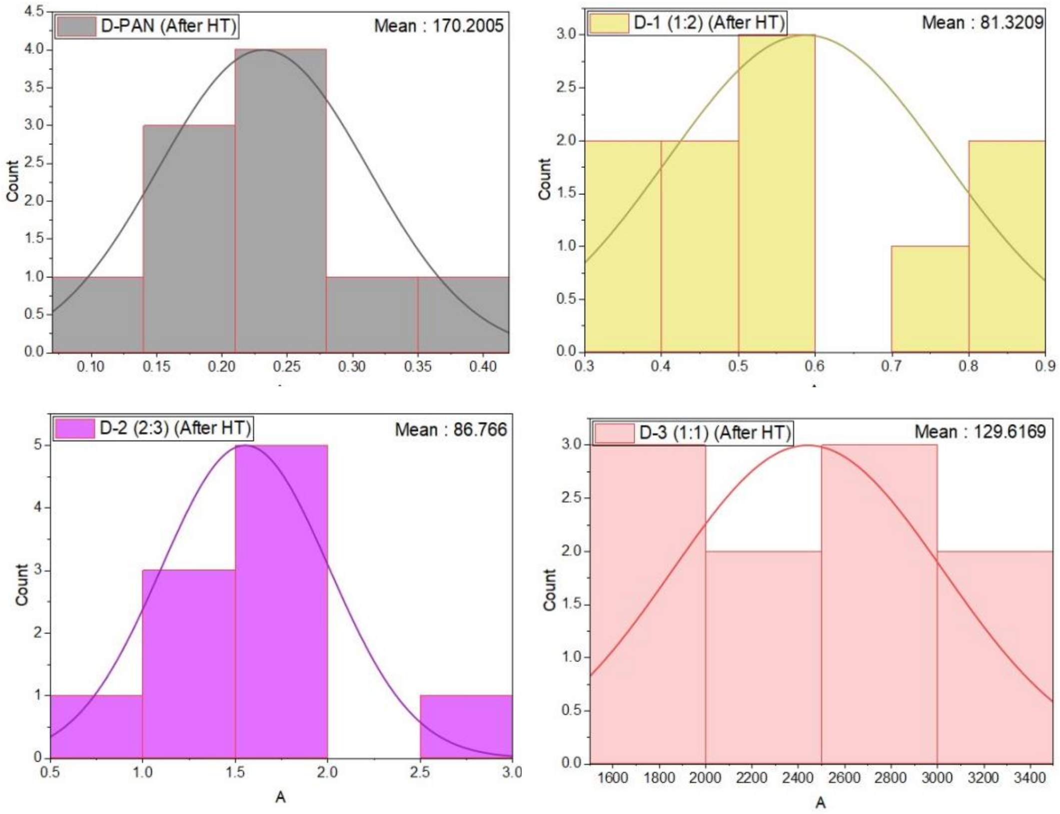
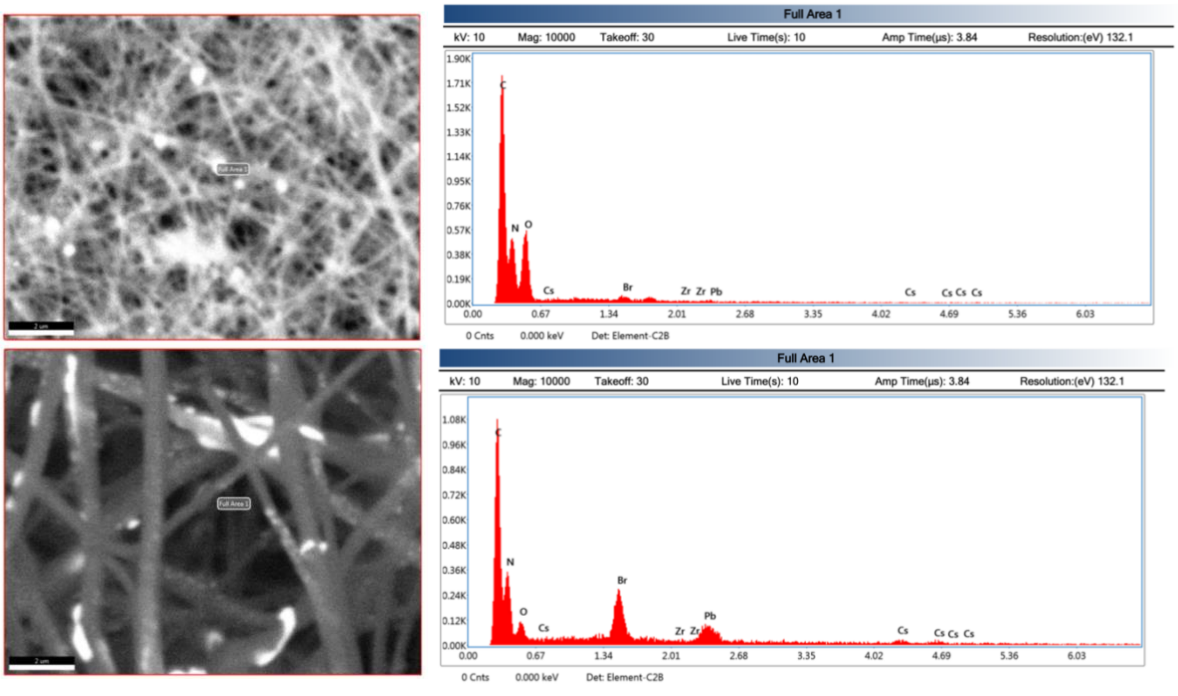


Figure 4.6 Nanofiber spread data of PAN/CsPBBr3 After Heat Treatment.

After the heat treatment procedure towards the nanofiber in the temperature of 250°C up until 300°C the common thing that we will found out is that the fiber will get distorted, in the pure polymer specimen of (PAN) Polyacrylonitrile it can be seen that the mean is spiking at 185.61 means that the fiber undergoes a swelling deformation on the polymeric structure. In the other hand for composite specimen such as DA-2 (2:3) specimen which is a mix of PAN and $CsPbBr_3$ ceramic component reacts better to the heat applied to them, where the mean value is only at 85.1199, means that thernal resistance are better on the following specimen. Heat treatments are used to improve the resistance of nanofiber membranes, especially against layered fouling (Bilad et al., 2011). Then the fiber size distribution was also determined by measuring the diameter of 10 fibers from each membrane from the SEM image. The bar in the figure shows the measurement distribution, while the line is an estimate of the distribution function based on the Gaussian distribution approximation. (Bahar yavuzturk., et.al. 2024). The mechanism of material degradation may be monitored by changes in sample's mass, its molecular weight, detection, and quantification, also can be monitored by the CO_2 that have been adsorpbed in the nanofiber membrane. The factor that can be directly attribute to the limitation of polymer thermal stability is the strength of the weakest bond in the polymer chain. Thermal degradation can be seperated into three main category such as : group elimination, random scission, and depolymerization (Krzystof Pielichowski, 2022). Polyacrylonitrile (PAN) considered to be in the type of side group elimination, where the heating used is around the temperature of 250°C – 260°C. The nitrile group chain of (-C-N) undergo cyclization, forming a lidder like structures, this usually involves. This leaves an unstable nitrile molecule that undergoes further reaction. When the PAN polymer specimen is heated in the temperature ranging from 250°C – 260°C, oftenly exothermic reaction occurred under this circumstances, where the PAN polymer release heat energy in the process (Krzystof Pielichowski, 2022).



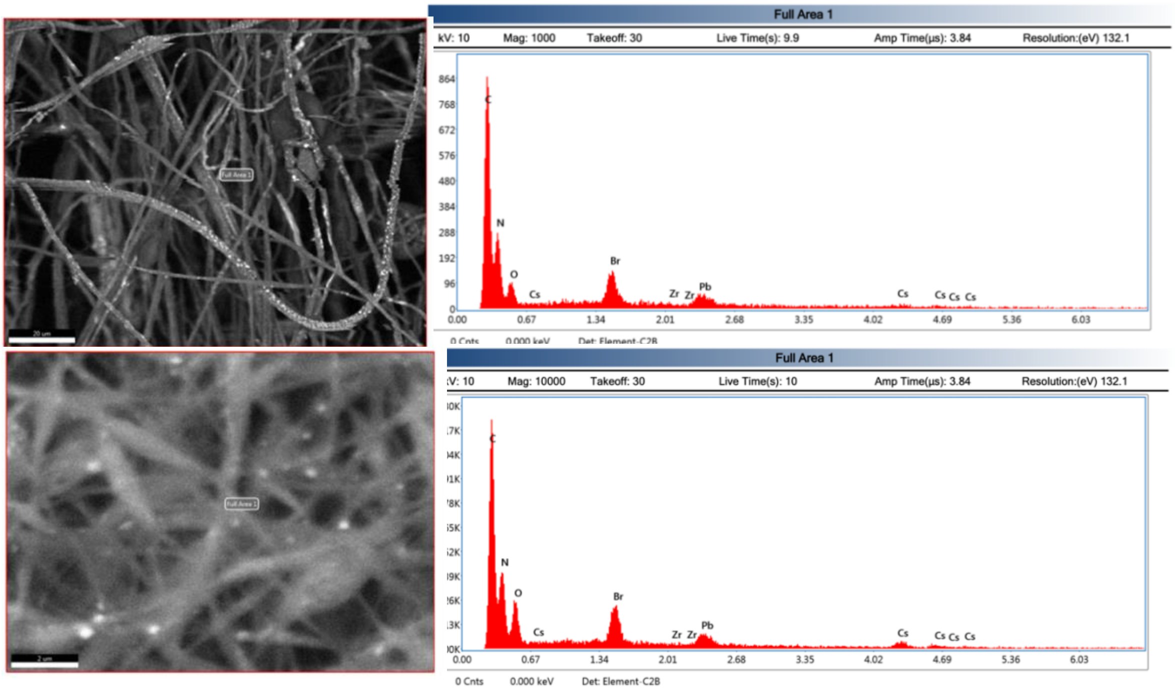


Figure 4.9 EDX of PAN/$CsPbBr_3$ Nanofiber Membrane.

In nanofiber specimen the common aspect that are thoroughly studied is the fiber diameter and the morphology of the specimen it self. However a common occurrence such as fouling is a thing to be further considered, the deposition of beads that accumulates in some areas across the nanofiber, it can be found on the surface or within the pores of the nanofiber material, thus it can degrades the nanofiber performance over time.

Table 4.4 SEM-EDX Element Smart Quant Results of PAN Only Nanofiber

Element	Weight %	Atomic %
CK	38.52	60.13
NK	20.53	27.48
OK	3.03	3.55
BrL	37.43	8.78
ZrL	0.03	0.01
PbM	0.27	0.02
CsL	0.19	0.03

The **Table 4.4** results is a elaboration of each elements weight% and atomic%, where this is quite important because it can confirms the exact elemental composition, elemental distribution, and distinguishes the PAN and ceramic addition effects.

Table 4.5 SEM-EDX Element Smart Quant Results of PAN/$CsPbBr_3$ Nanofiber

Element	**Weight%**	**Atomic%**
CK	29.27	61.82
NK	13.42	24.31
OK	1.72	2.72
CsM	1.48	0.28
BrL	21.50	6.83
ZrL	0.27	0.07
PbM	32.33	3.96

The following table above shows the elemental weight composition that conifrms their presence and distribution. The filler addition of of $CsPbBr_3$ perovskite to the PAN polymer nanofiber membrane could also be further compare through their distribution in the nanofiber.

4.3 Tensile Testing

Conducted at Material Innovation Laboratory, This procedure aims to test the material mechanical properties, where a highly mullite nanofibers membrane with enhanced strength are to be expected from this research. A result of stress strain curve that indicates elsatic and the limitation of fracture behavior of nanofiber are then further observed. This testing procedure gives insight into failure possibilities such as brittle fracture, which is common to occur in ceramic materials. In case of our nanofiber materials tensile testing the procedure needs to be conducted in two phase, split between before and after heat treatment. After the process of tensile test procedure are finished we found out that on specimen of PAN composition that the yield strength is around 0.06 N/mm^2 and the tensile strength of 0.11 N/mm^2 before the fracture point, with young modulus of 4.98. From this statistics it can be said that the scatter of the mechanical properties of the nanofibers was rather significant, where the evidence of a high Young's modulus value is presented.

Electrospun based nanofibers are typically display tensile strength that are relatively low compare to other textile fibers made from the same polymers. Electrospun nanofibers typically display tensile strengths below 300 Mpa and a young modulus below 3 Gpa, which can be mainly ascribe to the low degree of orientation and chain extension of the polymer chains along the fiber axis. However in some cases added materials that can make the stiffness of the material increased are used (Jian Yao et.al., 2020). However in our research of PAN/$CsPbBr_3$ nanofiber materials the adition of $CsPbBr_3$ perovskite might affect the structural integrity of the nanofiber tensile strength is self. In the composition variation of (1:2) lower perovskite content and (2:3) higher perovskite content, the (2:3) variants shows a higher yield strength compare to the one with lower perovskite content. In the variant of (1:2) the yield strength doesn't even shows up on the final test report, this outcome means that the tensile test are failed. Therefore it can be sums up that the nanofiber material unable to withstand the shear force of stress that are applied. The tendencies of such material can be considered as brittle where it shows almost no deformation to no deformation at all before the fracture point. This can be explained as the combination of the macromolecular size and submicron diameter of the fibers defined the ultimate ductility of the fibers defined the ultimate ductility of the fibers as well as the effects of reinforcement component and the other way around. In the brittle tendencies nanofiber the young modulus usually possesed a very small Young's modulus value and the nanofiber with ductile tendencies usually have a higher Young's modulus value. Need to mentioned that the procedure of tensile test that we conducted are random nanofiber membranes (un-uniformed). Therefore, the tensile properties of random properties nanofiber membranes, which are easily obtained from macroscopic tensile test of the membrane, can be used as an indicator of the mechanical properties of individual nanofiber (Yunlei Yin, 2017).

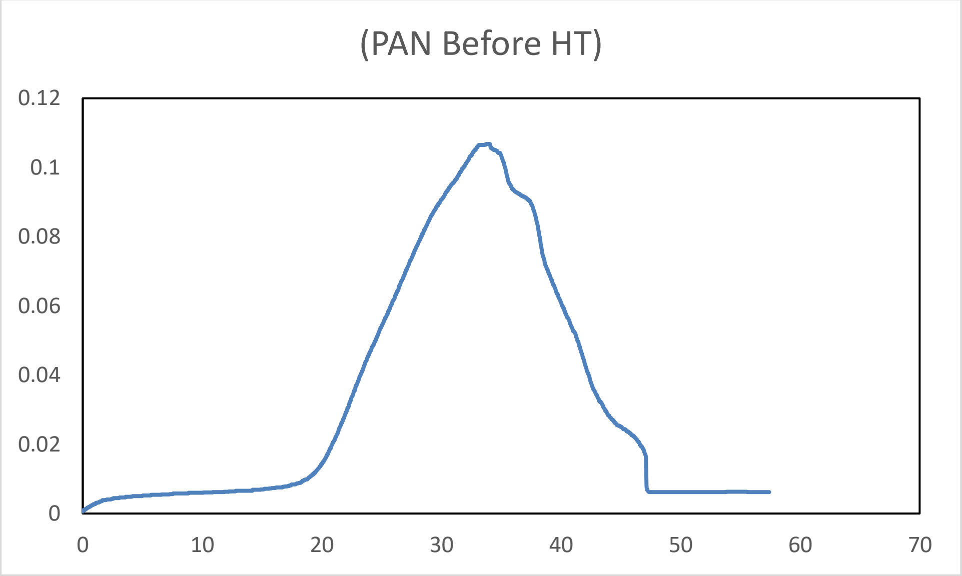


Figure 4.10 Tensile Test graph of PAN membrane Before Heat Treatment.

The following graph of PAN nanofiber membrane before the heat treatment, the elongation is recorded at 26.18 %. This would be expected as in the before heat treatment PAN and PAN/$CsPbBr_3$ nanofiber membrane would be more ductile therefore it is correlated directly to the elongation that are longer compare to the one after heat treatment.

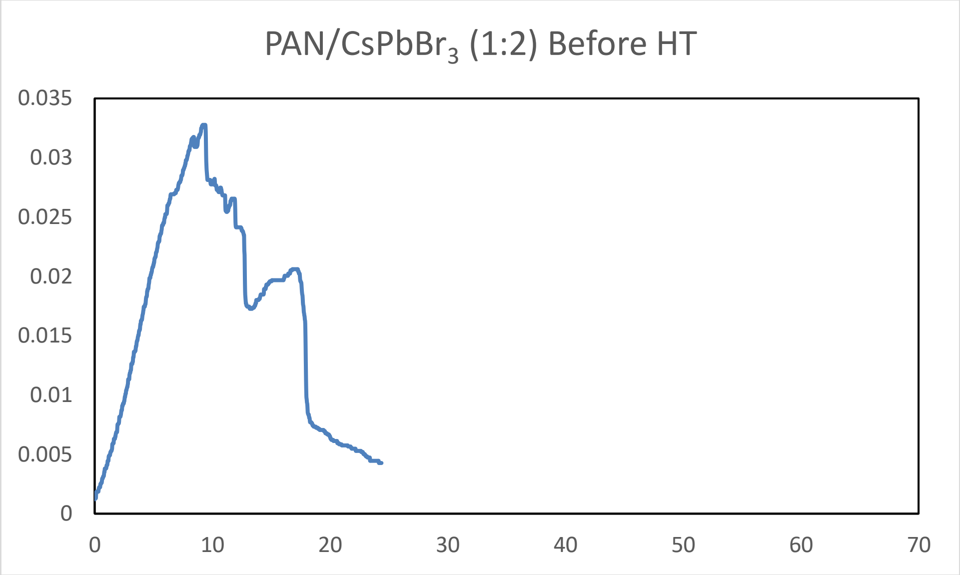


Figure 4.11 Tensile Test graph of PAN/CsPbBr$_3$ membrane Before Heat Treatment.

By directly comparing the PAN only to the PAN/CsPbBr$_3$ composite, we can elaborate that the overall tensile test shows, a more ductile nanofiber as shown based on the elongation of this (1:2) composite variants. Therefore the composite variants also shows less resistance when they are being pulled in both end of the nanofiber sides with Young's modulus of only 0.46. The yield strength is also lower in the composite matrial only showing 0.03.

Thermal analysis is one of the important aspects to be focused on when conducting a research with the focused on mechancial of materials. The PAN/CsPbBr$_3$ nanofiber membrane was heat treated at temperature of 200°C - 260°C for 30 minutes and then the morphology and mechanical properties of nanofiber membrane was examined. The PAN/CsPbBr$_3$ nanofiber membrane when terated with such temperature shows a different fracture point and yield point. The following are the PAN nanofiber membrane that are analyzed after the heat treatment is conducted.

Table 4.4 PAN/CsPbBr$_3$ Nanofiber Tensile Test (Before Heat Treatment).

Specimens	**Area mm^2**	**Max Force N**	**Yield Strength N/mm^2**	**Tensile Strength**	**Young's Modulus € N/mm^2**	**Elongation %**
PAN	8.908	0.9	0.09	0.10	2.01	26.18
1:2	16.643	0.5	0.03	0.03	0.46	24.37
2:3	17.038	0.3	0.01	0.02	0.06	158.69
1:1	15.973	1.7	0.01	0.11	0.80	57.42

After the process of tensile test before heat treatment, the next important step that needs to be done is heat treatment. As the purpose of this research that also focused on testing wether the effect of a diffierent composite materials, could results in a different mechanical tensile characteristic including after the heat treatment.

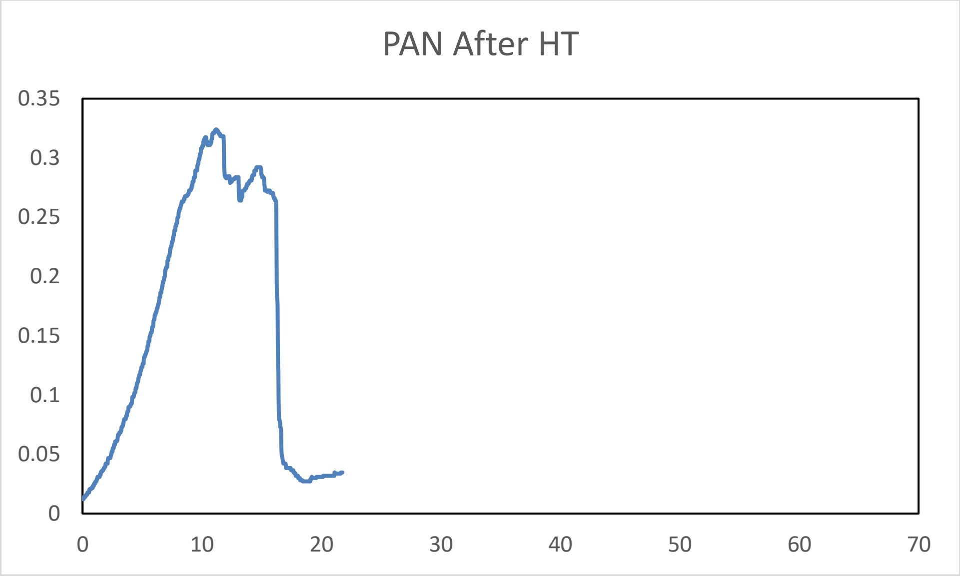


Figure 4.12 Tensile Test graph of PAN membrane After Heat Treatment.

From the graph on **Figure 4.12** We can see that the it has quite a short elongatuion, where it only able to reach up until 21.77 % elongation point. The test reported that the PAN specimen already reach the yield strength of 0.26 and the resistance of Young's Modulus of 3.82. Compare to the nanofiber membrane that has already been added with $CsPbBr_3$ the PAN only nanofiber membrane has a relatively low elongation point. In the other hand the PAN/$CsPbBr_3$ nanofiber membrane has a significantly different results in term of tensile testing, for example the (1:2) composition variants the elongations could reach 66.33 % and the Young's modulus of 0.41 and yield in the point of 0.01. Hence we can further elaborate that the adddition of $CsPbBr_3$ may affect the overall mechanical strength of the nanofiber, as we can see on the following information of PAN/$CsPbBr_3$ nanofiber membrane.

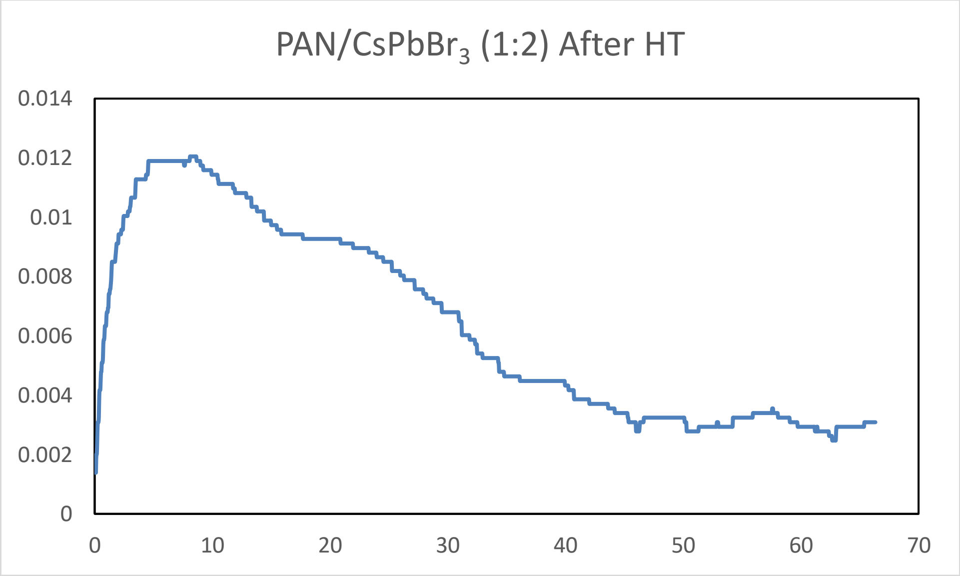


Figure 4.13 Tensile Test graph of PAN/$CsPbBr_3$ membrane After Heat Treatment.

From this data the composite materials have more endurance in term of the tensile mechanical test, the graph shown in the **Figure 4.13** is visually longer. This could indicates that the Pan only nanofiber membrane is stiffer compare to the one with added $CsPbBr_3$, furthermore the composite nanofiber membrane is more ductile compare to the PAN only variants, hence it can be interpret that PAN is more brittle and requires more stress to begin plastic deformation.

Table 4.5 PAN/$CsPbBr_3$ Nanofiber Tensile Test (After Heat Treatment).

Specimens	Area mm^2	Max Force N	Yield Strength N/mm^2	Tensile Strength	Young's Modulus € N/mm^2	Elongation %
PAN	1.650	0.5	0.26	0.32	3.82	21.77
1:2	10.000	0.1	0.01	0.01	0.41	66.33
2:3	10.000	0.2	0.00	0.02	0.09	99.47
1:1	-	-	-	-	-	-

Based on the after heat treatment data of tensile strength, it can be seen from the Young's Modulus that the material resistance is not as high as the one before heat treatment. This due to the nanofiber membrane material gets more brittle after the heat treatment is applied, hence the resistance when tension is applied are declining. However in such specimen like PAN only nanofiber the tensile strength seems to be higher after heat treatment, this could be elaborate thet the crystallization occurred after the heating are evenly achieved in the nanofiber surface.

4.4 Brunauer Emmet Teller (BET)

BET procedure are conducted to analyze the pores presented on the surface area and the adsorption capability of the PAN/$CsPbBr_3$ nanofiber membrane, witth the type of equipment being used is the BET NOVA. In our testing procedure of BET is conducted by using nanofiber material by comparing the quantity of PAN composition and $CsPBBr_3$ perovskite composition. The utilization of PAN variable as controlled variable are also tested by BET. The utilization of BET itself can be depended on the data that we wanted, wether we only need a conventional BET Specific Surface Area (SSA) or the BET Autosrption iQ, where they can automatically detected the physisorption and chemisorption characteristic of the specimen. The following would be the result from BET NOVA testing of PAN and PAN/$CsPbBr_3$ nanofiber membrane.

Table 4.6 BET Test Results of PAN/$CsPbBr_3$.

Sample	**Surface Area**	**Pore Size** (nm)
PAN	12.294 m^2/g	30.39
PAN/$CsPbBr_3$ (1:2)	11.335 m^2/g	2.609
PAN/$CsPbBr_3$ (2:3)	9.228 m^2/g	81.93
PAN/$CsPbBr_3$ (1:1)	4.993 m^2/g	43.56

From the **Table 4.6** We can see a variants of of different surface area measurements of PAN/$CsPbBr_3$ nanofiber membrane. Based from the provided data of PAN, it can be observed that the surface area is the biggest of them all, where the 12.294 m^2/g could provide a bigger surface area of CO^2 adsorption. Hence why in the adsorption capacity data PAN relatively has a bigger adsorption volume. PAN pore size are considerd to be mesopores, as it shown a pore size at around 30nm (under 50nm). Therefore the surface contact and molecular diffusion may results in a relatively good gas adsorption. The PAN/$CsPbBr_3$ variants of (1:2) and (2:3) shows some of the biggest surface area compare to other PAN/$CsPbBr_3$ variants, this is a sign that the more content of PAN are directly proportional to the adsorption ability. This idea are also applied to the $CsPbBr_3$ filler, where if the amount of this composite materials the pore size in nm will also get larger, hence the adsorption ability would also be affected directly.

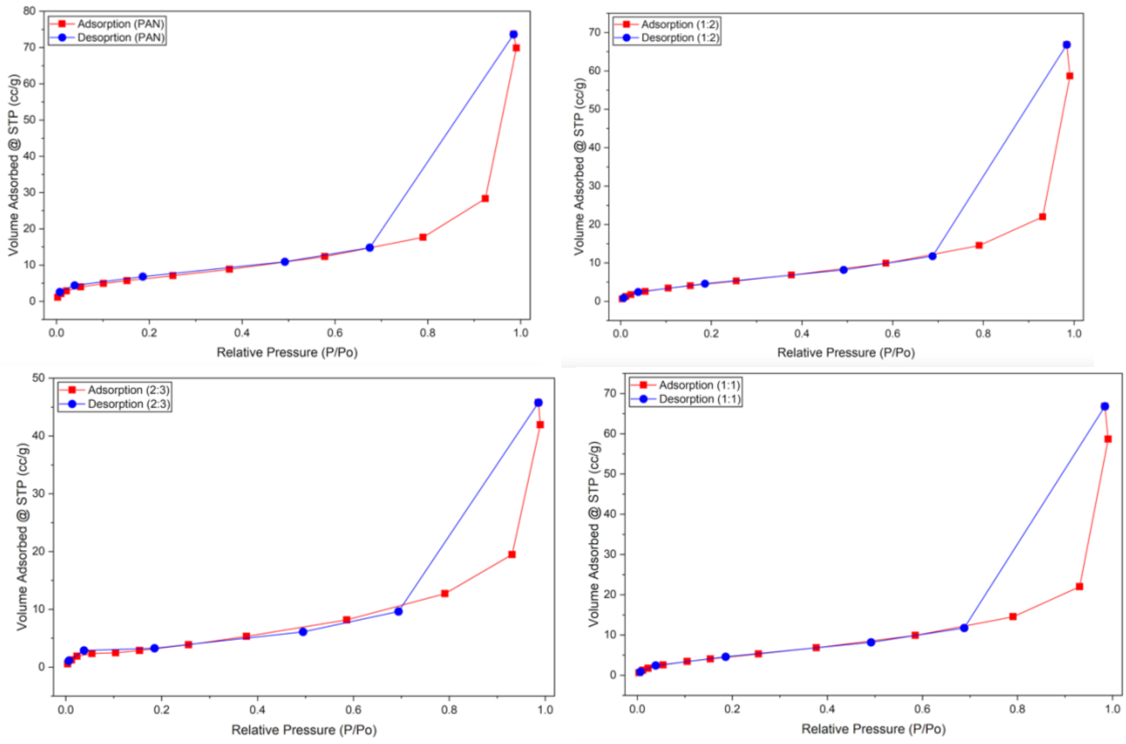


Figure 4.14 BET graph of PAN and PAN/$CsPbBr_3$ Nanofiber Membrane.

On the **Figure 4.14** of BET shoes the adsorption and desorption of isothermal from PAN/$CsPbBr_3$ nanofiber membrane. Based on the IUPAC standard the PAN polymer and $CsPbBr_3$ sample shown in the **Figure 4.14** It shown a type II graph. Therefore in the BET analysis by referring to the IUPAC standard, is mainly due to its simplicity and the approval needed for the IUPAC (Nader, 2015). In order to determine the adsorption and desorption of PAN/$CsPbBr_3$ a minimum of at least three data point between the adsorption and desorption it self, where in the data plot through Origin software it can eventually create a proper interconnected graph.

4.5 CO_2 Adsorption

4.5.1 CO_2 Adsorption Before Heat Treatment

The adsorption testing anlysis would be conducted in the atmospheric temperature and in the CO_2 pressure of ± 2.5 bar. The adsorption testing would be conducted in all 4 of the specimen variants. Including the PAN only nanodiber membrane, this would be useful to understand wether the addition of $CsPbBr_3$ ceramic materials could actually help the adsorption capability. The time period of adsorption testing procedure will be set in 200 minutes time stamp in all variant of compositions, the time stamp would be decide based on the PAN variable that have allready reach equilibrium at around 170 minutes. The following would be the adsorption capacity of each specimen sample before the heat treatment is conducted. Kinetic models are then utilized to determine gas transport mechanism and adsorption types of CO_2 into PAN/$CsPbBr_3$ nanofiber membrane (Triyanda et.al., 2018).

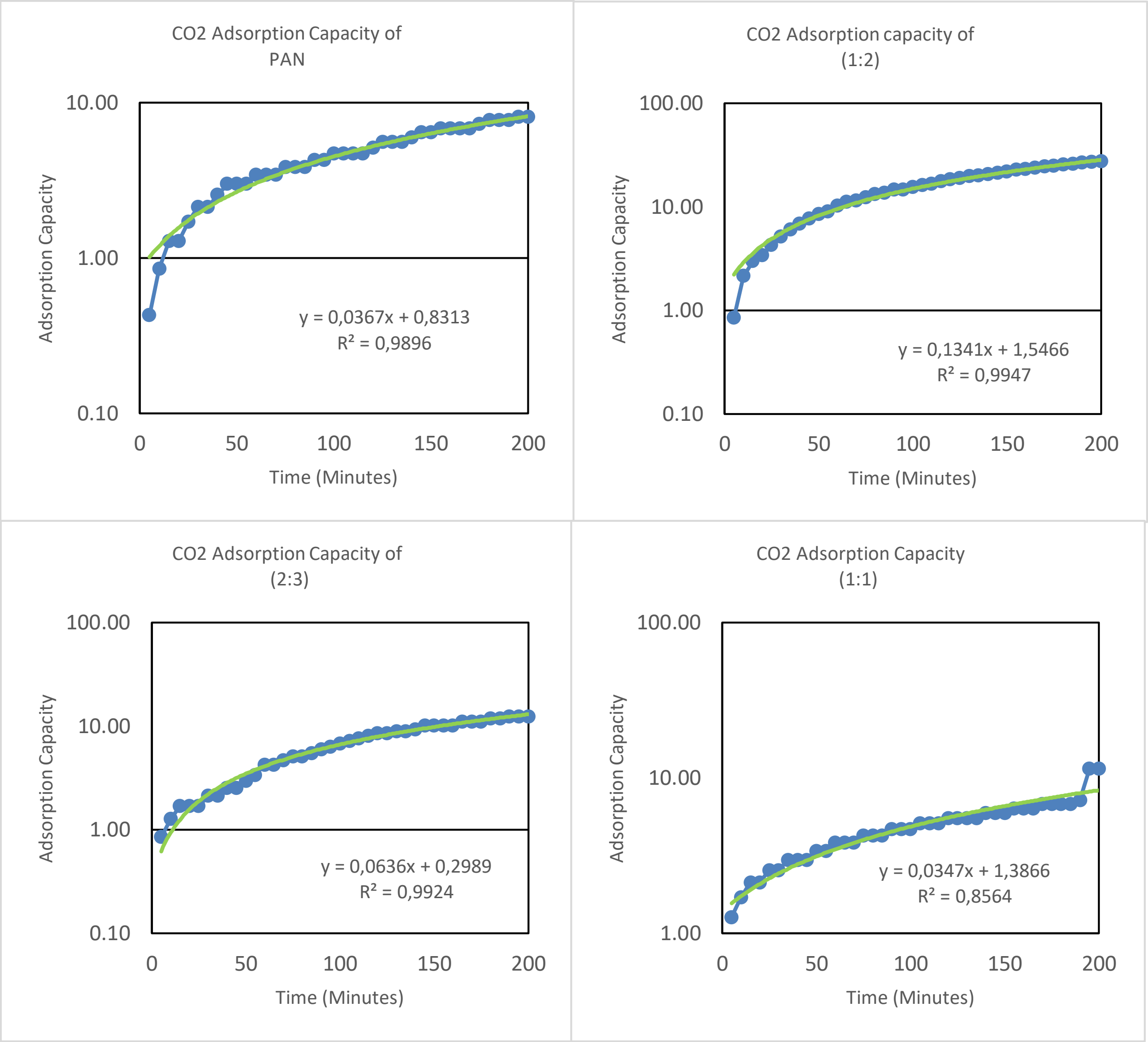


Figure 4.15 Adsorption Capacity of PAN/$CsPbBr_3$ Nanofiber Membrane

This figure of **4.** Shows the adsorption capacity of PAN/$CsPbBr_3$ nanofiber membrane, where ach of the specimen would show a different capacity of adsorption ability. Based on the R^2 value, we can see how good the adsorption ability of a nanofiber membrane specimen (e.g the adsorption ability of specimen that were added with $CsPbBr_3$ shows an improvement in the ability of adsorption, showed by the R^2, therefore the adsorption capacity would be better in those specific specimen). Then it would be continue to be analyzed based on two models, pseudo first order and pseudo second order models are used to study the adsorption kinetics of CO_2. All 4 of the nanofiber composition will be anlyzed through this model, by referring to the R^2 that will be displayed in the **Figure 4.** (linear regression coefficient) (Ding S et.al., 2020). From those two of kinetic adsorption study model, we can see wether the nanofiber membrane would be either physisorption or chemisorption. If the nanofiber membrane is rather have a higher R^2 value in the PFO, it means that the adsorption will be physisorption. In the other hand if the nanofiber membrane specimen rather have a higher R^2 in the pseudo second order, then the adsorption mechanism will happen by chemisorption. In order to create the graph of pseudo first order as follows on the figure **4.** In order to create the following figure of pseudo first order, pseudo seocnd order, and intraparticle diffusion table, it will required the calculation by using the formula that includes q_t (mmol g^{-1}) which is the amount of adsorbate adsorbed at the time of t (minute), q_e (mmol g^{-1}) is the adsorption capacity at equilibrium.

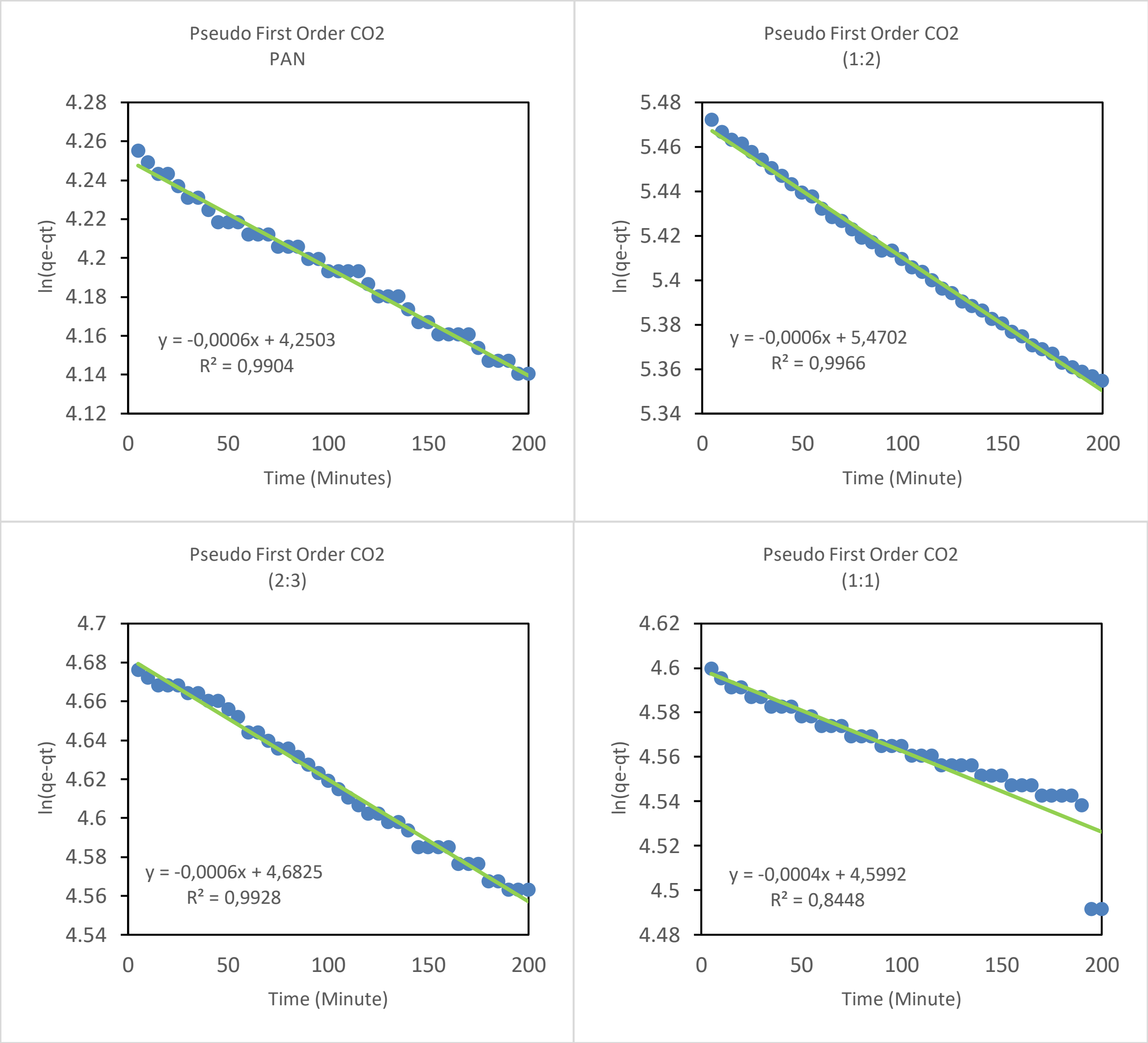


Figure 4.16 Pseudo First Order of PAN/$CsPbBr_3$ Nanofiber Membrane.

The pseudo first order, will be better fits the experimental data, which demonstrate that the external mass transfer plays a dominant role in CO_2 adsorption. The mechanism of pseudo first order models are used to study the adsorption kinetics of CO_2 over the PAN/$CsPbBr_3$ nanofiber materials. From the adsorption graph in **Figure 4.** It can be observed that specimen (1:2) have the highest R^2 value, which means this specific nanofiber membrane have the best physisorption ability compare to the opther three nanofiber membrane. By having a different PAN/$CsPbBr_3$ nanofiber membrane composition to compare we can better stated wether the amount of added perovskite could actually help the adsorption process. Therefore we can immadiately saw that the composition with more than 1 perovskite have a better adsorption by referring to their R^2 value. Next in the adsorption anlysis there's also the method of pseudo second order method of study, where in this adsorption mechanism the type of adsorption that will occur will be chemisorption. The equation to create the following graph of pseudo second order like presented in the **Figure 4.** Will be as follows, the initial conditions of $q_t = 0$ at $t = 0$ and $q_t = q_t$, at $t = t$.

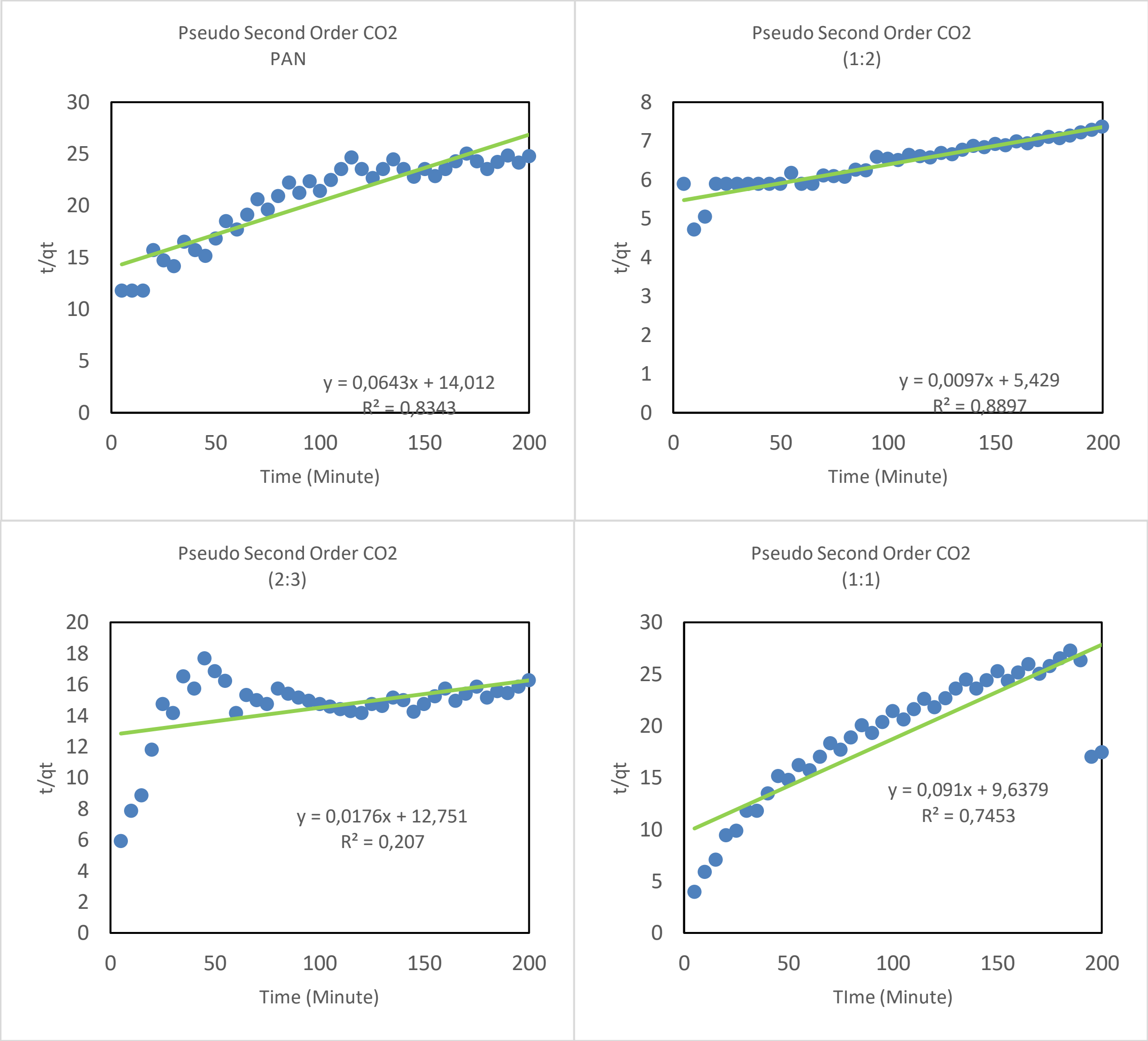
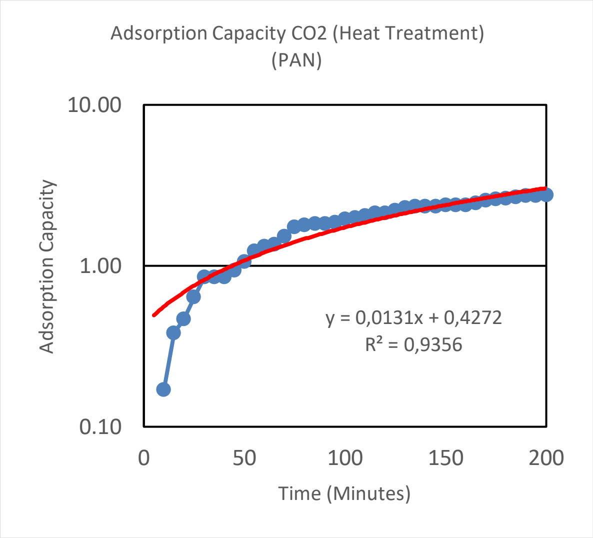


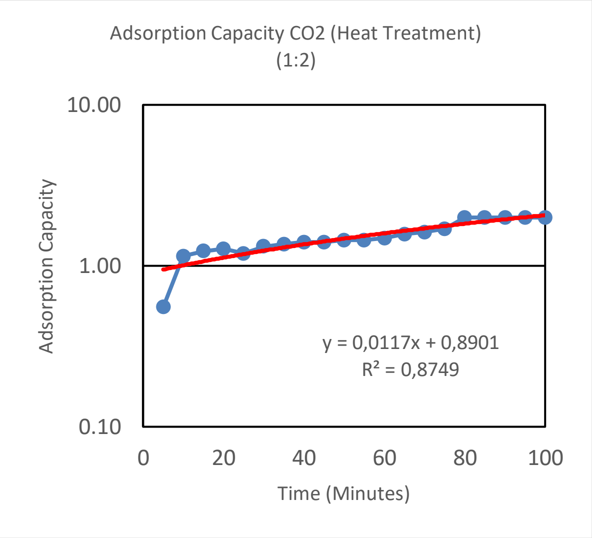
Figure 4.17 Pseudo Second Order of PAN/$CsPbBr_3$ Nanofiber Membrane.

The pseudo second order will elaborate further on how the adsorption happen by diffusion (chemisorption). The chemisorption will happen not just by physiscal contact on the membrane surface area, but with it also includes electron sharing or transfer, which is a chemical bonding will occur between adsorbent and CO_2.

4.5.2 CO_2 Adsorption After Heat Treatment

The adsorption are conducted to see how well the nanofiber membrane could adsorp the CO_2. The testing that will be conducted with our specimen will be done in atmsopheric temperature and the pressure of CO_2 as much as 2,5 bar. However the testing ar necessary to be set at relatively the same temperatrue, (e.g in the sample of all PAN/$CsPbBr_3$ the sample will be set in the 100 minutes time period, while for the PAN variants the sample will be set up until the 200 minutes time period). The difference in time period between the PAN only and PAN/$CsPbBr_3$ composition are correlated with the stabilization of the CO_2 adsorption, in the PAN variants the specimen are stabled in term of CO_2 adsorption in the ± 135 minutes, therefore the time for PAN are set up until 200 minutes. Both two models of pseudo first and pseudo second order models are used in this research to study the adsorption kinetics of CO_2 over PAN/$CsPbBr_3$ in the temperature of 250° – 260°. Additionally the accuracy of predicting the adsorption capacity by kinetic models is further evaluated based on R^2 (linear regression coefficient) (Ding S et.al., 2020).





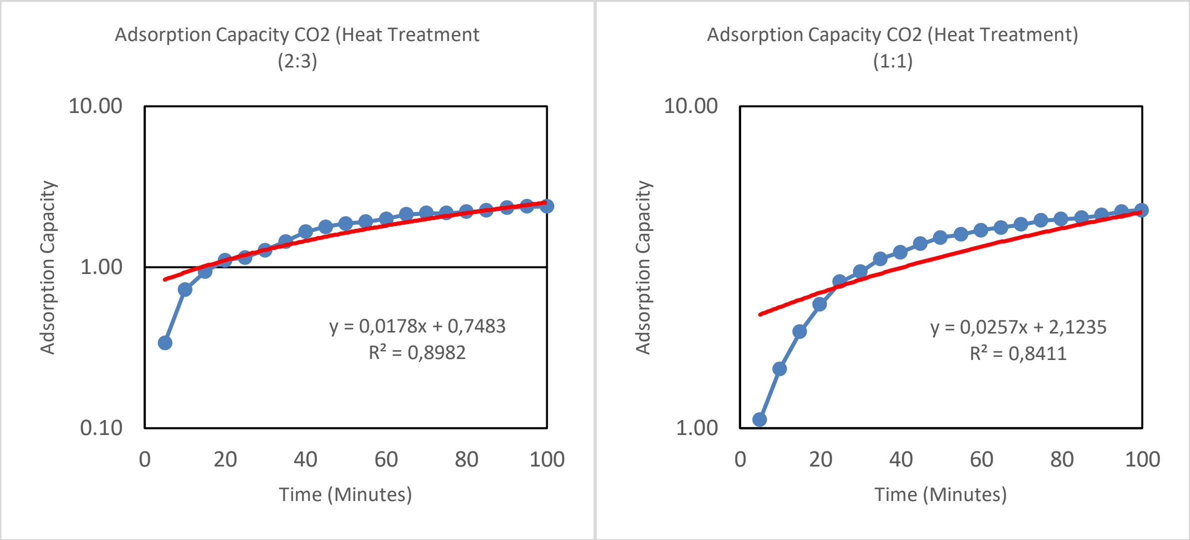
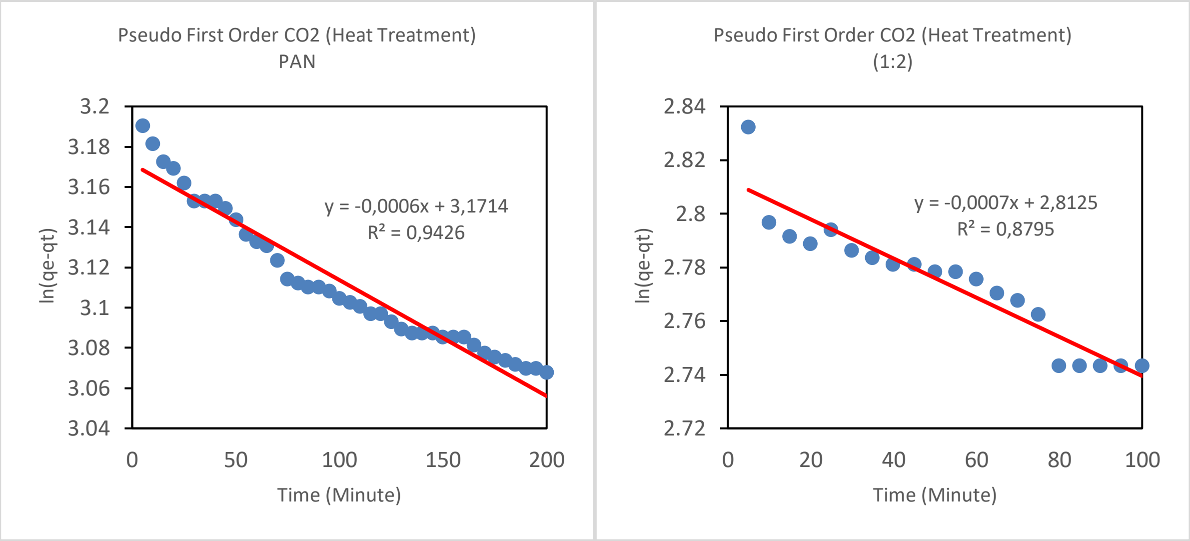


Figure 4.18 Adsorption Capacity Graph of PAN/$CsPbBr_3$ Nanofiber

These graph of PAN nanofibers exhibit a time-dependent and the stability of the nanofiber itself. The adsortion that occurred on the graph above are kinetics adsorption, where gas are really important to explain the adsorption mechanism. To be more specifics adsorption kinetics that occurred on this context is the adsorption kinetics of gases at solid surface, such as the PAN/$CsPbBr_3$ nanofiber. Therefore this method requires the utilization of pseudo first order, pseudo second order and intra particle diffusion (Yanxin Gao, 2018). It can be seen that the PAN specimen have the highest adsorption capacity after heat treatment, this can be elaborate by the crystallinity that increase after the stabilization (Heat Treatment) are succesfully conducted, because the heat treatment that are conducted to nanofiber membrane habe the aims to increase the adsorption capability.



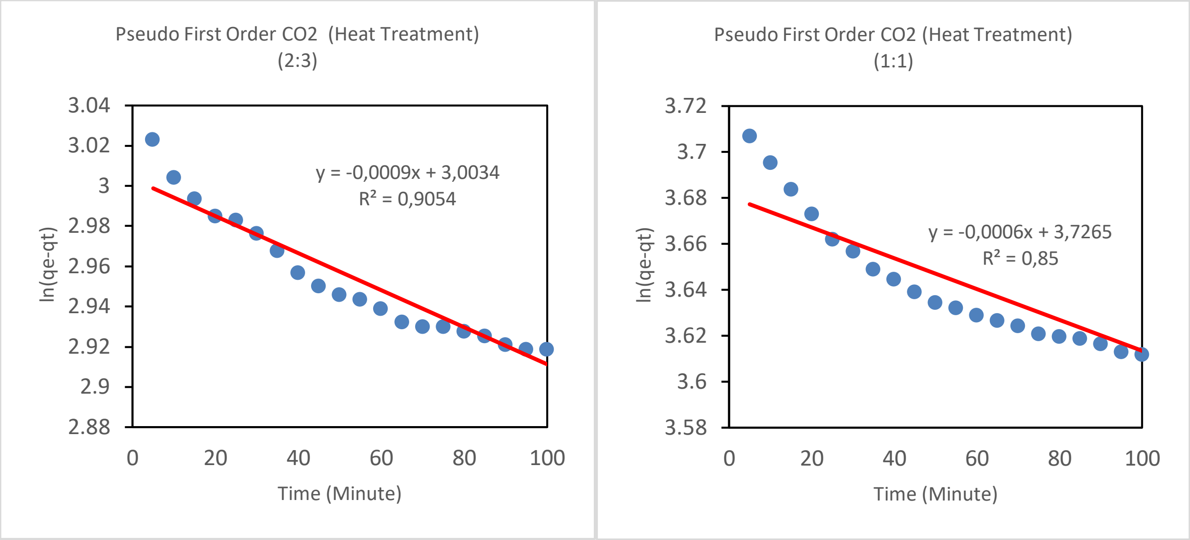
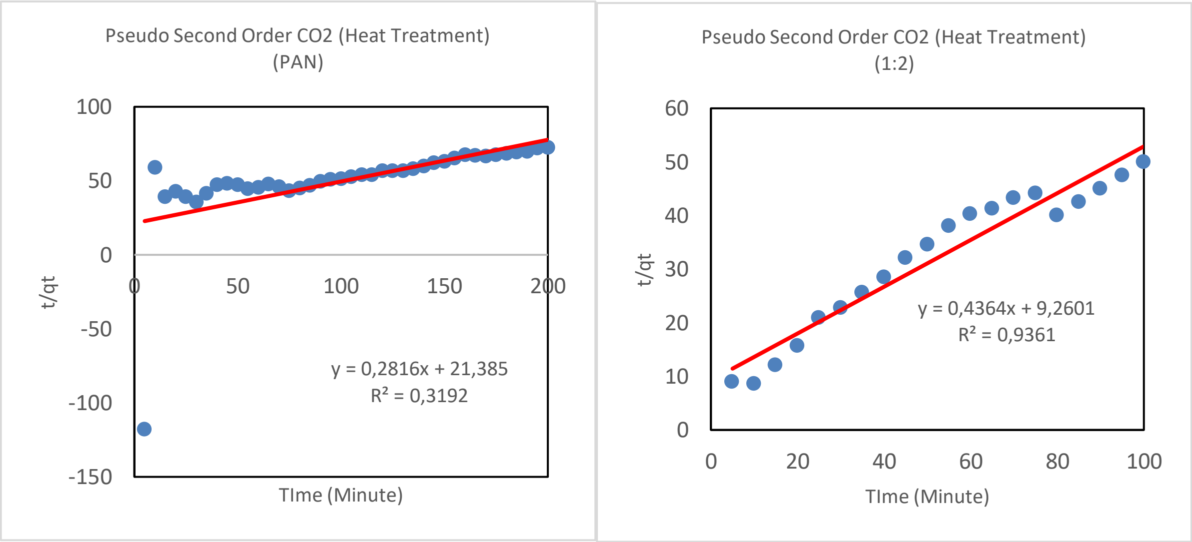


Figure 4.19 Pseudo First Order Graph of PAN/$CsPbBr_3$

The assumption of pseudo first order model utilization in this research, is that the time dependant way of testing is the gas contain in the chamber must present a decreased in numbers. The process of adsorption on PAN (Controlled Variable) specimen were going at slow pace until it reach the adsorption equilibrium. The reported equilibrium time from PAN specimen were around 135 minutes, the rather moderated adsorption equilibrium could be attributed to the pores characteristics of PAN, where as polimer nanofiber that has a rather large pores, the CO2 takes longer time to get adsorbed compare to the smaller pores nanofiber. Based on the actual data that are presented in the graph above, the heat treatment usually will make either capacity of CO2 adsorption change or the change from physisorption into chemisorption. In the data of adsorption before the heat treatment, the bias were tend to be on the physisorption as it shows a better value of R^2 in the pseudo first order.



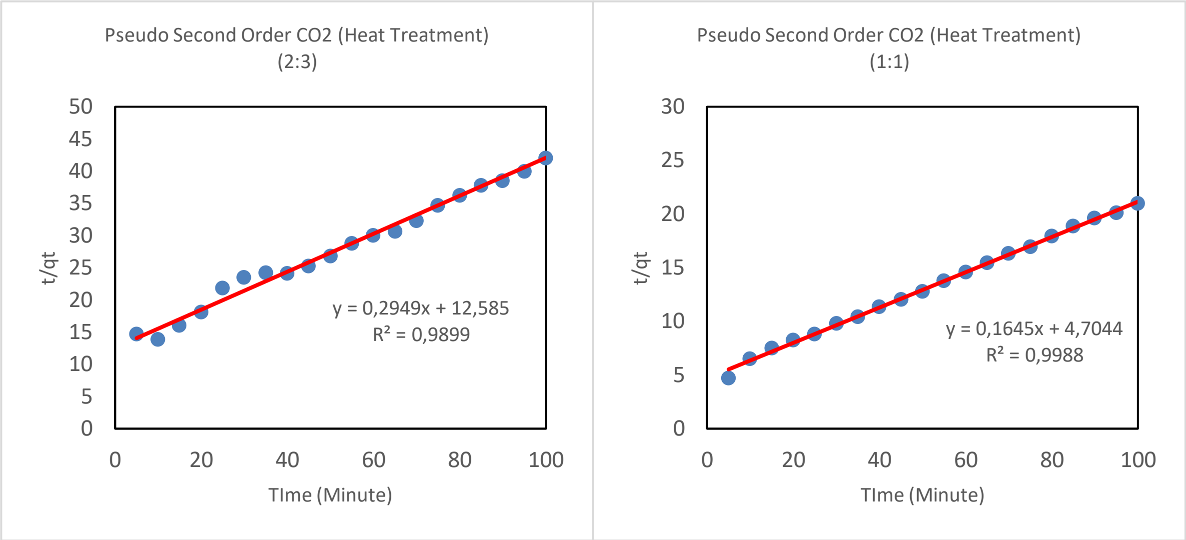


Figure 4.20 Pseudo Second Order Graph of PAN/$CsPbBr_3$

The values of R-square that are present on the pseudo second order can indicates the adsorption mechanism depends on two factors, the transport process of the adsorbates as well as the physiscal and chemical properties of the adsorbents (Yanxin Gao, 2018). The pseudo second order use the Langmuir Kinetics Theorem, in order to observed the amount of adsorbate adsorbed at any given time, *t* and at equilibrium respectively, *qmax* is the maximum adsorption capacity of the adsorbent. The estimated parameters of slope and intercept that are presented on the graph legends, are achieved by plotting ln $[q_e - q(t)]$ and $\frac{t}{q(t)}$ for PFO (pseudo first order) and (pseudo second order) as dictated by equations (Emmanuel D, (2020). The pseudo second order data that appear on the graph in **Figure 4.** shows the best chemisorption are achieved by the (1:1) PAN/$CsPbBr_3$, where the R^2 value are 0,9988 (near 1). The explanation of why after heat treatment some of the specimen can transform from physisorption into chemisorption is that after the heat treatment process, PAN undergo cyclyzation therefore it increase surface polarity, opens the active sites and heat treatment can also remove the extra solvents contained in the nanofiber membrane. Hence the diffusion with the added material of $CsPbBr_3$ are increase, which eventually allowing chemical binding of CO_2.

4.5.3 Tabulation of CO_2 Adsorption

On the following table we can better interpret the prese ted data of CO_2 adsorption. We can discuss wether the addition material of PAN/$CsPbBr_3$ (perovskite) could increase the ability of CO_2 adsorption.

Table 4.7 Pseudo first Order of PAN/$CsPbBr_3$ Nanofiber Before Heat Treatment.

Sample (Wt %)	**Kr**	**Qe (mg/g)**	R^2	**Sample Code**
PAN	-0.0006	4.2503	0.9904	D-PAN

PAN/CsPbBr3 **(1 : 2)**	-0.0006	5.4702	0.9966	D-1 (1:2)
PAN/CsPbBr3 **(2 : 3)**	-0.0006	4.6825	0.9928	D-2 (2:3)
PAN/CsPbBr3 **(1 : 1)**	-0.0004	4.5992	0.8448	D-3 (1:1)

From the following table all of the value of Kr, Qe, and R^2 can be each found from extracting it based on the adsorption stability and time frame aspects that are presented on **Figure 4.** From observing the R2 on the Pseudo first order, it can be conclude that the nanofiber membrane with R^2 value of (0.9966) have the best adsorption ability because of a near 1 R^2 value.

Table 4.8 Pseudo Second Order of PAN/$CsPbBr_3$ Nanofiber Before Heat Treatment.

Sample (Wt %)	**Kr**	**Qe (mg/g)**	R^2	**Sample Code**
PAN	0.0643	14.012	0.8343	D-PAN
PAN/CsPbBr3 **(1 : 2)**	0.0097	5.429	0.8897	D-1 (1:2)
PAN/CsPbBr3 **(2 : 3)**	0.0176	12.751	0.207	D-2 (2:3)
PAN/CsPbBr3 **(1 : 1)**	0.091	9.6379	0.7453	D-3 (1:1)

The interpretation regarding pseudo second order model assumes that almost all of the speciemen in before heat treatment, are tend to be pseudo second order, based from the R^2 value. Which is in overall observation PAN and PAN/$CsPbBr_3$ nanofiber membrane have the mechanism of physisorption before the heat treatment is conducted, and by comparing the PAN only and PAN/$CsPbBr_3$ nanofiber membrane we can see the difference of tha adition perovskite in most samples could actually help the CO_2 adsorption process quite significantly. However after the heat treatment is process are applied to all 4 of the nanofiber memebraane, the final results could be different in term of how efficient the adsorption process can occur. Therefore the following table would give such informations.

Table 4.9 Pseudo first Order of PAN/$CsPbBr_3$ Nanofiber After Heat Treatment.

Sample (Wt %)	**Kr**	**Qe (mg/g)**	R^2	**Sample Code**
PAN	-0.0006	3.1714	0.9426	D-PAN After Heat Treat
PAN/$CsPbBr_3$ (1 : 2)	-0.0007	2.8125	0.8795	D-1 (1:2) After Heat Treat
PAN/$CsPbBr_3$ (2 : 3)	-0.0009	3.0034	0.9054	D-2 (2:3) After Heat Treat
PAN/$CsPbBr_3$ (1 : 1)	-0.0006	3.7265	0.8500	D-3 (1:1) After Heat Treat

On the table of pseudo first order after heat treatment above, we can see that the value of R^2 are greatly reduces. Compare to the pseudo first order in the stage before heat treatment. This could occur because of in the stage before heat treatment the surface of PAN fibers are mostly left undamage (smooth), therefore the CO_2 before heat treatment are only loosely attached to the nanofiber membrane surface therefore the adsorption tend to be physisorption.

Table4.10 Pseudo Second Order of PAN/$CsPbBr_3$ Nanofiber After Heat Treatment.

Sample (Wt %)	**Kr**	**Qe (mg/g)**	R^2	**Sample Code**
PAN	0.2816	21.385	0.3192	D-PAN After Heat Treat
PAN/$CsPbBr_3$ (1 : 2)	0.4364	9.2601	0.9361	D-1 (1:2) After Heat Treat
PAN/$CsPbBr_3$ (2 : 3)	0.2949	12.585	0.9899	D-2 (2:3) After Heat Treat
PAN/$CsPbBr_3$ (1 : 1)	0.1645	4.7044	0.9988	D-3 (1:1) After Heat Treat

While in the stage of pseudo second order, the R^2 value are relatively higher compare to the one before heat treatment. This could be further elaborate by the purpose of heat treatmnet it self, which is to increase the crystalization and thus the CO_2 particle could be better adsorp through the pore of nanofiber membrane. Therefore chemisorption is the mechanism that is more dominant after heat treatment.

Table 4.11 PAN/CsPbBr3 Intraparticle Diffusion Data Set Before Heat Treatment.

Sample (Wt %)	**Kr**	**Qe (mg/g)**	R^2	**Sample Code**
PAN	0.0650	1.6445	0.9747	D-PAN
PAN/CsPbBr3 (1 : 2)	2.3827	7.5614	0.9855	D-1 (1:2)
PAN/CsPbBr3 (2 : 3)	1.1153	3.8843	0.9592	D-2 (2:3)
PAN/CsPbBr3 (1 : 1)	0.6031	0.8389	0.8109	D-3 (1:1)

Amorphous polymeric materials are good candidates for gas adsorption such as CO_2, due to their functional diversity, however most microporous polymers are amorphous with a poorly structural integrity and porosity., which may create a challenge for their design and characterization. Amorphous miroporous polymers are highly disordered polymers with a relatively high surface area and interconnected porosity. In the amorphous region of PAN from the morphology testing of FTIR, it can observed that nitrile groups of C-N offers a polar sites. These less ordered chains are more flexible, hence they are able to exposed individual nitrile that can act as the coordination sites for CO_2. In the FTIR test are allrady mentioned previously where the C-O bonds are relatively weak, therefore a physiscal adsorption are tend to happen before the heat treatment are conducted (Shukai Y et.al., 2023).

Table 4.12 PAN/CsPbBr3 Intraparticle Diffusion Data Set After Heat Treatment.

Sample (Wt %)	**Kr**	**Qe (mg/g)**	R^2	**Sample Code**
PAN	0.2394	0.5318	0.9886	D-PAN After Heat Treat
PAN/CsPbBr3 (1 : 2)	0.1522	0.4562	0.8815	D-1 (1:2) After Heat Treat
PAN/CsPbBr3 (2 : 3)	0.2497	0.0302	0.9718	D-2 (2:3) After Heat Treat
PAN/CsPbBr3	0.4039	0.7115	0.945	D-3 (1:1) After Heat Treat

(1 : 1)				

The change from physsorption into chemisorption after the heat treatment is conducted can also correlated to the, $CsPb_2Br_5$ and Cs_4PbBr_6, therefore we can further breakdown the elements. The Cs^+ contentand isolated Pb^+ activation site could ignite the chemisorption mechanism, after the heat treating process are conducted. The reason was because Pb^+ has more unsaturated coordiantion sites, which could active for CO_2.

4.6 DTA/TGA (Thermal Testing)

Focusing on thermal stability material properties, conducting this procedure of Differential Thermal Analysis (DTA)/Thermogravimetric Analysis (TGA) is very essential to make a pinpoint as to where our material thermal endurance can be enhanced. Conducted at Brawijaya University in their Chemist Department, thermogravic analysis is an important analysis that should be carried out before further measurement. Basically, the while concept of thermogravic analysis is the determination of the change in the sample mass during heating or time for a given temperature. The following graph is the DTA data of PAN and $CsPbBr_3$ specimen.

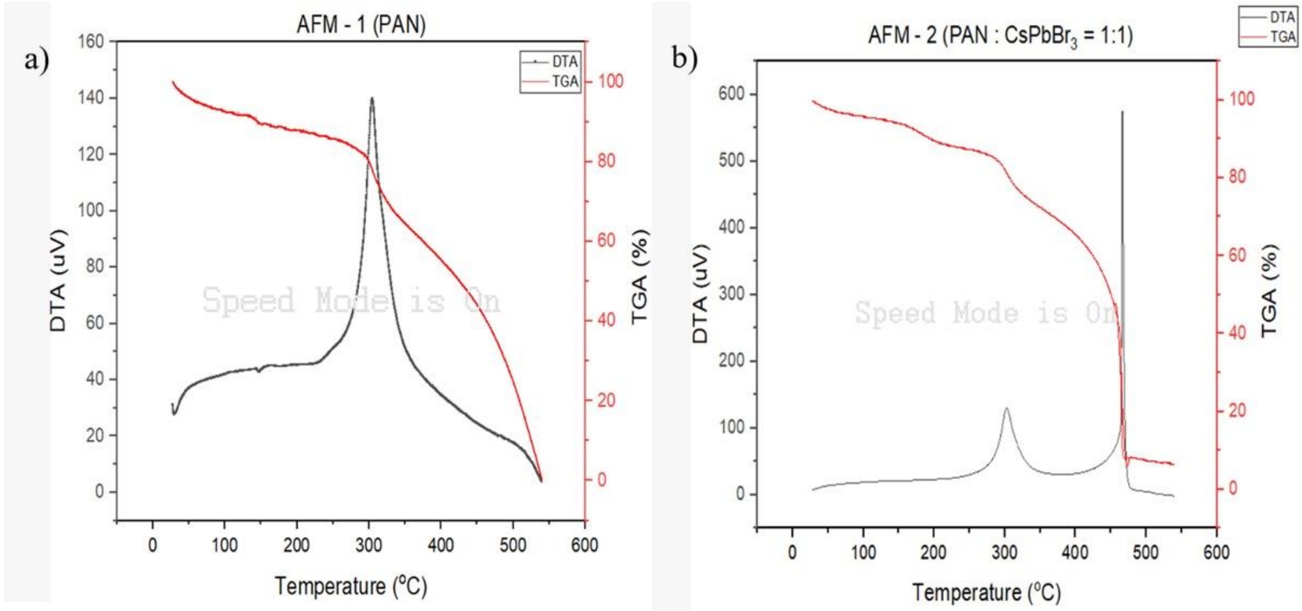


Figure 4.21 Differential Thermal Analysis (DTA) of $PAN/CsPbBr_3$ Nanofiber

Observing Differential Thermal Analysis (DTA) has significant temperature differences relatively to a thermally inert material that are measured during heating or cooling of a sample. Thermogravic analysis technique is a method where it analyse the weight change profile is recorded when the sample is subjected to a heat treatment in a controlled temperature measurement. The weight change that are observed in this analysis is recorded as a function of time, then is termed as "Isothermal Mode". Where in the case of scanning mode, the weight change is recorded as a function of temperature. Therefore the basic main principle of thermogravic analysis (TGA) is that mass change of a sample can be studied under programmed conditions, hence TGA is mainly used for understanding certain thermal events such as adsorption, absorption, desorption, vaporization, sublimation, decomposition, oxidition, and reduction. In addition to this, TGA can be utilized for the evaluation of volatile or gaseous products. In the research we conduct adsorption test, and this method of TGA are also utilized for the evaluation of volatile or gaseous products lost during such chemical reaction for samples such as nanomaterials, fibers, and films. In the other hand TGA can also conduct the prediction of thermal stability for samples, it is also possible to study the kinetics of chemical reactions under various conditions using TGA. The research of developing a nanofiber membrane with high thermal stability, needs the help form DTA/TGA testing procedure in order to set the heat limit that the PAN/$CsPbBr_3$ nanofiber membrane can tolerate. Therefore this testing procedure is necessary to be conducted to support the heat treatment procedure. Deciding on which temperature the the nanofiber membrane needs to be heat treated are important, because of the main focus to create a better mechanical properties of a nanofiber membrane (Duan et al., 2012).

By referring to the provided graph that are displayed above it can be further elaborate that, Thermogravic (TGA) curve (Red line) indicates a gradual mass loss starting at 300°C and the decomposition of the PAN material as the main matrix of the nanofiber membrane start to occur. Differential Thermal Analysis (DTA) which is the (Black line) shows a major exothermic peak around 300°C, where this could indicates the PAN cyclization and stabilization. The procedure of heat treatment are conducted in the range of 250°C – 260°C, because in the temperature of 300°C pure PAN nanofibers allready undergo thermal stabilization (cyclization) and followed through by thermal degradation. This was further proven that if we set the temperature to 300°C the nanofiber membrane was visually observed to be broken (shattered into pieces) because it gets to dry, therefore they can’t be further utilized. Further from the graph data analysis we can compare between the PAN only specimen and the PAN/$CsPbBr_3$ specimen. It can be observed that the red line of TGA shows a better mass losses as it is heated overtime in the PAN/$CsPbBr_3$, where the decomposition starts to occurred at the 90-95 % TGA and it also a less steeper declined compare to the PAN only nanofiber membraane.

CHAPTER V

CONCLUSION AND SUGGESTION

5.1 Conclusion

The concept of CO2 capture required a thorough analysis on the nanofiber materials that are going to be utilized on the operation. Therefore we conducted a specific testing procedure to observed and test the whole mechanical properties and thermal stability of PAN/$CsPbBr_3$ nanofiber itself. After a careful analysis of our specimen, it is evident that the nanofiber composition of PAN/$CsPbBr_3$ significantly influences their thermal, mechanical, and CO_2 adsorption performance. In the aspect of morphological characterization (SEM-EDX and FTIR) confirmed successful synthesis and dispersion of nanofiber, within the matrix of the material Polyacrylonitirle (PAN) it can be observed a clear indictions of interaction of interaction between fucntional groups, escpecially the nitrile group that enhances CO_2 affinity. The mechanical resilience of nanofiber is then can be proven by tensile test, further observing the result of this test, hence a different composition of polymer and ceramic can results in a different outcome of how much a material can endure stress. Further analysis concerning the thermal testing by using DTA/TGA showed a promising thermal stability for composite nanofiber materials are finally decided between 250°C -260°C before the materials gets deteriorate, therefore application under large scale industrial operation can be applied. Stretching from mechanical and thermal analysis of material CO_2 adsorption kinetics can be evaluated. The mechanical testing shows that in before heat treatment the composition of PAN and (1:2) PAN/$CsPbBr_3$ have a more ductile characteristic while for the mechanical testing results after the heat treatment PAN and almost all three variants of PAN/$CsPbBr_3$ nanofiber membrane are ductile, by referring to the Young's Modulus and tensile strength value of data.

The heat treatment in order to achieved a better mechanical properties are also managed to be obtained in several specimen, in the other hand the addition of $CsPbBr_3$ also played a key role in the results of how the final mechanism of CO_2 adsorption would be. Physisorption are tend to be more dominant in the before heat treatment data, while for the after heat treatment the chemisorption is more dominant. . This could be further elaborate by the purpose of heat treatmnet it self, which is to increase the crystalization and thus the CO_2 particle could be better adsorp through the pore of nanofiber membrane. Therefore chemisorption is the mechanism that is more dominant after heat treatment, it can also be attribute to the activation site of Pb^+.

5.2 Suggestion

These are the following suggestion that can be reviewed for further research operation :

1. The CO_2 adsorption equipment should be improved for future research, for the better of adsorption analysis.
2. The materials that are used in the research should be ordered and prepared in the early time period, to avoid delay in the data processing phase.

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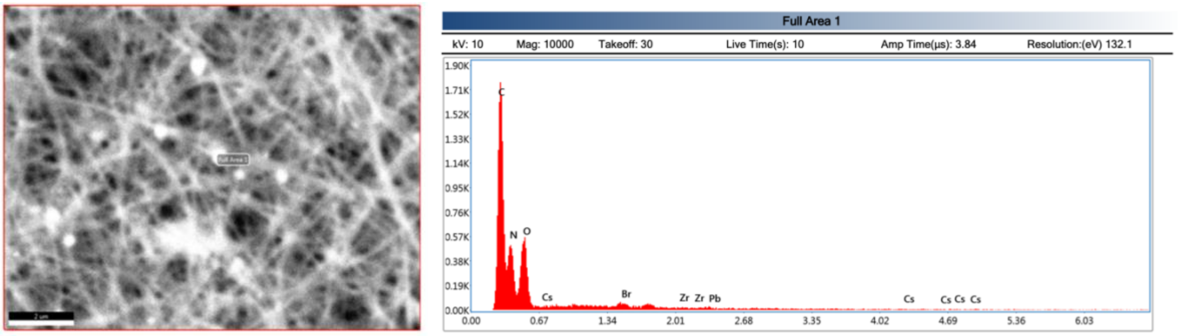
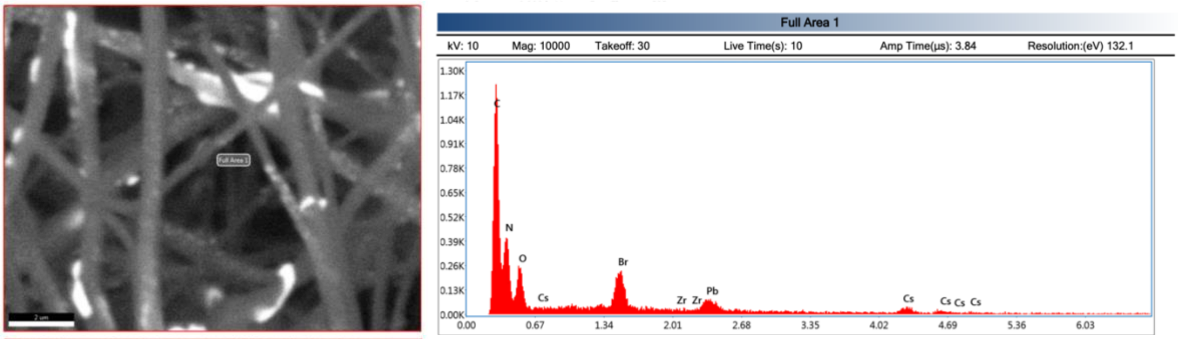
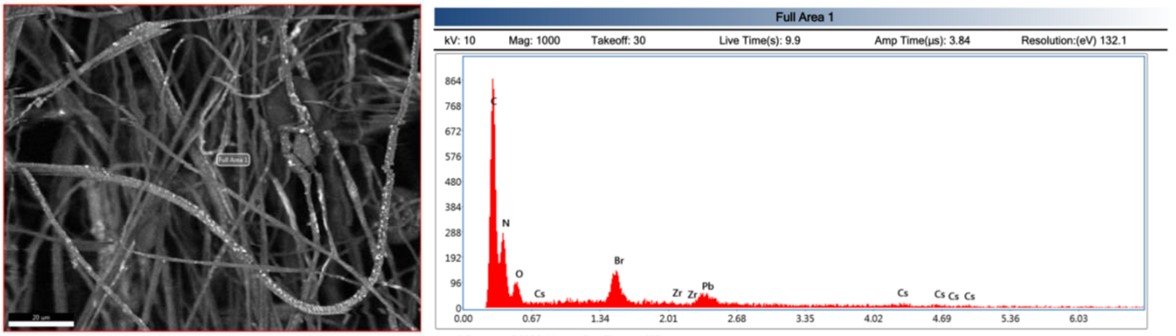
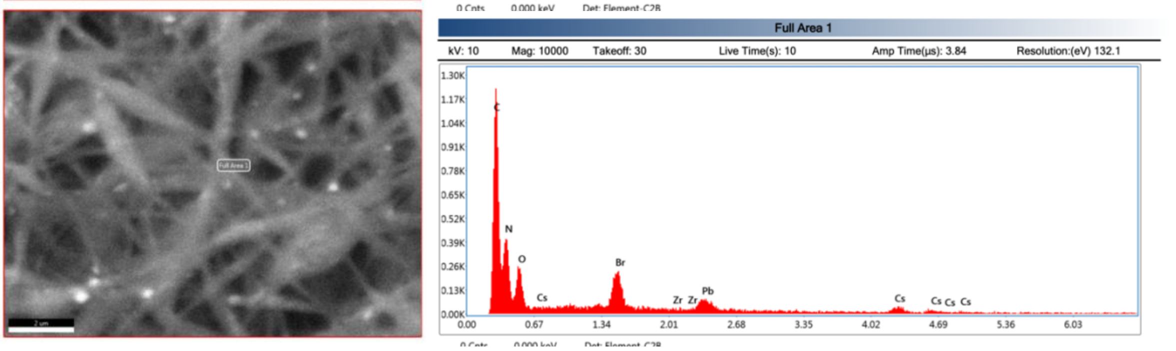
APPENDIX

SEM EDX Image of PAN/$CsPbBr_3$ Nanofiber Membrane



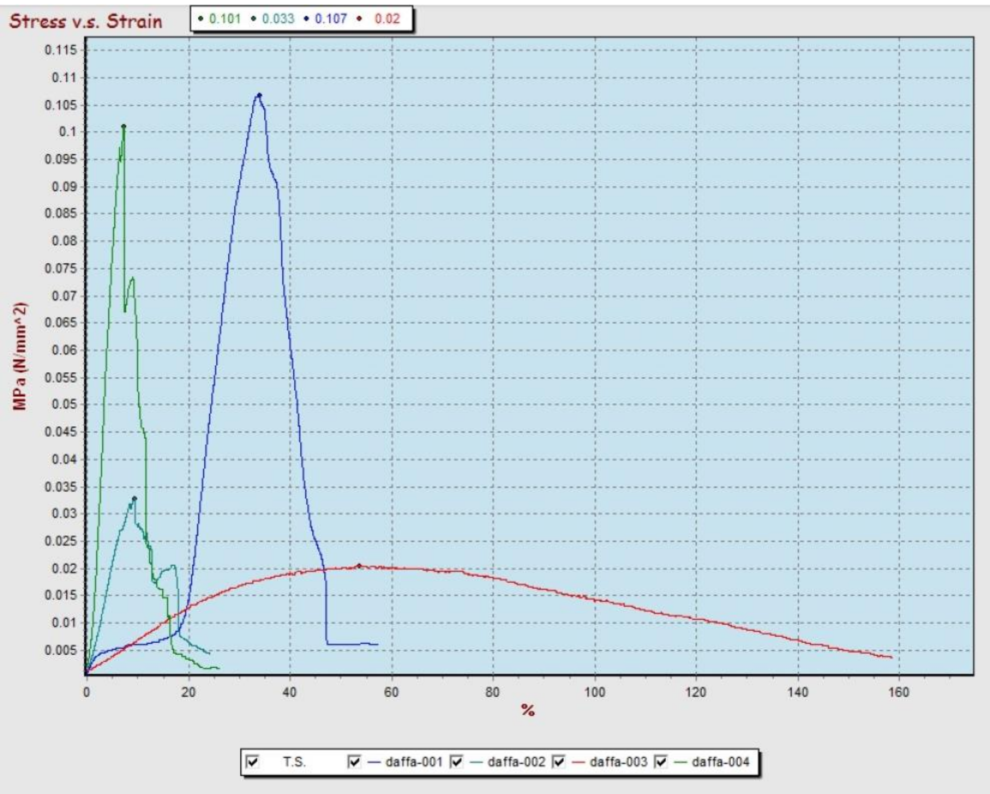




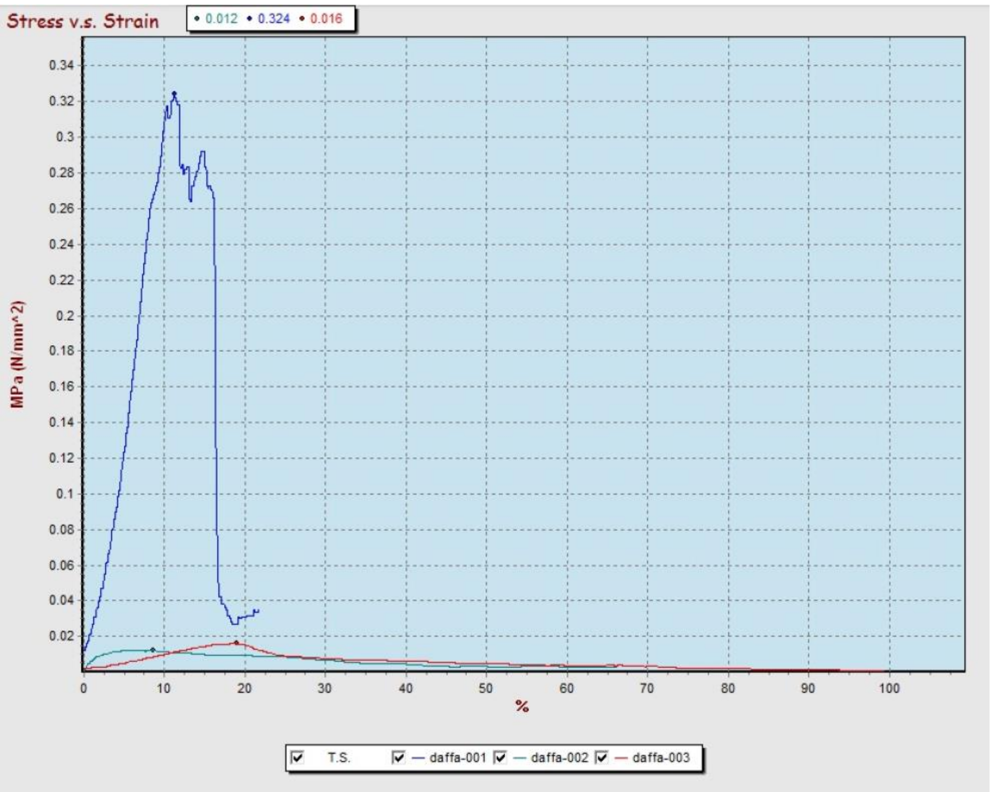


Tensile Raw Data Imagery

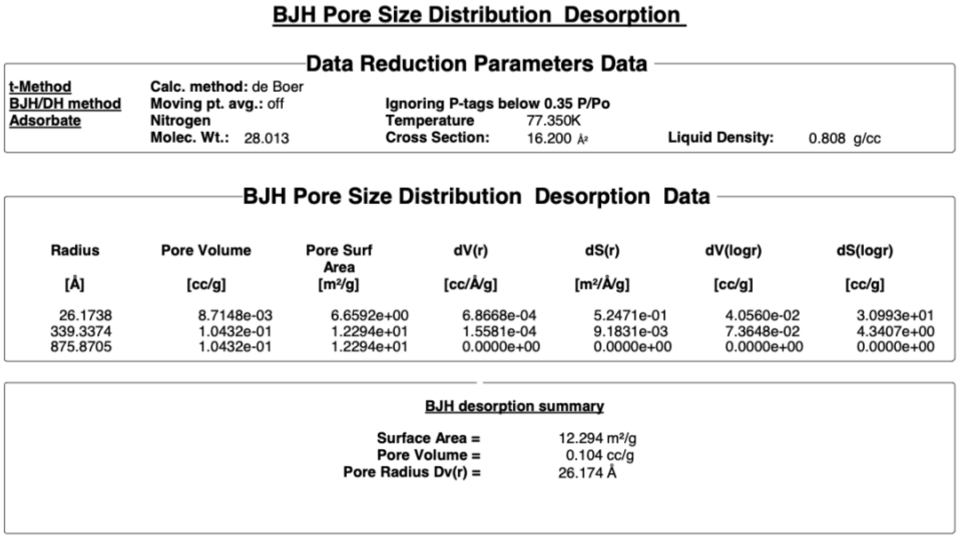
Before Heat Treatment



After Heat Treatment



BET Pore Size Distribution



BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

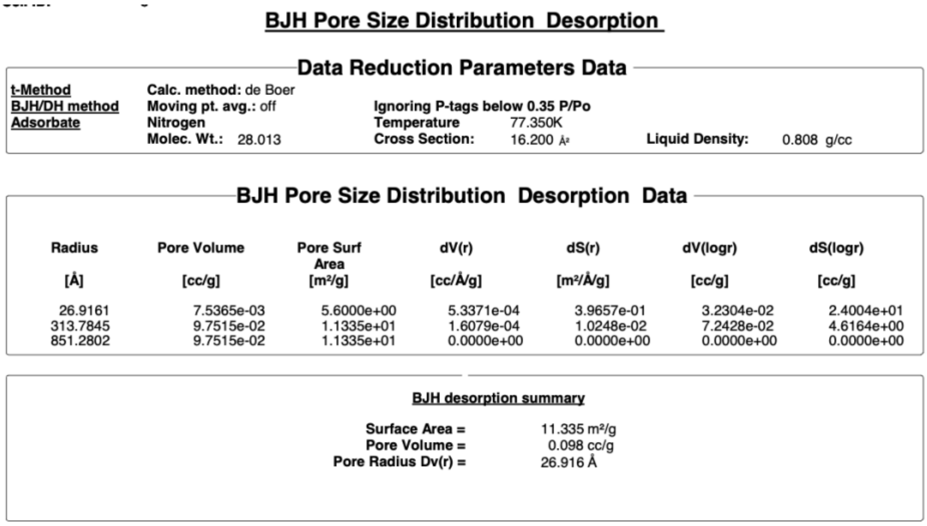
t-Method **Calc. method:** de Boer
BJH/DH method **Moving pt. avg.:** off **Ignoring P-tags below 0.35 P/Po**
Adsorbate **Nitrogen** **Temperature** 77.350K
Molec. Wt.: 28.013 **Cross Section:** 16.200 Å² **Liquid Density:** 0.808 g/cc

BJH Pore Size Distribution Desorption Data

Radius [Å]	Pore Volume [cc/g]	Pore Surf Area [m²/g]	dV(r) [cc/Å/g]	dS(r) [m²/Å/g]	dV(logr) [cc/g]	dS(logr) [cc/g]
26.1738	8.7148e-03	6.6592e+00	6.8668e-04	5.2471e-01	4.0560e-02	3.0993e+01
339.3374	1.0432e-01	1.2294e+01	1.5581e-04	9.1831e-03	7.3648e-02	4.3407e+00
875.8705	1.0432e-01	1.2294e+01	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00

BJH desorption summary

Surface Area = 12.294 m²/g
Pore Volume = 0.104 cc/g
Pore Radius Dv(r) = 26.174 Å



BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

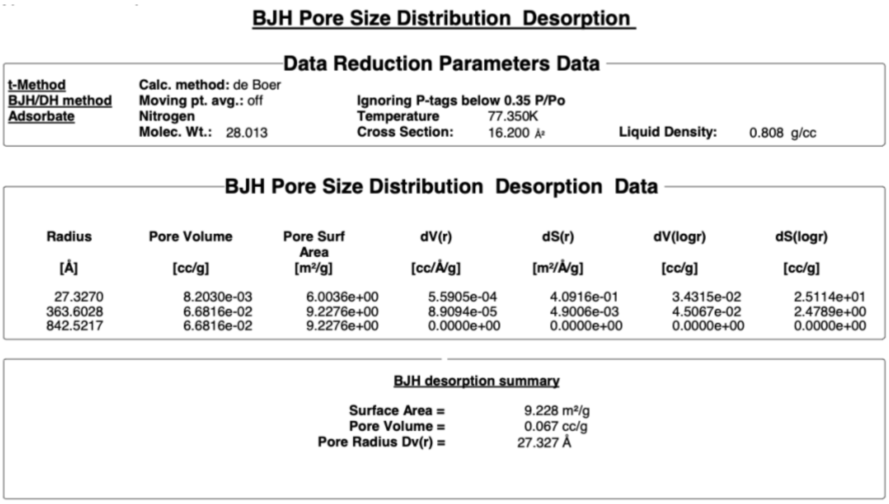
t-Method **Calc. method:** de Boer
BJH/DH method **Moving pt. avg.:** off **Ignoring P-tags below 0.35 P/Po**
Adsorbate **Nitrogen** **Temperature** 77.350K
Molec. Wt.: 28.013 **Cross Section:** 16.200 Å² **Liquid Density:** 0.808 g/cc

BJH Pore Size Distribution Desorption Data

Radius [Å]	Pore Volume [cc/g]	Pore Surf Area [m²/g]	dV(r) [cc/Å/g]	dS(r) [m²/Å/g]	dV(logr) [cc/g]	dS(logr) [cc/g]
26.9161	7.5365e-03	5.6000e+00	5.3371e-04	3.9657e-01	3.2304e-02	2.4004e+01
313.7845	9.7515e-02	1.1335e+01	1.6079e-04	1.0248e-02	7.2428e-02	4.6164e+00
851.2802	9.7515e-02	1.1335e+01	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00

BJH desorption summary

Surface Area = 11.335 m²/g
Pore Volume = 0.098 cc/g
Pore Radius Dv(r) = 26.916 Å



BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

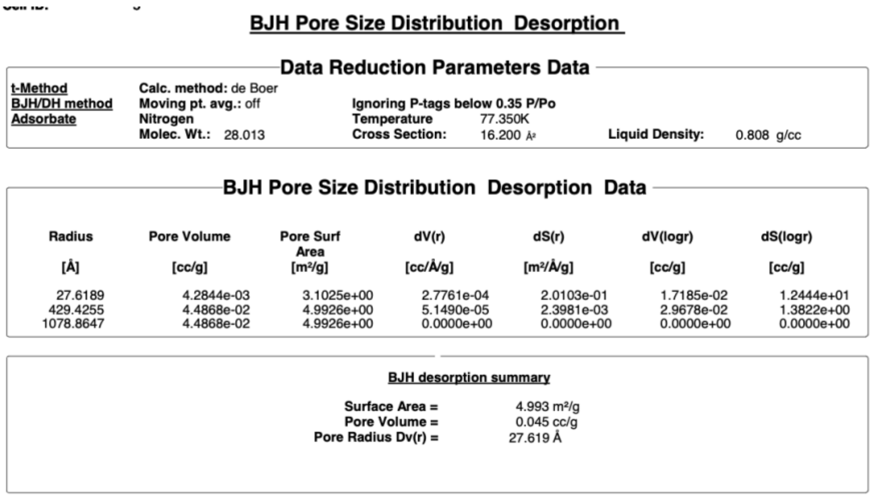
t-Method **Calc. method:** de Boer
BJH/DH method **Moving pt. avg.:** off **Ignoring P-tags below 0.35 P/Po**
Adsorbate **Nitrogen** **Temperature** 77.350K
Molec. Wt.: 28.013 **Cross Section:** 16.200 Å² **Liquid Density:** 0.808 g/cc

BJH Pore Size Distribution Desorption Data

Radius [Å]	Pore Volume [cc/g]	Pore Surf Area [m²/g]	dV(r) [cc/Å/g]	dS(r) [m²/Å/g]	dV(logr) [cc/g]	dS(logr) [cc/g]
27.3270	8.2030e-03	6.0036e+00	5.5905e-04	4.0916e-01	3.4315e-02	2.5114e+01
363.6028	6.6816e-02	9.2276e+00	8.9094e-05	4.9006e-03	4.5067e-02	2.4789e+00
842.5217	6.6816e-02	9.2276e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00

BJH desorption summary

Surface Area = 9.228 m²/g
Pore Volume = 0.067 cc/g
Pore Radius Dv(r) = 27.327 Å



BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

t-Method	**Calc. method:** de Boer				
BJH/DH method	**Moving pt. avg.:** off	**Ignoring P-tags below 0.35 P/Po**			
Adsorbate	**Nitrogen**	**Temperature**	77.350K		
	Molec. Wt.: 28.013	**Cross Section:**	16.200 Å²	**Liquid Density:**	0.808 g/cc

BJH Pore Size Distribution Desorption Data

Radius [Å]	Pore Volume [cc/g]	Pore Surf Area [m²/g]	dV(r) [cc/Å/g]	dS(r) [m²/Å/g]	dV(logr) [cc/g]	dS(logr) [cc/g]
27.6189	4.2844e-03	3.1025e+00	2.7761e-04	2.0103e-01	1.7185e-02	1.2444e+01
429.4255	4.4868e-02	4.9926e+00	5.1490e-05	2.3981e-03	2.9678e-02	1.3822e+00
1078.8647	4.4868e-02	4.9926e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00

BJH desorption summary

Surface Area = 4.993 m²/g
Pore Volume = 0.045 cc/g
Pore Radius Dv(r) = 27.619 Å

Nanofiber of PAN/$CsPbBr_3$ Final Form

CO$_2$ Adsorption Equipment

GRATITUDE

I want to express my gratitude of being able to conduct this final project with all of my best effort. I can’t think of a lecture,mentor,friend,and all of my colleagues who could have made this past year any more special than they did. Therefore the following are my gratitude that I want to genuinely express to all of you :

1. First of all, I want to express my gratitude to the most high, ALLAH S.W.T
2. Both of my parents who always support me through all of my campus journey, either morally and financially.
3. Azzah Dyah Pramata and Prof Sigit Tri Wicaksono as my advisor in this final project, that always help me with their helpful feedback to what I’m working on.
4. Abdulah Abraham Abror and Akhdan Fadhil Muhammad, who never stop to give me encouragement and help me with all of my final project progress.
5. All three of my IUP classmates Rafi Thoriq Yasar, Abdulah Abraham Abror, and Daffa Handyan Mahardhika, who always be there whenever I needed them the most.
6. All of my Materials Engineering department friends that accompany me through my campus journey
7. All of my close friends that I Can’t mentioned one by one here, I just wanted to say thank you for all of your moral support.

I will never forget all the fun activities that we all conducted in our teenage phase, to enhance the learning experience. It’s a previlege for me that, I have experienced all of this in my college life with all of you guys.

Sincerely,

Daffa Maulana

AUTHOR BIOGRAPHY

Daffa Maulana was born on June 26, 2003. He's a Material and Metallurgical engineering student at Sepuluh Nopember Institute of Technology. Raised in Malang and born in Bali, with a Javanese decendant from both of his parents. Daffa often spent time with his family in Malang, East Java. Daffa's love of engineering field drove him to pursue his degree in material and metallurgical engineering, there he felt he could explore and learn new things regarding the development of future manufacturing and energy industry. Daffa's also involved in some of campus Oil & Gas competition either as participant and voulenteer. He began to participate in fracturing fluid design competition as participant and there he gets a top 5 in the final leaderboards of the competition. This led him to finally further exploit his potential for energy industry research, therefore he take the topics of Carbon Capture and Utilization Storage (CCUS). Daffa's campus journey also include a summer program at National University of Singapore (NUS), as an ITS International Undergraduate Program (IUP) student. He took 2 course at NUS summer program : Introduction to data science and Advance qualitative data analysis. Afterwards he also took an intenrship opportunity at Pertamina EP Cepu, where he appointed as the Reliability, Availability, and Maintainability (RAM). Today's Daffa continue to pursue his carrers after graduating form ITS campus.