

Zeolitic Imidazole Framework-8 Synthesis with Hydrothermal and Addition of Tin Metal Ions

Rahmatul Fajri^{1*}, Jofrisha², Muslimah¹, Yulida Amri¹, Hatijah¹,
Dian Permana³, Siow-Ping Tan⁴

¹Department of Chemistry, Faculty of Sains and Technology, Universitas Samudra, Langsa-Aceh, 24415, Indonesia

²Department of Chemistry, Faculty of Teacher Training and Education, Universitas Samudra, Langsa-Aceh, 24415, Indonesia

³Department of Chemistry, Faculty of Teacher Training and Education, Universitas Sembilanbelas November Kolaka-Sulawesi Tenggara, 93517, Indonesia

⁴Department of Physical Science, Faculty of Applied Sciences, Tunku Abdul Rahman University Management and Technology, 53300 Kuala Lumpur, Malaysia.

*Corresponding author's email: rahmatulfajri@unsam.ac.id

Article History:

Received date: November 15 2024

Received in revised from: December 5 2024

Accepted date: December 8 2024

Available online: December 15 2024

Citation:

Rahmatul Fajri., Jofrisha, , Muslimah, Yulida Amri, Hatijah. 2024. ZIF-8 synthesis with hydrothermal and addition of Sn Metal ions. *JIPI (Jurnal IPA dan Pembelajaran IPA)*, 8(4):392-402.

Abstract. This research is intended to synthesize Sn-ZIF-8 with an environmentally friendly hydrothermal method by exploring the potential of the utilization of aqueous solvents as the main solvent. Sn-ZIF-8 material has been successfully synthesized with water solvent at room temperature and has been characterized using XRD, FTIR, and SEM instrumentation to determine the extent of synthesis success. In this study, the use of Sn doping varied from 5, 10, and 15%, while MeIM, NH₄OH, and water precursors were kept constant. Instrumentation observations showed the XRD patterns of Sn-ZIF-8 compounds for percentages of 5, 10, and 15% of Sn²⁺ displayed specific peaks of ZIF-8 at $2\theta = 7.24^\circ, 10.28^\circ, 12.62^\circ, 16.34^\circ, \text{ and } 17.92^\circ$. Meanwhile, the FTIR spectra of all synthesized solids presented the same functional group absorption peaks as the simulated ZIF-8 solids. SEM observation revealed a regular crystal shape of Sn-ZIF-8 without any contaminant on its surface. The characterization results show no change in the basic structure and the addition of other structures from ZIF-8. The implication of this finding can be utilized as a reference source for synthesizing inorganic materials using eco-friendly stages without affecting the synthesized product.

Keywords: Sn-ZIF-8, water solvent, eco-friendly, hydrothermal

Introduction

ZIF-8 comprises a Zn²⁺ metal cation coordinated with an organic 2-methylimidazole linker (Etxeberria, et al., 2020). There are numerous ways to prepare ZIF-8, all of which may impact its surface characteristics (Kenyotha, et al., 2020). Solvothermal and hydrothermal mainly were employed because they were straightforward and typically provided a large surface area (Lee, et al., 2015). In the solvothermal method, the solvents used are organic solvents such as methanol, N, N-dimethylformamide (DMF), N-methyl pyrrolidine, and N, N-diethyl formamide. However, the organic solvent is difficult to remove from the ZIF-8 pores. Whereas in the hydrothermal method, the solvent used is water. In recent years, the synthesis of ZIF-8 using aqueous solvents has attracted interest and has become an alternative approach. Using water as a solvent to dissolve precursors is

considered more practical. Water is a common solvent that is abundant, economical, and environmentally friendly (Kenyotha, et al., 2020). General organic compounds for solvothermal N, N-dimethylformamide (DMF), N-methyl pyrrolidine, and N-diethylformamide are employed solvents. Methanol was used instead since the organic solvents were challenging to get out of the pores of ZIF-8, a more often used solvent for producing ZIF-8 (Kida, et al., 2013).

The solvothermal approach can give ZIF-8 the desired qualities, but using too much organic solvent has drawbacks because it is expensive, combustible, poisonous, and bad for the environment. The green synthesis approach is therefore required to solve this issue. The synthesis of ZIF-8 using an aqueous solution has attracted interest recently and has developed into a different strategy known as the "water-based synthesis method." It can expressly refer to a synthesis process carried out in the water that was boiled above its normal boiling point and at autogenous pressure as a hydrothermal approach. The 2-methylimidazole (MeIM) can be further coordinated with Zn^{2+} to generate a compound after being deprotonated by an aqueous solvent (water) in the water-based synthesis process (Hu, et al., 2018). Finally, we speculate that the new ZIF-8 might have a sort of "eco-label" thanks to its more environmentally friendly synthesis (García, et al., 2020). The synthesis of ZIF-8 with water solvent has a relatively large molar ratio of Zn^{2+} metal and imidazole ligand (1:70), so a method is needed to reduce the molar ratio of Zn^{2+} metal and imidazole ligand. Adding several basic amine compounds can act as deprotonating agents for organic ligands, reducing the use of organic ligands in the synthesis of ZIF-8. The amine base used is ammonium hydroxide (NH_4OH), which functions as a deprotonating agent with a low molar ratio of Zn^{2+} :MeIM (1:2) (García, et al., 2020).

ZIF-8 can be modified by adding metal ions (Doping) to improve performance. Doping is a synthetic process that is carried out by mixing the precursors used in a certain composition ratio to improve the performance of ZIF-8. The addition of Sn doping in this synthesis is not to replace all of Zn^{2+} ions with Sn^{2+} , but Sn^{2+} ions will replace some Zn^{2+} ions in the ZIF-8 structure, thus damage or changes in the ZIF-8 structure caused by the presence of Sn metal ions can be avoided. Sn metal has a d^{10} electron configuration, where the structural and physicochemical properties d^{10} are interesting and important because its applications can be developed in nanotechnology and catalyst materials compared to Zn. Zn^{2+} is an example of a divalent d-block transition metal with a d^{10} electron configuration. A special property of d transition metals is their ability to form complexes with ligands, both anions and neutral molecules, which can act as free electron donor (Tanaka and Miyashita, 2017).

Based on these principles, this research aims to synthesize Sn-ZIF-8 using water as a solvent, and the overall synthesis stage was carried out at room temperature. The utilization of the mechanism is considered an eco-friendly method. Furthermore, as a deprotonating agent, the addition of NH_4OH is carried out at the synthesis stage. The advantage of this research is to explore the effect of Sn metal addition in the synthesis of ZIF-8 on its structure through the green synthesis method. Besides a contribution to the environment, the use of this method is considered effective in increasing the adsorption capacity and catalytic activity of the material, as previously Reported by (Yang, et. al, 2014).

Methods

The materials utilized for the synthesis of Sn-ZIF-8 were ammonium hydroxide, zinc nitrate, 2-methylimidazole, tin (II) chloride obtained from Merck-Germany, while distilled water was produced in the laboratory using a water rain distiller (Iwaki). Instrumentation analysis was conducted to confirm the formation of ZIF-8, Zn-ZIF-8, and Sn-ZIF-8, the instrumentation used were X-ray diffraction (Shimadzu XD 610), Fourier-transform infrared

spectroscopy (IRXross-Shimadzu), and morphological analysis using a scanning electron microscope (JEOL JSM-6510LA).

Zeolitic Imidazole Framework-8 doped with Sn metal ions was synthesized by hydrothermal and adding ammonium hydroxide and a metal/ligand ratio ($\text{Sn}^{2+}/\text{MeIM}$) of 1:4 at room temperature using a modified method. Sn-ZIF-8 was synthesized by dissolving Zinc Nitrate and tin (II) chloride in 9.0 mL of distilled water and 0.986 g of MeIM dissolved in 6.3 mL of NH_4OH . The compositions of mixing each precursor are shown in Table 1. The combination of zinc nitrate with SnCl_2 is intended to encourage competition between Zn^{2+} and Sn^{2+} in their interaction with the MeIM ligand. Meanwhile, the dissolution of MeIM in NH_4OH and water was meant to deprotonate MeIM, hence the reaction between the ligand and metal ions (Grimmett, 1997) as shown in Figure 1. The amount of SnCl_2 added was 5, 10 and 15% of the amount of $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ precursor used. Each solution was stirred to obtain a homogeneous solution. Then, the two solutions were mixed and stirred with a magnetic stirrer for 10 minutes at room temperature. The application of room temperature conditions is performed with the consideration that the ZIF-8 formation reaction can proceed under these circumstances, these results are in accordance with previous reports by (Bustamante, Fernández and Zamaro, 2014). The precipitate formed was then decanted and washed with distilled water for 72 hours each to dissolve the remaining ammonium hydroxide.

Table 1. The precursor quantities used in Synthesis of Sn-ZIF-8

Codes	SnCl_2 (%)	$\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (g)	MeIM (g)	SnCl_2 (g)	NH_4OH (mL)	Water (mL)
Z1	5	0.8478	0.986	0,0446	6.3	9.0
Z2	10	0,8032	0.986	0,0892	6.3	9.0
Z3	15	0,7586	0.986	0,1338	6.3	9.0

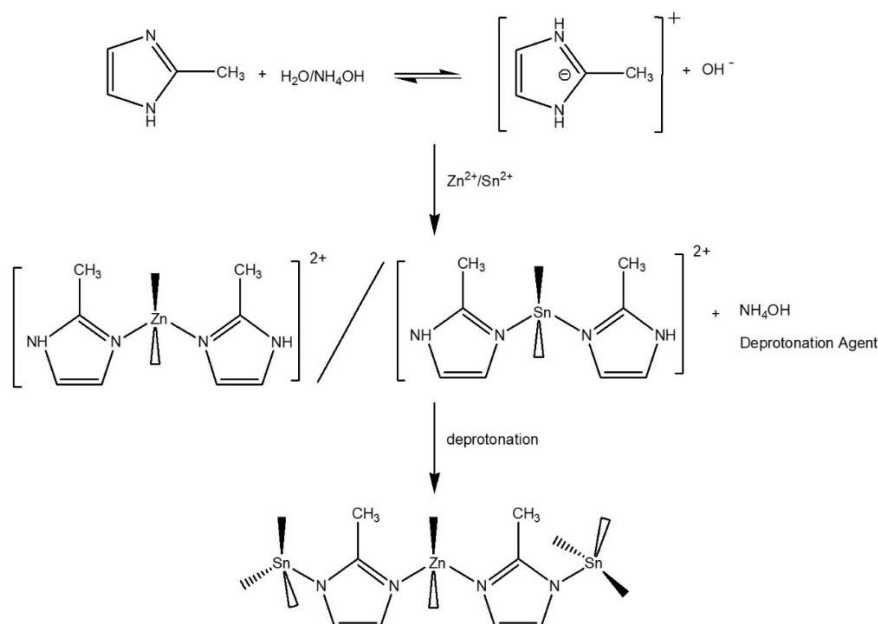


Figure 1. Reaction mechanism of Sn-ZIF-8 formation in aqueous solvent

The precipitate was dried under vacuum at 90°C for 4 hours and then dried in an oven at 100°C for 6 hours. The solids obtained are denoted according to the amount of Sn added in the synthesis, namely Sn-ZIF-8 (5%), Sn-ZIF-8 (10%), and Sn-ZIF-8 (15%). The overall scheme of work for this research is shown in Figure 2.

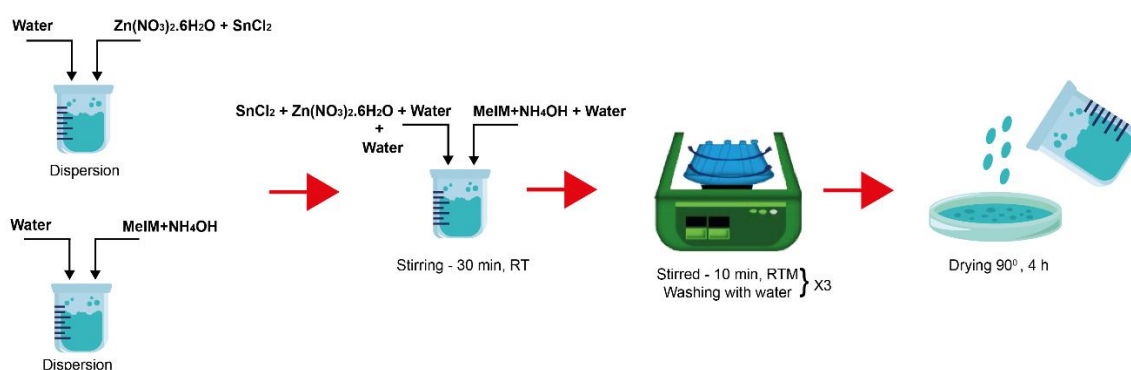


Figure 2. Overall research schematic work steps

XRD characterized the obtained Sn-ZIF-8 samples. ± 0.5 gram of Sn-ZIF-8 was taken and placed in the sample holder. The sample was then irradiated with a Cu K α light source ($\lambda = 1.54056 \text{ \AA}$) at 40 kV and 30 mA with a 2θ scale of $5 - 40^\circ$ and a scan speed of $0.020^\circ/\text{sec}$. The data obtained are d spacing, 2θ , and the intensity of the diffraction peaks from the sample. After the characterization data is obtained, the data is matched with the reference data. A functional group analysis of Sn-ZIF-8 was conducted using FTIR. The Sn-ZIF-8 sample was mixed in KBr with a sample ratio of KBr = 1: 99. The sample and KBr were mixed and pounded with agate mortar and then molded into pellets by compressing using hydraulic pressure. The formed pellet is placed in a sample holder, and the spectra are recorded in the wave number region $4000 - 400 \text{ cm}^{-1}$ with a spectral separation of 4 cm^{-1} .

Results and Discussion

Synthesized processes and products

Sn-ZIF-8 material was synthesized with the precursor zinc nitrate hexahydrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$) as a metal Zn^{2+} source, 2-methylimidazole (MeIm) as an organic ligand source, and SnCl_2 as a metal ion doping. The synthesis of Sn-ZIF-8 was started by dissolving $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ with SnCl_2 in water as a solvent. SnCl_2 variations used were (5, 10, and 15%). Mixing $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ with SnCl_2 aims to create competition between Zn^{2+} and Sn^{2+} in their interactions with MeIm ligands. This mixing produces a colorless solution. Then, 2-methylimidazole is dissolved in NH_4OH to produce a colorless solution elsewhere. The mixing aims to cause deprotonation of MeIm. Next, the two solutions were mixed and stirred with a magnetic stirrer for 10 minutes at room temperature to produce a homogeneous mixture and a cloudy white solution, indicating a reaction between the protonated ligand and the metal ions. The stirred solution is allowed to stand until it produces a precipitate. ZIF-8 crystallizes quickly at room temperature, and this process is anticipated to continue as the solid product is recovered via centrifugation. During the crystallization process, fast nucleation and slow crystal development are necessary to manufacture nano sized ZIF-8 (García, et al., 2020).

The resulting precipitate is then decanted so that it is separated from the first filtrate. After the decantation process, the solids obtained were washed. Washing was carried out by immersing the solids in water and leaving them for 72 hours, with the water changing every 24 hours (Fajri, et al., 2021). The washing process aims to remove the residual ammonium hydroxide trapped in the ZIF-8 framework, doped with Sn metal. After washing with water, the solids were dried using an oven at 90°C for 4 hours. Drying aims to increase the porosity of the synthesized solids by removing residual solvents that are still trapped in the pores of the solids. After that, the solid was dried again using an oven at 100°C for 6 hours. After drying, the Sn-ZIF-8 solid changes color from cloudy white to light yellow. Even with varying levels of Sn metal addition, there is no discernible difference in the color and texture of the Sn-ZIF-8 material formed. The uniformity of color and texture across a range of Sn concentrations indicates that the ZIF-8 lattice is not considerably disrupted by Sn inclusion (Sayed, Soliman and Abdelhamid, 2024). The light yellow solid produced is the result of the reaction of Zn^{2+} and/or Sn^{2+} metals with MeIm ligands (Park, et al., 2006).

Drying is carried out at 100°C because this temperature is the boiling point of water solvent and can produce high crystallinity. Sn-ZIF-8 solid, after drying, changed color from cloudy white to light yellow. The resulting light yellow solid is the product of the reaction of Zn^{2+} and Sn^{2+} metals with MeIm ligands (Parkash, 2020). The mass of Sn-ZIF-8 solids that have been synthesized with water solvents has decreased along with the increase in the number of Sn metal ions added. The resulting decrease in mass (as shown in Figure 3) is probably caused by the lower reactivity of Sn^{2+} metal compared to Zn^{2+} thus the reaction occurred between MeIm ligand with Sn^{2+} is fewer than with Zn^{2+} (Kotz, et al., 2010). The addition of metal ions in ZIF-8 crystals may slow down the formation of precipitates during synthesis. Moreover, the addition of excessive metal ions in the synthesis of ZIF-8 could damage the structure of ZIF-8. Even when doped with metals like Sn, the ZIF-8 structure is guaranteed to remain intact thanks to the synthesis techniques used, which include solvothermal and hydrothermal procedures (Pan, et al., 2023).

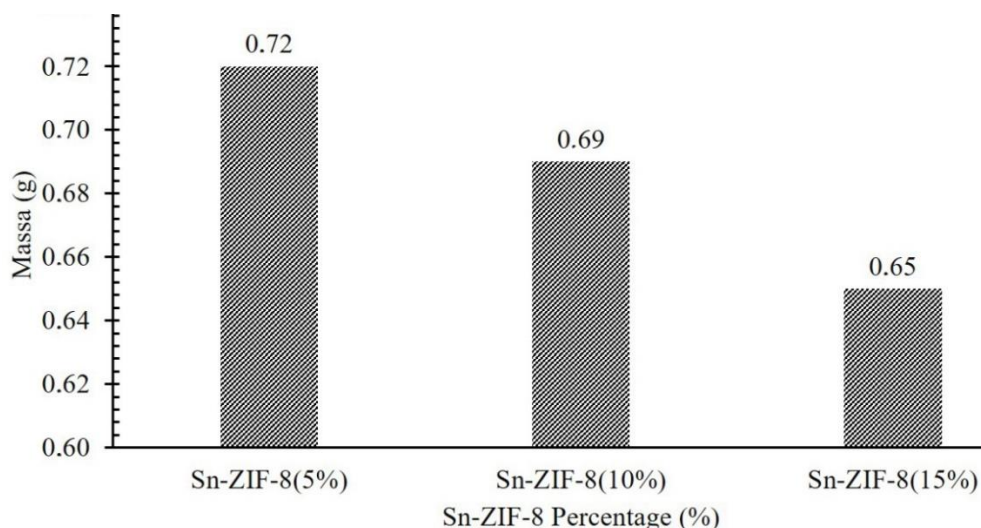


Figure 3. Graph of solid mass versus percentage of Sn^{2+} metal doping

X-ray diffraction analysis

X-ray diffraction characterization was conducted to determine the crystallinity, structure, and purity level of the synthesized Sn-ZIF-8 solids. The synthesized Sn-ZIF-8 (5, 10, and 15%) solid diffractogram was compared with the ZIF-8 reference diffractogram Mohammadi and Nakhaei synthesized (2023). As shown in the Figure 4, the solid X-ray

diffraction patterns synthesized by 5% Sn-ZIF-8 showed characteristic peaks at $2\theta = 7.24^\circ$, 10.28° , 12.62° , 16.34° and 17.92° . This is in accordance with the reference diffractogram (Mohammadi & Nakhaei, 2023). which has characteristic peaks at $2\theta = 7.2^\circ$, 10.3° , 12.5° , 16.4° and 18.0° . This indicates that Sn-ZIF-8 has been successfully synthesized. All Sn-ZIF-8 (10 and 15%) diffractograms also showed characteristic peaks that were not much different from the reference. The diffractogram of Sn-ZIF-8 with Sn^{2+} doping variations showed no new peaks. This indicates that Sn^{2+} has succeeded in replacing a small part of Zn^{2+} in ZIF-8 and does not affect the structure of ZIF-8 (Schejn, 2015).

The crystallinity of each solid produced can be seen from the peak intensity level shown, especially the intensity at 7° peak. At 2θ of 7° , the highest intensity is owned by Sn-ZIF-8 5% at $2\theta = 7.24^\circ$. Whereas in Sn-ZIF-8 (10 and 15%), the peak intensity is at $2\theta = 7.20^\circ$ and 7.22° , it is assumed that ZIF-8 synthesized with the addition of Sn metal has the highest degree of crystallinity (Wang, et al., 2020). This indicates that the addition of Sn^{2+} metal can replace a small portion of Zn^{2+} (Yuliantika, 2016). Doping Sn metal ions in the synthesis does not change the framework structure of ZIF-8 itself. Instead, there is only a change in peak intensity represented by the XRD diffractogram. The difference in peak intensity indicates that there are different levels of crystallinity. The crystallinity increases as the amount of Sn metal added increases.

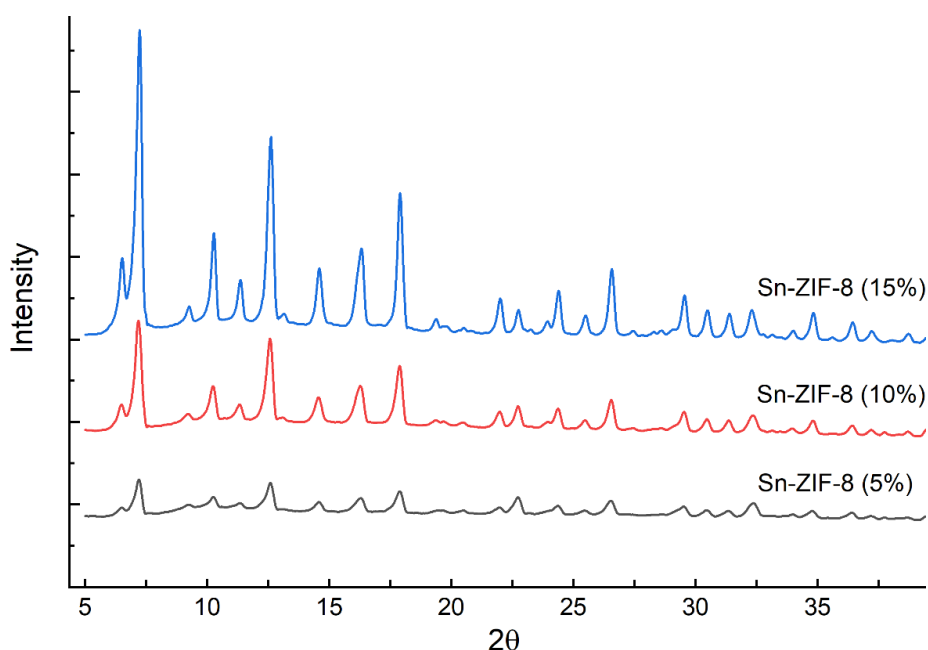


Figure 4. Diffractogram of Sn-ZIF-8

FTIR analysis was conducted to identify the functional groups present in the synthesized solids. Characterization processes were conducted in the wavelength range between $400\text{--}4000\text{ cm}^{-1}$. Based on research that has been reported by Mohammadi and Nakhaei., (2023), the ZIF-8 spectra has a characteristic peak or absorption at wave number 422, 760, 997, 1146, 1586; 1682, 2930, and 3130 cm^{-1} .

Figure 5, illustrates that the sharp absorption band in the region of wave number 421 cm^{-1} indicates a Zn-N stretching vibration, which indicates that in the ZIF-8 sample, a bond is formed between zinc and nitrogen, which originates from the reaction of zinc nitrate and 2-methylimidazole ligand. The peak at 600 cm^{-1} signifies the presence of Sn-O bonds, which is important in confirming that Sn was successfully incorporated into the ZIF-8 framework. This addition of tin metal has the potential to enhance the catalytic activity of

Sn-ZIF-8 materials, given the role of tin in various catalytic reactions, including in organic oxidation and degradation reactions (Ahmad, et al., 2024). The region of wave numbers 994 cm^{-1} and 1145 cm^{-1} indicates the presence of C-N stretching vibrations. Besides that, stretching C=N appears in the wave number region of 1580 cm^{-1} . Furthermore, in the wave number area around 1682 cm^{-1} . It shows a C=C stretching vibration. Moreover, wave number 2930 cm^{-1} indicates the presence of C-H sp^3 bonds, and wave number 3130 cm^{-1} indicates the presence of C-H sp^2 bonds (Pangastuti, et al., 2015).

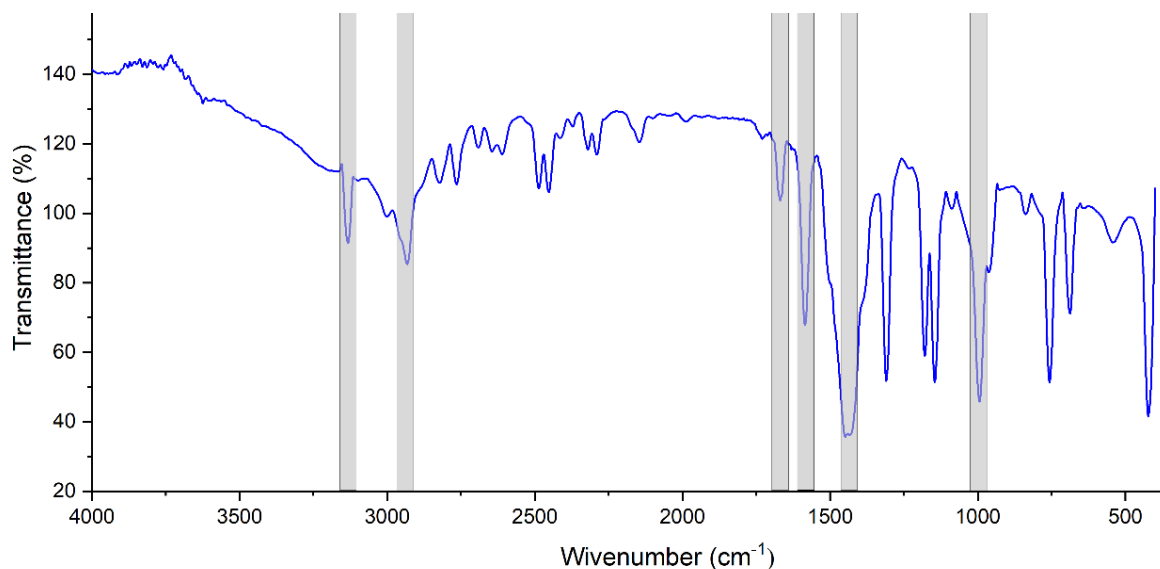


Figure 5. FTIR Spectra of ZIF-8 Synthesized

FTIR results of 5% synthesized Sn-ZIF-8 showed no new absorption peaks in the FTIR spectra. Overall, the FTIR analysis results showed the functional groups' suitability in the synthesized 5% Sn-ZIF-8 solid material without new absorption bands. Adding Sn^{2+} to ZIF-8 causes a slight shift or decrease in peak intensity at several wave numbers. However, this did not affect the appearance of the absorption band from the synthesized functional group (Fajri, et al., 2022). This strengthens the results of the XRD characterization, namely, Sn metal doping using the hydrothermal method on ZIF-8 has been successful and does not damage the structure of ZIF-8. Overall, this FTIR analysis provides evidence that the Sn-ZIF-8 material has a stable structure, with appropriate modification through tin addition. These FTIR spectra provide important insights into the interactions between tin and imidazole groups in the ZIF-8 framework, as well as showing that the material has potential for applications in various fields (Sarwar, et al., 2023).

Surface Morphology

SEM analysis was performed to determine the surface morphology of the synthesized Sn-ZIF-8 material. An essential method for examining the microstructure of Sn-ZIF-8, a metal-organic framework (MOF) with special characteristics, is scanning electron microscopy (Talukder, et al., 2024). SEM is appropriate for researching the morphology and composition of ZIF-8 materials because it offers high-resolution pictures and enables elemental analysis. The surface morphology of the synthesized Sn-ZIF-8 samples with different magnifications is shown in Figure 6. Based on the picture, it shows that Sn-ZIF-8 has a regular structure, and there are no small particles attached. These box-shaped crystals are similar to crystals that have sodalite topology type with

micrometer size (Yang, et al., 2014). Figure 7 (a) (b) Illustrations that, and it also made the Sn-ZIF-8's diameter size more uniform (Mustaqim, et al., 2018). Because of its large specific surface area and porosity, ZIF-8 has a strong framework that enables it to hold various metal ions without undergoing appreciable structural alterations (Li, et al., 2024).

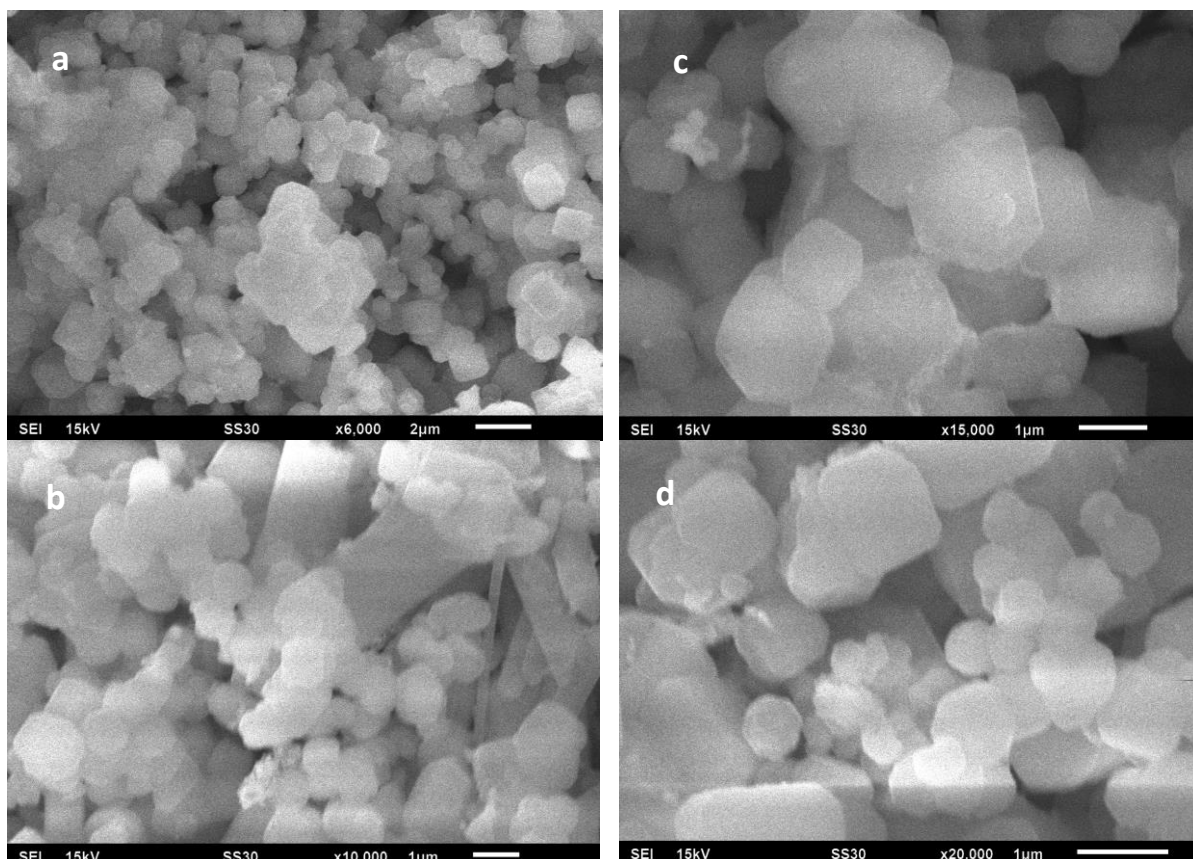


Figure 6. SEM of Sn-ZIF-8 at 6000 $\times$ (a), 10000 $\times$ (b), 15000 $\times$ (c) and 20000 $\times$ (d) magnification.

Conclusion

The synthesis of Sn-ZIF-8 material using an eco-friendly method has been successfully synthesized. This is shown through several stages of XRD and FTIR characterization that have been performed. The characterization results show no change in the basic structure and the addition of other structures from ZIF-8. The implication of this finding can be utilized as a reference source for synthesizing inorganic materials using eco-friendly stages without affecting the synthesized product.

Acknowledgement

We express the highly gratitude to the Universitas Samudra for the research grant and for technical assistance and facilities.

References

- Ahmad, M., Patel, R., Lee, D. T., Corkery, P., Kraetz, A., Prerna., Tenney, S. A., Nykypanchuk, D., Tong, X., Siepmann, J.I., Tsapatsis, M., & Boscoboinik, A. 2024. ZIF-8 vibrational spectra: peak assignments and defect signals. *ACS Applied Materials & Interfaces*, 16(21):27887–27897. <https://doi.org/10.1021/acsami.4c02396>.
- Bustamante, E.L., Fernández, J.L., & Zamaro, J.M. 2014. Influence of the solvent in the synthesis of zeolitic imidazolate framework-8 (ZIF-8) nanocrystals at room temperature. *Journal of Colloid and Interface Science*, 424:37–43. <https://doi.org/10.1016/j.jcis.2014.03.014>.
- Etxeberria-Benavides, M. Johnson, T., Cao, S., Zornoza, B., Coronas, J., Sanchez-Lainez, J., Sabetghadam, A., Liu, X., Andres-Garcia, E., Kapteijn, F., Gascon, J., & David, O. 2020. PBI mixed matrix hollow fiber membrane: Influence of ZIF-8 filler over H₂/CO₂ separation performance at high temperature and pressure. *Separation and Purification Technology*, 237: 116347. <https://doi.org/10.1016/j.seppur.2019.116347>.
- Fajri, R. Wahyuningsi, P., Jofrisha, J., and Ediaty, R. 2022. Doping nikel (Ni) metal in zeolitic imidazolate framework-8 using green synthesis method. *E3S Web of Conferences*, 339(3): 8–11. <https://doi.org/10.1051/e3sconf/202233902003>.
- Fajri, R., Amri, Y. and Ediaty, R. 2021. Synthesis and Characterization of Fe-ZIF-8 by Utilizing Waste Filtrate as Solvent. *Proceedings of the 2nd International Conference on Science, Technology, and Modern Society (ICSTMS 2020)*, 576:78–80. <https://doi.org/10.2991/assehr.k.210909.019>.
- García-Palacín, M. Martínez, J. I., Paseta, L., Deacon, A., Johnson, T., Malankowska, M., Téllez, C., & Coronas, J. 2020. Sized-Controlled ZIF-8 Nanoparticle Synthesis from Recycled Mother Liquors: Environmental Impact Assessment. *ACS Sustainable Chemistry and Engineering*, 8(7):2973–2980. <https://doi.org/10.1021/acssuschemeng.9b07593>.
- Hu, L. Chen, L., Fang, Y., Wang, A., Chen, C., & Yan, Z. 2018. Facile synthesis of zeolitic imidazolate framework-8 (ZIF-8) by forming imidazole-based deep eutectic solvent. *Microporous and Mesoporous Materials*, 268:207–215. <https://doi.org/10.1016/j.micromeso.2018.04.039>.
- Kenyotha, K. Chanapattarapol, K. C., McCloskey, S., & Jantaharn, P. 2020. Water Based Synthesis of ZIF-8 Assisted by Hydrogen Bond Acceptors and Enhancement of CO₂ Uptake by Solvent Assisted Ligand Exchange. *Crystals*, 10(7). <https://doi.org/10.3390/cryst10070599>.
- Kida, K. Okita, M., Fujita, K., Tanaka, S., & Miyake, Y. 2013. Formation of high crystalline ZIF-8 in an aqueous solution. *CrystEngComm*, 15(9):1794–1801. <https://doi.org/10.1039/c2ce26847g>.

- Lee, Y.R. , Jang, M. S., Cho, H. Y., Kwon, H. J., Kim, S., & Ahn, W. S. 2015. ZIF-8: A comparison of synthesis methods. *Chemical Engineering Journal*, 271:276–280. :<https://doi.org/10.1016/j.cej.2015.02.094>.
- Li, Q., Song, D., Zhan, X., Tong, X., Hu, C., & Tian, J. 2024. A networked iron and nitrogen-doped ZIF-8/MWCNTs heterostructure for oxygen reduction reaction. *The Journal of Chemical Physics*, 160(20):204704. <https://doi.org/10.1063/5.0201482>.
- Mustaqim, A., Yulianto, B., & Nugraha, N. 2018. Modification of ZIF-8 using direct mixing method at a room temperature. *IOP Conference Series: Materials Science and Engineering*, 432(1):6–9. <https://doi.org/10.1088/1757-899X/432/1/012053>.
- Pan, J., Yang, X., Zhou, J., Cheng, W., and Cheng, K. 2023. Novel ZIF-8/ZnS hollow polyhedral heterostructures derived from ZIF-8 with enhanced photocatalytic activity for degradation of aflatoxin B1. *Progress in Natural Science: Materials International*, 33(5): 575–580. <https://doi.org/https://doi.org/10.1016/j.pnsc.2023.11.001>.
- Pangastuti, P., Mudjahid, M.N., & Ediaty, R. 2015. Sintesis Zif-8 dengan metode solvotermal dalam pelarut etanol dan dimetilformamida, *Jurnal Sains dan Seni ITS*, 4(1):13–16.
- Park, K.S. , Ni, Z., Côté, A. P., Choi, J. Y., Huang, R., Uribe-Romo, F. J., Chae, H. K., O'keeffe, M., & Yaghi, O. M. 2006. *Exceptional chemical and thermal stability of zeolitic imidazolate frameworks*. www.pnas.org/cgi/doi/10.1073/pnas.0602439103.
- Parkash, A. 2020. Copper Doped Zeolitic Imidazole Frameworks (ZIF-8): A New Generation of Single-Atom Catalyst for Oxygen Reduction Reaction in Alkaline Media', *Journal of The Electrochemical Society*, 167(15): 155504. <https://doi.org/10.1149/1945-7111/abaaa5>.
- Sarwar, B., Khan, A. U., Aslam, M., Bokhari, A., Mubashir, M., Alothman, A.A., Ouladsmame, M., Aldossari, S.A., Chai, W.S., and Khoo, K. S. 2023. Comparative study of ZIF-8-materials for removal of hazardous compounds using physio-chemical remediation techniques. *Environmental Research*, 220:115168. <https://doi.org/10.1016/j.envres.2022.115168>.
- Sayed, M., Soliman, A. and Abdelhamid, H.N. 2024. Metal-organic framework (ZIF-8) for Knoevenagel condensation and multi-components Biginelli Reaction', *Journal of Solid State Chemistry*, 332: 124534. <https://doi.org/https://doi.org/10.1016/j.jssc.2023.124534>.
- Schejn, A. 2015. *Synthesis and catalytic activity of ZIF-8 and doped-ZIF-8 crystals . Stability and cytotoxicity evaluation*. Universite De Lorraine.
- Talukder, N., Wang, Y., Nunna, B. B., Tong, X., and Lee, E.S. 2024. An investigation on the structural stability of ZIF-8 in water versus water-derived oxidative species in aqueous environment. *Microporous and Mesoporous Material*, 266: 112934. <https://doi.org/10.1016/j.micromeso.2023.112934>.
- Tanaka, S. and Miyashita, R. 2017. Aqueous-system-enabled spray-drying technique for the synthesis of hollow polycrystalline ZIF-8 MOF Particles. *ACS Omega*, 2(10): 6437–6445. <https://doi.org/10.1021/acsomega.7b01325>.
- Wang, Q., Sun, Y., Li, S., Zhang, P., and Yao, Q. 2020. Synthesis and modification of ZIF-8 and its application in drug delivery and tumor therapy', *RSC Advances*, 10(62): 37600–37620. <https://doi.org/10.1039/d0ra07950b>.

- Yang, J.M., Liu, Q., & Sun, W.Y. 2014. Shape and size control and gas adsorption of Ni(II)-doped MOF-5 nano/microcrystals', *Microporous and Mesoporous Materials*, 190: 26–31. <https://doi.org/10.1016/j.micromeso.2014.01.020>.
- Yuliantika, L.A. 2016 *Synthesis and characterization of Sn-ZIF- 8 and applications as catalyst, Thesis*.