|  |  |  |
| --- | --- | --- |
|  | **Maghr. J. Pure & Appl. Sci., 2023, Vol. 9, Issue xx, Page xxx-xxx**  <https://revues.imist.ma/index.php/mjpas> | **Maghrebian Journal of Pure and Applied Science**  **e-ISSN : 2458-715X**  **Copyright © 2023,**  **University of Mohammed Premier**  **Oujda Morocco** |

# Design of Reactor for The Production of Zinc Oxide (ZnO) Nanoparticles Using The Direct Precipitation Method

**Anisa Noorlela1\*., Asep B. D. Nandiyanto1\*\*., Risti Ragadhita1., Teguh Kurniawan2**

*1Departement of Chemistry, Universitas Pendidikan Indonesia, Bandung, Indonesia*

*2Department of Chemical Engineering, Universitas Ageng Tirtayasa, Serang, Indonesia*

*\*Corresponding author, Email address:* [*anisanoorlela@upi.edu*](mailto:anisanoorlela@upi.edu)

*\*\*Corresponding author, Email address:* [*nandiyanto@upi.edu*](mailto:nandiyanto@upi.edu)

|  |  |
| --- | --- |
| **Received** xx xxx 2023, **Revised** xx xxx 2023, **Accepted** xx xxx 2023  **Keywords:**   * *ZnO nanoparticles;* * *Reactor design;* * *CSTR;* * *Mass balance* * *Reactor stirrer*   ***Citation****: Anisa N., Asep B. D. N., Risti R., Teguh K. (2023) Design of Reactor for The Production of Zinc Oxide (ZnO) Nanoparticles Using The Direct Precipitation Method, Maghr. J. Pure & Appl. Sci., 9(X), xxx-xxx. DOI:* | **Abstract:** This study aims to design a continuous stirred tank reactor (CSTR) type reactor used in the production of zinc oxide (ZnO) nanoparticles. Mass balance calculations were carried out in this study as a benchmark to find out whether the reactor was working properly by knowing the flow of incoming raw materials and the products produced by the reactor. Furthermore, the design of the reactor and the design of the stirrer used in the reactor is calculated manually using Microsoft Excel. Based on the calculation results of the reactor design, the reactor volume is 8224.359 liters, with a vessel diameter of 73.298 in, a cylinder height of 166.090 in and a cylinder thickness of 73.444 in. The top cover of the reactor measures 12.387 inches with a thickness of 0.072 inches while the bottom cover measures 21.185 inches with a thickness of 0.083 inches. So that the overall height of the reactor is 37.552 in. The reactor is equipped with 1 stirrer with an impeller diameter of 36.722 in, impeller height from the bottom of the tank is 24.433 in, impeller width is 7.344 in and impeller length is 9.180 in. Turbulent stirring flow conditions with a standard motor power for the stirrer is 6.849 HP. It is hoped that this design will serve as a reference for building more economical, more efficient and highly demanding reactors. |

# 1. Introduction

Zinc oxide (ZnO) is a type of n-type semiconductor from group II-VI which has a wide band gap of 3.2 eV at room temperature (Bessegato *et al*., 2015). This metal oxide has properties that are environmentally friendly, non-toxic and resistant to corrosion. This material has been widely studied for its activity as antifungal (Sun *et al*., 2018), antibacterial (Dadi *et al*., 2019), anti-inflammatory (Agarwal & Shanmugam, 2020), antimicrobial and antioxidant (Safawo *et al*., 2018), anticancer (Bisht & Rayamajhi, 2016), sunscreen (Lu *et al*., 2018), photoanode in solar cells (Sagadevan *et al*., 2020), photocatalyst (Khalafi *et al*., 2019), and anticorrosive (Setiawan, 2018). The characteristics and performance of ZnO are highly dependent on particle size, shape and morphology (Riwanda & Elvaswer, 2017). The synthesized ZnO particles can produce micro-sized particles to nanoparticles. Based on previous studies, ZnO nanoparticles have been widely used as rubber accelerators (Sahoo *et al*., 2007), efficient adsorbents (Lee *et al*., 2008), photocatalytic degradation (Tian *et al*., 2009), and as gas sensors (Lin *et al*., 1998), (J. Xu *et al*., 2000).

Several synthesis methods have been carried out to obtain ZnO nanoparticles, such as the direct deposition method (Siqingaowa *et al*., 2006), (Chen *et al*., 2008), the homogeneous deposition method (Song *et al*., 2008), the sol-gel technique (Mondelaers *et al*., 2002), and the hydrothermal processing method (Mamat *et al*., 2009), (H. Xu *et al*., 2004). At present, many industries for the manufacture of ZnO nanoparticles use homogeneous precipitation methods. However, there is a simpler method with cheaper raw materials needed, namely the direct deposition method. The direct precipitation method has several advantages, namely it can produce better particle size and morphology, finely dispersed active substances, and easy control of particle size as desired.

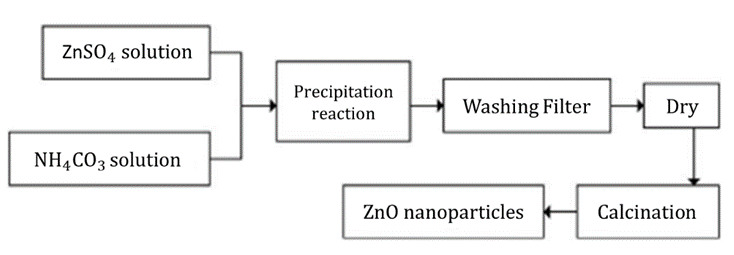
Various researchers have proposed several methods to prepare ZnO nanoparticles using direct precipitation methods, such as adding surfactants (Aimable *et al*., 2010) or using ultrasound fields. Hong *et al*. described how to synthesize ZnO nanoparticles by monodispersion direct precipitation method using a diameter of 30 nm. ZnAC2.2H2O and (NH4)2CO3 were slowly dripped into a vigorously stirred polyethylene glycol (PEG) solution, while surface modification of the synthesized ZnO nanoparticles was carried out by capping with oleic acid and SiO2 (Hong *et al*., 2006). Siqingaowa *et al*. prepared ZnO nanoparticles with ZnCl2.2H2O and (NH4)2CO3 as raw materials through the direct precipitation method with the help of an ultrasonic field, resulting in an average grain diameter of 12 nm (Siqingaowa *et al*., 2006).

In the industry to carry out the synthesis of a chemical, a tool is needed as a place where a reaction occurs, called a reactor. A reactor is a device that acts as a place for a reaction to occur, whether it's a chemical reaction where in this reaction a material can change from one form to another. In making reactors, it must be ensured that a reaction will produce the highest efficiency towards the desired output product, this is so that the industry that makes the reactor can minimize operational costs to obtain maximum product. So in this research to optimize the production of ZnO nanoparticles, it is necessary to design an efficient and accurate reactor design. So that it can be useful as a reference in designing reactors and as a teaching and learning method for the design process, working mechanism, to the performance of the reactor.

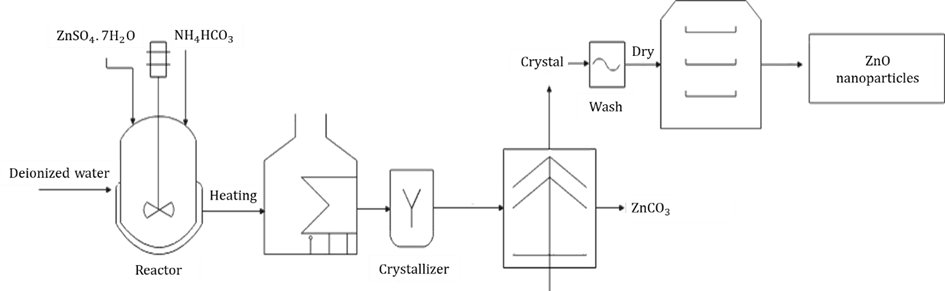
# 2. Methodology

## 2.1 Synthesis of ZnO Nanoparticles

The manufacture of ZnO nanoparticles is based on research that has been carried out by (Wang *et al*., 2010). The first step that must be done is to dissolve NH4HCO3 and ZnSO4·7H2O in deionized water. Then the dispersed feed is pressed through the membrane into the microchannel to mix with the continuous feed coming from the continuous feed inlet. The two solutions are mixed in the microchannel which will lead to saturation of the zinc hydroxy carbonate and produce a crystalline product. After this process, the by-product (NH4)2SO4 was removed by washing the powder with distilled water at room temperature (298 K) until no white precipitate was produced when the washing water was tested with 6% BaCl2 solution. After that, the precursor was washed with ethanol three times. The washed powder was then dried at 100°C overnight and followed by calcination. All precipitation experiments were carried out at room temperature. The schematic and PFD of the ZnO nanoparticle manufacturing process using the direct precipitation method are shown in **Figures 1 and 2**.



**Figure 1.** The overall procedure of preparing ZnO nanoparticles



**Figure 2.** PFD on the manufacture of ZnO nanoparticles

## 2.2 Mathematical Models for Designing Reactors

**Table 1** shows the reactor parameters to be calculated. Data analysis is in the form of manual calculations using basic Microsoft Office applications based on equations 1-20.

**Table 1.** Calculation of reactor parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Section** | **Parameter** | **Equation** | **Eq** |
| 1. | Reactor  Planning | Volume  Reaktor  (Vtotal) | Vtotal = V material + V free space | (1) |
| Vessel  Diameter  (𝐷𝑖) | Vtotal = V top lid + V cylin + V top cov  V = + x Ls + 0,0847 di3  𝐷𝑖 = vessel diameter  𝜋 = the value of 3.14  𝐿𝑠 = cylinder height | (2) |
| Volume of Liquid in The Cylinder  (𝑉𝑙𝑠) | Vls = V liq + V top lid  Vls = V liq  𝑉𝑙𝑠 = the volume of liquid in the cylinder  𝐷𝑖 = vessel diameter  𝜋 = the value of 3.14 | (3) |
| High Liquid in The Cylinder (L𝑙𝑠) | Lls =  𝐿𝑙𝑠 = high liquid in the cylinder  𝑉𝑙𝑠 = the volume of liquid in the cylinder  𝜋 = the value of 3.14  𝐷𝑖 = vessel diameter | (4) |
| Design  Pressure (Pi) | Pi = P atm + P hydrostatic  P hydrostatic = + C | (5) |
| Cylinder Thickness (Ts) | Ts = + C  𝑇𝑠 = cylinder thickness  𝑃𝑖 = design pressure  𝐷𝑖 = vessel diameter | (6) |
| Cylinder  Height (Ls) | Vtotal = V top lid + Vcylinder + V top cov  V total = + x Ls + 0,0847 di3  𝐷𝑖 = vessel diameter  𝜋 = the value of 3.14  𝐿𝑠 = cylinder height | (7) |
| Top Cover Thickness  (tha) | tha = + C  𝑡ℎa = top cover thickness  𝑃𝑖 = design pressure  𝐷𝑖 = vessel diameter | (8) |
| Top Cover Height (ha) | ha = 0,169 𝐷𝑖  ℎ𝑎 = top cover height  𝐷𝑖 = vessel diameter | (9) |
| Bottom Cover Thickness  (thb) | thb = + C  𝑃𝑖 = design pressure  𝐷𝑖 = vessel diameter | (10) |
| Bottom Cover Height  (hb) | hb = | (11) |
| 2. | Reactor  stirrer | Impeller Diameter  (Da) | Da = Dt × 0.5  𝐷𝑎 = impeller diameter  𝐷𝑡 = cylinder inside diameter | (12) |
| Impeller  Height from Tank Bottom  (C) | C = × 𝐷𝑖  𝐶 = cylinder inside diameter  𝐷𝑖 = vessel diameter | (13) |
| Impeller  Length (L) | L = × 𝐷𝑎  𝐿 = impeller length  𝐷𝑎 = impeller diameter | (14) |
| Impeller  Width (W) | W = 0.20 × 𝐷𝑎  𝑊 = impeller width  𝐷𝑎 = impeller diameter | (15) |
| Number of Stirrer (n) | n =  𝑛 = the number of stirrer  𝐷𝑎 = impeller diameter | (16) |
| Reynold  Number  (NRe) | 𝑁𝑅𝑒 =  𝑁𝑅𝑒 = the Reynold number  𝐿 = impeller length  𝑛 = stirrer rotation, set = 100 rpm = 1,67 rps  𝜌 = density (lb/ft3) | (17) |
| Stirring Power (P) | P =  P required = (0,1 + 0,15)P + P  P = stirring power  𝜌 = density (lb/ft3)  𝐷𝑖 = impeller diameter  𝑔𝑐 = 32,2 lb.ft/s2.lbf | (18) |
| Stirrer Shaft Diameter  (D) | D =  𝐷 = stirrer shaft diameter  𝑇 = torsion number (lb.in = )  𝜋 = the value of 3.14  𝑆 = maximum allowable design shearing stress | (19) |
| Shaft Length  (L) | 𝐿 = ℎ + 𝑙 − 𝑍𝑖  ℎ = cylinder height + top cover height  𝑙 = impeller distance from tank bottom  𝑍𝑖 = length of shaft above tank vessel | (20) |

# 3. Results and Discussion

## 3.1 Main Reaction

In this research the production of zinc oxide (ZnO) was carried out using a Continuous Stirred Tank Reactor (CSTR) type reactor. The precursor compounds used in the synthesis of ZnO nanoparticles are NH4HCO3 and ZnSO4·7H2O. The reactions that occur in this production process are shown in equations number (1) and (2).

5ZnSO4(aq) + 10NH4HCO3(aq) → Zn5(CO3)2(OH)6(s) + 5(NH4)2SO4(aq) + 8CO2(g) + 2H2O(l) **(1)**

Zn5(CO3)2(OH)6(s) → 5ZnO(s) + 2CO2(g) + 3H2O(g) **(2)**

The above reaction shows that when NH4HCO3 is reacted with ZnSO4·7H2O it will produce white solid ZnO as the main product and white solid (NH4)2SO4 as a side product.

## 3.2 Reactor Type

The reactor is a process tool where a reaction takes place, both in small sizes such as test tubes to large sizes such as industrial scale reactors. In this study, the reactor was used as a place for the reaction between NH4HCO3 and ZnSO4·7H2O to produce white ZnO nanoparticles as the main product. The reactor used in this study was the CSTR type in the form of an upright cylinder with a standard dished top lid and a conical bottom lid with a peak angle of 120° and using SA 240 Grade M Type 316 stainless steel. In the CSTR type reactor, parameters such as temperature, concentration, and the rate of reaction between the reacting substances will be the same at all positions of the reactor. In controlling a reactor system, several controls are needed to be placed on the CSTR reactor, one of which is a pressure controller. High and continuous pressure in the system can cause an explosion. So that the pressure in a closed system needs to be maintained by controlling the pressure in the reactor to keep it safe.

In addition to controlling pressure, stirrers are also very important in the manufacture of CSTR type reactors. The success of a treatment process often depends on the effective mixing of the liquids in the process. Agitation is the reduction of movement in a certain way in a material in a vessel, where the movement usually has some sort of circulation. The purpose of stirring is to create a suspension of solid particles, to dissolve liquids that cannot be mixed with other liquids, to form fine-grained emulsions or suspensions, and to accelerate heat transfer between the liquid and the mantle. Mixer is expected to produce the best mix with the lowest possible power. In CSTR, reactants and products flow continuously. Raw materials are continuously added and reaction products are continuously removed during the process. To achieve uniform composition and temperature, CSTR requires mechanical or hydraulic stirring. Description of the ideal reactor for CSTR can be achieved with perfect stirring conditions to produce a well-mixed reaction mixture. To achieve high homogeneity, perfect mixing is required so that the composition and temperature are uniform at all points, assuming the density does not change (negligible) because the volume does not change.

## 3.3 Reactor Parameter Calculation Results

The results of mass balance calculations can be used to select the appropriate type of tool and size, as well as to provide volume for the process (Meijon Fadul, 2019). **Table 2** shows the results of mass balance calculations in ZnO production.

**Table 2.** Recapitulation of the mass balance of ZnO production

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Component** | **Mr**  **(g/mol)** | **Reactants** | | | **Product** | | |
| **Massa** | **Mol** | **Fr.Mol** | **Mol** | **Fr.Mol** | **Massa** |
| Zn5(CO3)2(OH)6 | 548.96 | 4742.840 | 8.640 | 0.044 | 0.432 | 0.001 | 237.142 |
| 5ZnO | 406.90 | 5435.420 | 13.358 | 0.069 | 76.810 | 0.113 | 31253.666 |
| 2CO2 | 88.02 | 5850.968 | 66.474 | 0.342 | 192.774 | 0.285 | 16967.807 |
| 3H2O | 54.05 | 5712.452 | 105.696 | 0.544 | 406.931 | 0.601 | 21992.941 |
| Total |  | 21741.680 | 194.168 | 1.000 | 676.947 |  | 70451.555 |

Based on the data, it is known that the mass of Zn5(CO3)2(OH)6 that enters is 4742.840 kg/h. While the masses of ZnO, CO2, and H2O that came out were 5435.420; 5850.968; and 5712.452 kg/h. So that the total product mass obtained from the reactor is 70451.555 kg/h.

Next, the calculation of the dimensions of the reactor is carried out. The type of reactor used is an upright cylinder with a standard dish top lid and a conical bottom lid with a peak angle of 120°. The condition of the reactor for the manufacture of ZnO nanoparticles was at a temperature of 100°C, a pressure of 1 atm with an operating time of 1 hour, had an allowable stress (f) of 18750, double welded butt joint E of 0.8, and a corrosion factor of 0.0625. **Table 3** shows the results of calculating the general dimensions of the reactor.

**Table 3.** Reactor dimension specifications based on calculation results

|  |  |  |
| --- | --- | --- |
| **No.** | **Parameter** | **Result** |
| 1. | Type of reactor | Upright cylinder with standard dished top cap and conical bottom cap with a peak angle of 120° |
| 2. | Volume Reaktor (𝑉𝑡𝑜𝑡𝑎𝑙) | 8224.359 liter |
| 3. | Vessel Diameter (𝐷𝑖) | 73.298 in |
| 4. | Volume of Liquid in The Cylinder (𝑉𝑙𝑠) | 6114.993 liter |
| 5. | High Liquid in The Cylinder (𝐿𝑙𝑠) | 2505.423 in |
| 6. | Design Pressure (Pi) | 4.304 psig |
| 7. | Cylinder Thickness (Ts) | 73.444 in |
| 8. | Cylinder Height (Ls) | 166.090 in |
| 9. | Top Cover Thickness (tha) | 0.072 in |
| 10. | Top Cover Height (ha) | 12.387 in |
| 11. | Bottom Cover Thickness (thb) | 0.083 in |
| 12. | Bottom Cover Height (hb) | 21.185 in |
| 13. | Reactor Height | 37.552 in |

The results of calculating the dimensions of the reactor obtained a reactor volume of 8224.359 liters, with a vessel diameter of 73.298 in, a cylinder height of 166.090 in and a cylinder thickness of 73.444 in. After getting the diameter of the vessel, the next calculation is to calculate the height of the top cover and the height of the bottom cover. Such calculations will yield an overall high result. The result of the top cover calculation is 12.387 in with a thickness of 0.072 in while the result of the bottom cover calculation is 21.185 in with a thickness of 0.083 in. So that the overall height of the reactor is 37.552 in.

The dimensions of each component including the calculation of the stirrer from the reactor also need to be considered. Stirrer or it can also be called an agitator generally consists of a series of motors as a drive pad and an impeller or blade that is adapted to the organic organic materials used. The existence of stirring in the process of forming ZnO nanoparticles will form a flow pattern in the reactor. The type of stirrer to be used is an axial turbine with 4 blades at an angle of 45° with impeller construction made of High Alloy Steel SA 240 Grade M type 314, and the material used for the construction of the stirrer shaft is Hot Rolled Steel SAE 1040. After selecting the stirrer plan, then calculating the dimensions. stirrer to be used, the calculation results are presented in **Table 4**.

**Table 4.** Specification of stirring dimensions based on calculation results

|  |  |  |
| --- | --- | --- |
| **No.** | **Parameter** | **Result** |
| 1. | Impeller Diameter (Da) | 36.722 in |
| 2. | Impeller Height from Tank Bottom (C) | 24.433 in |
| 3. | Impeller Length (L) | 9.180 in |
| 4. | Impeller Width (W) | 7.344 in |
| 5. | Number of Stirrer (n) | 1 piece |
| 6. | Reynold Number (NRe) | 99796.530 |
| 7. | Stirring Power (P) | 6.849 Hp |
| 8. | Stirrer Shaft Diameter (𝐷) | 1.070 in |
| 9. | Shaft Length (𝐿) | 163.224 in |

In the calculation obtained the number of stirrers 1 unit with an impeller diameter of 36.722 in, impeller height from the bottom of the tank 24.433 in, impeller width of 7.344 in and impeller length of 9.180 in. It is known that the plate used in the stirrer is an axial turbine type with 4 blades angle of 45°. Turbine stirrer type is a type of stirrer that has many blades and is shorter in size. This type of stirrer is used at high speeds for liquids over a very wide range of viscosities. The turbine agitator diameter is 30 - 50% of the tank diameter. In turbines with 45° inclined blades, several axial flows will be generated so that a combination of axial and radial flows will be formed. This type is useful in suspension of solids because the flow is directly downward and will sweep the solids upward.

The amount of input power obtained is 6.849 Hp. Mixing power is the power that utilizes the occurrence of chemical reactions from raw materials to the desired product. The power of this stirrer will affect the magnitude of the resulting velocity gradient. Stirring power is generated by the mixing system, for example the stirrer and its rotational speed, water flow, airflow, and so on. In the calculation of the stirrer shaft with a shaft power of 6.849 Hp with a stirrer rotation of 100 rpm, the diameter of the stirrer shaft is 1.070 in and the length of the shaft is 163.224 in. The shaft serves as a transmission of power or torque which is usually round in cross-section. Based on the literature, the material used for the manufacture of the shaft must be selected which is corrosion resistant (Meijon Fadul, 2019). Therefore the shaft material used in this design is Hot Rolled Steel SAE 1040 which is corrosion resistant.

In addition, the Reynolds number is 99796.530. The Reynolds number is the ratio between inertia and viscosity. Processes with mechanical agitators occur under conditions of laminar or turbulent flow, depending on the Reynolds number of the impeller. The type of flow that occurs here is turbulent flow because the value of Re > 2100. Turbulent flow is a fluid flow in which the particles move randomly and are unstable which causes the flow lines between the fluid particles to intersect. So that the opportunity for materials to interact or collide with each other is greater than in laminar conditions, namely fluid conditions that move statically and regularly without crossing each other. The agitator with this type of turbulent flow provides the best possible mixing.

# Conclusion

Based on the calculation of the reactor design, the obtained reactor volume is 8224.359 liters, with a vessel diameter of 73.298 in, cylinder height of 166.090 in, and cylinder thickness of 73.444 in. The top cover of the reactor measures 12.387 inches with a thickness of 0.072 inches while the bottom cover measures 21.185 inches with a thickness of 0.083 inches. So the overall height of the reactor is 37.552 in. The reactor is equipped with 1 stirrer with an impeller diameter of 36.722 in, impeller height from the bottom of the tank is 24.433 in, impeller width is 7.344 in, and impeller length is 9.180 in. Turbulent stirring flow conditions with a standard motor power for the stirrer is equal to 6.849 HP. This design is expected to be a reference for building more economical, efficient and high-demand reactors.

# Acknowledgement, The technical inputs of Mr xxxx of Engineering Department are acknowledged.

# Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.

*Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

# References

Bessegato, G. G., Guaraldo, T. T., de Brito, J. F., Brugnera, M. F., & Zanoni, M. V. B. (2015). Achievements and trends in photoelectrocatalysis: from environmental to energy applications. *Electrocatalysis*, *6*(5), 415-441.

<https://link.springer.com/article/10.1007/s12678-015-0259-9>

Sun, Q., Li, J., & Le, T. (2018). Zinc oxide nanoparticle as a novel class of antifungal agents: current advances and future perspectives. *Journal of agricultural and food chemistry*, *66*(43), 11209-11220.

<https://pubs.acs.org/doi/abs/10.1021/acs.jafc.8b03210>

Dadi, R., Azouani, R., Traore, M., Mielcarek, C., & Kanaev, A. (2019). Antibacterial activity of ZnO and CuO nanoparticles against gram positive and gram negative strains. *Materials Science and Engineering: C*, *104*, 109968. <https://www.sciencedirect.com/science/article/pii/S0928493119307192>

Agarwal, H., & Shanmugam, V. (2020). A review on anti-inflammatory activity of green synthesized zinc oxide nanoparticle: Mechanism-based approach. *Bioorganic chemistry*, *94*, 103423.

<https://www.sciencedirect.com/science/article/pii/S0045206819315020>

Safawo, T., Sandeep, B. V., Pola, S., & Tadesse, A. (2018). Synthesis and characterization of zinc oxide nanoparticles using tuber extract of anchote (Coccinia abyssinica (Lam.) Cong.) for antimicrobial and antioxidant activity assessment. *OpenNano*, *3*, 56-63.

<https://www.sciencedirect.com/science/article/pii/S2352952018300306>

Bisht, G., & Rayamajhi, S. (2016). ZnO nanoparticles: a promising anticancer agent. *Nanobiomedicine*, *3*(Godište 2016), 3-9. <https://hrcak.srce.hr/clanak/232449>

Lu, P. J., Fang, S. W., Cheng, W. L., Huang, S. C., Huang, M. C., & Cheng, H. F. (2018). Characterization of titanium dioxide and zinc oxide nanoparticles in sunscreen powder by comparing different measurement methods. *journal of food and drug analysis*, *26*(3), 1192-1200.

<https://www.sciencedirect.com/science/article/pii/S1021949818300383>

Sagadevan, S., Vennila, S., Suraiya Begum, S. N., Wahab, Y. A., Hamizi, N. A. B., Marlinda, A. R., ... & Algarni, H. (2020). Influence of incorporated barium ion on the physio-chemical properties of zinc oxide nanodisks synthesized via a sonochemical process. *Journal of nanoscience and nanotechnology*, *20*(9), 5452-5457. <https://www.ingentaconnect.com/contentone/asp/jnn/2020/00000020/00000009/art00023>

Khalafi, T., Buazar, F., & Ghanemi, K. (2019). Phycosynthesis and enhanced photocatalytic activity of zinc oxide nanoparticles toward organosulfur pollutants. *Scientific reports*, *9*(1), 1-10.

<https://www.nature.com/articles/s41598-019-43368-3>

Setiawan, A. (2018). Sintesis dan Karakterisasi ZnO sebagai Coating Antikorosi ZnO/Al (OH) 3 Pada Material Baja Karbon. *Jurnal Teknik*, *39*(1), 55-61.

<http://download.garuda.kemdikbud.go.id/article.php?article=1394664&val=1254&title=Sintesis%20dan%20Karakterisasi%20ZnO%20sebagai%20Coating%20Antikorosi%20ZnOAlOH3%20Pada%20Material%20Baja%20Karbon>

Riwanda, R., & Elvaswer, E. (2017). Karakteristik Arus-Tegangan Komposit dari Bahan Semikonduktor ZnO-TiO2 Sebagai Sensor Gas Hidrogen. *Jurnal Fisika Unand*, *6*(3), 211-216.

<http://jfu.fmipa.unand.ac.id/index.php/jfu/article/view/293>

Sahoo, S., Maiti, M., Ganguly, A., Jacob George, J., & Bhowmick, A. K. (2007). Effect of zinc oxide nanoparticles as cure activator on the properties of natural rubber and nitrile rubber. *Journal of applied polymer science*, *105*(4), 2407-2415.

<https://onlinelibrary.wiley.com/doi/abs/10.1002/app.26296>

Lee, Y. J., Park, N. K., Han, G. B., Ryu, S. O., Lee, T. J., & Chang, C. H. (2008). The preparation and desulfurization of nano-size ZnO by a matrix-assisted method for the removal of low concentration of sulfur compounds. *Current Applied Physics*, *8*(6), 746-751.

<https://www.sciencedirect.com/science/article/pii/S1567173907001368>

Tian, J., Chen, L., Yin, Y., Wang, X., Dai, J., Zhu, Z., ... & Wu, P. (2009). Photocatalyst of TiO2/ZnO nano composite film: preparation, characterization, and photodegradation activity of methyl orange. *Surface and Coatings Technology*, *204*(1-2), 205-214.

<https://www.sciencedirect.com/science/article/pii/S0257897209005787>

Lin, H. M., Tzeng, S. J., Hsiau, P. J., & Tsai, W. L. (1998). Electrode effects on gas sensing properties of nanocrystalline zinc oxide. *Nanostructured Materials*, *10*(3), 465-477.

<https://www.sciencedirect.com/science/article/pii/S0965977398000877>

Xu, J., Pan, Q., & Tian, Z. (2000). Grain size control and gas sensing properties of ZnO gas sensor. *Sensors and Actuators B: Chemical*, *66*(1-3), 277-279.

<https://www.sciencedirect.com/science/article/pii/S0925400500003816>

Siqingaowa, Z., & Yao, H. (2006). Preparation and characterization of nanocrystalline ZnO by direct precipitation method. *Frontiers of Chemistry in China*, *1*(3), 277-280.

<https://link.springer.com/article/10.1007/s11458-006-0036-7>

Chen, C., Liu, P., & Lu, C. (2008). Synthesis and characterization of nano-sized ZnO powders by direct precipitation method. *Chemical Engineering Journal*, *144*(3), 509-513.

<https://www.sciencedirect.com/science/article/pii/S1385894708004440>

Song, R., Liu, Y., & He, L. (2008). Synthesis and characterization of mercaptoacetic acid-modified ZnO nanoparticles. *Solid State Sciences*, *10*(11), 1563-1567.

<https://www.sciencedirect.com/science/article/pii/S1293255808000551>

Mondelaers, D., Vanhoyland, G., Van den Rul, H., D’haen, J., Van Bael, M. K., Mullens, J., & Van Poucke, L. C. (2002). Synthesis of ZnO nanopowder via an aqueous acetate–citrate gelation method. *Materials research bulletin*, *37*(5), 901-914.

<https://www.sciencedirect.com/science/article/pii/S0025540802007274>

Mamat, M. H., Sahdan, M. Z., Amizam, S., Rafaie, H. A., Khusaimi, Z., & Rusop, M. (2009). Properties of Nanostructured Zinc Oxide by Hydro‐Thermal Aqueous Chemical Growth Method. In *AIP Conference Proceedings* (Vol. 1136, No. 1, pp. 586-590). American Institute of Physics.

<https://aip.scitation.org/doi/abs/10.1063/1.3160212>

Xu, H., Wang, H., Zhang, Y., He, W., Zhu, M., Wang, B., & Yan, H. (2004). Hydrothermal synthesis of zinc oxide powders with controllable morphology. *Ceramics International*, *30*(1), 93-97.

<https://www.sciencedirect.com/science/article/pii/S0272884203000695>

Aimable, A., Buscaglia, M. T., Buscaglia, V., & Bowen, P. (2010). Polymer-assisted precipitation of ZnO nanoparticles with narrow particle size distribution. *Journal of the European Ceramic Society*, *30*(2), 591-598.

<https://www.sciencedirect.com/science/article/pii/S0955221909003148>

Hong, R., Pan, T., Qian, J., & Li, H. (2006). Synthesis and surface modification of ZnO nanoparticles. *Chemical Engineering Journal*, *119*(2-3), 71-81.

<https://www.sciencedirect.com/science/article/pii/S1385894706000969>

Wang, Y., Zhang, C., Bi, S., & Luo, G. (2010). Preparation of ZnO nanoparticles using the direct precipitation method in a membrane dispersion micro-structured reactor. *Powder Technology*, *202*(1-3), 130-136.

<https://www.sciencedirect.com/science/article/pii/S0032591010002184>

Himmelblau, D. M., & Riggs, J. B. (2012). *Basic principles and calculations in chemical engineering*. FT press.

<https://books.google.com/books?hl=en&lr=&id=Jk26u6f5-roC&oi=fnd&pg=PR7&dq=+D.+M.+Himmelblau+and+J.+B.+Riggs,+Basic+principles+and+calculations+in+chemical+engineering,+FT+press,+(2012).&ots=7HhsSaqt5F&sig=OzzZtNyP1FVhuZF79dxkkypYVug>

(2023) ; <http://www.jmaterenvironsci.com>