JURNAL TEKNIK MESIN
(JOURNAL OF MECHANICAL ENGINEERING)

VOL. 14, NO. 02 , June 2025
https://publikasi.mercubuana.ac.id/index.php/jtm/index
DOI :10.22441/jtm.v14i2.31993

Analysis of the Effect of Temperature Variations and Natural Gas Flow on the Quality of Zinc Oxide (ZnO) Using the French Method

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Abstract--*This study aims to analyze the effect of temperature and gas flow variations on the quality of Zinc Oxide (ZnO) produced in terms of particle size and product purity using the French method. The French method is a standard production technique used to manufacture ZnO, which utilizes the oxidation of zinc metal at high temperatures. The problem in the ZnO manufacturing process is determining what natural gas temperature and flow will be used to obtain the best quality, considering fuel consumption and production efficiency. In this study, temperature variations of 900°C, 1000°C, and 1100°C and natural gas flow using CNG (Compressed Natural Gas) with variations of 50 m³/hour, 55m³/hour, 60m³/hour were applied to understand how these parameters affect the properties of the resulting ZnO, characterization of the results was carried out using the complexometric titration method with ethylenediaminetetraacetic acid (EDTA) solution to determine the purity of the resulting ZnO and using a laser diffraction instrument to examine the size of ZnO particles. The results showed that the process temperature significantly affected the purity of ZnO. At a temperature of 1100 °C, the purity of ZnO reached 99.94%, which is the testing value in this study. At a gas flow of 60 m³/h, the purity of ZnO tends to be stable at a value of 99.93–99.94%. Meanwhile, the results of particle measurements at a temperature of 900°C with a gas flow of 50 m³/h, D50 reached 1.235 µm. At a temperature of 1100°C with a gas flow of 60 m³/h, D50 decreased to 1.089 µm. This particle size indicates that high temperatures encourage agglomeration reduction, resulting in finer ZnO particles. This study concludes that temperature and gas flow parameters play an important role in controlling the quality of ZnO produced through the method, with oxygen gas flow at high temperatures giving optimal results.*

Article History:
Received: January 26, 2025
Revised: January 28, 2025
Accepted: January 30, 2025
Published: June 09, 2025
Keywords: *Zinc Oxide, French Method, Temperature Variation, Gas Flow, ZnO, CNG*

1. INTRODUCTION

Zinc oxide (ZnO) is a multifunctional inorganic material with superior properties, such as electrical conductivity, thermal stability, antimicrobial properties, and high optical transparency. Therefore, ZnO is widely used in various industrial applications, including as an additive in cosmetics, a semiconductor component in electronic devices, and a coating in the paint and rubber industry [1]. The quality of ZnO used for this application is primarily determined by its physical and chemical properties, such as particle size, crystal morphology, and purity. The ZnO production process is crucial to ensure this quality can be achieved. This study used the French process method, which changes the zinc ingot heated in a furnace using CNG (Compressed Natural Gas) fuel at high temperatures, evaporating and oxidizing into zinc oxide (ZnO). This process was first developed in the 19th century and remains popular today because of its ability to produce ZnO with high purity and in large quantities [2]. However, although this process is known to be efficient, there are several challenges faced in improving the quality of the resulting ZnO, especially in controlling the particle size and crystal structure of ZnO.

In addition to temperature, the natural gas flow used as fuel in the French Process has a significant influence. Natural gas (CNG) plays a role in maintaining the temperature in the furnace and ensuring optimal combustion. Improper natural gas flow can cause uneven heat distribution, ultimately affecting the zinc oxidation process and the quality of the zinc oxide produced [3]. Efficient use of natural gas is also important in sustainability and reducing production costs, especially in industries oriented towards energy efficiency. In several previous studies, many studies have been conducted on the effect of temperature on ZnO production. However, few have explored the combined effect of temperature and natural gas flow in the French Process. Combining these two factors may offer a more optimal approach to producing ZnO with certain specifications, such as uniform nanoparticle size and high purity. This research is important considering the increasing industrial need for high-quality ZnO, especially for high-tech applications such as sensors, electronic devices, and photocatalysts [5].

This study aims to determine the effect of temperature variations and natural gas flow on the quality of zinc oxide, namely ZnO purity and particle size. This study is important because the results can guide the industry in improving the quality of ZnO products while optimizing energy efficiency in the production process. With a better understanding of the interaction between temperature and gas flow, this study is expected to significantly improve the performance of zinc oxide production in the industry. This background explains the importance of the research topic, the problems to be solved, and the study's relevance in the context of industrial applications.

2. RESEARCH METHODS

The temperature variations to be used are 900°C, 1000°C, and 1100°C. This temperature range is selected based on previous research stating that temperatures are relevant for zinc oxide production using the French Process. The natural gas flow will be varied at three levels, namely 50 m^3/hour, 55 m^3/hour, and 60 m^3/hour.

2.1 ZnO Purity Testing

The purity of ZnO will be analyzed using a complexometric titration method using a standard EDTA solution (0.05 mol/L), as shown in **Figure 1.** ZnO purity testing equipment and instruments, the sample is weighed 0.15 grams (± 0.001 grams), which has been dried previously in an oven at a temperature of (105°C ± 2) for 1 hour. Put it into a 500 mL Erlenmeyer flask and moisten it with water. Add 3 mL of HCl (1:1) and shake until dissolved. Add 200 mL of water. Neutralize with ammonia (1:1) to pH 7-8 (zinc oxide precipitate appears). Add 10 mL of buffer. Ammonia-Ammonium Chloride and five drops of Chrome Black T indicator. Titrate with 0.05 mol/L EDTA standard solution until the sample solution changes from purple to blue. Record the Volume of 0.05 mol/L EDTA used during the titration process.

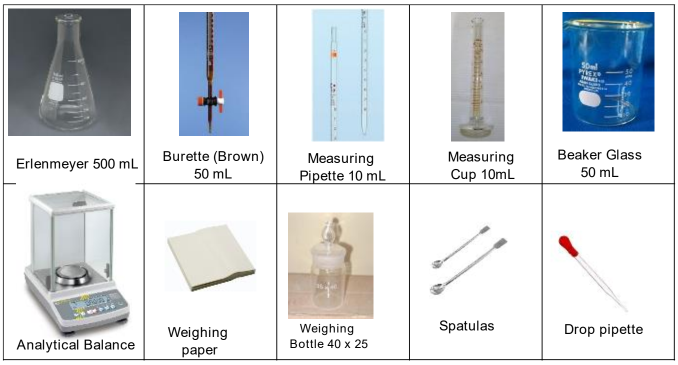

Figure 1. ZnO purity testing devices and instruments

After that, it will be entered into the formula:

$$X = \frac{C \times V \times 0{,}08138}{m} \times 100\% \qquad (1)$$

X = Purity of ZnO
C = Concentration of standard EDTA solution (mol/L)
V = Volume of standard EDTA solution used for sample titration (mL)
m = Mass of the weighed sample (grams)

2.2 ZnO Particle Size Testing

Laser diffraction utilizes the interaction of light with particles to determine particle size distribution. The Bettersize BT-2600 Laser Diffraction Instrument is a particle size distribution measuring instrument that uses the laser diffraction method shown in Figure 2. The Bettersize BT-2600 Laser Diffraction Instrument is designed to measure small particles in a specific size range accurately. It is commonly used in various industries, including chemicals, pharmaceuticals, and technological materials such as ZnO. Laser diffraction technology ensures precise particle size distribution measurements, measuring particle sizes from 0.1 µm to several millimeters. The measurement results can be visualized in the form of particle distribution graphs.

Figure 2. Bettersize BT-260 Laser Diffraction Instrument (www.bettersizeinstruments.com 2024)

3. RESULTS AND DISCUSSION

Process temperature has a significant effect on the purity of ZnO. At low temperatures (900–950 °C), the purity of ZnO is slightly lower than at high temperatures (1050–1100 °C). This is due to impurity compounds' more optimal decomposition process at high temperatures, resulting in ZnO with higher purity. At a temperature of 1100 °C, the purity of ZnO reaches 99.94%, and the testing value in this study is shown in Table 1—results of the ZnO purity study. The process at high temperatures accelerates the reaction between EDTA solution and Zn^2 ions$^+$, thus reducing the possibility of impurities. Variations in gas flow also have an impact on the purity of ZnO. A higher gas flow (60 m^3/h) produces better ZnO purity than a lower one (50 m^3/h). Higher gas flow supports a more even heat distribution in the furnace, allowing a more perfect reaction process. At a gas flow of 60 m^3/h, the purity of ZnO tends to be stable at 99.93–99.94%, indicating that this condition is optimal for reducing impurities in the product. The complexometric titration method with EDTA used in this study showed good accuracy and precision for measuring the purity of ZnO. The Concentration of EDTA solution of 0.049711 mol/L and the average solution volume of 38.95 mL provided consistent calculation results. The calculation process for the purity of ZnO is based on the complex reaction between EDTA and Zn^2 ions, which follows a 1:1 reaction stoichiometry. Thus, this method is feasible for characterizing the purity of ZnO under various fabrication conditions. The results of this study indicate that increasing the process temperature and gas flow can significantly improve the purity of ZnO. For industrial applications, especially in anticorrosive coatings, high purity (>99.9%) is essential to ensure optimal performance.

Table 1. Results of ZnO purity research

Sample	*Temperature (℃)*	*Gas Flow (Sm^3/h)*	*EDTA Solution Concentration (mol/L)*	*Volume of EDTA solution (mL)*	*Sample weight (grams)*	*ZnO Purity (%)*
1	900-920	50	0.04971	38.95	0.1578	99.86%
2	930-950	50	0.04971	37.49	0.1518	99.91%
3	960-980	50	0.04971	38.95	0.1577	99.92%
4	990-1010	55	0.04971	38.11	0.1543	99.92%
5	1020-1040	55	0.04971	37.72	0.1527	99.93%
6	1050-1070	60	0.04971	39.06	0.1581	99.94%
7	1080-1100	60	0.04971	38.02	0.1539	99.94%

The results of particle size measurements of Zinc Oxide (ZnO) produced using the French method, with variations in temperature and gas flow, are presented in Table 2. Measurements were carried out using a BT-2600SE laser diffraction instrument, producing particle size parameters such as D03, D10, D50, D90, and D97. The D50 value represents the average particle size, where 50% of the particles are above or below that value. D03, D10, D16 These parameters indicate the particle size distribution in the smallest range, which provides information about the dominant particle size. D90 and D97 These values indicate the most extensive particle size distribution, providing an overview of the coarse particles that may be formed. A combination of temperature parameters and gas flow rates in the production process influences the particle size distribution. The measurement data shows a decreasing trend in particle size (D50) and increasing temperature from 900°C to 1100°C. For example: At 900°C with a gas flow of 50 m^3/h, the D50 reaches 1.235 µm. At 1100°C with a gas flow of 60 m^3/h, the D50 decreases to 1.089 µm. This decrease in particle size indicates that high temperature promotes agglomeration reduction, resulting in finer ZnO particles. Effect of Gas Flow Rate on Particle Size Increasing the gas flow rate from 50 m^3/h to 60 m^3/h also contributes to the decrease in particle size. This may be due to the faster cooling rate inhibiting particle growth.

Table 2. Results of research on ZnO particle size

Sample	*Temperature (℃)*	*Gas Flow (Sm^3/h)*	D03	D10	D50	D90	D97
1	900-920	50	1.008	1.010	1.235	1.706	1.890
2	930-950	50	1.105	1.010	1.235	1.706	1.890
3	960-980	50	1.005	0.985	1.145	1.696	1.798
4	990-1010	55	0.943	0.978	1.141	1.358	1.473
5	1020-1040	55	0.929	0.975	1.140	1.353	1.468
6	1050-1070	60	0.842	0.910	1.110	1.358	1.473
7	1080-1100	60	0.828	0.880	1.090	1.324	1.439

The particle size distribution graph obtained from the BT-2600SE measurement shows a peak at a size of 1.124 µm with a focused distribution value, as shown in Figure 3. Test results using the Bettersize BT-2600SE Laser Diffraction Instrument

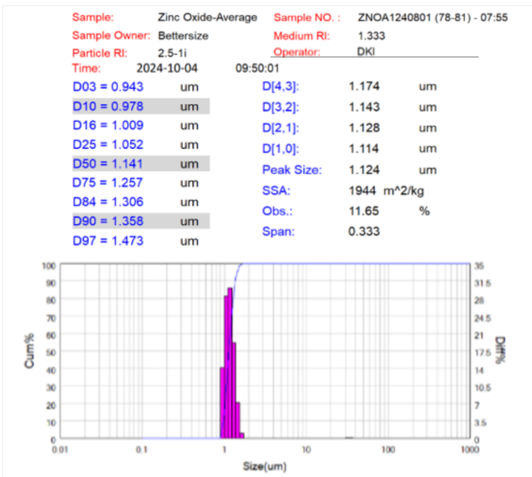

Figure 3. Test results Bettersize BT-2600SE Laser Diffraction Instrument

Smaller particle size (D50 < 1.1 µm) shows high potential for anti-corrosion coating application on mild steel. Uniform particle size will provide efficiency in covering the surface of the steel substrate, reducing the possibility of micro-crack formation that can trigger corrosion. The combination of high temperature (1100°C) and gas flow of 60 m^3/h gives optimal results to obtain ZnO with smaller particle size and uniform distribution. These parameters can be used as a reference in industrial-scale fabrication. The span of particle size distribution was calculated to evaluate uniformity. The Span value = 0.333 indicates a narrow particle size distribution, which means ZnO is uniform and suitable for specific applications such as coating materials. The results of this research are similar to previous research by Mishra Y K and Adelung R, who also found that the narrow particle size distribution of ZnO plays an important role in increasing the effectiveness and quality of coatings, especially in anti-corrosion, optical coating, and UV protection applications. This shows that optimizing the ZnO particle size in the production process is crucial to producing products with high performance in the coating industry [7].

4. CONCLUSION

Increasing the temperature using the French method significantly increases the purity of ZnO. At 1100°C, the purity reached 99.94%, indicating a more optimal decomposition process of impurity compounds. Variations in gas flow affect the quality of ZnO, a gas flow of 60 m^3/hour provides a more stable and higher ZnO purity of 99.93–99.94% compared to a lower gas flow. Combining a temperature of 1100°C and a gas flow of 60 m^3/h produces ZnO with a small particle size and high purity, making it optimal operating conditions for industrial applications.

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