

CARBON CAPSULES: A SMART SOLUTION FOR RENEWABLE LIGHT ENERGY CONDUCTORS

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Abstract: This research explored the potential of pencil graphite as an alternative filament in incandescent lamps, replacing the commonly used tungsten. Using a quantitative approach and experimental methods, the study tested the effectiveness of two forms of graphite, rods and powder, as electrical conductors. The results showed that the graphite rods, with a voltage of 8.18 V and a current of 9.0 A, were able to conduct electricity and produce light, making them a potential alternative filament for incandescent lamps. In contrast, the graphite powder could not generate a significant electric current because of its high electrical resistance, which resulted from low particle density. Further analysis showed that the electrical resistance of the graphite rods was quite low, allowing the current to flow efficiently and the rods to emit light. This study concludes that graphite rods have potential as environmentally friendly and economical filaments in incandescent lamps, whereas graphite powder proved ineffective as an electrical conductor. This research provides initial insights for the development of more sustainable lighting technologies, although additional research is needed to evaluate the durability and energy efficiency of graphite in practical applications.

Keywords: *energy efficiency, graphite, incandescent lamp, lighting technology, renewable energy*

Abstrak: Penelitian ini mengeksplorasi potensi grafit pensil sebagai filamen alternatif pada lampu pijar untuk menggantikan tungsten yang umum digunakan. Dengan pendekatan kuantitatif dan metode eksperimen, penelitian ini menguji efektivitas dua bentuk grafit, yaitu batang dan serbuk, sebagai penghantar listrik. Hasil penelitian menunjukkan bahwa batang grafit dengan tegangan 8,18 V dan kuat arus 9,0 A mampu menghantarkan listrik dan menghasilkan cahaya sehingga berpotensi menjadi filamen alternatif pada lampu pijar. Sebaliknya, serbuk grafit tidak mampu menghasilkan arus listrik yang berarti karena hambatan listriknya tinggi akibat kerapatan partikel yang rendah. Analisis lebih lanjut menunjukkan bahwa hambatan listrik batang grafit cukup rendah sehingga arus dapat mengalir secara efisien dan batang memancarkan cahaya. Penelitian ini menyimpulkan bahwa batang grafit berpotensi menjadi filamen lampu pijar yang ramah lingkungan dan ekonomis, sedangkan serbuk grafit terbukti tidak efektif sebagai penghantar listrik. Penelitian ini memberikan wawasan awal bagi pengembangan teknologi pencahayaan yang lebih berkelanjutan, meskipun penelitian lanjutan diperlukan untuk mengevaluasi ketahanan dan efisiensi energi grafit pada aplikasi praktis.

Kata kunci: *efisiensi energi, energi terbarukan, grafit, lampu pijar, teknologi pencahayaan*

A. Introduction

Natural resources are generally divided into two categories: renewable and non-renewable. Renewable resources can be replenished through human effort, whereas non-renewable resources are depleted by continuous use and cannot be replenished. Examples of the latter include crude oil, natural gas, gold, silver, and coal (Bakhri, 2021). These resources will eventually run out and will be difficult to obtain again. The rapid development of technology and the increase in global energy consumption therefore urge us to seek solutions to the depletion of non-renewable resources. In this regard, using materials that are easy to find and remain available in the long term could serve as a substitute for these limited resources.

Graphite is an allotrope of carbon that conducts electricity and heat well, which is why it is widely used as an electrode in electrolysis cells. In graphite, each carbon atom forms covalent bonds with three other carbon atoms, creating layered hexagonal sheets that resemble a stack of cards. Because a carbon atom has four valence electrons, each atom in graphite retains one free electron (Putra, 2021). The carbon atoms bond only within each layer, with no bonds above or below, so the electrons can move freely, which makes graphite a conductive material.

Technology continued to evolve with the invention of the electric light bulb by Thomas Alva Edison on October 21, 1879, at the Edison laboratory in Menlo Park, United States. An incandescent lamp works by passing an electric current through a filament, which heats the filament until it reaches a temperature at which it emits light (Pujotomo, 2015). The filaments used in lamps today are made of tungsten wire with a melting point of 3,655 K (Insani et al., 2017). According to Nurrohmah (2019), graphite has a melting point not much different from that of tungsten, between 3,652 and 3,697 °C.

Siti Nurul Khotimah et al., in a study entitled “Electrical Circuits Using Pencil Contents,” concluded that pencil graphite has a different resistivity depending on the type of pencil. Motivated by this finding, the researchers conducted further research on the conductivity of pencil graphite. This study aims to explore the potential of graphite as a renewable energy material in incandescent lamps by analyzing its advantages and disadvantages as a filament. The research is expected to contribute to the development of innovative technology that is lower in cost and environmentally friendly.

B. Research Methods

a. Research Approach

This study used a quantitative approach with experimental techniques. Quantitative research produces findings through statistical procedures or other means of quantification, that is, measurement (Mentari, 2021). This approach was chosen because the study aims to measure and analyze numerical data obtained from experiments on the use of pencil graphite as a renewable conductor of light energy.

b. Research Design

A research design is a plan, pattern, or framework used to achieve the objectives of a study (Pakpahan et al., 2021). The design used in this study was experimental: the researchers conducted a series of experiments to test the ability of pencil graphite to act as a conductor in light energy conversion. The results of these experiments were analyzed to determine the effectiveness of pencil graphite in this application.

c. Population and Sample

The population consisted of the various types of pencil graphite available on the market, including variations in quality and well-known brands. The samples were purposively selected to represent this variation: Kenko 2B mechanical pencil lead (0.5 mm) and Joyko 2B mechanical pencil lead (2.0 mm).

d. Data Collection Instruments

The tools used in this study were a plastic jar, a glass fuse, a multimeter, crocodile clips, nail clippers, a vernier caliper, and a screw micrometer. The materials were pencil graphite, cable, a glue gun, and matches.

e. Data Collection Procedure

The data were collected through the following stages:

- 1) *Measurement.* The length of the graphite was measured with a caliper, and its diameter was measured with a screw micrometer.
- 2) *Filament preparation.* Two forms of graphite were prepared as samples: rods and powder. The graphite rods were cut into 4 cm lengths, while the graphite powder was produced by grinding graphite into fine particles and filling a glass fuse with them.
- 3) *Bulb construction.* The lid of a plastic jar was perforated to insert the wires. Two pairs of wires were inserted into the jar and connected with crocodile clips. The holes were sealed with hot glue to prevent outside air from entering.
- 4) *Filament testing.* A multimeter was used to determine the voltage and the electric current produced. For the graphite rods, the ends were clamped with crocodile clips connected to the cable inside the jar, whereas for the graphite powder, the crocodile clips were connected to the glass fuse.

f. Data Analysis

The research data, namely voltage (V) and electric current (I), were analyzed quantitatively using Ohm's law and the resistivity equation:

$$R = \frac{V}{I}$$

$$R = \rho \frac{l}{A}$$

$$\rho = \frac{R \cdot A}{l}$$

where:

R	= resistance (Ω)
V	= voltage (V)
I	= current (A)
A	= cross-sectional area (m^2)
l	= length (m)
ρ	= resistivity ($\Omega \cdot \text{m}$)

g. Interpretation of Results

The results of the data analysis were interpreted to answer the research problem. The interpretation focused on the ability of graphite to conduct renewable light energy and on how the hardness of graphite affects electrical resistance and conductivity efficiency. The findings were then compared with the existing literature to determine whether pencil graphite can serve as an alternative conductor in renewable energy applications.

C. Results and Discussion

a. Results

This research was conducted at MA Unggulan K.H. Abd. Wahab Hasbulloh in May 2024. The measurements of length, diameter, electric current, and voltage are presented in Table 1.

Table 1: Research Result Data

No	Magnitude Measured	Graphite Rods	Graphite Powder
1	Voltage (V)	8.18 V	0 V
2	Current (I)	9.0 A	0 A
3	Length (l)	4.38×10^{-2} m	–
4	Diameter (d)	0.00055 m	–
5	Cross-sectional area (A)	2.37×10^{-7} m ²	–

Source: Author's measurement results

Based on Table 1, the data were analyzed as follows.

Cross-sectional area. The cross-sectional area of the graphite rod was calculated from its diameter:

$$A = \frac{1}{4} \pi d^2$$

$$A = \frac{1}{4} \cdot 3.14 \cdot (0.55)^2$$

$$A = 0.237 \text{ mm}^2 = 0.237 \times 10^{-6} \text{ m}^2 = 2.37 \times 10^{-7} \text{ m}^2$$

Resistance. Resistance was calculated using Ohm's law:

$$R = \frac{V}{I} = \frac{8.18}{9.0} = 0.909 \, \Omega$$

Resistivity. The resistivity of the graphite filament was calculated from the resistance, cross-sectional area, and length:

$$R = \rho \frac{l}{A} \Rightarrow \rho = \frac{R \cdot A}{l}$$

$$\rho = \frac{0.909 \times 2.37 \times 10^{-7}}{4.38 \times 10^{-2}} = \frac{2.154 \times 10^{-7}}{4.38 \times 10^{-2}} = 0.49 \times 10^{-5} \, \Omega \text{ m}$$

Graphite powder. In the first experiment, graphite powder was used as the filament. It did not light up, and no voltage was measured. The powder was loosely packed, so the electric current could not flow properly through all the particles. Density greatly affects the electrical conductivity of a material: graphite powder has large gaps between its particles, which result in high electrical resistance and prevent it from conducting current effectively.

Graphite rods. In the second experiment, graphite rods were used as filaments. The rods lit up with a voltage of 8.18 V and an electric current of 9.0 A. Graphite rods have a denser and more solid structure than graphite powder, and their tightly packed structure and strong interatomic bonds allow them to conduct electricity better. The current flowing through the rods produces heat, which in turn produces light, as shown in Figure 1.



Figure 1. Experimental results using graphite rods
Source: Personal documentation

b. Discussion

Performance differences between graphite rods and graphite powder. The results showed a significant difference between the two forms of graphite in their ability to conduct electricity. The graphite rods produced a voltage of 8.18 V with a current of 9.0 A, while the graphite powder produced no measurable voltage or current. This difference is due to the difference in physical structure. Graphite rods have a dense and organized structure in which the atoms are tightly arranged, allowing electricity to flow smoothly and efficiently. In contrast, graphite powder consists of small particles separated by sizable gaps. These gaps increase the electrical resistance, so the current is impeded and cannot flow properly through the powder.

Electrical resistance of the graphite rods. The resistance of the graphite rods was calculated using Ohm's law, $R = V/I$, which gave a value of $0.909 \, \Omega$. This resistance is relatively low, indicating that the graphite rods conduct electricity well. The low resistance allows the current to flow efficiently, which then generates heat and light as the current passes through the rods.

Resistivity of the graphite rods. Resistivity (ρ) is a parameter that indicates the intrinsic ability of a material to conduct electricity; it depends on the properties and crystal structure of the material. The calculation gave a resistivity of $0.49 \times 10^{-5} \, \Omega \cdot \text{m}$. This value suggests that the graphite rods have fairly good electrical conductivity, especially when compared to insulating materials. The low resistivity indicates that the material has good potential as an electrical conductor in renewable energy applications, particularly in technologies that require stable and efficient electrical conduction.

Effectiveness of graphite rods in light energy conversion. In the experiment, the graphite rod emitted light when an electric current was applied, showing that electrical energy was converted into light energy through heating of the graphite. This indicates the potential of graphite rods for applications that convert electrical energy into light energy, such as lamps or heating elements. The light emitted by the rod shows that a sufficiently large current can heat graphite to a temperature at which it glows. This phenomenon is similar to the working principle of incandescent lamps, in which a filament, in this case graphite, is heated until it emits light.

Weaknesses and challenges of graphite powder. Graphite powder was unable to conduct electric current and produced no measurable voltage. This is due to its low density and the gaps between its particles, which result in high electrical resistance.

Without tight compaction, the current tends to disperse and meet resistance, which reduces conduction efficiency. Graphite powder is therefore not effective as a conductor in renewable energy applications, especially when compared to graphite rods.

D. Conclusion

The research showed that pencil graphite, especially in rod form, has potential as a filament in incandescent lamps. The graphite rods successfully conducted electricity and produced light, while the graphite powder could not because of its low particle density. These results indicate that the physical structure of graphite greatly affects its ability to conduct electricity and generate light energy. With their higher density, graphite rods gave better results and can be considered an environmentally friendly and economical alternative for incandescent lamp filaments.

For further research, trials on various types of graphite with different levels of hardness and different particle sizes are recommended to determine their effect on electrical conductivity and light production. In addition, the durability of graphite as a filament should be tested over a longer period to evaluate its reliability and stability. The research could also be extended by exploring the use of graphite in other types of lamps or lighting technologies to identify its potential for wider commercial application.

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