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UTILIZATION OF INDUCTION HEATING IN ELECTRIC STOVE APPLICATION

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ABSTRACT

Electric stoves with the concept of electromagnetic induction use coils to generate magnetic fluxes that can conduct heat. This research is urgently needed to optimize the efficiency and sustainability of induction-based cooking systems as a cleaner, faster, and more energy-efficient alternative to conventional stoves in the face of rising global energy demands. This study aimed to determine how induction-based electric stoves work and the effect of working coil variations on the electromotive force of induction and the temperature of water when cooked. The research method used was an experiment with data analysis using simple and multiple linear regression. The results sho wed that induction-based electric stoves utilize eddy currents that arise when a ferromagnetic conductor material is placed in the working coil, thus producing heat for cooking. The effect of the working coil on the electromotive force of induction and the temperature of water when cooking uses three working coil variants, namely enamel wire with a diameter of 0.5 mm with a length of 80 m, a diameter of 0.5 with a length of 112 m and a diameter of 1.5 mm with a length of 8 m. After testing, the results showed that the coil variant with a diameter of 0.5 mm and a length of 80 m had a strong influence on the induced emf, and the coil variant with a diameter of 0.5 and a length of 112 m had a substantial impact on the temperature of the water when cooked. This study implies that optimizing the coil configuration, such as using a 0.5 mm diameter enamel wire with a length of 80 m for the induced electromotive force and a 0.5 mm diameter wire with a length of 112 m to increase the water temperature, can improve the efficiency and performance of induction-based electric stoves.

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1. INTRODUCTION

Indonesia has abundant natural resources, one of which is natural gas, which is utilized in various aspects of life (Mohammad et al., 2021). The utilization of natural gas can be divided into 3, namely: as fuel, raw materials, and energy commodities for export (Sugiyono & Adiarso, 2021). liquefied petroleum gas (LPG) is primarily derived from propane or butane gas, or a mixture of both (Kumar Sharma, 2025). At room temperature, LPG exists as a gas, but under high pressure or very low temperatures, it becomes a liquid that is tasteless, colorless, and odorless. The compounds contained in LPG are ethane (C_2H_6), propane (C_3H_8), normal butane (nC_4H_{10}), isobutane (i-nC_4H_{10}), pentane, and even heavier hydrocarbons. LPG production involves two main processes (Kumar Sharma, 2025). The first is a pretreatment process to remove unwanted levels of CO_2, H_2S, and H_2O, followed by a fractionation process to separate heavy hydrocarbons in natural gas, resulting in LPG with a high methane content.

Gas stoves are a daily necessity for people as a cooking tool to meet basic needs (Williams et al., 2021). The common use of LPG stoves is due to the ease of acquiring them and the affordable cost of gas. This is made possible by subsidized LPG provided by the government for those in need, while non-subsidized LPG is available for those who can afford it.To meet the community's need for LPG and support the energy diversification program, it is essential to regulate the provision and distribution of LPG. This regulation should ensure the development of LPG infrastructure and increase the role of business entities. According to Regulation Number 26 of 2009, the provision and distribution of LPG must be carried out in an integrated, transparent, accountable, competitive, and fair manner (Kivevele et al., 2020; Weyant et al., 2019). Distribution activities are owned by business entities that have obtained LPG trading business permits, namely cooperatives, small businesses, and/or national private business entities (Sofwan & Rokilah, 2024).

The kerosene (krosin) to 3 kg LPG gas conversion program has been running since 2007 until now (Setiyo et al., 2020). However, in reality, 3 kg of LPG gas is also enjoyed by the wealthy community and industrial players, causing LPG gas distribution to be inaccurate. This occurs because there is no computerized monitoring system regarding the distribution of 3 kg LPG gas carried out by agents and bases. Several efforts have been made to address inaccuracies in LPG gas distribution to ensure proper recording (Sadiyah et al., 2021). One of these efforts is the implementation of an application system that grants admins access to input essential data, such as customer information, base data, and distribution details to both bases and customers.With this system, it makes it easier for agents in the process of distributing 3 kg LPG gas and also helps in the monitoring process to always be on target. In reality, LPG scarcity often occurs in the community because the demand for LPG is not adequately met. Additionally, fraud by agents causes LPG shortages and leads to the selling of gas above the specified Highest Retail Price (HET).

Indonesia's population growth and rapid technological advancements have led to a growing need for energy (Raihan, 2023). Humans consistently use energy in their daily lives, primarily natural gas. LPG consumption reached 7.5 million tons in 2018, with domestic LPG production reaching 2 million tons (26%) and imports accounting for 5.5 million tons (74%) (Hidayat et al., 2023). Cooking is a major factor influencing global energy consumption and greenhouse gas emissions(Arrieta & González, 2019). The success of the kerosene-to-LPG conversion program has led to a continued increase in LPG consumption. At the same time, the supply of LPG from domestic LPG refineries and oil refineries is limited. Many innovations have sought to reduce LPG use, one of which is the use of induction heating in stoves (Méndez-Lozano et al., 2022).

Induction stoves represent an advanced cooking technology using electromagnetic fields to heat cookware directly (Méndez-Lozano et al., 2022). This method provides a more energy-efficient alternative to traditional gas or electric stoves. Unlike conventional cooking methods that use open flames or electric coils to heat the cooking surface, induction stoves generate a magnetic field beneath the cookware. This magnetic field induces electric currents in the metal, which generate heat, offering a more energy-efficient alternative to traditional gas or electric stoves. This method allows for precise temperature control and fast, even cooking, as the heat is generated directly in the pot or pan rather than on the stove surface. One of the main benefits of induction cooking is its efficiency, as it heats food more quickly and uses less energy compared to traditional methods. Additionally, induction stoves enhance safety. The cooktop remains cool to the touch, reducing the risk of burns or accidental fires. The cooktops are also easy to clean since spills and splashes are less likely to burn onto the surface. However, induction stoves require cookware from ferrous materials, such as cast iron or magnetic stainless steel, to work effectively.

Induction heating, which has long been used in industrial and household applications (Vishnuram et al., 2021), relies on the principles of power electronics and involves factors such as operating frequency, input voltage, current values, and the shape of the object being heated. In induction stoves, heat is generated in the cookware due to eddy currents or vortex currents created by the induction of magnetic flux. These currents penetrate the metal of the cookware, generating heat (Patel, 2019). The strength of the magnetic field, known as magnetic induction, is directly related to the electric current flowing through the conductor in the stove's working coil, which produces the electromagnetic field responsible for the heat. One of the environmental advantages of induction heating is its cleanliness; it does not produce exhaust gases or combustion residue. However, the technology has limitations, as it only works with ferromagnetic materials or a magnetic field. This research explores the operation of induction-based electric stoves and examines how variations in the working coil affect the induced electromagnetic field (emf) and water temperature during cooking.

2. METHOD

This type of research uses an experimental method, creating an induction-based electric stove with various working coils during the water-boiling experiment. The dependent variables are induced emf and temperature, while the independent variables are time and the working coil.In making an induction-based electric stove, several materials are needed, including: a 24 DCV power supply, a 24 V ZVS module, a DC fan, a working coil (0.50 mm diameter with a length of 80 m, 0.50 mm diameter with a length of 112 m, and a 1.50 mm diameter with a length of 8 m), and a digital voltmeter and volt ampere meter.

Data analysis in this study was performed using simple and multiple linear regression techniques to assess the relationship between the working coil variants and the induced electromotive force (emf) as well as the temperature of the water. The regression models helped identify how changes in time and coil configuration impacted the emf and water temperature. The analysis also examined the effect of the number of coils and coil length on the induced emf, with data collected at specific time intervals. The results were interpreted through statistical measures, including R^2 values, which indicated the strength of the relationship between the variables.

The working principle of an induction stove is to utilize an AC source rectified by a power supply to become a DC voltage source in the Zero Voltage Switching (ZVS) module, as the basic component of an induction stove. The ZVS module will regulate the current until an AC occurs in the inductor so that the working coil is able to produce magnetic flux. When a conductive object containing ferromagnetic material is placed above the coil, an induced emf process will occur and is able to produce eddy currents. This current plays a very dominant role in the induction heating process. Thus, the workpiece exposed to the eddy current will heat and can be used for cooking.The induction-based electric stove is already producing heat, so the next step is to test the working coil for induced emf and water temperature. Data collection is done simultaneously. The variables used in this experiment are the number of turns, cross-sectional area, coil length, current change, and time change. The induced emf value can be calculated using the formula in equation 1.

$$\varepsilon_{in} = \frac{-\mu N^2 A}{l} \frac{dl}{dt} \tag{1}$$

where ε_{in} isinducedemf (v), μ ispermeability, N is the number of turns, A is the cross sectional area (m^2), and l is the length of the coil (m).

3. RESULTS AND DISCUSSION

Data collection in this study was conducted through an experimental approach, focusing on testing induction-based electric stoves using different working coil configurations. The main variables measured included induced electromotive force (emf) and water temperature, with time and coil variants as independent variables. The experiment involved boiling 200 mL of water while recording current changes and induced emf values at various times. Data was collected simultaneously for each coil variant, using equipment like volt-ampere meters and digital voltmeters to track the necessary variables throughout the experiment.

Induction-based electric stoves operate through electromagnetic induction to generate heat for cooking. The stove uses a coil to produce a magnetic field, which induces electric currents (eddy currents) in the cookware placed above the coil. These eddy currents create heat directly in the cookware, bypassing the need for traditional heating methods. Unlike conventional electric stoves, induction cooking is more energy-efficient because it heats the cookware directly, without wasting energy on heating the surface. This process allows for precise temperature control and faster cooking times, as the heat is generated in the pot, not the stove.

Induction stoves work by utilizing an AC source rectified by a power supply to convert it into DC as a voltage source in the ZVS module, the basic component of the induction stove. The ZVS module regulates the DC input current to the AC in the inductor, enabling the working coil to generate magnetic flux. When a conductive object containing ferromagnetic material is placed above the coil, an induced emf occurs and can produce eddy currents. These currents play a very dominant role in the induction heating process. Thus, the workpiece exposed to the eddy currents will heat up and can be used for cooking.

3.1 Effect of Time on Induced EMF

Data analysis begins by observing the effect of time on the induced emf of the water when cooked in each experiment. An experiment was conducted to boil 200 ml of water with a working coil variant of 0.5 mm wire diameter, number of coils of 240, and 80 m length for 60 mins. The change in current read on the volt-ampere meter was recorded every 10 mins, and the induced emf value was obtained using the formula by entering the variables obtained in the experiment. The effect of the working coil on the induced emf is shown in Table 1.

Table 1. The Effect of Time on The Induced Emf with The Number of Coils of 240

t (mins)	N	A (m^2)	l (m)	I (A)	ε_{in} (v)
10	240	706.5	80	0.55	-0.035
20	240	706.5	80	0.55	-0.022
30	240	706.5	80	0.55	-0.015
40	240	706.5	80	0.55	-0.011
50	240	706.5	80	0.55	-0.009
60	240	706.5	80	0.55	-0.007

Table 1 shows that the current changes increased at 10, 20, and 30 mins, resulting in 0.55, 0.70, and 0.75 A, respectively, but remained unchanged in the following minutes. Meanwhile, the induced emf decreased with time, decreasing every 10 mins. This data can be clarified in the graph in Figure 1 to determine the effect of time on the induced emf. The current change at 10, 20, and 30 mins likely corresponds to an increase in the rate of change of the magnetic field or a change in the physical properties of the coil, such as its resistance or inductance. This initial increase in induced emf can be attributed to a higher rate of magnetic flux variation, which induces a larger current according to Faraday's Law of Induction. As the magnetic field changes rapidly at these points, the induced emf rises, resulting in the observed current values of 0.55, 0.70, and 0.75 A.

However, after 30 mins, the rate of change of the magnetic field may have stabilized, or the system reached a steady state where the magnetic flux no longer increased significantly. This could mean that the factors driving the change in emf no longer vary, causing the induced current to plateau. Additionally, any potential resistance or inductive effects in the circuit could have limited further increases in current. As a result, the current remained unchanged in the following minutes, indicating that the system reached an equilibrium point where the rate of change of magnetic flux had slowed or stabilized.

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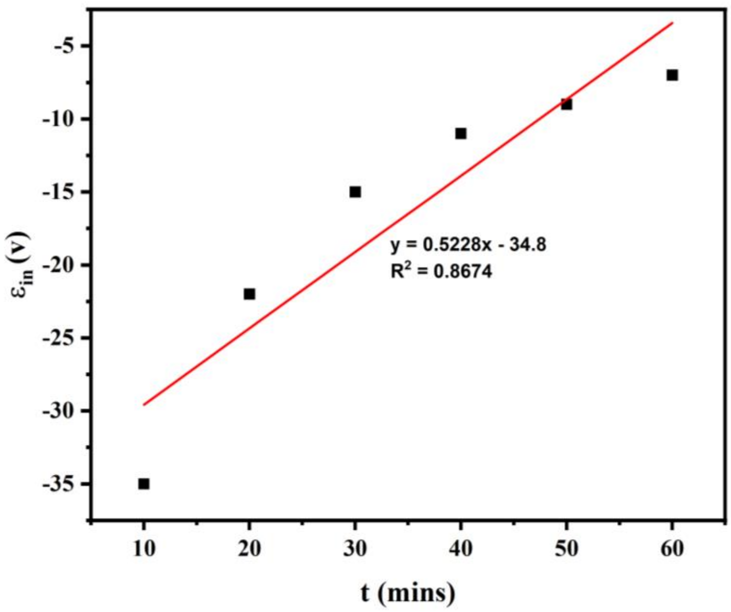

Figure 1. Effect of Times on Induced Emf with The Number of Coils of 240

In Figure 1 simple linear regression, the equation $y=0.5228x-34.8$ represents the relationship between the independent variable x (time) and the dependent variable y (induced emf). The slope of 0.5228 indicates that the induced emf increases by 0.5228 units for every one-unit increase in time. This means that the induced emf grows steadily over time, suggesting a linear relationship between the two variables. The intercept of -34.8 implies that the induced emf is -34.8 units when time is zero. While this negative intercept might not be physically meaningful in some contexts, it is a mathematical outcome of the regression model. It indicates that the emf would be negative at the starting point (time zero), although this could be interpreted as a baseline value that shifts over time.

The R^2 value of 0.8674 indicates that 86.74% of the variation in induced emf is explained by changes in time. This high R^2 value shows a strong relationship between time and induced emf, meaning that time is a key predictor of induced emf. An R^2 value close to 1 would indicate that the model explains most of the variability in the data, while values closer to 0 would suggest a weaker or less predictive relationship. In this case, the relatively high R^2 value suggests that the linear regression model fits the data well. Time is a significant factor in determining the induced emf, although other factors not accounted for by the model may still influence the emf. The fact that the R^2 is not perfect (1.0) suggests that there might be some degree of error or variation that cannot be explained solely by the time variable.

The slope of 0.5228 also tells us about the rate of change of induced emf concerning time. As time increases, the induced emf consistently increases by 0.5228 units for each time unit. The linear nature of the relationship suggests that this rate of change remains constant across the observed time period, making the model simple yet effective for prediction. In practical terms, this regression model allows for the prediction of the induced emf at any given time. For example, if we know the time value, we can easily substitute it into the equation to estimate the corresponding induced emf. The model implies that the induced emf is directly proportional to time, though there may be other external factors influencing the emf that the linear model does not capture. In conclusion, the simple linear regression equation $y=0.5228x-34.8$ provides a valuable and effective model for understanding the relationship between time and induced emf. The R^2 value of 0.8674 confirms the model's strength in explaining the variation in the induced emf. However, while the model is strong, it does not capture all the possible influences on emf, suggesting that additional factors may be at play beyond just time.

The results found in the experiment can be explained through a combination of principles from electromagnetic induction and the system's physical properties. The initial increase in induced electromotive force (emf) at 10, 20, and 30 mins can be attributed to a rapid change in the magnetic flux. According to Faraday's Law, this change in the magnetic field induces a higher emf.The induced current increases as the magnetic field changes more quickly during this period. However, after 30 mins, the magnetic field's change rate likely stabilizes, reducing the variation in emf and causing the current to plateau. Factors such as resistance in the wire and inductance can influence the induced emf. These factors may limit further increases in emf as the system reaches equilibrium. The linear regression model demonstrates a strong relationship between time and emf. An R^2 value of 0.8674 indicates that time is a significant predictor of the induced emf. However, other factors may still play a role.

3.2 Effect of Number of Coils on Induced EMF

The effect of time on the induced emf with the number of coilsof 378 when cooked was also observed. An experiment was conducted to boil 200 ml of water with a working coil variant of 0.5 mm wire diameter and 112 m length for 60 mins. The change in current read on the volt-ampere meter was recorded every 10 mins, and the induced emf value was obtained using the formula by entering the variables obtained in the experiment. The effect of time on the induced emf with the number of coils of 378 is shown in Table 2.

Table 2. The Effect of Numberof Coils on The Induced Emf with The Number of Coils of 378

t (mins)	N	A (m^2)	l (m)	I (A)	ε_{in} (v)
10	378	642.1	112	0.15	-0.015
20	378	642.1	112	0.18	-0.009
30	378	642.1	112	0.15	-0.005
40	378	642.1	112	0.25	-0.006
50	378	642.1	112	0.25	-0.005
60	378	642.1	112	0.25	-0.004

Table 2 shows that the current changes increased at 10 to 20 mins in 0.15 to 0.18 A, 30 to 40 mins in 0.15 to 0.25 A. Meanwhile, at 40 to 60 mins, the current value was the same, namely 0.25 A. Something different happened at 20 to 30 mins, the resulting current value actually decreased from 0.18 to 0.15 A. This data can be clarified in the graph in Figure 2 to determine the effect of the number of coils on the induced emf.The observed variation in current values over time, particularly from 10 to 20 mins and 30 to 40 mins, indicates fluctuations in the induced emf or changes in the system's parameters. From 10 to 20 mins, the current increased from 0.15 A to 0.18 A, likely due to a rising induced emf. This increase could be attributed to an accelerating rate of change in the magnetic field or the changing position of the magnet relative to the coil.The increase in induced emf may result from factors such as a higher speed of motion or stronger magnetic flux.

Similarly, from 30 to 40 mins, the current further increased from 0.15 A to 0.25 A. This larger increase might indicate a more significant change in the magnetic field, such as a change in the coil's orientation or a stronger external magnetic source. The rate of change in the magnetic field could accelerate, thus increasing the induced emf and, consequently, the current.However, at 40 to 60 mins, the current remained constant at 0.25 A. This plateau suggests that the system reached a steady state where the magnetic flux or the rate of change in the magnetic field remained stable. The coil's position or the strength of the magnetic field may have been constant during this period, which could explain the absence of further current increases.

An anomaly occurs between 20 and 30 mins when the current decreased from 0.18 A to 0.15 A. This decrease in current may be due to a temporary reduction in the rate of change of the magnetic flux. It is possible that the coil's position relative to the magnetic source changed in such a way that the induced emf weakened. Alternatively, other factors like resistance changes in the circuit, temperature fluctuations, or interference from other external sources could have caused the drop in current. The key to understanding these fluctuations lies in the relationship between the magnetic field, the motion of the conductor, and the induced emf. As the system evolves, these factors interact, resulting in periods of increasing and decreasing induced emf and current. Analyzing the magnetic field dynamics and the specific conditions of the experimental setup could provide more insight into the cause of these variations in Figure 2.

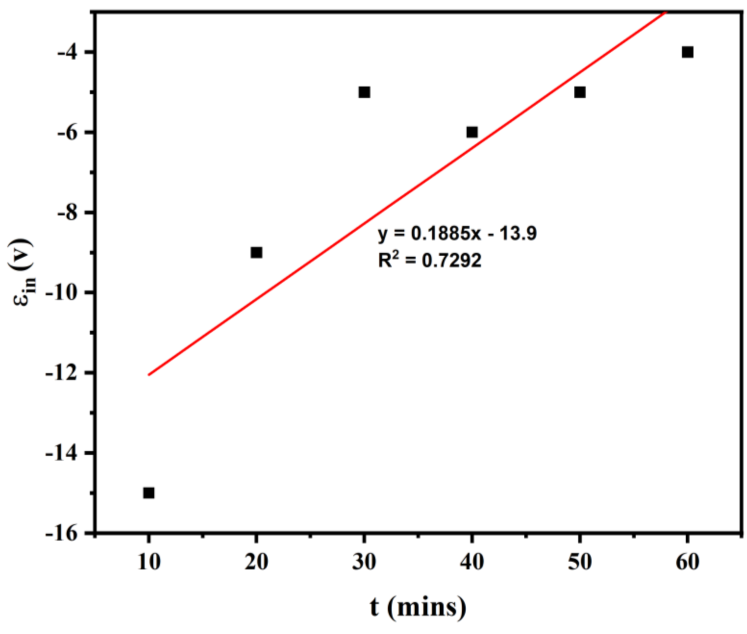

Figure 2. Effect of Times on Induced Emf with The Number of Coils of 378

In Figure 2 simple linear regression, the equation $y=0.1885x-13.9$ represents the relationship between the independent variable x (time) and the dependent variable y (induced emf).In this context, the variable x represents time, while y represents the induced emf. The slope of the equation, 0.1885, indicates that for each unit increase in time, the induced emf increases by 0.1885 units. This shows a positive linear relationship between time and emf. The intercept of -13.9 is the value of the induced emf when time (x) is zero. While this negative value might not have physical significance in the real world, it still has a mathematical meaning. It represents the point where the regression line intersects the y-axis. This negative value may not have physical significance in the real world. However, it holds mathematical meaning as the point where the regression line intersects the y-axis.

The slope value, 0.1885, is critical because it quantifies the rate of change in induced emf over time. As time increases, the induced emf rises consistently at a rate of 0.1885 units per time unit. This indicates a steady increase in the emf, suggesting that time is directly proportional to the emf in this scenario. The linearity of the relationship makes the model simple and predictable, where every increase in time produces a predictable change in emf. The R^2 value of 0.7292 is a measure of the goodness of fit of the regression model. This value implies that approximately 72.92% of the variability in induced emf is explained by the time variable. This means that time is a significant factor in explaining the changes in emf. However, the remaining 27.08% of the variation in emf is due to factors not included in the model, indicating that there may be other influences on the emf that this equation has not captured.The R^2 value also suggests that while time is a good predictor of induced emf, the model is not perfect. There are other variables or potential measurement errors that could account for the remaining unexplained variance. The higher the R^2, the better the model explains the relationship between the variables. While 0.7292 is a relatively strong value, it still leaves room for improvement in terms of capturing all of the variation.

In this experiment, the number of coils, 378, is an important factor that can influence the magnitude of the induced emf. The number of coils determines how much magnetic flux passes through the coil, which in turn affects the induced emf. A greater number of coils would lead to a higher induced emf, as more turns in the coil would increase the magnetic flux. Although the number of coils is not explicitly included in the equation, it is crucial for understanding the full context of the experiment. The induced emf is directly related to the number of coils and time. A higher number of coils increases the emf for a given rate of change in the magnetic field, and this factor would be incorporated in more complex models that include coil characteristics. The linear regression model assumes that the relationship between time and induced emf is linear, which means that the increase in emf is proportional to time. This assumption works well as long as the relationship between time and emf remains consistent and linear throughout the observed period. The linearity assumption simplifies the relationship, making it easier to model and interpret.

The model also assumes that the residuals, or the differences between the observed and predicted values, are randomly distributed with constant variance. This assumption is crucial for ensuring the reliability of the regression results. If the residuals exhibit patterns or heteroscedasticity, the model may not adequately capture the underlying data structure. Despite these assumptions, the linear regression model provides a good approximation of the relationship between time and induced emf in this experiment. The R2 value of 0.7292 indicates that time is a significant predictor of emf, and the model can reliably estimate the induced emf based on the elapsed time. However, the remaining 27.08% of unexplained variation suggests that other factors, such as the strength of the magnetic field, the material properties of the coil, or environmental influences, may play a role. This model provides a useful tool for predicting induced emf over time, but it should be interpreted with caution. The model may not fully capture the complexities of the physical system and the influence of other variables. To improve the model, additional variables could be included, such as the number of coils, the magnetic field strength, or coil resistance, to account for the unexplained variation.

The difference in the R^2 values, 0.8674 for 240 coils and 0.7292 for 378 coils, indicates that the model fits the data better for 240 coils. A higher R^2 value means that the independent variable(s) explain more of the variability in the dependent variable. For the 240 coils dataset, the relationship between the variables is likely stronger or more linear, which makes the model's predictions more accurate. For 378 coils, the lower R^2 suggests that the relationship is either weaker or more complex. This could imply that as the number of coils increases, other factors might be influencing the dependent variable, which the current model does not account for well. Additionally, the data for 378 coils might have more noise or outliers, reducing the predictive accuracy of the model.

It is also possible that 240 coils represent a more consistent or uniform dataset, while 378 coils might have more variation in the measurements. A smaller dataset (like 240 coils) can often produce a higher R^2 if the data points are more clustered around the fitted line. Conversely, with more data points (378 coils), the variability in the data may reduce the model's ability to explain the variance, resulting in a lower R^2. In summary, the higher R^2 for 240 coils suggests a clearer, more predictable pattern, whereas the lower R^2 for 378 coils indicates more complexity and less consistency in the relationship.

The observed fluctuations in induced electromotive force (emf) can be attributed to the varying rates of change in the magnetic field. This is particularly noticeable during the 10 to 20 mins and 30 to 40 mins intervals, suggesting adjustments in the coil's position or an increase in the external magnetic field. A temporary reduction in the rate of change of the magnetic flux could cause a decrease in current between 20 to 30 mins. This reduction may result from shifts in the coil's alignment or external factors such as resistance changes or temperature fluctuations. From 40 to 60 mins, the constant current value of 0.25 A indicates a steady state where the magnetic flux and the rate of change in the magnetic field became stable. The linear regression model supports the hypothesis that time is directly proportional to induced emf, as the emf consistently increases with time. However, factors like coil characteristics and environmental conditions might account for the unexplained variation. Lastly, the difference in R^2 values between 240 coils (0.8674) and 378 coils (0.7292) suggests that the model fits the data better for fewer coils. This indicates a more predictable relationship when the experiment has fewer coils. The lower R^2 for 378 coils points to additional complexities not captured in the current model.

4. CONCLUSION

The experiment demonstrated that induction-based electric stoves operate efficiently through the creation of eddy currents in ferromagnetic materials, which generate heat for cooking. The research revealed that the number of coils and coil length significantly impact both the electromotive force (emf) and the water temperature. Specifically, the coil variant with a 0.5 mm diameter and an 80 m length produced a strong emf, while the 0.5 mm diameter coil with a 112 m length significantly increased water temperature. The study suggests that optimizing coil configurations, particularly the coil length and diameter, can improve the stove's performance and efficiency. Furthermore, the results highlighted a strong correlation between time and induced emf, with higher R^2 values indicating a good fit for the 240 coils setup compared to the 378 coils.

Overall, this research provides valuable insights into the design and optimization of induction heating systems for more efficient cooking appliances. The findings also suggest that further studies should explore additional factors influencing the induction heating process, such as material properties and external environmental factors.

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