Influence of Input Voltage Variation on the Energy Efficiency of Induction Cookers

Budi Sudiarto[1], Justinus Dipo Nugroho[2], Faiz Husnayain[3], Agus R. Utomo[4], I Made Ardita[5]

[1,2,3,4,5] Departemen Teknik Elektro Fakultas Teknik Universitas Indonesia, Depok 16424 INDONESIA (tel.: 021-7270078; fax: 021-7270077; email: [1]budi.sudiarto@ui.ac.id, [2]justinus.dipo@ui.ac.id, [3]faiz.h@ui.ac.id, [4]arutomo@eng.ui.ac.id, [5]i.made61@ui.ac.id)

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Corresponding Author: Budi Sudiarto

ABSTRACT — Efficiency in energy use is essential for achieving national energy security. Dependence on energy supplies with high levels of imports can make a nation to be more susceptible to crises and dependence. It also includes the provision of energy sources for cooking needs. An electric induction cooker is one of the alternatives to the liquified petroleum gas (LPG) gas stove used for cooking. Given the high government import subsidy for LPG procurement, diversification of energy sources for cooking needs to be done. Cooking with an induction cooker is more efficient than cooking with a gas stove because it requires a shorter cooking time, and less heat energy is wasted. The energy efficiency of induction cookers ranges is approximately 80% or twice that of gas cookers ranges, which is at 40%. Nonetheless, the level of energy efficiency of induction cookers can be affected by the electricity supply voltage. Electricity conditions in Indonesia with a voltage service quality level of 220 V ± 10% result in the energy efficiency of induction cookers varying. This study analyzes the effect of input voltage variations on the energy efficiency of induction cookers. The input voltage was varied from 230 V to 200 V with a difference of 10 V using four brands of induction cookers. The test results indicate that the efficiency is directly proportional to the input voltage, where the higher the input voltage will provide the greater the induction cooker's energy efficiency.

KEYWORDS — Induction Cooker, Energy Efficiency, Input Voltage Change, Power Quality.

I. INTRODUCTION

Energy security is one of the fundamentals of a nation's resilience. Indonesia currently has a significant import value in the liquefied natural gas (LNG) sector, one of which is to meet basic cooking needs [1]. State subsidies are not small for the provision of the liquified petroleum gas (LPG) supply. In addition to the high world gas import price, many subsidies are not well-targeted [2]–[3]. Therefore, the Indonesian government needs to take the best alternative steps to overcome the conditions of energy security and economic subsidies. One alternative solution is the application of induction cookers. This electric cooker with a high level of safety can maintain national energy security and reduce subsidies on LNG [4]. It can be achieved through the utilization of existing energy resources in Indonesia for the generation of electrical energy [5].

Diversification of energy sources, including the use of induction cookers, is believed to increase the electricity system's efficiency and is also expected to be a solution to two other current global problems, namely the energy crisis and climate change [6]. The study shows that using gas stoves is less efficient because the heat generated is partially wasted due to the distance between the fire and the cookware [7]. It results in higher household consumption costs. Regarding safety factors, induction cookers have a higher safety level compared to other types of cookers. It is because the heating system on induction cookers does not use fire, thus preventing fires due to sparks. In induction cookers, only cookware is heated. As a result, less energy is used, the cost is more efficient, and the cooking time is faster [8]–[10].

Various studies have been conducted related to the optimal design of induction cooker performance systems, ranging from the supply power system using both single phase and three phases [11]–[12], the type of equipment switching which includes low-high operating frequency and low power consumption levels, [13]–[15]. In addition, control algorithms include power factor and harmonic control, cooking temperature levels, and optimal operational power [16]–[17] to the design of semiconductors used with various shapes, distribution of heat energy in the cooker, and types of good ferromagnetic materials [18]–[22]. In addition, research related to the use of induction cookers on networks with renewable energy supply systems has also been carried out, including the impact on the quality of the electrical system both on the network and other equipment connected to the electricity network and evaluation of its performance [23]–[25]. All of them strive to increase the level of energy efficiency used, as well as the selection of materials and optimal control algorithms to make induction cooker technology safer and more comfortable to use.

Referring to previous research, the efficiency of induction cookers is better than gas stoves [7]. However, the efficiency of an induction cooker is contingent on the power quality, power regulation, and material of the cookware used. In addition to the energy security factor, the factual condition of the electricity grid in Indonesia is also unstable. The presence of voltage fluctuations in the electricity network also impacts the level of performance and efficiency of electrical equipment connected to the network. The level of voltage fluctuations is also regulated in the Minister of Energy and Mineral Resources No. 20 of 2020 concerning power system network rules (grid code). Regarding the conditions in Indonesia, there are still limited references on the efficiency level. So that scientific research is needed to become an alternative reference for the community to be able to use induction cookers. Therefore, in this study, researchers tested four different brands of induction cookers with voltage variations to determine the effect of voltage variations on energy efficiency in induction cookers. It is hoped that the results of this study can be a reference in the development of further induction cookers.

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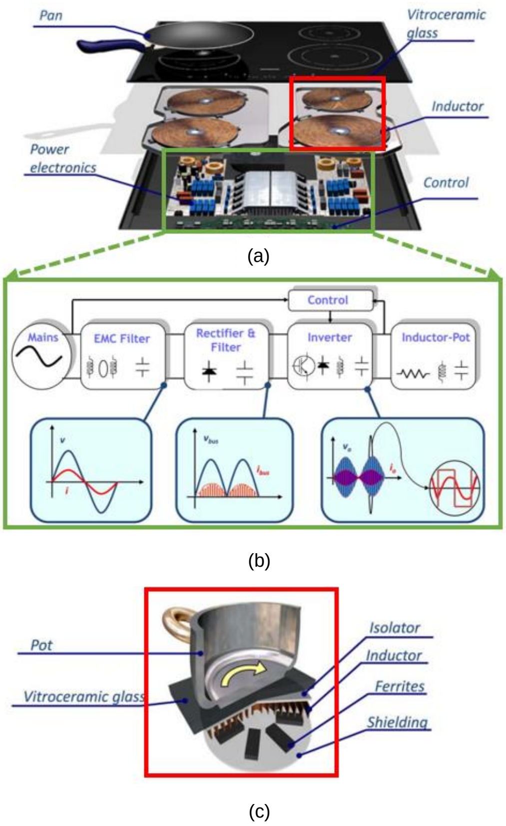

Figure 1. Induction cooker configuration. (a) the entire system, (b) power electronics system, and (c) component details per induction cooker [12].

II. INDUCTION COOKERS OPERATING SYSTEM

The operating principle of induction cookers, electromagnetic induction, eddy currents, Ampere and Lenz laws, and efficiency calculations are discussed in this section.

A. INDUCTION COOKERS

Induction cookers work on the principle of induction with high-frequency electric current flowing in the induction cooker coil. The induction current generated by the inverter will then induce a pan made of ferromagnetic so as to produce heat in the pan. The heat generated is used for the cooking process. In an induction cooker, a coil of copper wire is under the cooking pot. An alternating electric current flowing through the coil generates oscillations in the magnetic field. This magnetic field induces the cooking pot. The induced current flowing in the metal pot results in the resistive nature of the heater that will heat the food/water. The electric current is high, but the voltage is low. The induction cooker system's foundation lies in its electronic components' design, which has digital power and temperature control functions. Figure 1 illustrates the general operating principle and configuration of current induction cookers [12]. The entire system consists of four main parts: the power electronics system, vitroceramic coating glass, coil, and electronic circuit control parts [12].

Furthermore, details of the power electronics or power conversion system used in general in induction cookers are illustrated in Figure 1(b). The system consists of a power supply, an electromagnetic compatibility (EMC) filter, a rectifier diode circuit with its filter, an inverter circuit, and the coil and control of the entire power electronics circuit. In addition, Figure 1(c) depicts the details of the components making up the induction cooker for each cooker.

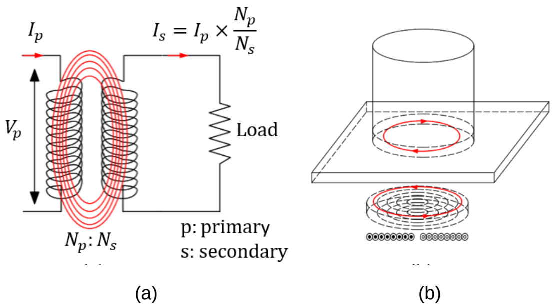

Figure 2. Induction cooker heating system, (a) a scheme of the transformer balance in the induction cooker heating system and (b) Inductive current generated at the bottom of the pot.

In regard to its operating principle, the heat generated in an induction cooker adheres to the Joule effect. The generated heat energy is the product of the coil resistance value (R) with the square value of the induced current (i^2) so that the total value becomes i^2R. In some induction cooker circuits, additional overvoltage and overcurrent protection are included. In addition, the majority of certified products adhering to the Institute of Electrical and Electronics Engineers (IEEE) or the International Electrotechnical Commission (IEC) safety standards also feature an efficient heat management system.

Induction heating is the process of heating metal by electromagnetic induction. This process generates an eddy current in the metal, and its resistance leads to Joule heating, as illustrated in Figure 1(b). This phenomenon also generates magnetic hysteresis losses through the materials in the pan. An induction cooker consists of a typical copper coil through which a high-frequency alternating current (AC) is passed. The AC frequency used is based on the maximum switching frequency of the switch, which usually uses an insulated-gate bipolar transistor (IGBT) type. Higher frequencies can reduce coil inductance and resonant capacitor size, making it possible to make cost savings on unit procurement. Induction heating is based on electromagnetic laws. The entire system can be approached with an electrical transformer, in which the primary coil is the copper of the induction cooker, and the outermost bottom layer of the pan is shown in Figure 2.

B. ELECTROMAGNETIC INDUCTION

Faraday's law governs electromagnetic induction, stating that the induced electromotive force (EMF) in any closed circuit equals the negative of the time rate of change of magnetic flux through the circuit. As an illustration, electromagnetic induction occurs when a primary circuit with alternating current flows through the circuit. It will produce a current in the secondary circuit due to the flux of alternating magnetic field lines. Alternating current flowing in a conductor with a winding coil will produce a magnetic field, as in (1) to (5) [26].

$$\oint H \,.\, dl = \sum i \tag{1}$$

$$\Phi = \iint_A \; B \,.\, dA \,. \tag{2}$$

$$B = \mu \,.\, H \tag{3}$$

$$\mu = \mu_0 \,.\, \mu_r \tag{4}$$

$$e = -N \,.\, d\Phi/dt. \tag{5}$$

C. EDDY CURRENTS

Eddy currents are the main mechanism that causes heating in induction cookers. The heat generated in the material is

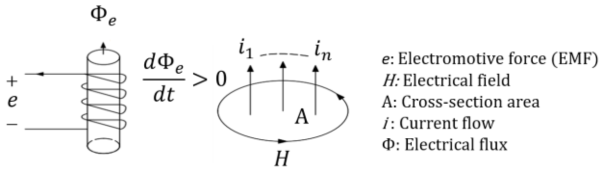

Figure 3. Illustration of Ampere's law and Lenz's law [26].

highly dependent on the magnitude of the eddy current induced by the inducing coil, as can be seen in Figure 3. When the coil is powered by alternating current, a magnetic field around the conducting wire arises. The magnitude of the magnetic field changes according to the current flowing in the coil. If a conductive material surrounds a fluctuating magnetic field, a current known as eddy current will flow on the conductive material.

The principle of eddy current is based on the law of Faraday, stating that when a conductor is cut by lines of force from a magnetic field or in other words, an EMF will be induced into the conductor. The magnitude of the EMF depends on the size, strength, and density of the magnetic field; the speed at which the magnetic lines of force are cut; quality of the conductor [26].

D. ENERGY EFFICIENCY OF INDUCTION COOKER

The energy efficiency of the induction cooker can be calculated from the ratio between the generated heat energy and the electrical supply energy used. In this study, (6) to (9) are used in calculating energy efficiency.

$$\eta(\%) = \frac{Q_{Out}}{Q_{In}} \times 100\% \tag{6}$$

$$\eta(\%) = \frac{M_{air} \times C_{air} \times \Delta T}{V \times I \times P_F \times \Delta t} \times 100\% \tag{7}$$

$$Q_{in} = V \times I \times P_F \times \Delta t \tag{8}$$

$$Q_{out} = M_{air} \times C_{air} \times \Delta T \tag{9}$$

where,

Q_{In} : Supply energy (J)
Q_{Out} : Energy consumption (J)
M_{air} : Water mass (g)
C_{water} : Specific heat of water (J/g.°C)
ΔT : Temperature change (°C)
V : Supply voltage (V)
I : Supply current (A)
P_F : Power factor.

III. RESEARCH METHOD

This study aims to determine the effect of supply voltage variations on the average power consumption of several induction cookers commonly distributed in the community. The research method includes mapping problems related to induction cookers to performance tests by measuring the average power, operating time, and electrical energy consumption in heating 2 L of water to boiling from an initial temperature of 30ºC. Input voltage variations were carried out in the test to illustrate the impact of the voltage variation phenomenon in the National Electricity Company (Perusahaan Listrik Negara, PLN) power grid on the induction cooker performance.

A. RESEARCH FLOWCHART

The flowchart of the energy efficiency testing of the induction cooker in this study is illustrated in Figure 4. This energy efficiency test aims to obtain the quality profile and

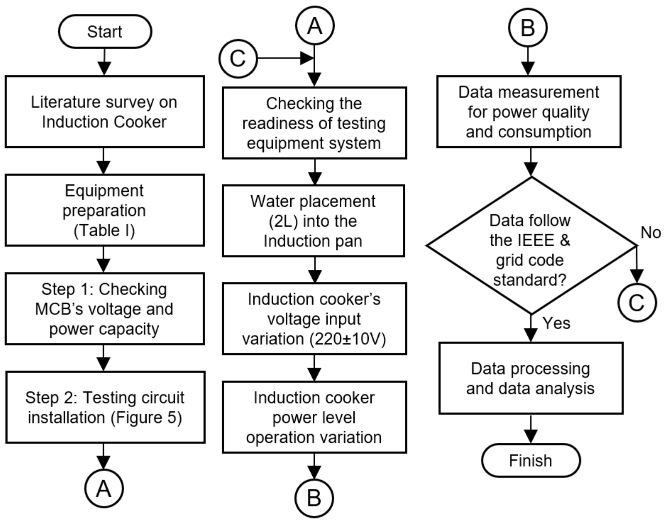

Figure 4. Flow chart of induction cooker energy efficiency testing.

TABLE I
POWER OPTIONS OF THE TESTED INDUCTION COOKERS

No.	Induction Cooker	Induction Cooker Power Level Operation Option (W)						
		600	800	1000	1200	1300	1400	1800
1	Brand A			√			√	√
2	Brand B	√	√	√		√		
3	Brand C	√	√	√	√			
4	Brand D	√	√					

electrical power consumption for each input voltage variation given to each brand according to the available operating power level shown in Table I. As illustrated in Figure 4, the test scenario conducted in this study is divided into three stages. First, it began with a review of voltage stability conditions and power capacity at the location of the test point. Second, it was the installation stage of the testing equipment. And the third stage was testing changes in induction cooker input voltage on electrical energy efficiency at each available operating power level. In this study, the operating power of the induction cooker was adjusted to the power level available on each stove brand as can be seen in Table I. There are two standard references used in this study. The first was the grid code used by PLN published by the Ministry of Energy and Mineral Resources in providing electricity services on its network. The second was the IEEE No. 1159–1995 standard for evaluating the quality of electrical power on the grid.

B. TESTING SEQUENCES

The test sequences in this study are illustrated in Figure 5. Four popular brands were used as test samples, namely in alphabetical order Advance, Cyprus, Idealife, and Philips to obtain data on energy efficiency levels representing the condition of induction cookers in Indonesia. Furthermore, a power quality measuring instrument was used to record the quality and energy consumption used in each test scenario. The results of these power quality analyzer (PQA) measurements became the basis for evaluation in this study to determine the efficiency level of each brand of induction cooker at each operating power level option. A voltage regulator was used in the tests to vary the input voltage of the induction cooker. In addition, this study also used one 1000 mL measuring cup, one thermometer, and two ferromagnetic pots.

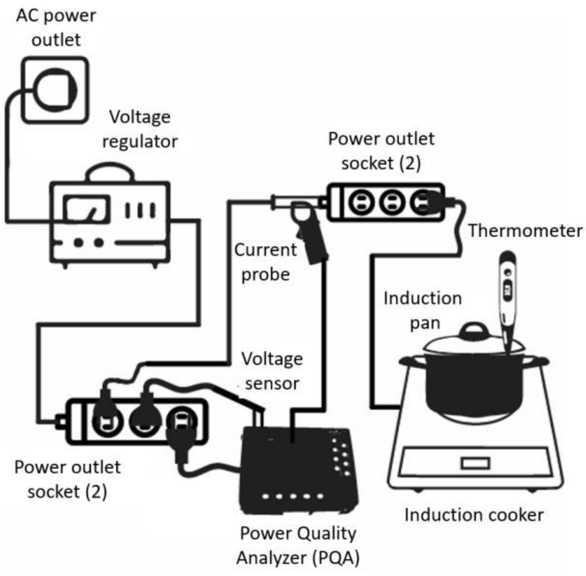

Figure 5. Induction cooker energy efficiency testing circuit.

C. ENERGY EFFICIENCY CALCULATION

The energy efficiency of the induction cooker from the testing results can be calculated using (6). The energy input calculated referring to (8) is the amount of electrical energy the induction cooker absorbs to boil water. The amount of electrical energy consumption is used as an input energy parameter. The calculation of electrical energy consumption is affected by the electric power used by the stove and the length of time to boil water.

Energy consumption expresses the amount of heat/heat energy needed to boil 2 L of water, with the calculation referring to (9). The amount of heat was used as an energy consumption parameter with a water density of 1 g/cm^3 or 1 kg/L, the mass of water used in this study was 2 kg. Specific heat is the amount of heat a substance needs to raise the temperature of 1 g by 1 ^{o}C. In this test, water was used as a parameter to determine how long it took to boil water so that the specific heat of the water was 4,200 kJ/kg. ^{o}C or 4.2 kJ/kg. ^{o}C. The water's heat calculation is affected by the mass of water used, the specific heat of water, and the temperature change between the initial water temperature and the temperature at which the water was brought to a boil. By comparing energy consumption and input energy, the ratio of the heat of water produced to the use of energy consumption in induction stoves can be obtained.

Table II indicates that the water used in this test is 2 L. The initial temperature of the water in the pot in the preheated condition is 30 ^{o}C. The water is then heated to boiling with a final temperature of 100 ^{o}C. So that the amount of temperature change (ΔT) that occurs is 70 ^{o}C. The energy consumption value (Q_{out}) can be calculated using (9):

$$Q_{out} = M_{water} \times C_{water} \times \Delta T$$

$$Q_{out} = 2 \times 4.2 \times 70 \ = 588\ kJ.$$

If the energy consumption (kJ) is converted to energy consumption (kCal).

$$Q_{out} = \frac{588\text{kJ}}{4.186} = 140.47\text{kKal}.$$

The measured amount of electrical energy consumption refers to (10):

TABLE II
SPECIFICATIONS OF THE TESTED RESEARCH OBJECTS

Description	Amount
Water volume (L)	2
Specific heat of water (kJ/kg ℃)	4.2
T0 (℃)	30
T1 (℃)	100
Δ*T* (℃)	70
Calories of 2 L of water (kKal)	140

$$Q_{out}E(kWh) = \frac{P \times t}{1000} \quad (10)$$

where:
E = electrical energy consumption (kWh)
P = active power (W)
t = cooking time (hour).

This study also employed linear regression to predict the efficiency function of the input voltage changes that occur. As a result, later, each level of operating power had an efficiency function against the input voltage as an attempt to predict the phenomenon of the effect of input voltage variations on the efficiency of the induction cooker. The function follows (11).

$$\eta(\%) = (\alpha \times \text{supply voltage}) + \beta \quad (11)$$

where:
η = level of electrical energy efficiency (%)
α = rate of change of η against voltage change (%/V)
β = initial value of efficiency from linear regression (%)

IV. RESULTS AND ANALYSIS

The discussion focus is based on the effect of supply voltage variations on the energy efficiency of induction cookers. The analysis of the research results is divided into two parts, namely the analysis of the measurement profiles of induction cookers of brands A, B, C, and D according to the design of the operating power of each brand; and the analysis of the impact of operating power selection on energy efficiency with variations in supply voltage.

A. TESTING RESULTS

Table III and Table IV are the results of measuring supply voltage variations' impacts on energy consumption, time, and energy efficiency. The measurement results indicate that the amount of energy consumption produced by the induction cooker is directly proportional to the average output power used.

Calculation of energy supply on the induction cooker taken from the 1st parameter data, namely on brand A induction cookers with operating power selection of 1000 W and 230 V voltage. Based on the 1st parameter measurement data, the average power consumed by the brand A induction cooker was 901 W and the time required to boil 2 L of water was obtained for 13 minutes 10 seconds. Converted to hours, the cooking duration was 0.2190 hours. Using (8), it can be calculated that the consumed energy supply value (*Qin*) was 0.1983 kWh.

Furthermore, Table III of the test results shows that the magnitude of the generated energy efficiency is inversely proportional to the energy consumption used. Consequently, the energy efficiency value of the brand A induction cooker with a power of 1000 W at a voltage of 230 V calculated using (6) was 82.1%.

$$\eta(\%) = \frac{Q_{Out}}{Q_{In}} \times 100\%$$

TABLE III
RESULTS OF TESTING THE EFFECT OF VOLTAGE VARIATIONS ON POWER CONSUMPTION, COOKING TIME, AND ENERGY CONSUMPTION ON INDUCTION COOKERS

Brand	Operating Power (W)	Average Power Consumption (W) per Input Voltage Variations				Cooking Time (Minutes) at Input Voltage Settings				Energy Consumption (kWh) at Input Voltage Settings			
		230 V	*220 V*	*210 V*	*200 V*	*230 V*	*220 V*	*210 V*	*200 V*	*230 V*	*220 V*	*210 V*	*200 V*
Brand A	1000	901.0	913.3	917.3	932.0	13:10	13:16	13:30	13:33	0.198	0.204	0.207	0.211
	1400	1333.3	1336.3	1356.7	1375.7	8:40	8:50	9:00	9:10	0.194	0.201	0.206	0.208
	1800	1661.0	1673.7	1676.3	1679.7	6:50	7:00	7:10	7:20	0.190	0.195	0.202	0.203
Brand B	600	597.3	567.7	572.0	540.3	21:53	22:40	23:00	24:27	0.217	0.218	0.220	0.221
	800	848.3	826.7	800.7	748.3	14:40	15:16	16:00	17:00	0.209	0.211	0.213	0.214
	1000	1036.7	1026.3	966.0	912.3	11:43	12:03	13:06	13:53	0.205	0.207	0.208	0.212
	1300	1254.7	1216.7	1151.7	1118.7	9:40	10:00	10:40	11:16	0.203	0.204	0.207	0.211
Brand C	600	938.3	916.7	836.7	736.3	13:13	13:50	15:23	17:43	0.208	0.212	0.215	0.218
	800	1015.9	996.3	899.7	785.7	12:06	12:33	14:06	16:20	0.206	0.209	0.212	0.215
	1000	1064.7	1022.5	922.0	806.0	11:26	11:46	13:30	15:50	0.204	0.208	0.209	0.213
	1200	1138.3	1108.7	979.3	839.7	10:36	11:03	12:53	15:00	0.203	0.205	0.209	0.211
Brand D	600	691.0	669.0	NA	NA	18:10	18:20	NA	NA	0.211	0.216	NA	NA
	800	814.3	809.3	803.0	800.7	15:20	15:30	15:40	15:50	0.209	0.210	0.210	0.212

NA = not applicable

TABLE IV
RESULTS OF TESTING THE EFFECT OF VOLTAGE VARIATIONS ON ENERGY EFFICIENCY OF INDUCTION COOKER

Brand	Power (W)	Energy Efficiency (%) per Input Voltage Variation			
		230 V	*220 V*	*210 V*	*200 V*
Brand A	1000	82.1	82.1	79.9	78.6
	1400	83.8	83.8	80.8	79.0
	1800	85.8	85.8	83.6	80.7
Brand B	600	75.1	75.1	74.5	74.1
	800	77.9	77.9	77.1	76.5
	1000	79.3	79.3	78.6	78.1
	1300	80.1	80.1	79.8	78.6
Brand C	600	78.4	78.4	76.7	75.6
	800	79.1	79.1	77.8	76.8
	1000	79.7	79.7	78.1	77.7
	1200	80.1	80.1	79.2	78.1
Brand D	600	77.1	77.1	75.5	NA
	800	78.0	78.0	77.6	77.4

NA = not applicable

$$\eta(\%) = \frac{140}{170.62} \times 100\%$$

$$\eta(\%) = 82.1\%.$$

The focus of the discussion of this study is to empirically determine the impact of supply voltage fluctuations on the performance of induction cookers commonly distributed and used today in the community. Each induction cooker brand has a unique operating power level, as can be seen in Table I, so the value cannot be generalized. However, it can be observed that the general phenomenon refers to the change in input voltage. The delivery of measurement results commences from brand A to brand D and then their comparisons.

B. ENERGY EFFICIENCY ANALYSIS OF BRAND A INDUCTION COOKER

Figure 6 shows the effect of supply voltage variation on the energy efficiency produced by brand A induction cookers. This brand A induction cooker has three levels of operating power, namely 1800 W, 1400 W, and 1000 W. At the 1800 W operating power level, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 85.8%, 83.6%, 80.7%, and 80.3%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages reached 5.5%. At this operating power of 1800 W, the rate of change in efficiency follows the linear regression equation.

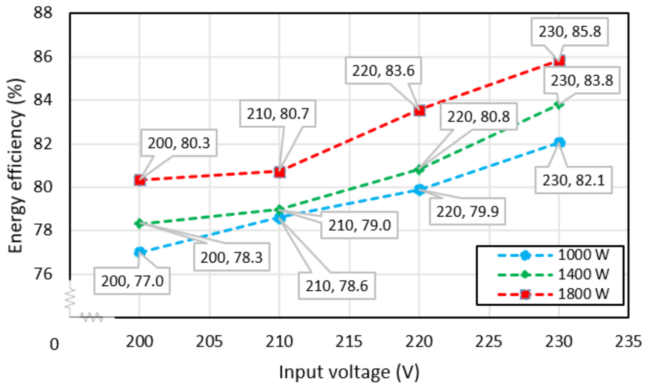

Figure 6. Comparison profile of supply voltage variation on energy efficiency of Brand A induction cooker.

$$\eta(\%) = (0.193 \times \text{supply voltage}) + 41.078.$$

At an operating power of 1400 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 83.8%, 80.8%, 79.0%, and 78.3%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level reached 5.5%. At this operating power of 1400 W, the rate of change in efficiency follows the equation:

$$\eta(\%) = (0.183 \times supply\ voltage) + 41.132.$$

At an operating power of 1000 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 82.1%, 79.9%, 78.6%, and 77.0%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level was 5.0% or 0.5% less than the previous two power levels. At this operating power of 1000 W, the rate of change in efficiency follows the equation:

$$\eta(\%) = (0.1644 \times supply\ voltage) + 44.036.$$

It can be observed that the more the supply voltage decreases on brand A induction cookers, the smaller the energy

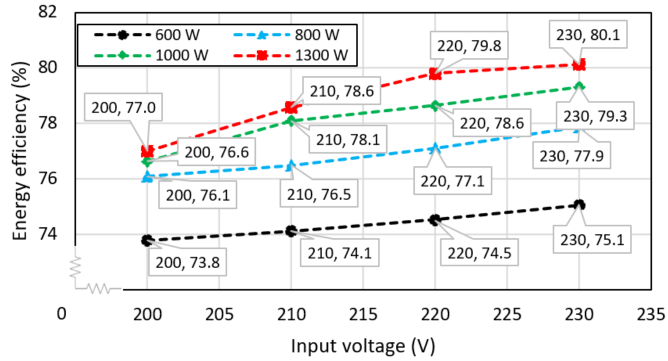

Figure 7. Comparison profile of supply voltage variation on energy efficiency of brand A induction cooker.

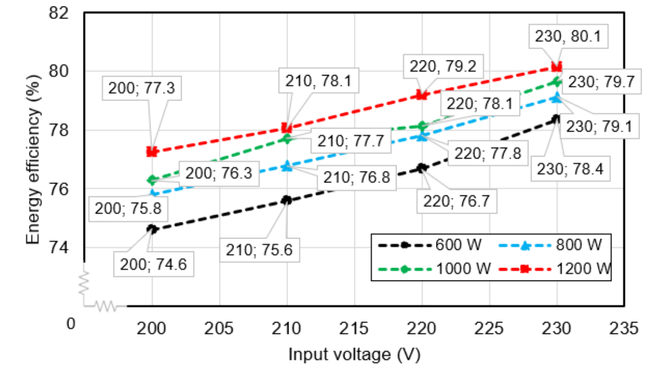

Figure 8. Comparison profile of supply voltage variation on energy efficiency of brand A induction cooker.

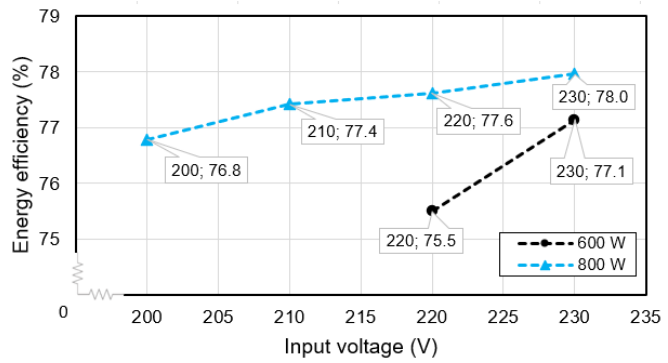

Figure 9. Comparison profile of supply voltage variation on energy efficiency of Brand D induction cooker.

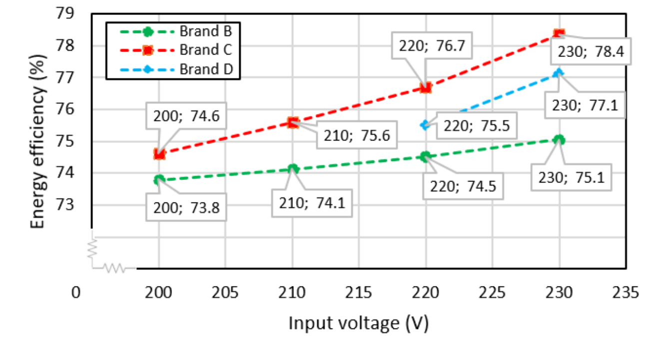

Figure 10. Comparison of supply voltage variations on energy efficiency of induction cookers between induction cockers at 600 W power.

efficiency produced. It happens because, based on the measurement results, it was found that the energy consumption data of brand A induction cookers increased along with the decrease in supply voltage. In addition, the time required for cooking also increases. Hence, with the increase in these two components, power consumption and cooking time, the energy efficiency value decreases as the supply voltage decreases.

C. ENERGY EFFICIENCY ANALYSIS OF BRAND B INDUCTION COOKER

Figure 7 shows the effect of supply voltage variation on the energy efficiency produced by brand B induction cookers. This brand B induction cooker has four levels of operating power, namely 1300 W, 1000 W, 800 W, and 600 W. At the 1300 W operating power level, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 80.1%, 79.8%, 78.6%, and 77.0%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages reached 3.1%. At 1300 W operating power, the rate of occurring efficiency changes follows the equation:

$$\eta(\%) = (0.1059 \times \text{ supply voltage}) + 56.116.$$

At an operating power of 1000 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 79,3%, 78,6%, 78,1%, and 76,6%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level reached 2,7%. At an operating power of 1000 W, the rate of the occurring efficiency change follows the equation:

$$\eta(\%) = (0.0862 \times supply\ voltage) + 59.632.$$

At an operating power of 800 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 77.9%, 77.1%, 76.5%, and 76.1%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level reached 1.8%. At this operating power of 800 W, the rate of the occurring efficiency change follows the equation:

$$\eta(\%) = (0.0594 \times \text{supply voltage}) + 64.108.$$

At an operating power of 600 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 75.1%, 74.5%, 74.1%, and 73.8%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level is 1.3%. At this operating power of 600 W, the rate of the occurring efficiency change follows the equation:

$$\eta(\%) = (0.0422 \times supply\ voltage) + 65.301.$$

Similar to the induction cooker of brand A, in brand B, it was found that an increase in the supply voltage of the cooker results in an increase in the energy efficiency value. In addition, it can be seen in the measurement results that the power consumption value of brand B became larger with an increase in supply voltage. Despite this phenomenon, the time required to heat the water became much shorter as the voltage increases. Thus, the increase in voltage has an impact on increasing the efficiency value of this brand B induction cooker.

D. ANALYSIS OF BRAND C INDUCTION COOKER

Figure 8 shows the effect of supply voltage variations on the energy efficiency produced by the brand C induction cooker. This brand C induction cooker has four levels of operating power, namely 1200 W, 1000 W, 800 W, and 600 W. At an operating power level of 1200 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 80.1%, 79.2%, 78.1%, and 77.3%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages reached 2.9%. At this operating power of 1200 W, the rate of the occurring efficiency change follows the equation:

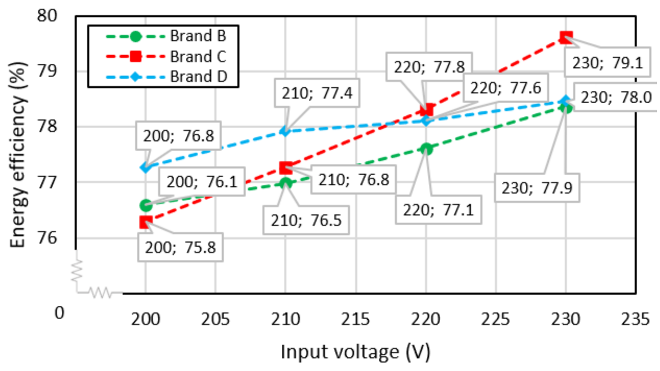

Figure 11. Comparison of supply voltage variation on energy efficiency of induction cooker between induction cooker brands at 800 W power.

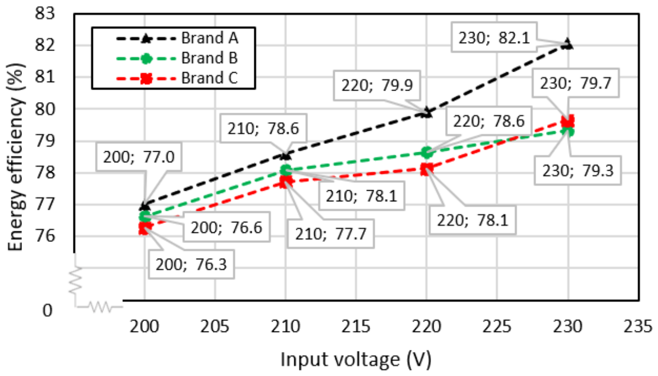

Figure 12. Comparison of supply voltage variation on energy efficiency of induction cooker between induction cooker brands at 1000 W power.

$$\eta(\%) = (0.0979 \times \text{supply voltage}) + 57.614.$$

At an operating power of 1000 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 79,7%, 78,1%, 77,7%, and 76,3%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level reached 3,4%. At an operating power of 1000 W, the rate of the occurring efficiency change follows the equation:

$$\eta(\%) = (0.1054 \times supply\ voltage) + 55.28.$$

At an operating power of 800 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 79,1%, 77,8%, 76,8%, and 75,8%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level reached 3,3%. At this operating power of 800 W, the rate of the occurring efficiency change follows the equation.

$$\eta(\%) = (0.1099 \times supply\ voltage) + 53.745.$$

At an operating power of 600 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 78.4%, 76.7%, 75.6%, and 74.6%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages at this power level was 3.7%. At this operating power of 600 W, the rate of the occurring efficiency change follows the equation:

$$\eta(\%) = (0.123 \times supply\ voltage) + 49.862.$$

It can be observed that as the supply voltage of the induction cooker decreases, the energy efficiency decreases. As can be observed in Table III and Figure 8, there is a phenomenon of decreasing power consumption with decreasing supply voltage. In contrast, the cooking time was increased significantly with a decrease in voltage, resulting in an increase in the total energy required for cooking. It results in a decrease in efficiency.

E. ENERGY EFFICIENCY ANALYSIS OF BRAND D INDUCTION COOKER

Figure 9 shows the effect of supply voltage variation on the energy efficiency generated by brand D induction cookers. This brand D induction cooker has only two operating power levels, namely 800 W and 600 W. At the operating power level of 800 W, the efficiency for voltages of 230 V, 220 V, 210 V, and 200 V were 78.0%, 77.6%, 77.4%, and 76.8%, respectively. The difference in efficiency between the 230 V and 200 V supply voltages reached 1.2%. At this operating power of 800 W, the rate of the occurring efficiency change follows the equation.

$$\eta(\%) = (0.0376 \times \text{supply voltage}) + 69.36.$$

Whereas, at an operating power of 600 W, the efficiency for 230 V and 220 V voltages was 77.1% and 75.5%, respectively. At this 600 W operating power level, the supply voltage variations of 210 V and 200 V cannot activate the induction cooker. Therefore, no measurement data was obtained at these two voltage levels. Meanwhile, the difference in efficiency between the 230 V and 220 V supply voltages at this power level reached 1.6% or 0.4% greater than at 800 W. At an operating power of 600 W, the rate of the occurring efficiency change follows the equation:

$$\eta(\%) = (0.1622 \times \text{supply voltage}) + 39.81.$$

Furthermore, as can be observed in Table III and Figure 9, there is a phenomenon that the more the supply voltage decreases on the induction cooker, the more energy efficiency decreases. This condition is similar to brand B and brand C induction cookers, where there is a phenomenon of decreasing power consumption with a decrease in supply voltage. In contrast, the cooking time is increased significantly with a decrease in voltage, resulting in an increase in the total energy required for cooking. It results in a decrease in the efficiency of the brand D induction cooker.

In all types of induction cooker brands, all measurement results have the same phenomenon, i.e., the efficiency level increases with increasing supply voltage. It is illustrated in Figure 10, Figure 11, and Figure 12 for power supply conditions of 600 W, 800 W, and 1000 W for comparison on all induction cookers. Referring to the three figures, the increase in voltage leads to higher average power consumption but with shorter cooking times for all brands. This results in the total energy consumption for cooking being smaller and the level of energy efficiency being better. As an illustration, the phenomenon in brand A induction cookers, for the operating power options of 1000 W, 1400 W, and 1800 W has a total energy efficiency change rate against the supply voltage variation of 0.164; 0.183; and 0.193 $\Delta\eta/V$, respectively.

V. CONCLUSIONS

Based on the research that has been carried out, referring to all test results, it is known that the energy efficiency of the induction cooker is affected by changes in supply voltage with a large value of change approaching linear. The higher the supply voltage, the higher the energy efficiency.

This condition occurs in all brands of induction cookers used in this study, even though the four cooker brands used have different operating power options. At the operating power of the 1800 W induction cooker, namely cooker A, the difference in supply voltage from 230 V to 200 V causes a 5.5% decrease in the efficiency of the induction cooker. The change in supply voltage from 230 V to 200 V also caused a decrease in the efficiency of brand A induction cookers for 1400 W and 1000 W operating power by 5.5% and 5.0%, respectively. A decrease in efficiency also occurred for operating powers of 800 W and 600 W for all induction cookers used in this study. In general, the change in supply voltage from 230 V to 200 V causes a decrease in efficiency for the entire operating power of the induction cooker between 1.2% and 5.5%, depending on the cooker brand and the employed operating power. The test results indicate that energy efficiency is affected not only by the supply voltage but also by the selection of the operating power of the induction cooker. The higher the operating power of the stove, the higher the efficiency is obtained. The highest efficiency is obtained for 1800 W operating power with a supply voltage of 230 V, which is 85.8% on brand A stoves, while the lowest efficiency is obtained at 600 W stove operating power with a supply voltage of 200 V, which is 74.1% on brand B cooker. With the condition that the efficiency of the induction cooker is affected by the magnitude of the supply voltage, it is hoped that the supply voltage can be kept at a higher limit so as to increase the energy efficiency of the induction cooker, especially in the future the induction cooker is predicted to be one of the cooking utensils that can replace the currently popular gas stove because of the advantages of energy efficiency and energy security.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest in the research and preparation of this paper.

AUTHOR CONTRIBUTION

Conceptualization, Budi Sudiarto and Justinus Dipo Nugroho; methodology, Justinus Dipo Nugroho; software, Budi Sudiarto, and Justinus Dipo Nugroho; validation, Budi Sudiarto, Justinus Dipo Nugroho, and Faiz Husnayain; formal analysis, Budi Sudiarto, Justinus Dipo Nugroho, and Agus R Utomo; investigation, Budi Sudiarto, Justinus Dipo Nugroho and I Made Ardita; resources, Budi Sudiarto, Justinus Dipo Nugroho, Agus R Utomo and I Made Ardita ; data curation, Budi Sudiarto, Justinus Dipo Nugroho, and Faiz Husnayain; writing-original drafting, Justinus Dipo Nugroho; writing-reviewing and editing, Budi Sudiarto and Faiz Husnayain; visualization, Budi Sudiarto, Justinus Dipo Nugroho, and Faiz Husnayain; supervision, Budi Sudiarto, Agus R Utomo and I Made Ardita; project administration, Budi Sudiarto; funding acquisition, Budi Sudiarto.

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