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Investigation The Effect of Various Temperature-Measuring Configurations on The Thermal Efficiency of Liquid Petroleum Gas Stoves

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Abstract: The paper presents the effect of different temperature measurement configurations of volumed water inside the vessel for the thermal efficiency estimation of liquified petroleum gas stoves (LPG Gas Stoves). For this purpose, initial and final water temperature were measured at nine different configurations, and then the thermal efficiency value at each configuration was determined. The reference test method for energy performance of LPG Gas Stove constituted in Indonesia National Standard SNI 7368:2011 was employed to determine the thermal efficiency of the LPG Gas Stove. A coverage interval method was applied to estimate uncertainties and to reliably compare the thermal efficiency measurement. It is found that the thermal efficiency values of temperature position variations are statically similar to the reference point. The interval level of estimated thermal efficiency values ranges from 2.49% to 2.65%. Furthermore, the temperature measurement is found to be the dominant contributor to coverage interval value of thermal efficiency estimation. Therefore, the temperature measurement of the water volume inside the vessel must be specified in the test method in the standard.

Keywords: temperature, thermal efficiency, thermal energy, national standard, test method, gas stove

1. Introduction

Every country's economic and social growth is seen to depend heavily on energy[1)]. The current global energy crisis has made energy conservation essential[2)]. The home building sector is the second-highest energy-user in the world. The ways that homes heat their water, cool their homes, and cook have a big impact on the energy they use. Many residences that previously used wood have transitioned to using liquefied petroleum gas (LPG) as their primary energy source[3)].

Indonesia is one of the fastest growing countries in terms of energy consumption. Energy consumption rose by approximately 38% between 2007 and 2017, and future growth is anticipated[4)]. To reduce energy subsidies due to rising energy usage, the Indonesian government launched the national energy conversion programme from kerosene LPG in 2007 for household sector[5)]. The government has established an Indonesian National Standard (SNI) for LPG Gas Stoves as part of the programme[6)]. Through SNI 7368:2007, "*Kompor gas bahan bakar LPG satu tungku dengan system pemantik*," the standard has been in place since 2007[7)]. The National Standardization Body (BSN) develops the standards, which are seen as technical criteria, procedures, or methods defined based on the agreement of all parties or governments[8)].

The assessment of the thermal energy and thermal efficiency of gas stoves is a component of the energy performance test technique[7)]. To satisfy a gas stove's minimum energy performance, the test procedure's development becomes essential[9)].

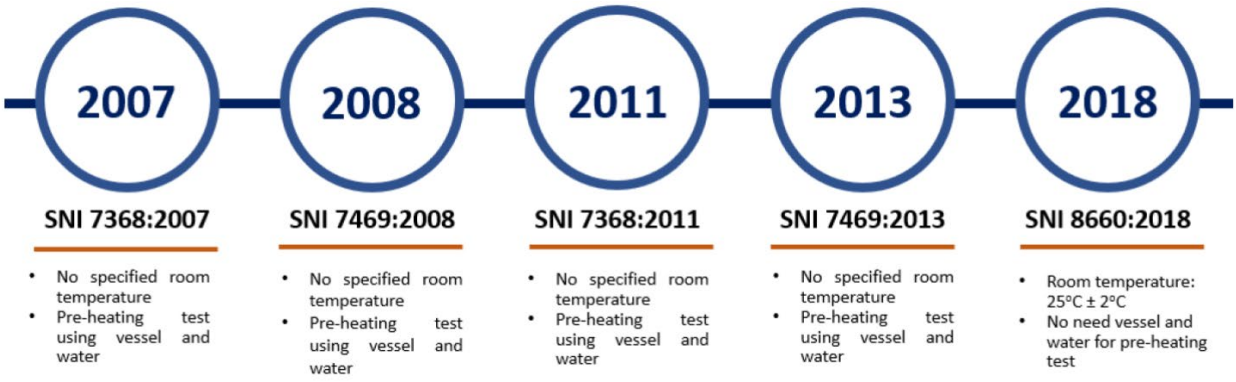


Fig. 1: The evolution of energy performance test method of Indonesian National Standard (SNI) for gas stoves.

Generally, domestic and commercial use can be distinguished in the evolution of the standard. SNI 7368:2007, the first domestic version, is designed for single low-pressure burner LPG gas stoves. SNI 7368:2011, *Kompor gas bahan bakar LPG satu tungku dengan sistem pemantik*, specified for a mechanical or electrical lighter system for low-pressure LPG Gas Stoves, updated the version[7),10)]. The government unveiled the SNI gas stove for double burner through SNI 7469:2008, *Kompor gas dua tungku*, to cover the other gas stove models[11)]. With the introduction of SNI 7469:2013, *Kompor gas tekanan rendah jenis dua dan tiga tungku dengan system pemantik*, the standard's scope to double and triple burners was expanded. The latter version also included the application of Natural Gas (NG) or Liquid Natural Gas (LNG) for domestic use[12)]. The government changed the standards as mentioned above into a single standard, SNI 8660:2018, *Kompor gas LPG dan LNG/NG tekanan rendah untuk rumah tangga*, due to the requirement for trade purposes and advancements in gas stove technology. The standard's application is extended to include low-pressure gas stoves with one or more burners. This most recent version includes coverage for gas stoves installed with LPG, LNG, or NG[13)].

Since the standard was introduced in 2007, little research has taken place to evaluate the test method for energy performance consisting of thermal energy and thermal efficiency. The thermal energy test must be completed within an hour according to all the standards mentioned above. Additionally, the performance characteristic of the acquired thermal energy should be at most 10 % of the value specified in the gas stove's product specification. Before conducting the thermal efficiency test, the procedure requires a pre-heating test. The procedure differs in that the pre-heating test is conducted using a vessel and water. Older editions of the standard required that the pre-heating test method be carried out by heating water inside the vessel for 10 minutes[7),10),11)12)].

The thermal efficiency performance is performed through the temperature measurement of water inside the vessel. The temperature of water should be between 19.5 °C and 20.5 °C for the initial condition. At the same time, the final temperature should be between 89 °C and 91 °C. The configuration for measuring the water's temperature inside the vessel during the thermal efficiency test is not mentioned in the standards either. It implies that any point can be employed to measure the water's temperature inside the vessel during the thermal efficiency test.

The most recent version, SNI 8660:2018, does not require a pre-heating test for thermal efficiency method. Although it was not specified in the earlier versions, the most recent version also stipulates that the thermal energy and thermal efficiency test technique be conducted at the lower and upper limit of room temperature of 23 °C and 27 °C, respectively[13)]. Fig. 1 shows the development of the LPG stove energy performance test procedure.

A study of the pre-heating test was conducted to determine the effect of initial LPG temperatures on thermal combustion efficiency and CO emissions. The thermal combustion efficiency was performed following the SNI 7468:2007 test procedure[14)]. In another study, the influence of varying inlet pressure and test duration on the thermal energy performance of LPG stoves was investigated by applying the SNI 7368:2011 and SNI 7469:2013 test method[15)]. A study was conducted regarding the effectiveness of energy performance tests by minimizing the consumption of LPG during thermal efficiency tests and thermal energy. According to this study, the thermal energy and thermal efficiency values were obtained in a single test via a thermal efficiency test instead of two tests of thermal energy and thermal efficiency conducted consecutively. In this investigation, the energy performance test procedure outlined in SNI 7369:2011 was used to determine thermal energy and thermal efficiency[16)]. A recent study on the energy performance of LPG stoves was conducted to evaluate the energy performance test method. The BS EN ISO/IEC 17043 standard for proficiency testing was applied to evaluate the SNI 7368:2011 test method for thermal energy and thermal efficiency through interpersonal comparative tests[17)].

A literature search revealed that few studies have examined how measuring water temperature affects thermal efficiency. Therefore, this study aimed to examine the effects of various temperature-measuring configurations on the thermal efficiency calculation of liquid petroleum gas stoves. The significance of this study

arises from the fact that the arrangement of temperature sensors within the amount of water during thermal efficiency testing is not specified in the thermal efficiency test method in the SNI gas stove. This unclear procedure could result in biased measurements of the gas stove's thermal efficiency. The urgency of this study lies in the need for improvement in the accuracy of the thermal efficiency method for gas stoves. This concern is crucial to provide an accurate test method for thermal efficiency of gas stoves and, thus, can be used as the accurate basis for designing a gas stove with high thermal efficiency.

2. Methods

2.1 Energy Performance Test

A single-burner LPG gas stove's thermal energy and thermal efficiency were determined. In this paper, thermal efficiency is defined as the ratio of the work done by heating and evaporating water to the energy used by burning fuel, which refers to the efficiency term in the SNI test method. Thermal efficiency estimates the entire amount of energy the fire produces to heat the water in the pot[18]. The term thermal energy is used in this paper, which refers to the heat input term in the SNI 7368:2011.

The test method and formula specified in SNI 7368:2011 were employed to determine the gas stove's thermal energy and thermal efficiency. Although the recent standard SNI 8660:2018 was not applied in this study, the test method and formula for determining thermal energy and thermal efficiency are still applicable to the procedure outlined in SNI 7368:2011. The disparity originates in the requirement that the initial test is conducted at room temperature[10),13)]. In accordance with SNI 8660:2018, the room temperature was maintained between 23 °C and 27 °C prior to the test in this investigation.

Table 1. The relation of heat input, volume water, diameter, and height of vessel[10].

Thermal Energy (kW)	Diameter of Vessel (mm)	Height of Vessel (mm)	Minimum Water Mass (kg)
1.16 ~ 1.64	220	140	3.7
1.65 ~ 1.98	240	150	4.8
1.99 ~ 4.20	260	160	6.1

In addition, both versions require the water mass and vessel specifications for thermal efficiency testing based on the determined thermal energy value. Consequently, the thermal energy test was conducted prior to the thermal efficiency test. Table 1 provides information regarding thermal energy values in relation to the vessel diameter, vessel height and water mass for the thermal efficiency test.

A commercial LPG stored in a 3 kg gas cylinder was used as a gas fuel for thermal energy and thermal efficiency tests. The thermal energy test was conducted for 60 minutes, and the quantity was determined using the following formula[10].

$$Q_n = \frac{1000 \times M_n \times H_s}{3600} \quad (1)$$

One of the most critical components of the thermal efficiency test is measuring the water's temperature inside the vessel. According to SNI 7368:2011, the test method for the initial temperature of the vessel's water mass must be between 19.5 °C and 20.5 °C. The final temperature is obtained by turning off the stove immediately after the water temperature reaches a temperature between 89 °C and 91 °C. To calculate the thermal efficiency value, the maximum temperature of the water mass within the vessel should be determined. However, the standard does not specify how to determine the maximum water temperature inside the vessel. In this experiment, the temperature increase was recorded every 10 seconds, and the maximum temperature was obtained five minutes after turning off the gas stove. The thermal efficiency value is calculated using the following formula[10].

$$\eta = \frac{4.186 \times 10^{-3} \times M_e \times (t - t_1)}{M_c \times H_s} \times 100\% \quad (2)$$

In the SNI 7316:2011 test method, the calorific value of LPG (H_s) is specified to have a constant value of 49.19 MJ/kg. Therefore, the LPG consumed during the test becomes crucial in thermal energy determination. As required by the standard test method, the working pressure of LPG for thermal energy testing was maintained at an input pressure between 275 mmH_2O and 285 mmH_2O. The input pressure was regulated using an adjustable gas regulator to avoid fluctuations. An analogue pressure gauge with a precision of 20 mmH_2O and the capability of sensing gas pressure up to 1000 mmH_2O was used to measure the input pressure. To determine the amount of LPG consumed throughout the test, a digital scale with a resolution of 0.1 g and traceability to the higher standard of 0.1 g was used[10].

2.2 Temperature Measurement Configuration

The concern regarding the temperature measurement of water inside the vessel is the configuration of temperature sensing placement to measure the temperature of water inside the vessel during the thermal efficiency test. This configuration raises concerns since the thermal efficiency test method in SNI 7368:2011, and the most recent version of SNI 8660:2018 fails to specify where the temperature sensing of the water should be located, potentially biassing the findings of the test for thermal efficiency. In order to estimate the thermal efficiency of gas stoves, this experiment investigated the potential temperature sensor configurations of the volume of water inside the vessel.

Configuration based vessel diameter and height of vessel was carried out for this, and their energy efficiencies were calculated in accordance with Eq. (2). The arrangement of water temperature measurement is shown in Fig. 2. For temperature sensing, a wire thermocouple with a 0.3 mm diameter was prepared in accordance with the Committee of Testing Laboratories – Operational Procedure (CTL-OP)[19].

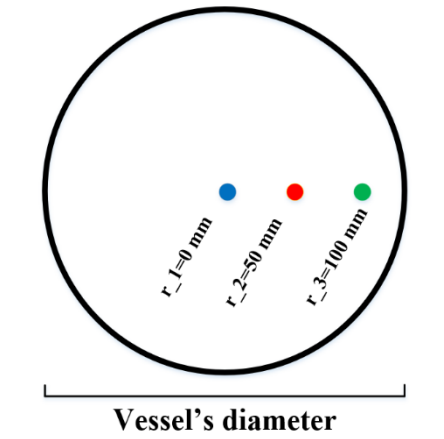


Fig. 2: Schematic of temperature measurement of water volume, (a) horizontal configuration, (b) vertical configuration.

As shown in Fig. 2(a), the measurement configuration was divided into three points based on vessel diameter: r_1 (center of vessel), r_2 (50 mm from center), and r_3 (100 mm from vessel). According to height of vessel, the measurement was done at three different heights relative to the vessel's lid, as shown in Fig. 2(b), h_1, h_2, and h_3, having distance from vessel's lid of 110 mm, 140 mm, and 170 mm, respectively. Nine distinct temperature measurements were set up as a result. The electric rice cooker's energy test used this method to characterize the temperature of the water mass. A similar method was performed in the previous study to investigate the accuracy of energy test method of electric rice cooker. A basic statical analysis was carried out for eleven distinct measurement points to look at the error value of the thermal efficiency value obtained[20]. In this work, the thermal efficiency values were examined using a coverage interval method based on the law of uncertainty propagation. The coverage interval determination process outlined in ISO/IEC GUIDE 98-3:2008(E) was followed. The coverage interval value is determined by calculating expanded uncertainty through formula as follow[21].

$$U=k\cdot u_c(y) \tag{3}$$

The standard uncertainty, $u_c(y)$, in Eq. (3) is determined according to the first-order Taylor series approximation through implementing the propagation of uncertainty. The coverage factor, k, is derived from t-distribution with practical degrees of freedom, v_{eff}, and is set to 2 for 95% confidence interval[21].

3. Results and Discussions

To ensure accurate results, measurements for thermal energy and thermal efficiency were performed in five repeatability. During the test, measurements of the water's temperature in the vessel were recorded every 10 seconds. The thermal energy and thermal efficiency of LPG Gas Stove were calculated according to Eq. (1) and Eq. (2) respectively.

3.1 Thermal Energy

Eq. (1) indicates that consumed gas during the test and the caloric value of the gas contributes to the thermal energy measurement result. The standard and expanded uncertainty derived from five repeatability measurements for thermal energy are summarized in Table 2.

As shown in Table 2, the estimated thermal energy acquired from five repeatable measurements is 2.60 kW. The standard uncertainty of repeatability, instrument resolution, and traceability to the higher standard results in an expanded uncertainty of 0.05 kW. This value means that the lower and upper limits of coverage interval values are 2.55 kW and 2.65 kW, respectively. Regarding the vessel dimensions and water mass for the thermal efficiency test, as shown in Table 1, these coverage interval values result in the range of thermal energy for a vessel with a diameter of 260 mm, a height of 160 mm, and a water mass of 6.1 kg.

Table 2. Uncertainty budget for thermal energy.

Parameter	ΔM_c (g)	Q_n (kW)
Estimated value	190.406	2.60
Standard Uncertainty	Repeatability (g)	1.327
	Resolution (g)	0.0289
	Traceability (g)	0.05
Combined Standard Uncertainty (kW)		0.018
Coverage Factor		2.77
Expanded Uncertainty (kW)		0.05

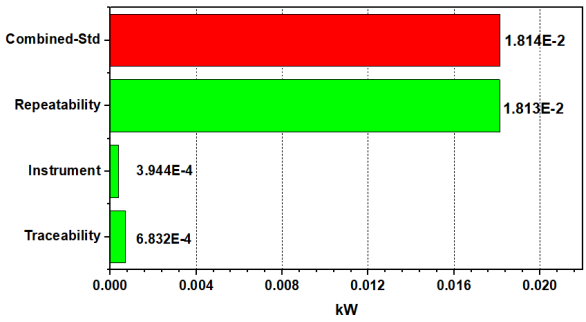
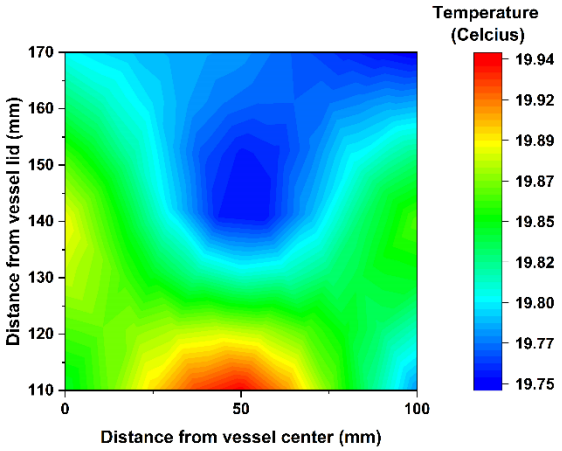


Fig. 3: Contribution of parameters to the expanded uncertainty of thermal energy

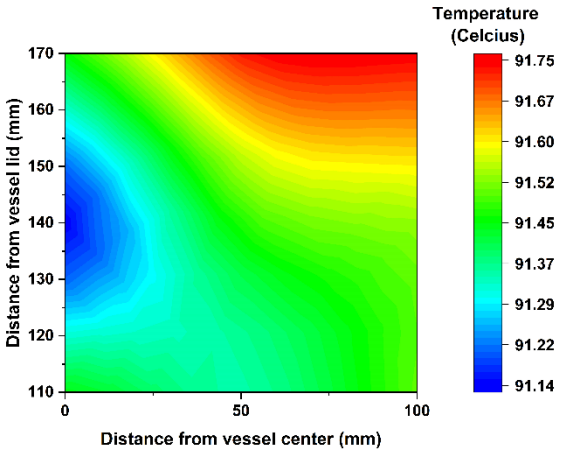
In addition, the standard uncertainty shown in Table 2 reveals that the repeatability of consumed gas during the thermal energy test is a major contributor to the expanded uncertainty. This element of repeatability is directly related to the sensor property employed in the measurements. Consequently, defining the measuring sensor specification in the standard may be essential. The standard deviation value of five repeatable weighing masses of consumed LPG may contribute to this significant source. The measurement of consumed LPG from five repeatability gives a standard deviation of 2.966 g. This value indicates that the repeatability of the LPG thermal energy consumption data from five observations is fairly dispersed. The contribution of repeatability, instrument resolution, and traceability to the higher standard is depicted in Fig. 3. Resolution and instrument traceability are categorised as systematic errors that can be compensated with a correction factor. Repeatability, in contrast, is a random error type that the correction factor cannot rectify. The error is the ratio between the measured value and the actual value.[22].

3.2 Temperature Distribution

To measure the water temperature, a wire thermocouple was used having a resolution of 0.1 °C and traceability to its higher standard of 1.66 °C + 0.06%t °C. According to the temperature measurement configuration shown in Fig. 2, the temperature distribution of water inside the vessel during the thermal efficiency test is depicted in Fig. 4. The water's initial temperature is typically greater towards the vessel's lid, as shown by Fig. 4(a). The water's final temperature rises in the vicinity of the stove's burner, as illustrated in Fig. 4(b). The area between 50 mm and 100 mm from the vessel's diameter center experiences the highest temperature rise.



(a)



(b)

Fig. 4: Temperature distribution of water inside vessel in thermal efficiency test: (a) initial temperature, (b) final temperature.

3.3 Thermal Efficiency

Eq. (2) of the thermal efficiency calculation method reveals that the gas's caloric value, the water's mass and vessel, the temperature of the water, and the gas used during the test all affect the thermal efficiency of the gas stove. The same formula was also applied to investigate the energy performance of dimethyl ether (DME) gas stove[23), 24)] and a gas-fired stove[25), 26)].

In nine distinct temperature combinations, the thermal efficiency of energy was calculated. The thermal efficiency was obtained by measuring the water's initial and final temperatures in each configuration of the vessel. These temperatures, along with other variables in Eq. (2), contribute to the expanded uncertainty. The thermal efficiency value and expanded uncertainty for nine temperature settings are shown in Table 3. This method was also applied to examine the impact of nozzle diameter and nozzle arrangement on heat transfer and CO emission characteristics. The experiment used a commercial LPG composed of 70% butane and 30% propane[27)]. However, the composition of commercial LPG used in this

experiment was not measured. It is important to note that neither the referenced SNI 7368:2011 test method nor the most recent SNI version (2018) specifies the composition of LPG used in energy performance tests[9), 13)].

Table 3 demonstrates that the thermal efficiency value for nine temperature configurations is around 69 %. The configuration center of the vessel, which is 140 mm from the vessel lid and center of the vessel's radius, has the lowest value of thermal efficiency, 69.18 %. The arrangement with a vessel radius of 50 mm and a distance from the lid of 170 mm results in the highest thermal efficiency value of 69.90 %. A higher thermal efficiency rating is typically found at 170 mm near the gas stove burner. Fig. 4(b) illustrates how closely it conforms to the temperature distribution. The shape of the burner on a gas stove is an essential factor in the resulting combustion effect on the water in the vessel. In this study, the gas stove burner is circular, in which the ring burner has 42 small fire holes to produce the stove's combustion. As the burner produces combustion on a gas stove, this will affect the heat transfer on the vessel and, thus, the thermal distribution of water inside the vessel. The water temperature distribution illustrated in Fig. 4 confirms the heat transfer effect due to combustion on the burner, resulting in the thermal efficiency trend on the configurations measurement. As in Eq. (2), the increase in water temperature rise $(t - t_1)$ is proportional to the thermal efficiency value. Therefore, the higher water temperature rise will produce greater thermal efficiency. A study regarding the importance of gas stove burners was carried out on the effect of burner design on the performance of LPG gas stoves. The thermal efficiency of LPG gas stoves with regular burner and face burner type were compared[28)]. In another study, a porous metal media was added to the gas stove burner to improve the thermal efficiency of LPG gas stove[29)].

Table 3. The thermal efficiency value and expanded uncertainty of nine temperature measurement configurations.

Temperature configuration		t_1 (°C)	t (°C)	η (%)	U (%)
r_1	h_1	20.08	91.43	69.60	2.49
	h_2	20.18	91.11	69.18	2.59
	h_3	20.04	91.45	69.66	2.60
r_2	h_1	20.20	91.34	69.39	2.59
	h_2	19.96	91.46	69.75	2.59
	h_3	20.01	91.67	69.90	2.65
r_3	h_1	20.00	91.41	69.65	2.59
	h_2	20.10	91.35	69.65	2.60
	h_3	19.87	91.21	69.58	2.59

Table 3 also shows that the temperature measurement close to the burner of a gas stove is observed to have more significant expanded uncertainty. The value of expanded uncertainty in Table 3 gives the value of the coverage interval is statistically unsignificant effect on the assessment of thermal efficiency across the nine temperature measurement configurations. It indicates that considering coverage interval will statistically result in the same thermal energy value regardless of the water temperature measurement arrangement.

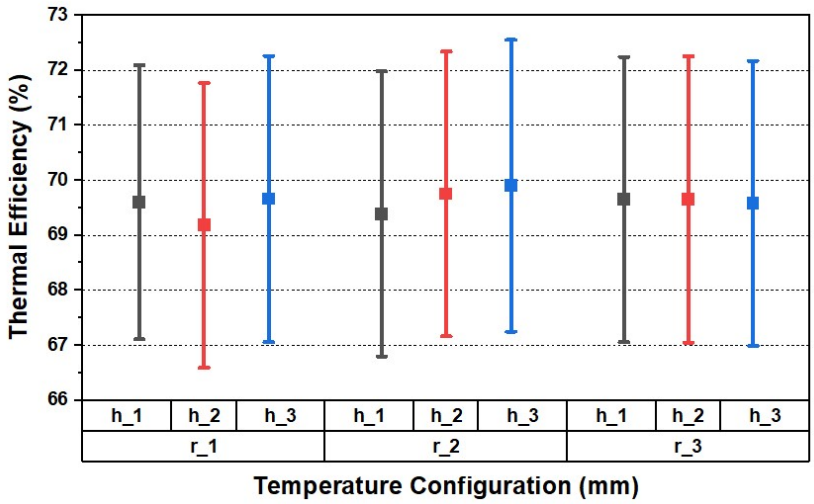


Fig. 5: Low and high points of coverage interval of thermal efficiency value obtained from nine temperature measurement configurations.

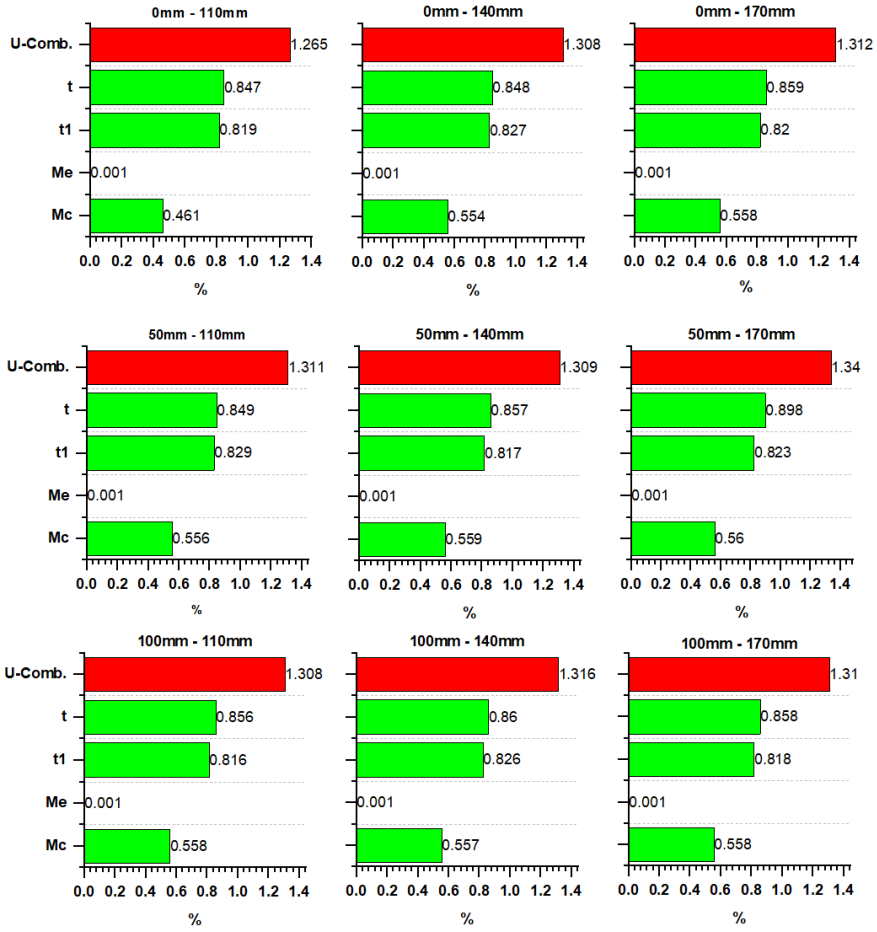


Fig. 6: Contribution of parameter to uncertainty value of thermal efficiency in each configuration

Although thermal efficiency has no significant value, further analysis reveals that variations in temperature measurement, t_1 and t, contribute to the overall uncertainty of thermal efficiency estimations. Temperatures are the most contributor factor compared to other parameters for all configurations of temperature measurement, as shown in Fig. 6. This finding leads to the concern that the temperature measurement of water inside the vessel needs to be configured clearly in the thermal efficiency test method in the SNI gas stove. The clear temperature measurement method could improve the accuracy of the test method and reduce the potential bias of the thermal efficiency value of the gas stove. There is also important to consider the measuring of the LPG temperature during the energy performance test. This is due to the fact that the preheating test's effects, the gas's initial temperature had an impact on the gas's thermal efficiency value[14]. In this study, the initial temperature of the LPG used for the thermal efficiency test was not measured in this investigation. This will lead to the limitation of the current study.

4. Conclusion

The effect of various temperature-measuring configurations on the thermal efficiency of liquid petroleum gas stoves is investigated in this paper. The average thermal efficiency in the configuration r_1 (center of vessel) produces the lowest value. The average thermal efficiencies obtained from configuration r_1, r_2, and r_3 is 69.48 %, 69.68 %, and 69.62 %, respectively. The derived coverage interval value produces statistically comparable thermal efficiency values for nine distinct temperature measurement configurations. The interval level of estimated thermal efficiency values ranges from 2.49% to 2.65%. In addition, the uncertainty contribution of parameters in the formulation of thermal efficiency reveals that temperature is the primary contributor to the uncertainty value of thermal efficiency. This finding could result in a substantial value for the standardization of thermal efficiency value in any configuration in which temperature measurements are performed. Consequently, the requirement to configure the temperature measurement of water within the vessel to be explicitly specified in the test method for the SNI gas stove might increase the accuracy of the test method and reduce the potential bias of the thermal efficiency value of the gas stove. In addition, the standard could also specify the type of temperature measurement sensors to adopt. The gas temperature measurement during the energy performance test was not performed and lead to the limitation of the

current study.

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Nomenclature

Q_n	thermal energy (kW)
M_n	mass flowrate of LPG during thermal energy test (kg hr^{-1})
H_s	caloric value of LPG (MJ kg^{-1})
M_e	total mass of vessel and water inside the vessel (kg)
M_c	total mass of consumed LPG during efficiency test (kg)
t	final temperature of water inside the vessel (℃)
t_1	initial temperature of water inside the vessel (℃)
U	expanded uncertainty
k	coverage factor
u_c	combined standard uncertainty

Greek symbols

η	efficiency (%)

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