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Sudarno Sudarno
Universitas Muhammadiyah Ponorogo, Faculty of Engineering, Department of Mechanical Engineering, Ponorogo, Indonesia
Universitas Brawijaya, Faculty of Engineering, Department of Mechanical Engineering, Malang, Indonesia

Agung Sugeng Widodo
Universitas Brawijaya, Faculty of Engineering, Department of Mechanical Engineering, Malang, Indonesia

Sudjito Soeparman
Universitas Brawijaya, Faculty of Engineering, Department of Mechanical Engineering, Malang, Indonesia

Slamet Wahyudi
Universitas Brawijaya, Faculty of Engineering, Department of Mechanical Engineering, Malang, Indonesia

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EFFECT OF THE EMBER ELEMENT IN INCREASING THE EFFICIENCY OF LIQUEFIED PETROLEUM GAS STOVES

Sudarno Sudarno[1,2], Sudjito Soeparman[2], Slamet Wahyudi[2], Agung Sugeng Widodo[2]*
[1]Universitas Muhammadiyah Ponorogo, Faculty of Engineering, Department of Mechanical Engineering, Ponorogo, Indonesia
[2]Universitas Brawijaya, Faculty of Engineering, Department of Mechanical Engineering, Malang, Indonesia

The purpose of this study was to determine the effect of use ember element from woven nickel wire to increasing the efficiency of the LPG stoves. It is supposed that high-temperature embers can burn more fuel around the wire, thereby increasing the area of complete combustion. The test was conducted by means of a Water Boiling Test (WBT) and the number of ember layers varied from one to four. It was found that the use of elements of fire without reflectors could increase efficiency by 8.32%, with the highest efficiency being with the use of a single layer ember element of the fire, of 61.71%. However, the use of elements of fire in the finned heat reflectors causes efficiency to decrease, as the pattern to put elements of fire interfere with the reflectivity. This means the heat reflection is blocked by the pattern and trapped between the reflector and pattern elements. As a result, the heat energy from the reflector reflection cannot be forwarded to the combustion zone. The test results also show that the temperature distribution from ember element use can increase the area of complete combustion.

Key words: LPG stoves, finned heat reflector, ember element, efficiency

INTRODUCTION

Changes to the burner head in conventional gas stoves can increase thermal efficiency. It was found that changes in the material and design of the head can increase thermal efficiency by 4% compared with conventional gas stoves, if the material burner head, previously made of cast iron, is replaced with a brass head burner. Efficiency is also increased by 10% when the burner head shape is changed to a flat face [1, 2]. A similar study was conducted by Zhen et. Al., it was found that the swirling burner design was able to increase efficiency and reduce CO levels compared to conventional gas stoves [3].

Using Porous Ceramic Rare (PCR), the results showed that its application causes a colour change from red to blue in the flame and a decrease in the concentration of CO and O_2 in the exhaust gases of 40.9% and 12.8% respectively [4]. Use of Porous Radiant Burners (PRB) on LPG stoves produces a maximum efficiency 10% higher than the maximum thermal efficiency of conventional LPG stoves and generates a stable process with a thermal efficiency above 72% [5]. In addition, using a Two-Layer Porous Radiant Burner (PRB), the combustion zone uses Silicon Carbon (SiC) porous, whereas in the preheating area alumina is used. Provided that the radial temperature distribution is almost uniform, the thermal efficiency of 68% increased by 3% compared to the standard stove. CO and NOx emissions dropped significantly for each standard stove, from 400-1050 mg/m^3 and 162-216 mg/m^3 to 25-350 mg/m^3 and 12-25 mg/m^3 respectively for the stove with a Two-Layer PRB [6, 7]. Using the same method, Mishra and Muthukumar found that the use of PRB was able to increase the thermal efficiency of LPG stoves by 10.1% and reduce CO and NOx emissions from 220-550 ppm and 5-25 ppm to 30-140 ppm and 0.2-3.5 ppm [8].

In 2009, Abdurrachim et. al. [9] stated that with the use of a means of collecting the flow of combustion gases are dispersed and directed to the pan wall can increase the burning of energy to the maximum. In 2011, Gohil and Channiwala stated that the thermal efficiency of a conventional gas compost by 66% and could be enhanced with the addition of casing material and optimisation of the combustion process [10]. In 2012, Syahrial examined the use of reflectors with varying hole diameters. Truncated cone-shaped reflector mounted facing upwards on biogas stoves. The research results show that thermal efficiency increased by 5.6% compared to a stove without a reflector [11]. We found that the use of heat radiation reflectors with three rows of fins can increase the efficiency of the LPG stove by 5.22% [12]. In 2014, Widodo examined the use of the veil of radiation on a gas stove. I have provided that the property of a material sheath greatly affects the efficiency of a gas stove. The highest efficiency was 46.36% with the casing with ceramic materials, which was an increase of 2.6% over the gas stove without the veil [13].

Research on improving the efficiency of kerosene stoves or gas wheelbases has been carried out, either by engineering construction or by efforts to optimize the use of fire. Efforts to optimise the utilisation of fire is still likely quite high in efficiency increase, considering that most researchers have focused on engineering construction. Efforts meant is to add a tool, namely the ember element.

An ember element is a model of a pile woven wire tool nickel arranged in a layered or stratified pattern. This refers to the nature of the metal when heated, which will

*darnotec@umpo.ac.id

anneal to form a high-temperature ember. Embers generated more perfectly will be able to burn fuel vapours in the area around the wire, thus increasing the area of complete combustion. It is expected that a perfect combustion process will be able to increase the efficiency of LPG stoves.

Table 1: Specifications of materials used

Material	Specification
LPG stove	Rinnai 511C, A single furnace, SNI 7368-2001
LPG tube	SNI 1452 2011
LPG fuel	LPG for household [14]
Regulator Winn gas	W688M SNI
Pan	Aluminium (alloy 2024-T6), diameter 220mm
Flowmeter	Coriolis mass flow meter, accuracy ± 0.01g
Stopwatch	Casio HS3
Thermometer	Krisbow thermometer digital, accuracy ± 0.5 ^{o}C
Digital scales	Matrix A12E Portable cap. 20 kg x 0.1g SNR: 1500246, accuracy ± 0.1g
Measuring cups	Ikea vardagen glass 1 litre
USB data logger type -4718	8-ch thermocouple input USB module
Thermocouple	1.2 mm diameter, 20 cm in length, max. 1200^{o}C
Camera	Canon DS126431 EOS 700D
Finned heat reflector	Stainless steel (AISI 304), three rows of fins, height of 30mm, angle of 22.5^{o} is measured from the vertical axis
Ember element	Frame diameter 170 mm, nickel wire diameter 0.30 mm, one to four layers

MATERIALS AND METHODS

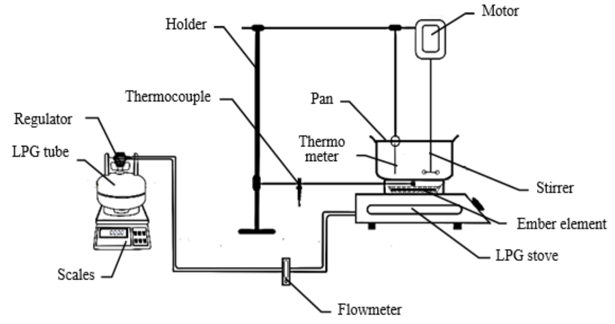
Specifications of materials

The materials and main equipment needed for the research were shown in Table 1.

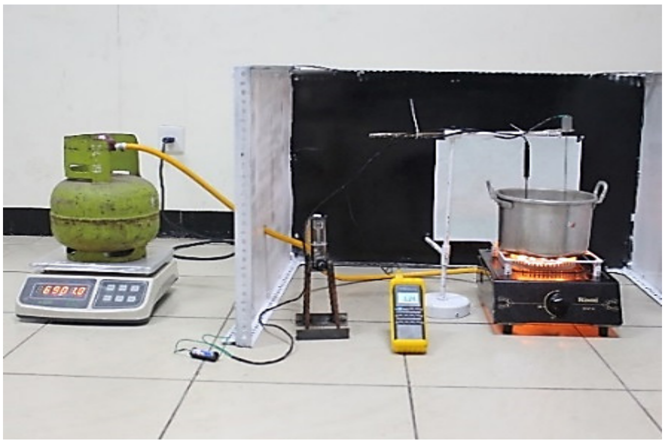
The research installation is shown in Figure 1.

The Model Ember Element

The embers are generating elements made of nickel wire 0.30 mm in diameter. Nickel was selected for its thermal resistance properties and faster burning when heated, while the selection of a material with a small diameter



(a)



(b)

Figure 1: (a) Research installation
(b) photo research installation

was intended to not interrupt the flow of the combustion flame.

The wire was woven in a circular pattern, with the diameter of the circle following the pattern of the reflector diameter. A triangular pattern of woven wire with the ends tied in a circular pattern and woven sequentially. With the webbing models in the middle of the ember elements circular pits are woven. The number of ember layers varied, namely one layer, two layers, three layers, and four layers.

The wires were woven in a circular pattern mounted on finned reflectors. The circuit was mounted on the burner head, between the fire with a load output. The setting of the ember mounting element is shown in Figure 2, while the ember element layer model is shown in Figure 3.

Sequence of test

1. *Power Test*: The amount of power the stove was calculated based on the amount of fuel consumption so that the necessary test of fuel consumption. The test starts after the flame is stable and the flow meter is in a fixed position. In this test there was no pan on the stove, the test was carried out for 30 minutes and repeated 8 times. Stove power was obtained and used as the basis for determining the diameter of the pan used.

2. *Test Efficiency*: In a test the efficiency, which is measured by fuel consumption and steam production. Efficiency test was performed by comparison between with the use of the fire element and without. A layer of embers varying elements, namely one to four layers. Tests to determine the efficiency of the stove were carried out with a WBT. The test begins by placing the pan on the stove when the fire has stabilized after five minutes of initial ignition. The flame is maintained at maximum blue conditions and to keep the LPG flow stable, control is carried out on the regulator, flow meter and gas valve openings on the stove. Water temperature and ambient temperature data are taken every 5 minutes until the water begins to boil. The heating continues for 60 minutes and this process is repeated eight times.

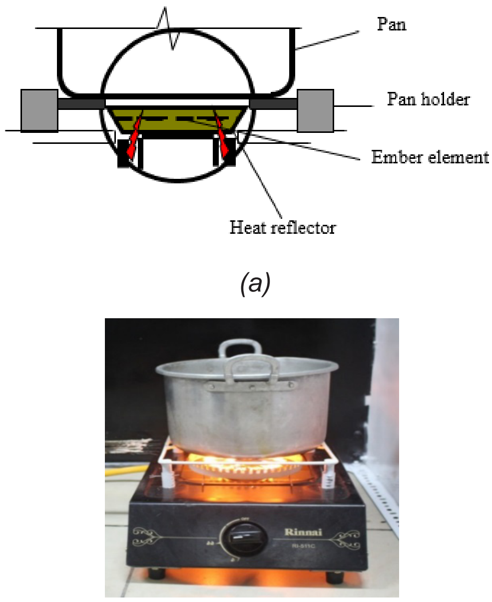


Figure 2: (a) The setting of the mounting ember element on LPG stove and (b) photo mounting ember element on LPG stove

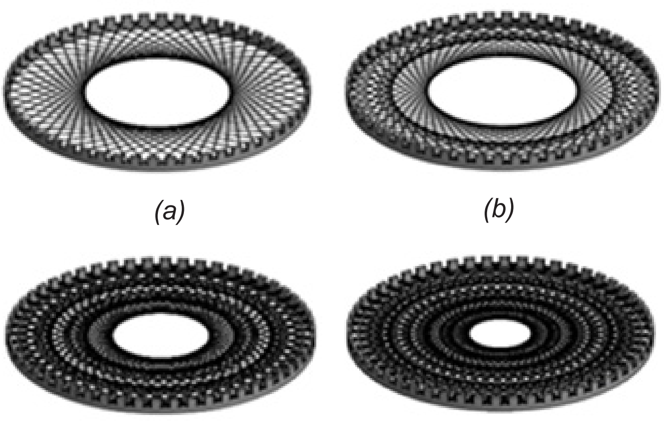


Figure 3: Ember elements (a) one layer (b) two layers (c) three layers and (d) four layers

3. *Test the Fire Temperature Distribution*: The temperature distribution of the fire was tested to obtain an idea of the temperature distribution isothermal contour fire. Through visualisation contours, isothermal temperature distribution can obtain valid conclusions about the effect of the use of this tool to increase the efficiency of LPG stoves. The test process was performed on the LPG stove with and without a load, with and without reflectors, without an element of the embers elements. Data processing was performed using the Matlab R2010a.

Making use of thermocouple temperature data, starting from the centre line of the stove, the friction with thermocouple per 5mm outwards to obtain data at one point amounted to 6x25 dot (distance measuring 12cm)=150 points. Retrieval of the data began with set time data readings from the tool for each position (consisting of a 6-channel thermocouple). Time readings at each point were for 5 seconds, with the number of readings 5 times per second. Thus the number of readings at any point was 25.

RESULTS AND DISCUSSION

Test stove power

Stove power is directly proportional to fuel consumption that is the stove. The power level will show the capacity of the stove to transfer fuel into the combustion chamber. The amount of power the stove is calculated by the following equation [15]:

$$I=\frac{m_f E_f}{\Delta t} \ldots (kW) \quad (1)$$

where I stove power (kW); m_f (kg) is the mass of fuel used after treatment; E_f 46110 kJ/kg is the net calorific value of LPG [15]; Δt 30 min time for the test.

To test the stove, the selection was made according to the pan size of the VEG Gas Institute of the Netherlands, which explains that the size of the pan should be selected based on the maximum power of the stove, with a ratio of maximum power and surface area of 7 W/m^2 [15] and amount of water used for test the efficiency of the WBT is a two-thirds volume of the pan [16-18].

Based on the analysis of data, the power obtained for the LPG stove with SNI 7368-2007 amounted to 1.71kW. Based on the burner power, it is possible to determine the amount of the pan diameter of 220mm with future water two-thirds volume of the pan of 3625g.

Test LPG stove efficiency

The efficiency of a stove is the ratio between the useful heat, which is needed to cook something in a certain amount from the initial temperature to cook with the heat provided by the fuel, which is used during the cooking. LPG stove thermal efficiency test conducted according to Indian Standard (IS) 4246:2002 is to WBT [19, 20], as shown in Figure 4. Based on the figure, the efficiency test begins with turning on the stove fire and setting it to the maximum blue flame condition. The initial ignition is carried out for five minutes and after the flame condition is steady, the pan that has been filled with water is placed on the stove and the measuring process begins. The water is heated from the initial temperature (T_a) and the temperature change is recorded every five minutes until the water boils (T_d). This process is called sensible heating. The heating process is continued until a total time of 60 minutes, from (T_a) to (T_d), this process is called latent heating. After that, the mass of LPG gas used and the mass of vapour lost are measured. This method uses an approach to cooking food at home.

Stove efficiency can be calculated by the following formula [15, 18, 21]:

$$\eta_{ov} = \frac{\{(m_w.C_{pw})+(m_b.C_{pb})\}\, x\, (T_{wf}-T_{wi})+m_u.H_u}{m_f.E_f} \qquad (2)$$

where η_{ov} (%) is stove efficiency; m_w 3.625 kg is water mass; C_{pw} 4.186 kJ /kg K [18] is the specific heat capacity of water; m_b 0.275 kg is the mass of the pan; C_{pb} 0.913 kJ/kg K [15] is the specific heat capacity of pan; T_{wf} (K) and T_{wi} (K) are the water temperatures before and after treatment, respectively, in kelvin; m_u (kg) is the mass of steam after handling; H_u 2257 kJ/kg [15] is the latent heat of vaporization; m_f (kg) is the mass of fuel used after treatment; and E_f 46110 kJ/kg is the net calorific value of LPG [15].

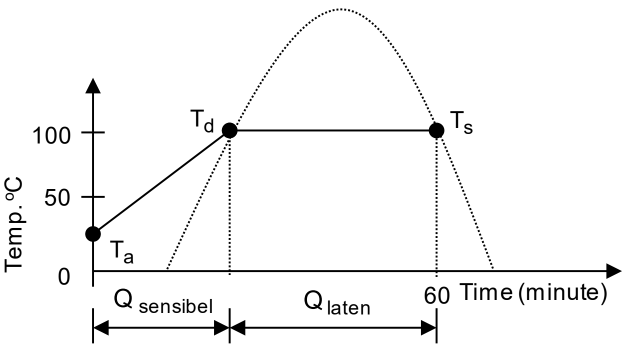


Figure 4: Temperature changes during the test

The test data on fuel consumption and the production of steam were used to determine the efficiency of the LPG gas stove, with power equal to 1.71 kW, pan diameter of 220 mm, and 3625 g of water.

1. Test Efficiency by Varying the Distance of the Burner to the Load on a Conventional Stove: This test was used to determine the optimal distance of the burner to the load on a conventional stove. The graph in Figure 5 shows that a distance of the burner to the load of 35 mm provides the highest efficiency of 53.39%. This optimal distance of the burner to the load was used as a reference for the subsequent test. These results are consistent with those found by Kotb, A., and Saad, H., that the load height affects the resulting thermal efficiency [22].
2. Test Efficiency Using a Reflector and Ember Element:

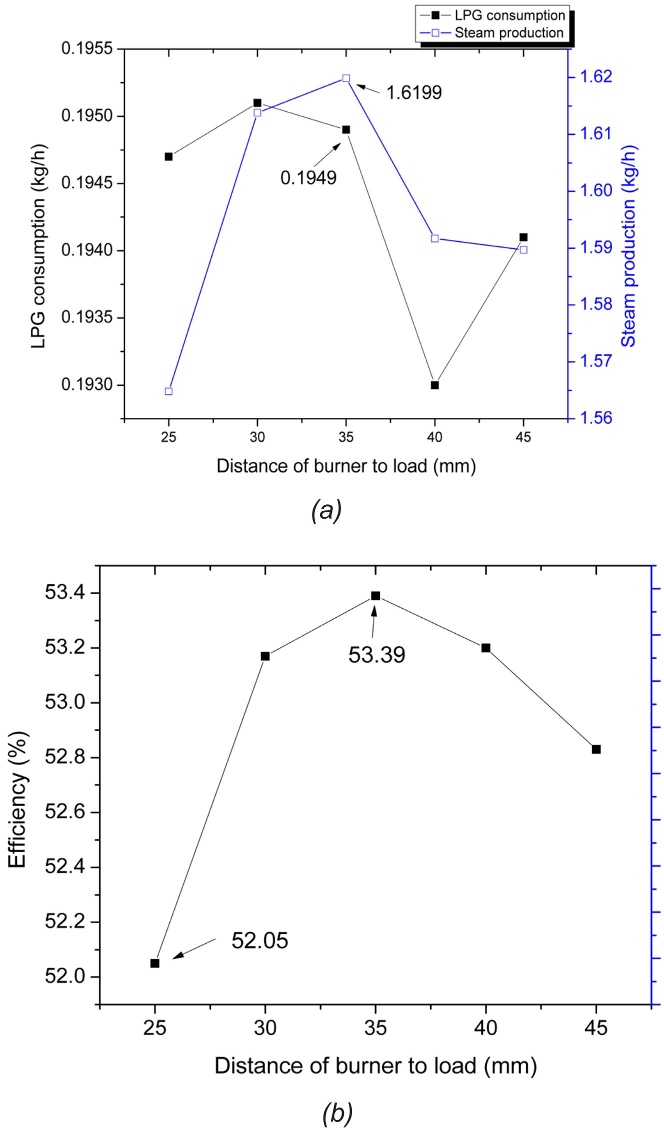
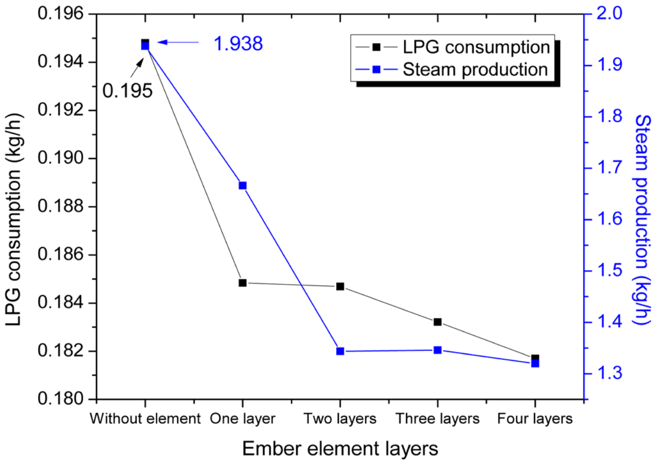


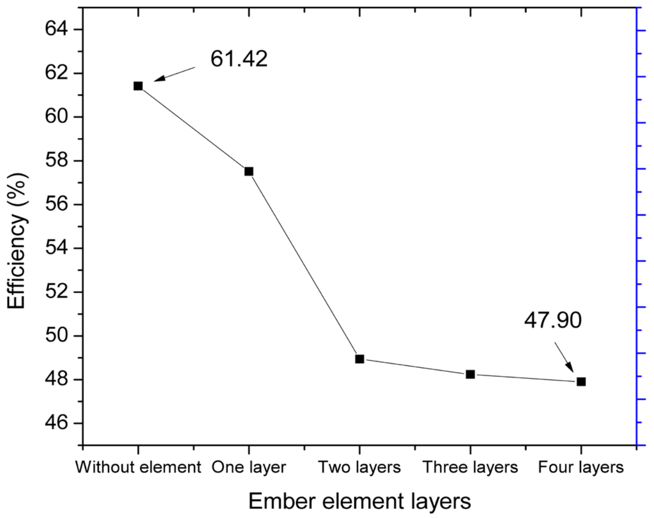
Figure 5: Test results of the distance of the burner to the load on a conventional stove: (a) fuel consumption-steam production and (b) efficiency

ment: The graph in Figure 6 shows that the addition of the ember element makes finned heat reflector efficiency decrease. This decline in efficiency is in line with the increased number of lining elements. This condition occurred because the installation of the ember element pattern attached to the reflector interfered with the reflectivity. With the pattern element attached to it, the reflection of heat from the reflector was blocked by the pattern elements, so the heat was trapped between the reflector and the pattern elements. As a result, the heat reflection of the reflector could not be passed to the combustion zone. Despite the presence of the ember element being able to burn unburned fuel vapour around the wire, the effect of increasing the area of heat was still small compared with the losses caused by the obstruction of reflectivity.

Efficiency decreased with the addition of a layer of the ember element. This condition occurred because of the

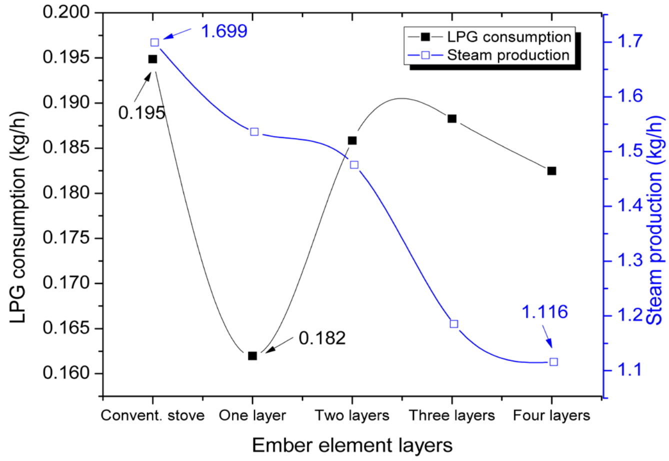


(a)

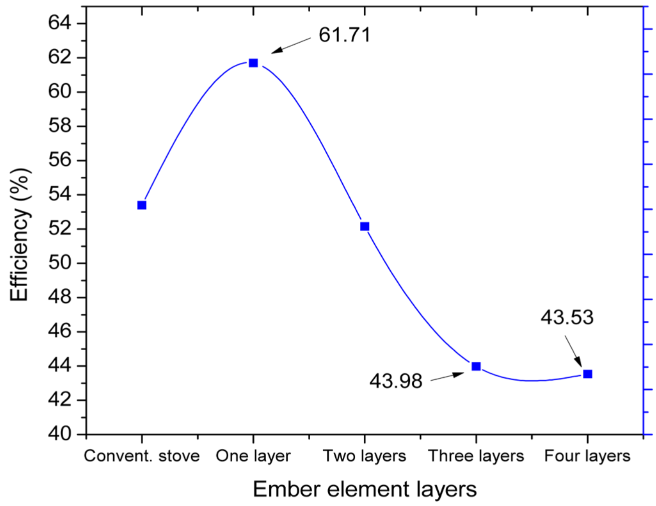


(b)

Figure 6: Test results using reflectors and ember element: (a) fuel consumption-steam production and (b) efficiency



(a)



(b)

Figure 7: Test results using ember elements without reflector: (a) fuel consumption-steam production and (b) efficiency

higher density of woven wire increasingly interfered with the heat flow rate of combustion. Although the function embers element work, the level of resistance of the woven wire density is much larger, so efficiency decreases.

3. Test Efficiency Using the Ember Element Without a Reflector: Based on the graph in Figure 7(a), in general, by adding layers of fire elements, steam production continues to decline, but fuel consumption fluctuates. Steam production is highest in the stove without the use of the ember element, amounting to 1,699 kg/h, and lowest in the stove with the four-layer ember element, equal to 1,116 kg/h.

The highest fuel consumption also occurred in the stove without the use of the ember element, equal to 0.195 kg/h, and the lowest occurred in the stove with a single layer ember element, equal to 0.162 kg/h. For the fuel consumption of without-element to an embers element layer drastically decreased from 0.195 kg/h to 0.162 kg/h, with a reduction of 0.033 kg/h.

Based on Figure 7(b), for the stove without an element, although the production of steam is very high, LPG consumption is also very high. This condition means efficiency without an element is much lower compared to that with the use of a single layer ember element, namely 53.39% without the element and 61.71% with the coating element.

This happens due to the use of a single layer ember element; embers function elements may work optimally, and the steam can burn perfectly unburned fuel. In addition, the density of the woven wire also does not interfere with the combustion gas flow rate.

The efficiency with the use of two-layer, three-layer, and four-layer elements continued to decrease, at respective levels of 52.15%, 43.97%, and 43.53%. This happens because the increasing number of layer elements will further inhibit the combustion gas flow rate. Although ember elements can serve the resistance that occurs due to the addition of the number of layers of elements is much greater, and it is this which leads to a decrease in inefficiency.

Fire temperature distribution test of LPG stoves

Through this test, the influence of mounting elements to contour the embers of fire isothermal temperature distribution can be seen. This test is required to ensure the positive impact caused by the installation of ember elements. Based on the test results of temperature distribution using weights and without the use of the finned heat reflector.

Based on Figure 8(a), the contour of isothermal temperature distribution shows that the stove without the ember

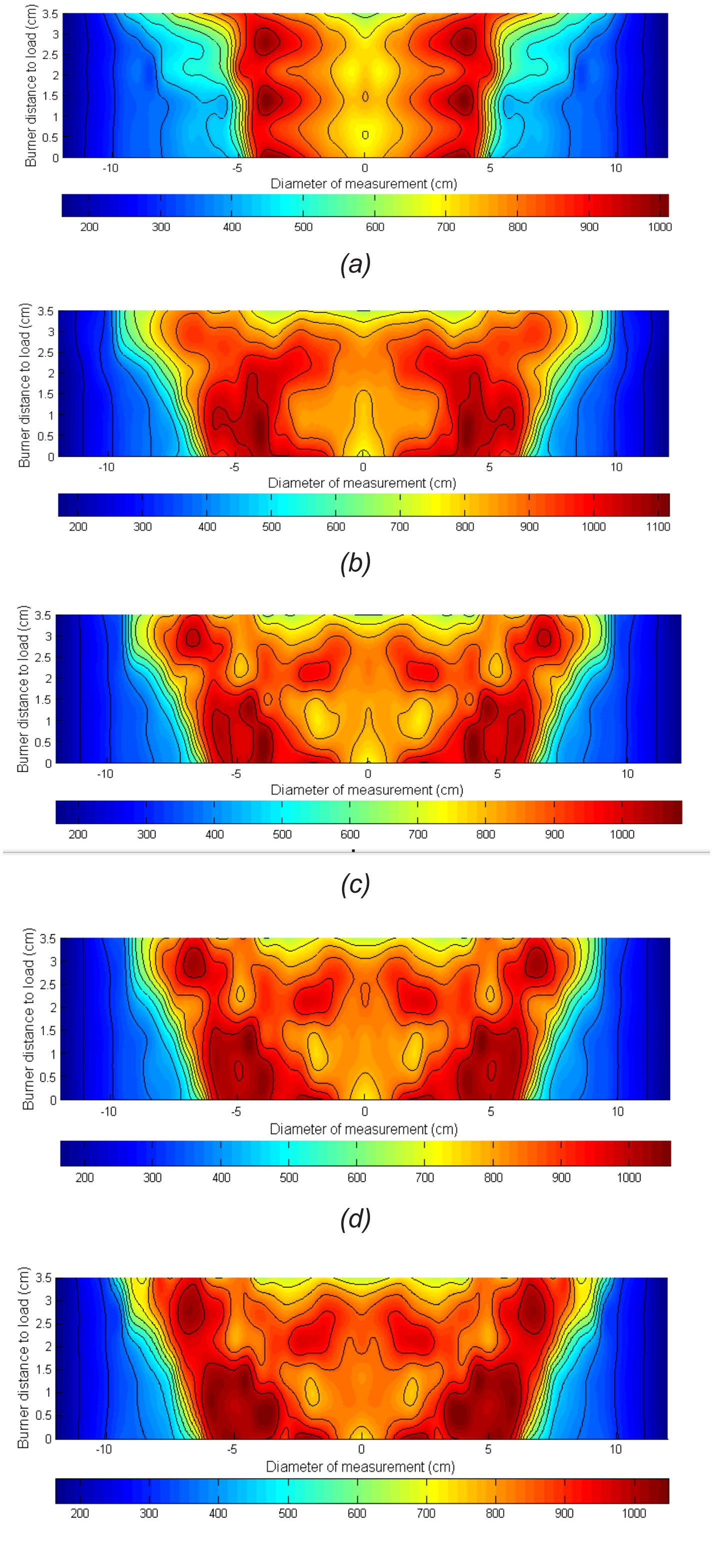


Figure 8: Temperature distribution: (a) conventional stove (b) with one layer ember element (c) with two-layer ember element (d) with three-layer ember element (e) with four-layer ember element

element produced a relatively low average temperature, with a relatively small area of high-temperature distribution. The highest temperature was 1081 °C and the high-temperature area is only around the firewall, while in the middle of the burner the temperature distribution is relatively low. This shows that in the middle of the burner there is still a considerable amount of fuel vapour that has not been burned completely.

Based on the contour of the temperature distribution, the most extreme point occurs with the use of the one layer element (Figure 8(b)), apart from the high temperature area being very wide, the highest temperature reaches 1199 °C. This is because the fire element can function optimally, that is, it can perfectly burn unburned fuel vapour and the density of wire woven also does not interfere with the combustion gas flow rate. With the wider area of heat, the touch of the hot area with the load is also wider, which will have an impact on the absorption of energy that is greater by the load. The amount of energy absorbed by the load is directly proportional to the amount of efficiency produced by the stove, so the greater the heat energy absorbed by the load, the higher the efficiency produced. This is shown by the results of the efficiency test, in which the use of the one layer ember element produces the highest efficiency of 61.71%.

On the other hand, with the use of the two, three and four-layer ember elements, the area of high temperature and the highest temperature decrease. The highest temperature for the two layers is 1147 °C, for three layers 1127 °C, and four layers 1114 °C, as shown in Figs. 8 (c) - (e). Based on these data, it can be seen that the addition of the number of layers of coal is a linear fire with a decrease in the highest temperature distribution. This is because the greater the number of layers of embers, the more they inhibit the combustion gas flow rate, which is what causes decreased inefficiency.

CONCLUSIONS

The use of ember elements in the LPG stove affects the efficiencies generated. The positive effect of increased efficiency, especially in the use of a single layer of the ember element. Provided that the use of a single layer ember element without using a reflector produces the highest efficiency value, equal to 61.71%.

Efficiency increased by 8.32% when compared to the stove without the use of a reflector or ember element, to a level of 53.39%. On the other hand, when compared with the use of a reflector but without using the ember element, efficiency is only increased by 0.29%, from 61.42% to 61.71%.

Concurrent use of the finned heat reflector and ember element did not have a positive impact on the increase in efficiency, since it was only able to produce the highest efficiency rating of 57.51%.

It was also found that the use of the ember element had a positive effect on the temperature distribution of the resulting flame. The use of a single layer of elements results in the greatest high-temperature area. This is because the density of the woven wire doesn't interfere with the flow rate of the combustion gas and the fuel vapour can burn completely.

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