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THE EFFECT OF FUEL PREHEATING ON THE PERFORMANCE OF USED OIL FUEL STOVES

Sudarno Sudarno*, Fadelan Fadelan, Wisnu Aji Setyatinika, Yoyok Winardi

Universitas Muhammadiyah Ponorogo, Faculty of Engineering, Department of Mechanical Engineering, Ponorogo, Indonesia

** darnotec@umpo.ac.id*

This research explores the utilization of used oil as an alternative fuel and investigates the impact of preheating on its performance in combustion chambers. The study employs an experimental approach to vary preheating methods, utilizing two models: a ring placed in the combustion chamber and a ring combined with a spiral between the inner and outer stove walls. A comparative analysis is conducted against conventional stoves. The investigation focuses on efficiency and flame temperature distribution. Results reveal that the stove incorporating the spiral-ring preheating model demonstrates the highest efficiency at 55.52%, marking a 9.76% increase over conventional stoves. Additionally, this model generates the largest average heat area and the highest temperatures, notably reaching 1077°C, with a broader area above 1000°C compared to other models. The preheating process aids in reducing fuel viscosity and enhancing evaporation, facilitating a more homogeneous air-fuel mixture, thereby promoting more complete combustion.

Keywords: used oil stove, fuel preheating, performance

1 INTRODUCTION

Global energy demand continues to increase as the economy and population grow. Meanwhile, oil and gas fuel, which is the main source of energy for combustion, is dwindling [1–5]. Limited fossil resources and the environmental impact of burning have encouraged the switch to renewable energy [6]. According to the latest BP Statistical Review of World Energy report for 2021, global energy consumption continues to increase, with burning oil and natural gas as the main sources [7]. The same problem also occurs in Indonesia, where the level of energy demand is also increasing due to rapid economic and population growth. The main sources of energy in Indonesia are oil, gas, and coal [8]. It was also reported that the household sector is the second largest energy user after industry, with a total consumption of 1,550,332 TJ [9].

Considering these conditions, used oil stoves are a promising alternative in an effort to meet the increasing demand for combustion energy [10]. The community responded well to this opportunity, with many trying to make stoves using used fuel oil. Even though the stoves that are made are still less efficient, this is due to a lack of in-depth research in the development of this technology [11].

Research related to the use of used oil-fired stoves is still very limited. One of them is the research conducted by Pratama et al. on a cylindrical stove design with a diameter of 115 mm and a height of 290 mm. Used oil flows directly from the tank to the combustion chamber through a pipe, and a blower is used to push the combustion air with a pressure of 3.5 bar. The results showed that the resulting fire had an orange colour [12]. A study with a similar design was also conducted by Nugroho et al., but they varied the diameter of the nozzle or fire passage of the hob head. It was found that the size of the nozzle hole was 7 mm, which was the most effective and able to boil 1 l of water in 3.21 minutes [13].

In another study, Dinesha et al. carried out experiments using used cooking oil as fuel in a stove. They designed a stove with a pressurized fuel tank that injects used cooking oil into the combustion chamber. However, the research results showed that combustion was not running optimally, producing red flames. The causal factors are a lack of adequate air supply for combustion and the need to increase turbulence in the fuel spray so that the combustion process can be more efficient [14].

Based on several studies above, it is proven that used oil can be used as an alternative fuel, although there are indications of relatively low efficiency, which is indicated by a red to orange flame colour. This is caused by incomplete combustion because used oil experiences degradation and contamination during use, such as water, solid particles, and unburned substances.

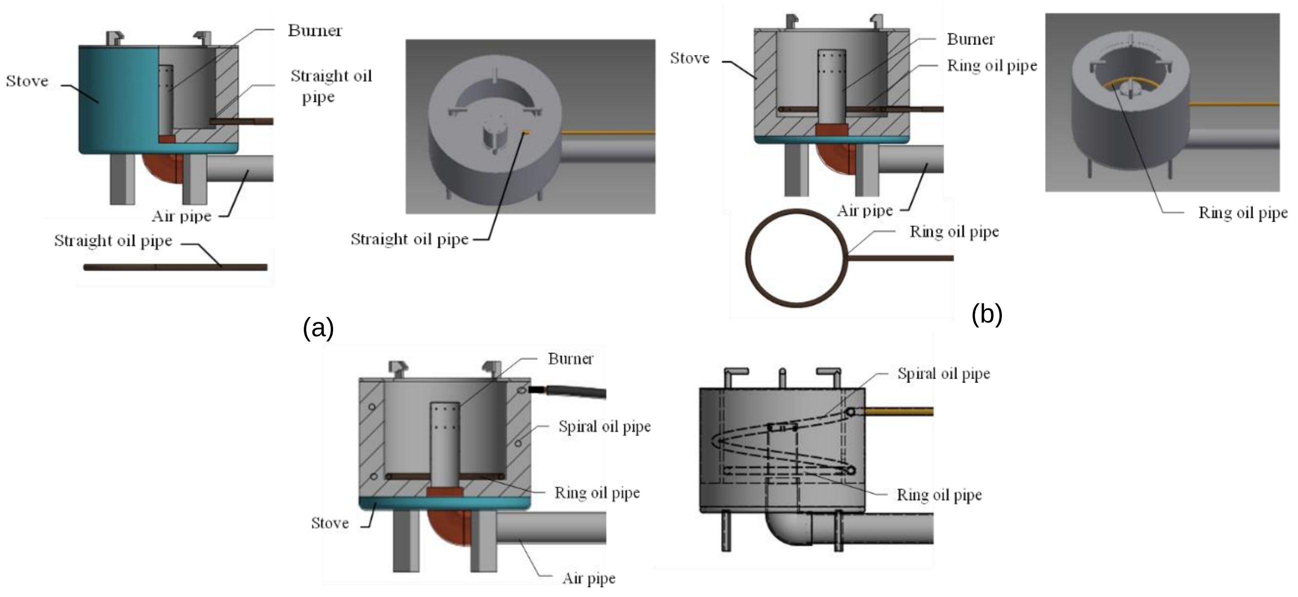
For this reason, efforts are needed to make the combustion process more perfect, namely by preheating the fuel before it enters the combustion chamber. The preheating process for the fuel will increase the speed of the combustion reaction so that combustion is more complete. Therefore, design improvements are needed to improve the performance of the used oil stove.

2 MATERIALS AND METHODS

2.1 Specifications of materials

The stoves used in this research consisted of conventional used oil stoves and stoves with fuel preheating. Fuel preheating is made in two models: a ring-shaped pipe that is placed in the combustion chamber and a spiral combination ring-shaped pipe that is installed in a circle between the inner and outer walls of the stove. The distance between the burner and the load is 35 mm [15–17]. The stove models are shown in Fig. 1.

The equipment used includes aluminum vessels, stopwatches, water thermometers (accuracy ± 0.5 ºC), digital scales (accuracy ± 0.1 g), measuring cups, data loggers (type USB-4718, 8-ch Thermocouple USB Input Module), thermocouples with type K (diameter 1.6 mm and maximum temperature 1300 ºC), flow meters (accuracy ± 0.01 g), water, a camera, and used oil. The oil used is used motor vehicle oil, so it is categorized as single-use used oil. Used oil is taken randomly and filtered using three layers of cotton cloth before use. This filtering process is carried out to separate impurity particles such as dust, rust, and metal powder from the oil. The separation of solid particles also causes a decrease in oil viscosity.



(c)

Fig. 1. (a) Conventional Stove; (b) Ring-Shaped Preheating Model; (c) Preheating Model Spiral combination Ring

The dimensions of the stove are shown in table 1.

Table 1. Dimensions of the stove tested

No.	Description	Mark	Unit
1	Inner hob height	160	mm
2	Height of the outer stove	210	mm
3	Stove inner diameter	200	mm
4	Outside diameter of the stove	280	mm
5	Burner distance of Load	35	mm
6	Burner height	125	mm
7	Distance burner tip to stove top body	35	mm
8	Diameter of the hole in the stove top body cover	170	mm
9	Air passage pipe diameter	50,8	mm
10	Diameter of the fuel pipe	13	mm
11	Number of turns of fuel preheating pipe	2	coil
12	Burner inner fuel pipe ring diameter	180	mmm
13	The diameter of the hole for fuel to exit through the ring to the burner	3	mm
14	Number of holes for fuel to exit through the ring to the burner	6	hole

No.	Description	Mark	Unit
15	Air passage hole diameter:	3.5	mm
16	Number of air passage holes	18	hole

Based on the stove power value, which is 8.896 kW, the diameter of the vessel used is 7 W/cm^2, which is 40 cm, with the mass of water (2/3 of the volume of the vessel) being 15.7893 kg [18-19]. Measurements carried out in this research include efficiency, flame temperature distribution, and exhaust emissions.

2.2 Efficiency measurement

Efficiency measurements are carried out using the Water Boiling Test (WBT). The process begins by turning on the stove for five minutes. After the fire is stable, the vessel filled with water is placed on the stove, and the measurement process begins. The flame is maintained at a blue level by controlling the flow meter. Water and room temperature data were recorded every 5 minutes until the water started to boil. Warming is continued for a total of 60 minutes. After that, the mass of used oil and the mass of steam lost are measured. This measurement process was repeated eight times. The test was carried out in a closed room with a wind barrier around the stove. Thus, the room temperature and air flow in the room are considered constant, so they do not affect the performance of the stove. Measurement installation shown in Fig. 2.

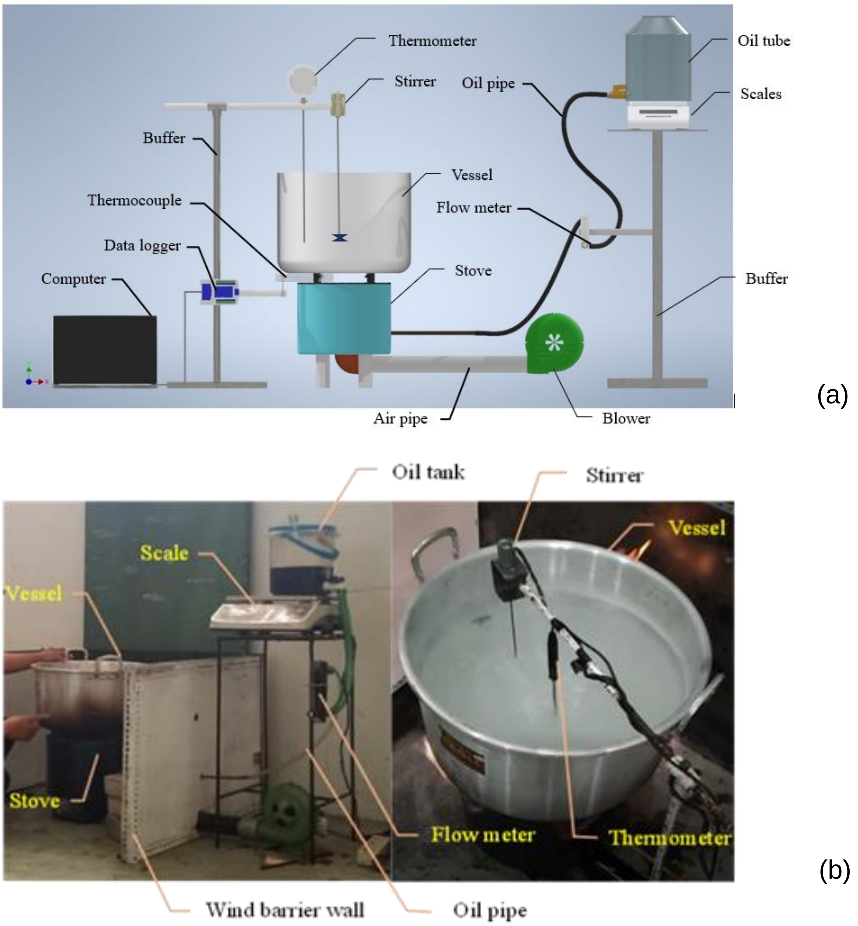


Fig. 2. (a) Efficiency Measurement Installation; (b) Photo of Efficiency Measurement Installation

To calculate the efficiency value of the stove according to the Indian Standard (IS) 4246:2002, which is with WBT. The measurement process is carried out by heating the water from the initial temperature to boiling, and heating is continued for a total of 60 minutes. Stove efficiency is obtained numerically with the equation below [15-17, 19-21]:

$$\eta_{th} = \frac{\Delta E_{H_2O,heat} + \Delta E_{H_2O,evap}}{E_{released}} \quad (1)$$

$$\Delta E_{H_2O,heat} = m_w . C_{pw}(T_{wf} - T_{wi}) \quad (2)$$

$$\Delta E_{H_2O,heat} = C_{pw}(m_{wi} - m_p)(T_{wf} - T_{wi}) \quad (3)$$

$$\Delta E_{H_2O,evap} = m_u . H \quad (4)$$

$$E_{released} = m_f . E_{Oil} \quad (5)$$

$$\eta_{th} = \frac{\{(m_{wi} - m_p) C_{pw} (T_{wf} - T_{wi}) + m_u . H_u\}}{m_f . E_{Oil}} \quad (6)$$

Where η (%) is the efficiency of the stove, $\Delta E_{H2O,heat}$ (kJ) is the energy to heat the water, $\Delta E_{H2O,evap}$ (kJ) is the energy to evaporate the water, $E_{released}$ (kJ) is the energy provided by the fuel, m_w (kg) is the mass of water, Cp_w (kJkg^{-1}K^{-1}) is the specific heat of water, T_{wf} (K) is the temperature of the water after treatment, T_{wi} (K) is the temperature of the water before treatment, m_{wi} (kg) is the mass of the water and vessel before treatment, m_p (kg) is the mass of the vessel, T_{wf} (K) is the water temperature after treatment, Twi (K) is the water temperature before treatment, m_u (kg) is the mass of steam after treatment, H_u 2,260 kJ/ kg [19] is the latent heat of water vaporization, mf (kg) is the mass of fuel used after treatment, E_{oil} 44,735 kJkg^{-1} [1] is the net calorific value of oil.

2.3 Measurement of temperature distribution

Fig. 3a shows the installation for measuring the isothermal temperature distribution of a fire. Temperature distribution measurements were carried out on conventional stoves and stoves with preheating [15-17].

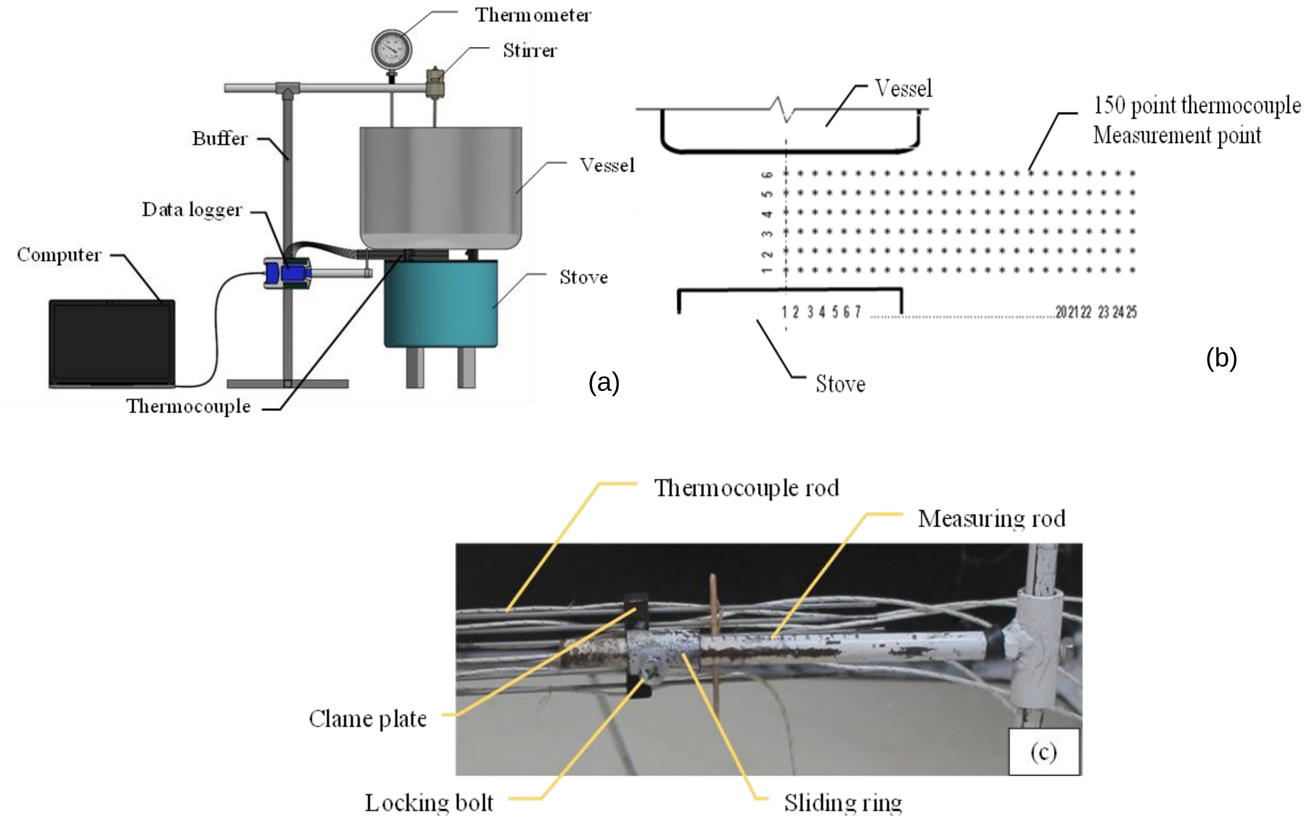


Fig. 3. (a) setting the fire temperature distribution measurement; (b) measurement position points; and (c) thermocouple mounting

Measurements from points on the outer side use 6-channel thermocouples and shift them towards the axis line at 5 mm intervals until data is obtained totaling 6 x 25 points (150 points), as shown in Fig. 3b. Data collection at each point was carried out 25 times. Then the average temperature reading results were visualized by using Matlab to get the temperature distribution contour.

To ensure the accuracy of the thermocouple position, the six thermocouple rods are arranged parallel with a distance of 5 mm each and clamped to a rigid manganese plate mounted on a metal ring. The position of this metal ring can be adjusted horizontally along the installed measuring rod. To keep its position fixed, the metal ring is locked at each horizontal measurement point, as shown in Fig. 3c.

3 RESULTS AND DISCUSSION

3.1 Efficiency measurement

Measurements of fuel consumption, steam production, and efficiency were carried out on conventional stoves, stoves with ring preheating, and stoves with spiral combination ring preheating. A stove with ring preheating is a stove with a fuel pipe that has a ring or circular end and is installed in the combustion chamber. Several holes are made in the inner wall of the ring to channel fuel from the pipe to the combustion chamber. With ring-shaped preheating, it can increase the heat contact surface area between the fuel flow rotating in the ring and the flame in the combustion chamber. Meanwhile, stoves with spiral combination ring preheating have ring-shaped preheating, as mentioned above, combined with a spiral, namely the fuel pipe, before entering the combustion chamber, which is installed in a circle between the inner and outer walls of the stove. This model can increase the heat contact surface area between the fuel pipe and the stove wall, thereby increasing the temperature of the fuel before it enters the combustion chamber.

Preheating used oil can cause some changes to its physical properties. The viscosity of used oil will decrease with increasing temperature. Used oil with low viscosity will be easier to atomize and mix with air, resulting in more complete combustion. The colour of the used oil will also become darker or blackish due to the decomposition of organic compounds during heating. In addition, the flash point of used oil will decrease with increasing preheating temperatures, making it more easily flammable. Based on this description, the properties of the oil before and after preheating can be seen in table 2 [22-24].

Table 2. Properties of used oil before and after preheating

Characteristic	Before preheating	After preheating	Explanation
Colour	Dark chocolate	Blackish brown	The colour of used oil becomes darker black due to oxidation and degradation of organic compounds.
Viscosity	High	Low	The viscosity of used oil decreases because long hydrocarbon chains are broken down into shorter chains.
Flash point	~200°C	~150°C	The flash point of used oil decreases to around 150°C due to the formation of more flammable compounds.
Burn Point	~250°C	~180°C	The burn point of used oil decreases to around 180°C due to the formation of more flammable compounds.

The efficiency measurement results are shown in Fig. 4.

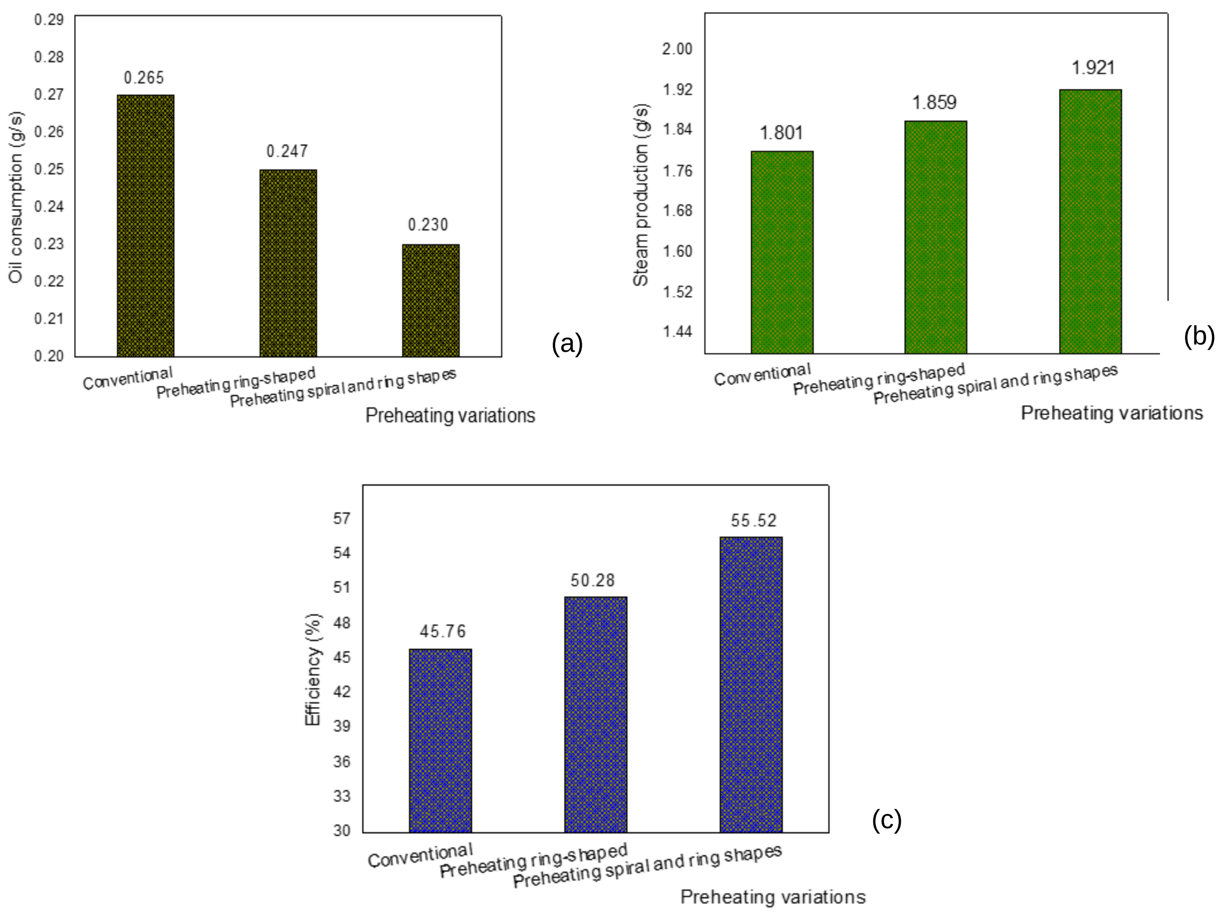


Fig. 4. Diagram of measurement results with variations in fuel preheating: (a) oil consumption; (b) steam production; and (c) efficiency

Based on the diagram in Fig. 4, it can be seen that conventional stoves produce the lowest performance compared to other variations. Conventional stoves produce the highest fuel consumption of 0.265 g/s (Fig. 4a), the lowest steam production of 1.801 g/s (Figure 4b), and the lowest efficiency of 45.76% (Figure 4c). In a conventional stove, air and fuel are flowed separately into the combustion chamber without going through a preheating process. Air and fuel are only mixed in the combustion chamber and undergo a heating process after the initial ignition process has been carried out in the combustion chamber. This process has a negative impact on combustion results by reducing efficiency and increasing pollutant emissions, which in turn makes a negative contribution to system performance and environmental impacts [25-26].

Stoves with ring-shaped preheating produce higher performance than conventional stoves but lower than preheating with a combination of rings and spirals. The resulting fuel consumption was 0.247 g/s (Fig. 4a), production was 1.859 g/s (Fig. 4b), and efficiency was 50.28% (Fig. 4c). This efficiency value increases by 4.52% compared to conventional stoves.

Meanwhile, for stoves with preheating, a combination of rings and spirals produces the best system performance compared to other variations. This preheating model produces fuel consumption of 0.230 g/s (Fig. 4a), steam production of 1.921 g/s (Fig. 4b), and an efficiency of 55.52% (Fig. 4c). Efficiency increases by 5.24% compared to stoves with ring preheating and 9.76% compared to conventional stoves.

This happens because, by preheating, the speed of the chemical reaction results in more complete combustion and reduces the formation of harmful nitrogen oxides (NOx). Preheating also helps produce cleaner combustion, reduce exhaust emissions, and optimize fuel use. This not only increases energy efficiency but also reduces the environmental impact of the combustion process [27–30].

3.2 Measurement of temperature distribution

The purpose of this measurement is to determine and strengthen the experimental results related to the preheating process in the fuel pipe, namely in the form of isothermal flame temperature distribution. To visualize temperature distribution data, we used Matlab R2010a. Temperature distribution measurements were carried out on all variations of the stove tested and given a load in the form of a vessel filled with water.

The visualization results of temperature distribution measurements on conventional and preheating stoves are shown in Fig. 5.

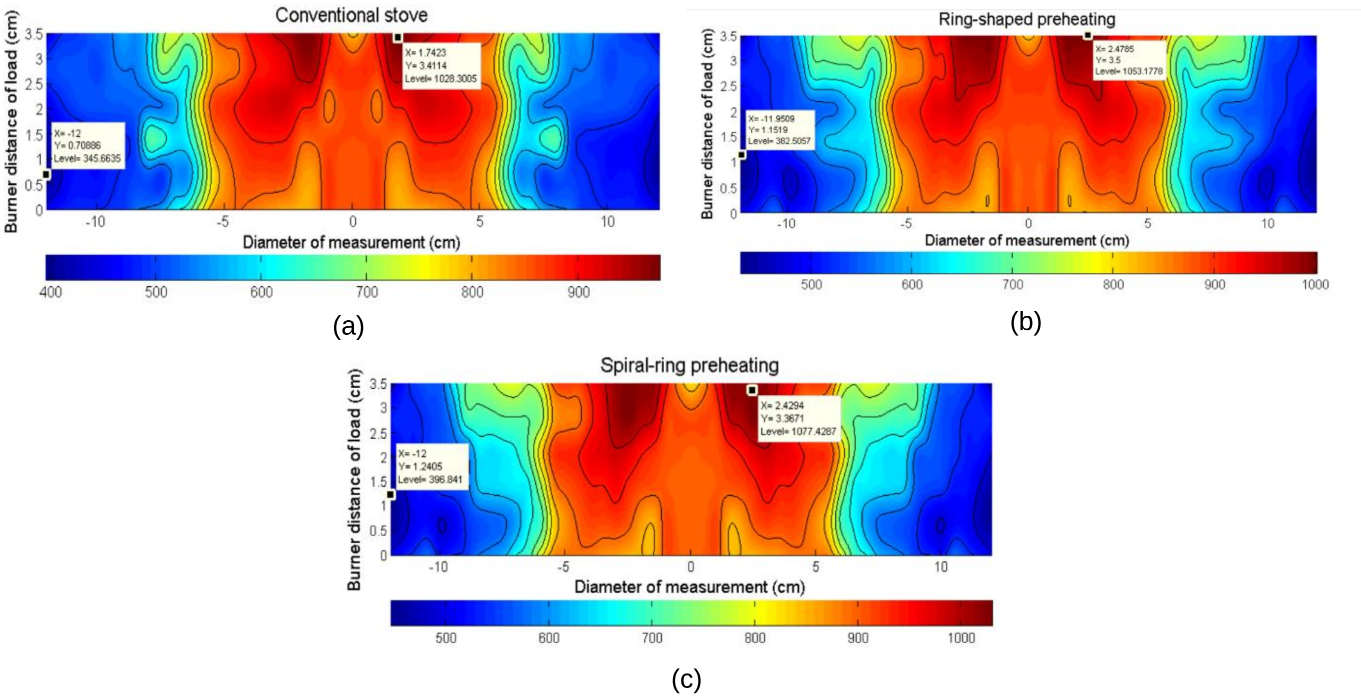


Fig. 5. Stove flame temperature distribution: (a) conventional; (b) ring preheating; (c) ring-spiral combination preheating

Based on Fig. 5a, it is found that the conventional stove produces the lowest temperature of 346 °C and the highest of 1028 °C. Based on this figure, it can be seen that conventional stoves produce a relatively low average temperature at each distribution point, as well as a relatively small high temperature area above 1000 °C. This is because the air and fuel enter the combustion chamber at a relatively low temperature, so the combustion process is not efficient enough to reach the optimal combustion temperature [31-32].

For Fig. 5b, by using ring-shaped preheating, it was found that the lowest temperature was 382 °C, an increase of 36 °C and the highest was 1053 °C, 25 °C higher than a conventional stove. Based on this picture, it can be seen that the high temperature area above 1000 °C is much wider than a conventional stove.

Meanwhile, based on Fig. 5c, it is found that the lowest temperature of 397 °C is higher at 15 °C and 51 °C, respectively, compared to stoves with ring-shaped preheating and conventional stoves. Meanwhile, the highest temperature of 1077 °C is 24 °C and 49 °C higher, respectively, compared to stoves with ring-shaped preheating and conventional stoves. Based on this figure, it can also be seen that the high temperature area above 1000 °C is much wider than conventional stoves and stoves with ring-shaped preheating. The preheating effect on the fuel causes the combustion process to be more complete, resulting in a more even flame temperature distribution. This can reduce temperature fluctuations and increase combustion efficiency [33-34].

4 CONCLUSIONS

Based on the experimental results, it was found that the preheating of the fuel had an effect on the efficiency and temperature distribution of the resulting flame. It was found that the stove with preheating in the form of a spiral combination ring produces the highest efficiency value of 55.52%, which is an increase of 9.76% compared to a conventional stove.

Meanwhile, for the flame temperature distribution, it was also found that preheating in the form of a spiral combination ring produced the largest heat area and the highest temperature compared to other variations, with the highest temperature value of 1077 °C.

This happens because, with preheating, the speed of the chemical reaction produces more complete combustion, so heat efficiency increases.

5 ACKNOWLEDGMENT

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6 REFERENCES

[1] White, D. J., Burrowes, G., Davis, T., Hajnal, Z., Hirsche, K., Hutcheon, I., Majer, E., Rostron, B., & Whittaker, S. (2004). Greenhouse gas sequestration in abandoned oil reservoirs: The International Energy Agency Weyburn pilot project. *GSA Today, 14*(77), 4–10. https://doi.org/10.1130/1052-5173(2004)014<004 >2.0.CO;2

[2] BP plc. (2020). *BP Statistical Review of World Energy 2020* (69th ed.). https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

[3] U.S. Department of Energy. (2020). *International Energy Outlook 2020*. U.S. Energy Information Administration. https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Full%20Report.pdf

[4] Abdullah, A. M., & Islam, A. R. M. T. (2023). Current status of renewable energy in Bangladesh and future prospects: A global comparison. *Heliyon, 9*(3), e14308. https://doi.org/10.1016/j.heliyon.2023.e14308

[5] Clerici, A., & Alimonti, G. (2015). World energy resources. *EPJ Web of Conferences, 98*, 1–15. https://doi.org/10.1051/epjconf/20159801001

[6] Capuano, L. (2020). *International Energy Outlook 2020 (IEO2020): United States milestones in meeting global energy consumption*. U.S. Energy Information Administration. https://www.eia.gov/outlooks/ieo/pdf/ieo2020.pdf

[7] Jessam, R. A. (2022). Experimental study of wind turbine power generation utilizing discharged air of air conditioner blower. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 9*(4), 1103–1109. https://doi.org/10.5109/6625722

[8] Kusnandar, V. B. (2022, June 10). Indonesian energy consumption by sector. *Databoks*. https://databoks.katadata.co.id/datapublish/2022/06/10/ini-sektor-dengan-konsumsi-energi-terbesar-di-ri-pada-2021

[9] Badan Pusat Statistik. (2021). *Energy balances of Indonesia 2016–2020*. https://www.bps.go.id/en/publication/2021/12/16/349e26e73429084dc3c0663d/energy-balances-of-indonesia-2016-2020.html

[10] Crabbe, E., Nolasco, H. C., Kobayashi, G., Sonomoto, K., & Ishizaki, A. (2001). Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties. *Process Biochemistry, 37*(1), 65–71. https://doi.org/10.1016/S0032-9592(01)00178-9

[11] Susilawati, Zamzami, R., & Buchori, A. S. (2020). The utilization of waste cooking oil (WCO) in a simple stove as an alternative fuel for household scale. *Journal of Physics: Conference Series, 1700*(1), 1–5. https://doi.org/10.1088/1742-6596/1700/1/012052

[12] Ramadhan, G. W., & Basyirun, B. (2020). The effect of air pressure on the burning temperature of used oil in stoves. *Jurnal Dinamika Vokasional Teknik Mesin, 5*(2), 163–168. https://doi.org/10.21831/dinamika.v5i2.34804

[13] Nugroho, A. S., Rahayu, A. T., & Rubiandana, N. A. (2021). Experimental study of the effect of nozzle diameter on fuel combustion. *Jurnal Mesin Industri & Otomotif, 2*(2), 1–8. https://doi.org/10.46365/jmio.v2i02.435

[14] Dinesha, P., Kumar, S., & Rosen, M. A. (2019). Performance and emission analysis of a domestic wick stove using biofuel feedstock derived from waste cooking oil and sesame oil. *Renewable Energy, 136*, 342–351. https://doi.org/10.1016/j.renene.2018.12.118

[15] Sudarno, S., Soeparman, S., Wahyudi, S., & Widodo, A. S. (2021). Construction of a finned heat radiation reflector for improved efficiency of liquefied petroleum gas stoves. *International Journal of Technology, 12*(1), 163–174. https://doi.org/10.14716/ijtech.v12i1.3958

[16] Widodo, A. S., Sudarno, S., Soeparman, S., & Wahyudi, S. (2022). The effect of finned heat reflector materials and diameters on the efficiency and temperature distribution of liquefied petroleum gas stove. *Results in Engineering, 16*, 100658. https://doi.org/10.1016/j.rineng.2022.100658

[17] Sudarno, S., Soeparman, S., Wahyudi, S., & Widodo, A. S. (2021). Effect of the ember element in increasing the efficiency of liquefied petroleum gas stoves. *Journal of Applied Engineering Science, 19*(2), 1–8. https://doi.org/10.5937/jaes0-28385

[18] World Bank. (1985). *Test results on kerosene and other stoves for developing countries*. http://documents.worldbank.org/curated/en/647871492128395293

[19] U.S. Environmental Protection Agency. (2014). *The water boiling test* (Version 4.2.3). International Workshop Agreement. https://cleancookstoves.org/our-work/standards-and-testing/learn-about-testing-protocols/

[20] Waluyo, J., Setianto, M. M., Safitri, N. R., Pranolo, S. H., Susanti, A. D., & Puryanto. (2023). Characterization of biochar briquettes from coconut shell with the effect of binder: Molasses, cow manure, and horse manure. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy, 10*(1), 539–545. https://doi.org/10.5109/6782158

[21] Raman, P., Murali, J., Sakthivadivel, D., & Vigneswaran, V. S. (2013). Performance evaluation of three types of forced draft biomass cookstoves. *Energy for Sustainable Development, 17*(5), 497–506. https://doi.org/10.1016/j.esd.2013.05.007

[22] Kartika, A., Kurniawan, A., & Krensa, A. (2023). Analysis of the temperature effect on the liquid's viscosity. *Jurnal Penelitian dan Pembelajaran Fisika Indonesia, 5*(1), 25–30. https://doi.org/10.29303/jppfi.v5i1.214

[23] Wenhao, Z. (2021). Influence of temperature and concentration on viscosity of complex fluids. *Journal of Physics: Conference Series, 1965*(1), 012064. https://doi.org/10.1088/1742-6596/1965/1/012064

[24] Zheng, F., Zhou, S., Xie, F., & Li, X. (2012). Analysis on lubricating and viscosity-temperature characteristics of the vegetable oil. *Applied Mechanics and Materials, 184–185*, 1451–1454. https://doi.org/10.4028/www.scientific.net/AMM.184-185.1451

[25] Najib, A. I., Raid, A. A., Mazlan, A. W., Aminuddin, S., & Mohammed, B. A. (2023). Effect of preheating on combustion characteristics of a swirling flameless combustor. *AIP Conference Proceedings, 2749*(1). https://doi.org/10.1063/5.0136486

[26] MacCarty, N., Still, D., & Ogle, D. (2010). Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. *Energy for Sustainable Development, 14*(3), 161-171. https://doi.org/10.1016/j.esd.2010.06.002

[27] Almosawi, Y. J. K., & Alshimmary, W. A. K. (2021). Effect of air combustion preheater on furnace efficiency by using refinery simulator. *Journal of Petroleum Research and Studies, 7*(3), 75–87. https://doi.org/10.52716/jprs.v7i3.161

[28] Ram, T., Santosh, B., & Subhash, L. (2020). Experimental investigation of effect of preheating of air and exhaust gas recirculation on four-stroke diesel engine. *IOP Conference Series: Materials Science and Engineering, 810*(1), 1-9. https://doi.org/10.1088/1757-899X/810/1/012032

[29] Mourad, M., & Noureldenn, E. H. (2019). Benefits of exhaust gas energy for preheating biodiesel fuel to enhance engine emissions and performance. *Journal of Mechanical and Energy Engineering, 3*(2), 157–168. https://doi.org/10.30464/jmee.2019.3.2.157

[30] Nadir, Y. (2012). Effects of intake air preheat and fuel blend ratio on a diesel engine operating on biodiesel–methanol blends. *Fuel, 94*, 444-447. https://doi.org/10.1016/j.fuel.2011.10.050

[31] Cengel, Y. A., & Ghajar, A. J. (2015). *Heat and mass transfer: Fundamentals and applications* (5th ed.). McGraw-Hill Education.

[32] Turns, S. R. (2011). *An introduction to combustion: Concepts and applications* (3rd ed.). McGraw-Hill Education.

[33] Jhessica, M. F., Joel, G. T., Vitor, D. C. A., & Camila, D. S. (2019). Biodiesel from waste frying oils: Methods of production and purification. *Energy Conversion and Management, 184*, 205-218. https://doi.org/10.1016/j.enconman.2019.01.061

[34] John, B. H. (2018). *Internal combustion engine fundamentals* (2nd ed.). McGraw Hill.

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