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The Effect of Combustion Tube Diameter on Flame Characteristics and Water Heating Time on *Multifuel Stove*

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ABSTRACT

Multifuel stove is an innovation of conventional stove that has the advantage of being able to use various types of fuel. In its operation, multifuel stove consists of many important components, one of which is the combustion tube. This study aims to find out the effect of variations in the diameter of the combustion tube on the characteristics of the flame and water temperature during the heating process. The method used in this study is a combination of experimental studies and literature studies. The variations in the diameter of the combustion tube tested were 4, 5, and 6 inches using used oil and kerosene as fuel. The test results showed that increasing the diameter of the combustion tube tended to accelerate the extinguishing of the fire, this was influenced by a phenomenon called the quenching effect. Meanwhile, the flame temperature tended to be lower with increasing tube diameter. The color of the flame and the temperature of the water were not too influenced by variations in tube diameter and type of fuel. The highest flame temperature was recorded on a 4-inch cylinder with used oil fuel, reaching 719.2 °C, while the longest flame duration was 16.92 minutes on a 4 -inch cylinder with used oil fuel. In conclusion, the performance of used oil can exceed that of kerosene.

INTRODUCTION

Multifuel stoves can be interpreted as stoves that can use many types of fuel as fuel (Bagariang et al., 2020) thus making multifuel stoves have advantages in the flexibility of fuel use. In multifuel stoves, the main components that play an important role in the combustion process, one of which is the stove tube as a place for the combustion process. One of the factors that affects the efficiency and performance of a multifuel stove is the diameter of the combustion tube. There have been several studies on the effect of the diameter of the combustion tube, including research conducted by (Soloklou & Golneshan, 2020) and research conducted by (Fajobi et al., 2022), from both studies it was concluded that the diameter of the combustion tube can affect the length of time the flame burns during the combustion process. Thus, research on the effect of tube diameter on multifuel stoves using used oil and kerosene has an important value in the development of more efficient and sustainable multifuel stove technology.

The development of efficient and environmentally friendly combustion technology has gained significant attention in recent years. Multifuel stoves, which are designed to operate using various fuel sources, offer an alternative to conventional stoves that rely on a single type of fuel (Surono et al., 2015). This flexibility makes multifuel stoves a potential solution for regions with limited access to specific fuel sources. The efficiency of these stoves is highly dependent on the design and structure of their combustion components, particularly the combustion tube, which plays a crucial role in determining flame characteristics and thermal performance (Glassman & Yetter, 2008).

In combustion engineering, the diameter of the combustion tube has been identified as a key factor influencing flame stability, temperature, and efficiency. Previous studies suggest that variations in tube diameter can significantly impact the combustion process by altering airflow dynamics and heat transfer mechanisms (Soloklou & Golneshan, 2020). The effect of tube diameter on flame characteristics is crucial for optimizing fuel consumption and minimizing energy loss. A better understanding of this parameter can contribute to the advancement of sustainable energy solutions.

Recent research has highlighted the relationship between combustion tube geometry and fuel efficiency. A study conducted by (Fajobi et al., 2022) demonstrated that larger tube diameters tend to reduce internal pressure, leading to lower flame temperatures and shorter combustion durations. This phenomenon, known as the quenching effect, plays a vital role in the overall performance of multifuel stoves. Understanding these effects is essential for improving stove designs that maximize energy utilization while minimizing environmental impact.

Furthermore, the selection of fuel type also plays an integral role in combustion efficiency. Used oil and kerosene, commonly used in multifuel stoves, exhibit distinct combustion behaviors. Studies indicate that used oil, despite its potential as a renewable fuel source, requires optimal combustion conditions to achieve efficiency comparable to conventional fuels (Delimayanti et al., 2021). Therefore, exploring the interplay between tube diameter and fuel type can provide valuable insights into the practical applications of multifuel stoves.

As the demand for sustainable and cost-effective cooking solutions increases, further investigation into multifuel stove technology becomes increasingly relevant. This research aims to analyze the effects of combustion tube diameter on flame characteristics and water heating efficiency in multifuel stoves using used oil and kerosene as fuels. By examining various tube diameters, this study seeks to identify optimal configurations that enhance stove performance while maintaining environmental sustainability.

The findings of this research will contribute to the existing knowledge on multifuel stove design and operation. By bridging the gap between theoretical combustion principles and practical applications, this study provides a foundation for future improvements in stove efficiency and fuel utilization. The results are expected to have significant implications for both household and industrial applications, particularly in regions where access to conventional fuel sources is limited.

The relationship between combustion tube diameter and flame characteristics has been extensively studied in combustion science. According to (Kim & Park, 2023), variations in tube diameter can alter the air-fuel mixing ratio, which subsequently affects combustion efficiency and flame temperature. A smaller diameter tube promotes more stable combustion due to increased turbulence and enhanced heat transfer, while larger diameter tubes tend to result in lower temperatures and shorter flame durations. These findings align with previous studies indicating that tube geometry plays a crucial role in determining combustion dynamics, particularly in multifuel stoves that operate with different fuel types.

Furthermore, the selection of fuel type in multifuel stoves influences overall performance and energy efficiency. Research conducted by (Quine, 2023) demonstrated that used oil, when optimized for combustion conditions, can achieve thermal efficiency comparable to kerosene, reducing reliance on fossil fuels. However, inefficient combustion of used oil may result in higher emissions, necessitating precise control over combustion parameters such as tube diameter and airflow. Similarly, a study by (Ahmad et al., 2022) emphasized the need for optimizing multifuel stove design to enhance heat transfer efficiency while minimizing environmental impact. Given these considerations, this study aims to investigate the interplay between combustion tube diameter and fuel type to improve the design and performance of multifuel stoves.

Several studies have examined the impact of combustion tube diameter on stove performance. (Soloklou & Golneshan, 2020) conducted a numerical analysis on methane-air non-premixed flames, demonstrating that tube diameter influences flame propagation speed and combustion stability. Their findings indicate that smaller diameters enhance flame stability by increasing local turbulence, whereas larger diameters tend to reduce flame temperature due to lower pressure conditions.

Another study by (Fajobi et al., 2022) explored entropy generation in fire-tube steam boiler heat exchangers. Their results showed that an increase in tube diameter correlates with a decrease in combustion efficiency, mainly due to the reduction in convective heat transfer. These findings align with (Suryadinata et al., 2022), who investigated the effect of Bunsen burner diameter variations on methane gas premix combustion, concluding that larger diameters lead to slower combustion speeds and lower energy transfer rates.

Further research by (Lee et al., 2021) examined the thermal efficiency of household stoves and found that tube diameter variations significantly affect heat retention and fuel consumption. Their study highlighted the importance of optimizing tube geometry to maximize heat transfer efficiency. Similarly, (Greenberg et al., 2022) conducted experimental research on alternative fuel combustion in portable stoves, demonstrating that changes in tube diameter can alter flame stability and overall combustion efficiency, influencing both energy consumption and emissions.

Despite extensive research on combustion tube geometry and fuel efficiency, there remains a lack of empirical studies examining the direct interaction between tube diameter variations and multifuel stove performance, specifically in the context of used oil and kerosene. Most previous studies focus on industrial-scale combustion systems or single-fuel configurations, leaving a research gap in the practical application of these principles to household multifuel stoves. This study aims to address this gap by providing experimental data on the effects of tube diameter variations on flame characteristics and water heating efficiency.

The novelty of this research lies in its exploration of the combined effects of combustion tube diameter and fuel type in multifuel stoves. Unlike previous studies that analyze combustion tube variations in isolated settings, this study integrates experimental and literature-based approaches to evaluate real-world applications. Additionally, this research introduces used oil as a primary fuel source, contributing to the development of sustainable energy alternatives and providing practical insights into optimizing multifuel stove designs for diverse fuel conditions.

The primary objective of this research is to analyze how variations in combustion tube diameter affect flame characteristics and water heating efficiency in multifuel stoves. By conducting experimental trials with different tube diameters and fuel types, this study aims to identify the optimal configuration for maximizing stove performance.

The findings of this research are expected to benefit both scientific and practical applications. From a scientific perspective, this study contributes to combustion engineering by expanding the understanding of how tube geometry influences flame dynamics. Practically, the results can inform stove manufacturers and policymakers on the design of more efficient and environmentally friendly cooking solutions. This research also supports sustainable energy initiatives by promoting the use of alternative fuels such as used oil, thereby reducing dependency on fossil fuels and minimizing waste.

METHOD

This study uses a combination of experimental studies and literature studies. The use of a combination of both methods aims to obtain valid results and in accordance with the subject matter that has been determined. In this study, testing was carried out 3 times for each cylinder and fuel, then the average value of each variable was taken, so that the number of tests carried out was 18 tests.

RESULTS AND DISCUSSION

Based on the research that has been conducted, the following results were obtained;

VARIATION OF USED OIL FUEL COMBUSTION CYLINDERS	Average Change in Water Temperature (°C) Every 30 Seconds							Average Water Boiling Time (minutes)	Average Water Evaporation Rate (ml)	Average Fire Temperature (°C)	Average Flame Drop (min)	Average Flame Time (minutes)
	0	30	60	90	120	150	180					
4 inch	31	56	82.6	100	100			1.5	50	719.2	13.6	16.92
5 inch	31	48.6	68.3	82.3	100			2	43.3	689.6	13.35	16.84
6 inch	31	50	70	87.5	100			2	50	637.2	13,13	16.1
VARIATION OF KEROSENE FUELED COMBUSTION CYLINDERS	Average Water Temperature Change (°C) Every 30 Seconds							Average Water Boiling Time (minutes)	Average Water Evaporation Rate (ml)	Average Fire Temperature (°C)	Average Flame Drop (min)	Average Flame Time (minutes)
	0	30	60	90	120	150	180					
4 inch	31	52	77	100	100			1.5	40	622.2	9.28	10.52
5 inch	31	61	82	100	100			1.5	30	563.8	8.35	10.42
6 inch	31	47	72	100	100			1.5	40	547.9	9.05	10.1

Figure.1 Research Results Data Table

Effect of Combustion Tube Diameter Variation on Flame Characteristics

Combustion Tubes Using Used Oil Fuel

Based on the duration of the flame in the used oil fuel tube, it was found that the variation in the diameter of the combustion tube affected the flame duration. In the 4-inch diameter tube, the average flame duration was 16.92 minutes. In the 5-inch diameter tube, the average flame duration was 16.84 minutes. And in the 6-inch diameter tube, the average flame duration was 16.1 minutes. The three variations in the diameter of the tube produced a good flame, as evidenced by the fire being able to continue to burn during the process of heating the water until it boiled. Then it can be concluded that the larger the diameter of the combustion tube, the faster the fire will go out. This is in line with research conducted by (Fajobi et al., 2022) which found that the larger the diameter of the combustion tube, the lower the pressure in the tube, which will cause the lifting power of the fire to decrease and the fire will go out faster.

Based on the flame temperature, in a 4-inch diameter tube, the flame produced has an average temperature of 719.2°C. In a 5- inch diameter tube, the flame produced has an average temperature of 689.6°C. and in a 6-inch diameter tube, the flame produced has an average temperature of 637.2°C. It can be concluded that the larger the diameter of the combustion tube, the lower the flame temperature produced. This is in line with research conducted by (Sarin, 2018)with the results that the larger the diameter of the bunsen burner, the lower the combustion process speed will be. So if the combustion process speed is smaller, it will cause the flame propagation speed to decrease because the effect of the combustion speed is more dominant on the flame propagation speed. The comparison of the temperatures of each tube can be seen in the following figure:

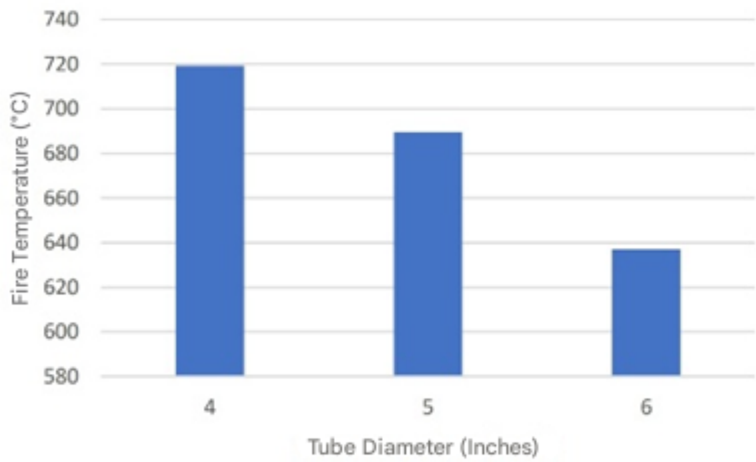

Figure. 2 Fire Temperature Graph

Based on the color of the fire, there is no difference in the color of the fire produced. This is because the color of the fire produced from the three variations of the tube diameter has the same color, which is reddish blue. The color of the three variations of the tube can be seen in the following picture:

Figure.3 Photos of Fire Colors

Combustion Tube with Kerosene Fuel

Based on the duration of the flame in the kerosene-fueled tube, it was found that the variation in the diameter of the combustion tube affected the flame duration. In the 4-inch diameter tube, the average flame duration was 10.52 minutes. In the 5-inch diameter tube, the average flame duration was 10.42 minutes. And in the 6- inch diameter tube, the average flame duration was 10.1 minutes. So it can be concluded that the larger the diameter of the combustion tube, the faster the fire will go out. This is in line with research conducted by (Fajobi et al., 2022) which found that the larger the diameter of the combustion tube, the lower the pressure inside the tube, which will reduce the lifting power of the fire and the fire will go out faster. The three variations in tube diameter produced a good flame, as evidenced by the fire being able to continue to burn during the heating process of the water until it boils.

Based on the flame temperature, in a 4-inch diameter tube, the flame produced has an average temperature of 622.2°C. In a 5-inch diameter tube, the flame produced has an average temperature of 563.8°C. And in a 6-inch diameter tube, the flame produced has an average temperature of 547.9°C. So it can be concluded that the larger the diameter of the combustion tube, the lower the flame temperature produced. This is in line with research conducted by (Phi et al., 2018) which found that the larger the diameter of the bunsen burner, the lower the combustion process speed will be. So if the combustion process speed is smaller, it will cause the flame propagation speed to decrease because the effect of the combustion speed is more dominant on the flame propagation speed. The comparison of the temperatures of each tube can be seen in the following figure:

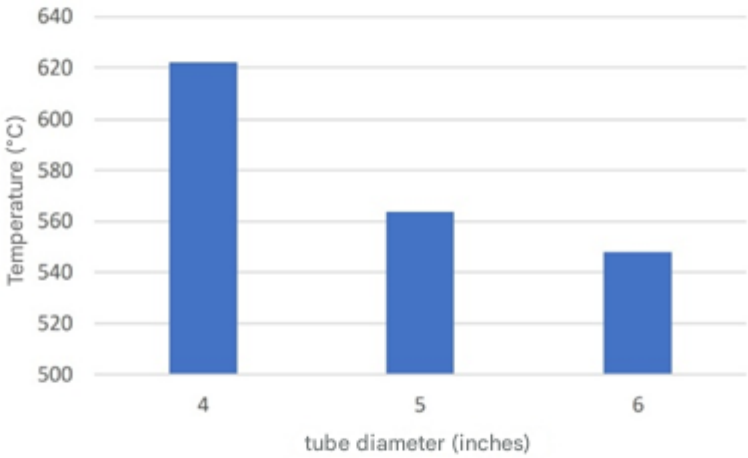

Figure.4 Fire Temperature Graph

Based on the color of the fire, there is no difference in the color of the fire produced. This is because the color of the fire produced from the three variations of the tube diameter has the same color, which is reddish blue. The color of the three variations of the tube can be seen in the following picture:

Figure.5 Fire Color Photos

Analysis of the Occurring Phenomena

Based on the description in the previous sub-point, it was found that the larger the diameter of the combustion tube, the faster the fire will go out. This is in line with research conducted by (Phi et al., 2018) which found that the larger the diameter of the Bunsen burner, the faster the combustion process will decrease. So that the larger the diameter of the combustion tube, the faster the combustion process will decrease, the speed of the flame propagation will decrease and the temperature of the flame will also decrease.

The larger the diameter of the combustion tube, the faster the fire will be extinguished because it increases the ratio of surface area to volume. This allows more air to come into contact with the fire, causing faster cooling and inhibiting the combustion process. As a result, the fire's ability to defend itself decreases more quickly, and the fire will be extinguished more quickly. This phenomenon is known as the "Quenching Effect".

An explanation of the quenching effect is found in the book entitled "Combustion" by (Glassman & Yetter, 2008) on page 192 which states that the quenching effect can be disrupted in tubes with small diameters. So that in tubes with smaller sizes the fire can last longer because the quenching effect is not too influential compared to tubes with larger diameters. The same explanation is also found in the book entitled "Combustion Techniques" by (Malik et al., 2024), on page 26 which explains that if the pipe diameter increases, the surface area of the fire that is in contact with it decreases. In addition to being related to the quenching effect, the diameter of the tube also has a relationship with the pressure in the tube, this relationship can be seen in the following figure:

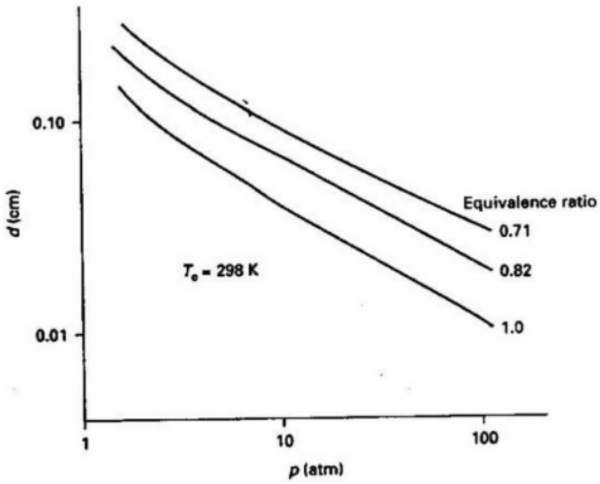

Figure.6 Graph of the Relationship between Pipe Diameter and Pressure

Based on the image, it is found that the larger the diameter of the combustion tube, the smaller the pressure inside the tube. The pressure inside the tube is related to the flame temperature. Based on the ideal gas law, it is stated that temperature is directly proportional to pressure. The greater the pressure inside the combustion tube, the higher the temperature of the resulting flame, and vice versa. The comparison of temperatures at various variations of tube diameters can be seen in the previous images 4 and 6, which show that the larger the diameter of the tube, the lower the flame temperature.

Effect of Combustion Tube Diameter Variation on Water Temperature

In the water heating process, the water temperature increases from the initial temperature of 31°C to boiling at a temperature of 100°C. The graph showing the increase in water temperature during the heating process at various variations of the diameter of the combustion tube and the fuel used can be seen in the following figure:

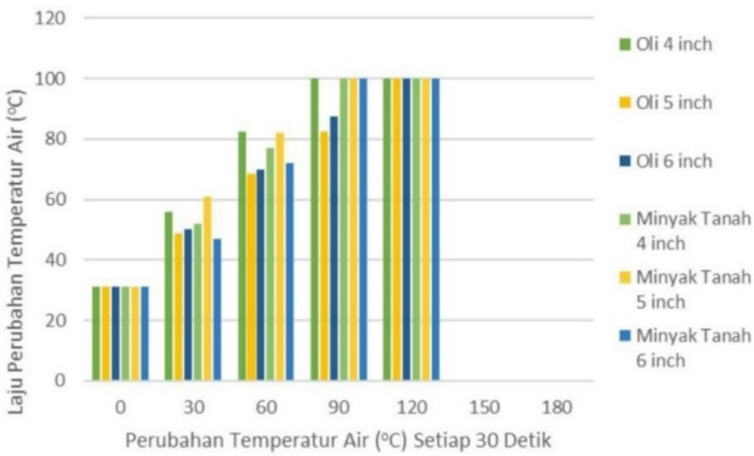

Figure.7 Graph of Water Temperature Increase During Heating Process

Based on the image above, it can be concluded that the variation in the diameter of the combustion tube does not show a significant effect on the water temperature during the heating process, because the heating process takes place well and stably, which is indicated by the absence of a decrease in water temperature during the heating process.

Heat Transfer Rate During Water Heating Process

During the process of heating water until it boils, a heat transfer process occurs, which includes heat transfer by radiation, conduction, and convection.

The amount of heat transfer by conduction can be calculated using the formula:

$$Q = \frac{k \times A \times \Delta T}{d}$$

Where:

Q: Amount of heat transferred (J)
k: Thermal conductivity of the material (202 W/m ².K)
: Surface area in contact with water (m2)
ΔT: Water temperature difference (°C)

d: Thickness of pan (0.001 m)
The amount of heat transfer by convection can be calculated using the formula:

$$Q = h \times A \times \Delta T$$

Where:
Q: Amount of heat transferred (J)
h: Heat transfer coefficient (10 W/m ^{2}.K)
A: Surface area (m ^{2})
ΔT: Water temperature difference (°C)

The amount of heat transfer by radiation can be calculated using the formula:

$$Q = \varepsilon \times \sigma \times A \times \Delta T^4$$

Where:
Q: Amount of heat transferred (J)
ε: Emissivity of the pan (0.5)
σ: Stefan-Boltzmann constant (5.67 ×10 $^{-8}$ W/m ^{2}.K ^{4})
A = Surface area (m ^{2})
ΔT^4: Water temperature difference (°K)

The following are the values of heat transfer by radiation, convection, and conduction for each tube variation calculated every 30 seconds:

4-Inch Tube with Used Oil Fuel			
Time (s)	Heat transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	8.55	479,750	23.75
60	20.06	990,204	49.02
90	29.13	1,324,110	65.55
120	29.13	1,324,110	65.55

5-Inch Tube with Used Oil Fuel			
Time (s)	Heat transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	5.6	337,744	16.72
60	13.54	715,787	35.43
90	19.91	984,447	48.73
120	29.13	1,324,110	65.55

6-Inch Tube with Used Oil Fuel			
Time (s)	Heat transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	6.31	346,379.5	18.05
60	14.27	673,569	35.1
90	22.48	1,084,235	53.67
120	29.13	1,324,110	65.55

Figure 10 Heat Transfer in Used Oil Fueled Cylinders

4-Inch Tube with Kerosene Fuel			
Time (s)	Heat transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	7.04	402,990	19.95
60	17.41	882,740	43.7
90	29.13	1,324,110	65.55
120	29.13	1,324,110	65.55

5-Inch Tube with Kerosene Fuel			
Time (s)	Heat transfer		
	Radiation (J)	Conduction (J)	Convection (J)

0	0	0	0
30	10.51	575,700	28.5
60	19.77	978,690	48.45
90	29.13	1,324,110	65.55
120	29.13	1,324,110	65.55

6-Inch Tube with Kerosene Fuel			
Time (s)	Heat transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	5.23	307,040	15.2
60	15.15	786,790	38.95
90	29.13	1,324,110	65.55
120	29.13	1,324,110	65.55

Table.1 Heat Transfer in a Kerosene-Fired Cylinder

Based on the calculations that have been done, it was found that the variation of the tube diameter and the fuel used did not have a significant effect on the rate of heat transfer that occurred during the heating process. This can be seen in the tables of previous calculation results which found that the magnitude of the heat transfer rate at second 0 and second 120 was the same for each variation of the tube diameter and fuel used.

However, there is a slight difference since the 30th second. Where in the used oil fueled cylinder, the cylinder with a diameter of 4 inches becomes the cylinder with the fastest increase in heat transfer rate. While in the kerosene fueled cylinder, the cylinder with a diameter of 5 inches becomes the cylinder with the fastest increase in heat transfer rate. The rapid increase in heat that occurs indicates that the heat transfer process that occurs is also fast. The graph showing the heat transfer that occurs in each cylinder and fuel can be seen in the following images:

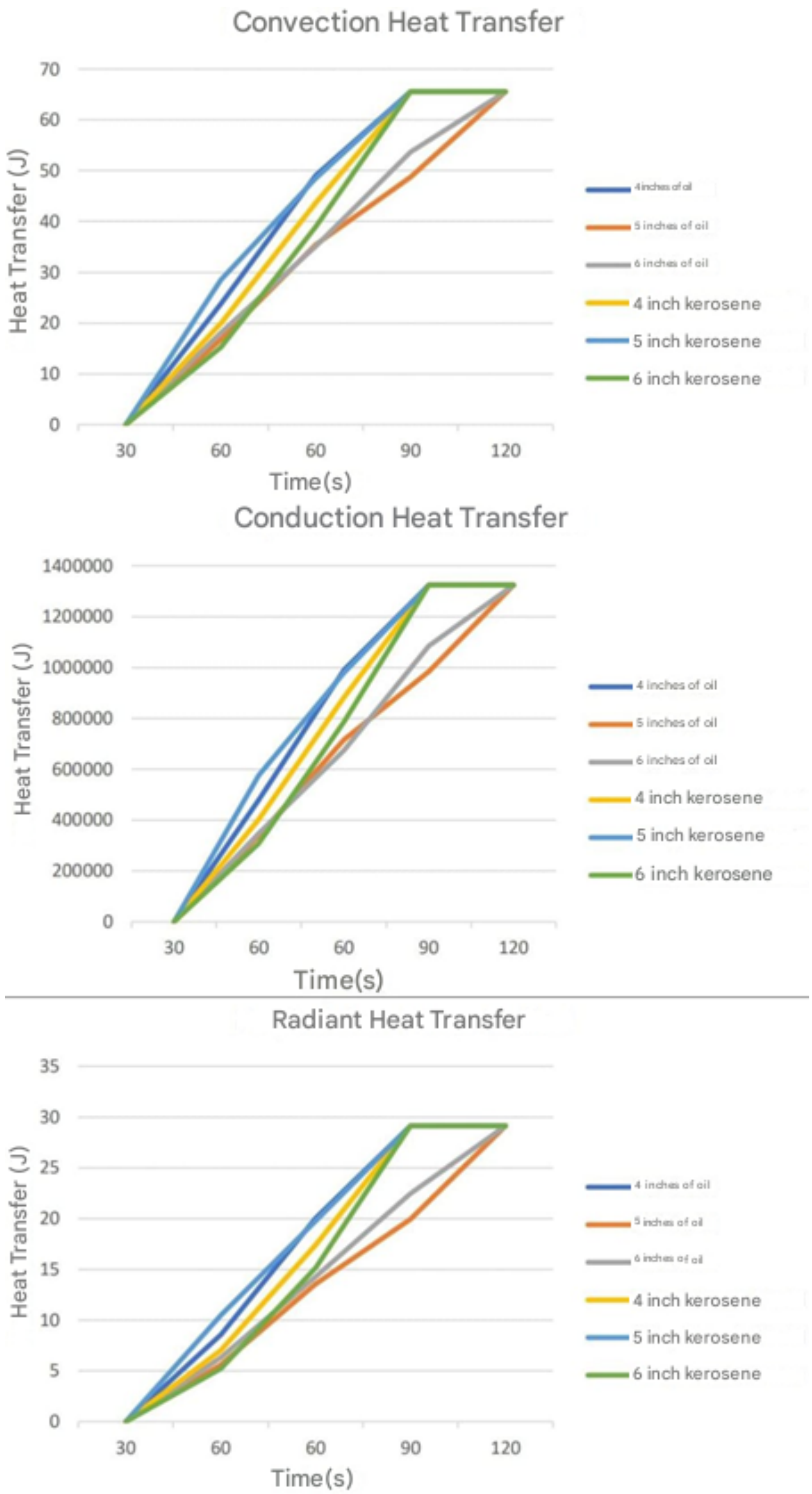

Figure.8 Heat Transfer Graph

Based on the images, it can be seen that during the water heating process there is an increase in the rate of heat transfer without any decrease. This indicates that the heat transfer that occurs during the water heating process is quite good.

The Best Cylinder

To find out which tube variation is the best, you can use a radar diagram. The radar diagram for various tube variations can be seen in the following picture:

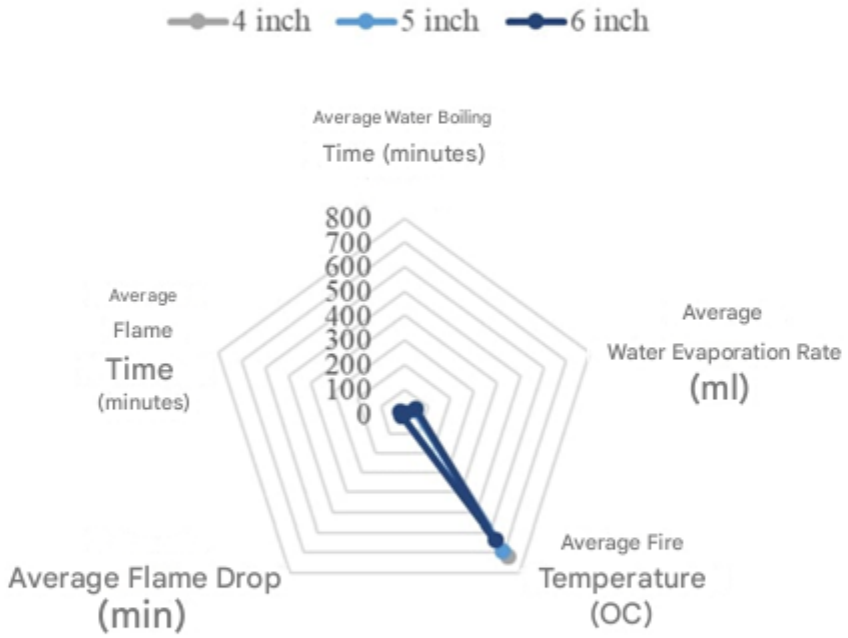

Figure.9 Radar Diagram For Used Oil Fuel Cylinder

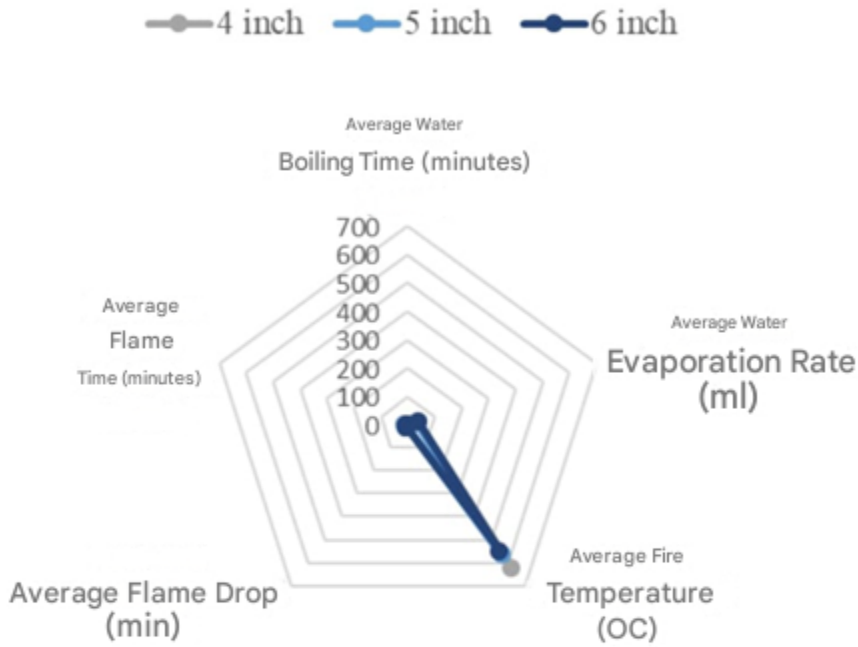

Figure.10 Radar Diagram for Kerosene Fueled Cylinders

Based on the two images above, it can be seen that in used oil fuel cylinders, a cylinder with a diameter of 4 inches is the best cylinder. Likewise, in kerosene fuel cylinders, a cylinder with a diameter of 4 inches is also the best cylinder.

CONCLUSION

Based on the research conducted, several conclusions have been drawn. This study utilized three variations of combustion tubes with diameters of 4 inches, 5 inches, and 6 inches, and two types of fuel—used oil and kerosene—to determine whether used oil could match the performance of kerosene. In terms of flame duration, the 4-inch diameter tube using used oil had the longest duration of 16.92 minutes. Regarding flame temperature, the 4-inch diameter tube produced the highest average temperature of 719.2°C. All three combustion tube variations, regardless of the fuel type, were able to bring water to a boil within a span of 1 minute 30 seconds to 2 minutes, a rate faster than conventional gas and electric stoves. The flame color remained consistent across all variations, exhibiting a reddish-blue hue. However, as the diameter of the tube increased, the fire extinguished more quickly, and the lower pressure within the tube resulted in a decrease in flame temperature. Despite these differences, the variation in tube diameter and fuel type had no significant effect on the water temperature during heating, as boiling consistently occurred within the same time frame. Based on these findings, the 4-inch diameter combustion tube was identified as the most efficient and optimal choice.

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