

*Article*

# Effect of Air Velocity on Temperature Distribution in B40 and B100 Oil Burners

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## Abstract

Dependence on fossil fuels has encouraged Indonesia to develop biodiesel, in line with the mandatory B40 policy. This study examines the effect of air velocity variations on the combustion performance of B40 (40% palm biodiesel and 60% diesel) and B100 (100% palm biodiesel) fuels. Experiments were conducted using an oil burner with air velocities of 20, 35, 45, 50, and 55 m/s. The flame temperature distribution was measured at distances of 150 mm, 300 mm, 450 mm, 600 mm, 750 mm, and 900 mm from the burner nozzle using a K-type thermocouple. The results showed that the flame temperature increased with air velocity, peaked at 45 m/s, and decreased at higher velocities. The B100 fuel produced a higher flame temperature than B40, with a maximum temperature of 1052°C. The decrease in temperature above 45 m/s is due to the cooling effect of the stronger airflow, which reduces combustion efficiency. The flame temperature also tends to decrease as the distance from the burner nozzle increases, reflecting the influence of turbulence and natural cooling on heat distribution. This study highlights the importance of controlling air velocity and measurement distance to optimize flame temperature and combustion efficiency in burner systems.

**Keywords:** Oil Burner, Biodiesel, Temperature, Flame, Combustion

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## 1. Introduction

Global energy demand continues to rise in tandem with rapid population growth and industrialization. The reliance on finite fossil fuels has driven the search for more sustainable alternative energy sources. The negative impacts of fossil fuel usage, particularly greenhouse gas emissions, exacerbate climate change. Renewable energy has emerged as a viable solution to ensure

long-term energy security and mitigate environmental damage [1].

Indonesia, as the world's largest producer of palm oil, possesses significant potential in the development of biodiesel as an alternative fuel. The Indonesian government has implemented the mandatory B40 policy, effective from January 2025, in an effort to reduce fossil fuel consumption [2]. B40 refers to a blend of fuel consisting of 40% palm oil-based biodiesel and

60% petroleum diesel. B100, which is entirely derived from renewable sources, also serves as an environmentally friendly alternative that supports the national energy transition. B100 is pure, unblended biodiesel (100% palm oil-based biodiesel). However, the differences in thermal characteristics and combustion performance between B40 and B100 must be analyzed to ensure the effectiveness of both as renewable fuels [3].

The temperature distribution during the combustion process is a key factor in evaluating energy efficiency and flame stability. Uniform temperature indicates more homogeneous and efficient combustion, as well as a reduction in the formation of harmful emissions. The study by [4] reveals that optimal temperature distribution is associated with improved efficiency and reduced emissions. The use of an experimental burner allows for temperature measurements at various points using thermocouple sensors to assess the thermal response of the tested fuels, B40 and B100, under varying air velocity conditions.

Factors such as viscosity, density, and oxygen content in B40 and B100 influence fuel atomization and combustion rate. The study by [5] demonstrates that the physical characteristics of fuels play a critical role in combustion quality and efficiency. The temperature distribution created during the combustion process provides valuable information about burner performance and the potential energy efficiency generated [6]. This study aims to evaluate and compare the temperature distribution between B40 and B100 under varying air velocity conditions to gain deeper insights into the thermal performance of both fuels.

## 2. Material and Methods

### 2.1 Biodiesel

Biodiesel was an increasingly utilized alternative fuel to replace conventional diesel. This fuel consisted of fatty acid esters obtained through a transesterification process, which was a reaction between vegetable oils or animal fats and alcohols such as methanol or ethanol, resulting in methyl esters or ethyl esters of fatty acids. The process also produced glycerol as a byproduct, which could be further utilized [7].

Biodiesel offered environmental advantages, as its combustion produced lower emissions,

particularly greenhouse gases such as carbon dioxide (CO<sub>2</sub>). In Indonesia, biodiesel produced from palm oil also supported the local agricultural and industrial sectors while reducing dependence on fossil fuels [8].

In Indonesia, biodiesel was required to comply with the Indonesian National Standard (SNI) 7182:2015. This standard regulated the quality of biodiesel to ensure efficient combustion and minimal environmental impact. Parameters regulated included water content, viscosity, flash point, and oxygen content in biodiesel. Adhering to this standard was crucial for supporting sustainable energy security and reducing air pollution. Key biodiesel characteristics were presented in Table 2.1.

Table 2.1. Key Parameters of Biodiesel Characteristics

| Parameter<br>(Unit)                            | Requirement     |                 | Method        |
|------------------------------------------------|-----------------|-----------------|---------------|
|                                                | Minimum         | Maximum         |               |
| Density<br>(g/cm <sup>3</sup> )                | 0,86 at<br>15°C | 0,90 at<br>15°C | ASTM<br>D4052 |
| Kinematic<br>Viscosity<br>(mm <sup>2</sup> /s) | 1,9 at<br>40°C  | 6,0 at 40°C     | ASTM<br>D445  |
| Flash<br>Point (°C)                            | 120             | -               | ASTM<br>D93   |
| Cetane<br>Number                               | 47              | -               | ASTM<br>D613  |

#### 2.1.1. B40

B40 was a type of biodiesel consisting of a 40% biodiesel blend and 60% fossil fuel, typically diesel. The B40 program was designed to support the national energy diversification efforts by reducing dependence on fossil fuels. This program also aimed to promote energy sustainability in Indonesia. B40 was a continuation of previous biodiesel programs, such as B30 and B35, which gradually increased the proportion of biodiesel in the fuel. The main objective was to reduce greenhouse gas emissions and support the achievement of renewable energy mix targets.

The characteristics of B40 fuel had a significant impact on its performance in engines, particularly in terms of combustion efficiency and the emissions produced. These parameters affected engine performance and their environmental impact, which were crucial factors in determining policies and the implementation of

B40 in the transportation and energy sectors. The characteristics of B40 fuel were presented in Table 2.2.

Table 2.2. Characteristics of B40

| Parameter              | Unit   | Results | Methods              |
|------------------------|--------|---------|----------------------|
| Cetane Number          | -      | 53.6    | ASTM D 613           |
| Viscosity at 40°C      | cSt    | 3.25    | ASTM D 4052 / D 1298 |
| Flash Point            | °C     | 88      | ASTM D 93            |
| Sulfur Content         | Ppm    | 820     | ASTM D 4294 / D5453  |
| Pour Point             | °C     | 12      | ASTM D 92            |
| Water Content          | Ppm    | 211.70  | ASTM 6304            |
| Oxidation Stability    | Hour   | 51.3    | EN 15751             |
| Copper Strip Corrosion | -      | 1a      | ASTM D 130           |
| Lubricity              | micron | 298     | ASTM D 6079          |

Source: [9]

### 2.1.1 B100

B100 was a type of biodiesel consisting of 100% pure biodiesel, produced from vegetable oils or animal fats through a transesterification process. Unlike B40, which blended biodiesel with conventional diesel, B100 used biodiesel exclusively without any diesel mixture. One of the key components of biodiesel was palmitic acid, a saturated fatty acid with 16 carbon atoms and the chemical formula  $C_{16}H_{32}O_2$ . Palmitic acid was commonly found in palm oil, which was a primary feedstock for biodiesel production in various countries, including Indonesia. The use of B100 as a fuel could reduce emissions, decrease air pollution, and support the use of renewable energy. [5]. The characteristics of B100 fuel are presented in Table 2.3.

Table 2.1. Characteristics of B100 Fuel

| Parameter                   | Unit              | Result | Methods     |
|-----------------------------|-------------------|--------|-------------|
| Cetane Number               | -                 | 60.1   | ASTM D 613  |
| Density at 40°C             | Kg/m <sup>3</sup> | 860.5  | ASTM D 4052 |
| Viscosity Kinematic at 40°C | cSt               | 4.42   | ASTM D 445  |
| Flash Point                 | °C                | 177    | ASTM D 93   |
| Copper Strip Corrosion      | merit             | 1a     | ASTM D 130  |
| Carbon Residue              | % mass            | Null   | ASTM D 4530 |
| Water Content               | Ppm               | 339.1  | ASTM 6304   |
| Oxidation Stability         | Minute            | 1087   | EN 15751    |

Source: [9]

## 2.2 Combustion

Combustion was an exothermic chemical reaction between fuel and oxygen that produced heat and exhaust gases. In a boiler, the combustion process aimed to convert the chemical energy contained in the fuel into thermal energy, which was then used to heat water and generate steam. This process required a precise balance between its supporting elements. These elements were interrelated and were summarized in the combustion triangle concept, which served as the fundamental basis for understanding and controlling the combustion process.

The combustion reaction process could occur when the combustion triangle was fulfilled. The combustion triangle was a fundamental concept that illustrated the three key elements required for combustion to take place: fuel, air, and heat [10]. These three elements must be present and interact in the correct proportions for combustion to occur effectively. If any one of the elements in the combustion triangle is absent or unavailable in sufficient quantities, the combustion process will either cease or fail to proceed efficiently.

### 2.2.1 External Combustion

External combustion was a process in which fuel was burned outside the main system that utilized thermal energy, such as in boilers, steam turbines, or oil burners. In this system, the thermal energy produced from the combustion of the fuel was used to heat a fluid, typically water, which then generated steam for various purposes, such as power generation or industrial heating [11]. Comprehending the phases of external combustion was key to enhancing combustion efficiency, reducing energy waste, and curbing the release of harmful emissions.

### 2.3 Experimental setup and procedure

This study was conducted using a Jinil JL-26D oil burner, equipped with a 5.00 GPM nozzle and a 60° spray angle. The combustion system was connected to a cylindrical chimney with a length of 1400 mm and a diameter of 500 mm to direct the exhaust gas flow (see Fig. 1). The fuels used in this study included B40 (a mixture of 60% diesel and 40% biodiesel) and B100 (pure biodiesel), each with its physical characteristics presented in Table 1 and Table 2. Fuel atomization was performed through a spray system with a fixed pressure of 17 bar to produce a stable and uniform combustion pattern.

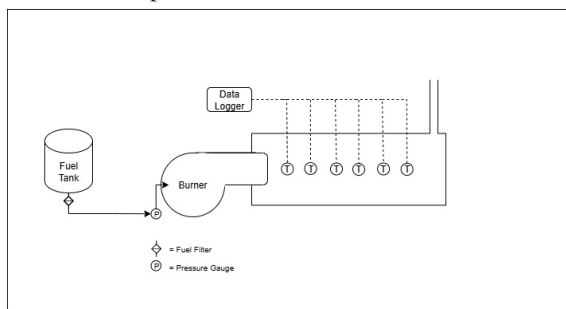


Fig. 1. Research scheme

The variations in air velocity used in the combustion process included 20, 35, 45, 50, and 55 m/s, controlled via a blower to ensure optimal air-fuel mixing. Temperature distribution measurements were conducted using six Type K thermocouples with a maximum temperature limit of 1600 °C. The thermocouples were arranged linearly along the combustion path, with a spacing of 150 mm between sensors, starting from the nozzle tip as the zero measurement point. The temperature data obtained from each point were used to evaluate the flame temperature distribution along the chimney.

Temperature distribution was selected as the primary parameter for analysis, as it reflects thermal efficiency and flame stability. Measurements were conducted repeatedly for each fuel combination and air velocity variation, and the results were compared to identify thermal distribution patterns and the influence of fuel characteristics on combustion performance. All data were collected in real time and analyzed quantitatively to support the conclusions drawn from the experiments.

## 3. Results and Discussion

### 3.1 Flame analysis

Flame temperature data were obtained using Type K thermocouples, which were installed at six different points along the spray path of the burner. The thermocouples were placed at specific distances from the burner nozzle to obtain longitudinal temperature distribution. The first measurement point was located 150 mm from the nozzle and labeled T<sub>1</sub>. The second point was at 300 mm (T<sub>2</sub>), followed by the third point at 450 mm (T<sub>3</sub>), the fourth at 600 mm (T<sub>4</sub>), the fifth at 750 mm (T<sub>5</sub>), and the sixth at 900 mm (T<sub>6</sub>). Each thermocouple was connected to a data logger that recorded and monitored the temperature in real time at each measurement point.

### 3.2 Temperature at T<sub>1</sub> (150 mm)

The thermocouples were placed at specific distances from the burner nozzle to obtain longitudinal temperature distribution, with the first measurement point (T<sub>1</sub>) located 150 mm from the nozzle. The graph in Figure 1 showed the variation in flame temperature with air velocity, comparing two curves: B40 and B100.

Both curves exhibited a similar trend: temperature increased with higher air velocity until reaching a peak at 45 m/s, after which it decreased at higher air velocities due to greater cooling effects (see Fig. 2). This peak-and-decline characteristic suggested the existence of an optimum stoichiometric ratio at 45 m/s, where the air supply was ideal for complete combustion. The subsequent temperature dropped implied that excess air at velocities above 45 m/s led to significant heat loss, reducing the overall thermal

efficiency of the system—a critical consideration for industrial boiler operation.

The observed trend contrasted with the study conducted by [12], which indicated that monotonically higher velocities resulted in higher temperatures, potentially due to differences in burner design or fuel composition. However, this study aligned with the research conducted by [13], which also found a velocity-dependent optimal point for maximum heat release.

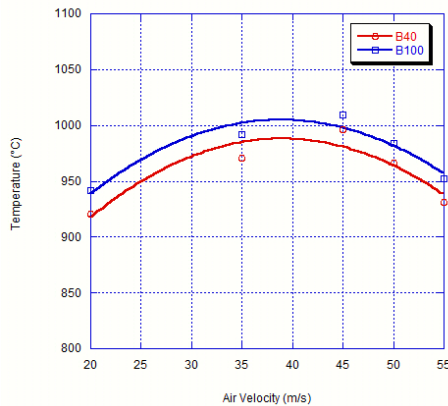


Fig. 2. Temperature distribution at thermocouple 1 (150 mm)

The peak temperature for B40 was 996.4°C, while B100 reached a peak temperature of 1009°C, confirming that B100 produced a flame with a higher maximum temperature compared to B40. This difference of 12.6°C illustrated the direct impact of the fuel's higher purity and energy content (zero fossil diesel) on thermal output. Furthermore, the higher peak temperature of B100 signified a potentially improved rate of heat transfer to the working fluid, which translated directly into better energy efficiency and reduced fuel consumption in industrial applications. This finding underscored the importance of optimizing air velocity (45 m/s) to maintain combustion efficiency and provided a strong operational argument for the superiority of pure biodiesel (B100) in achieving high thermal performance.

### 3.3 Temperature at T<sub>2</sub> (300 mm)

The graph in Figure 3 showed the variation in flame temperature at point T<sub>2</sub> (300 mm from the nozzle) with respect to air velocity for both B40 and B100 fuels. Flame temperature increased with the air velocity, reaching its peak at 45 m/s, but decreased at higher velocities. This peak behavior confirmed the identification of the optimal air

velocity at 45 m/s for maximum heat output in the mid-section of the flame.

The findings from [12] suggested that a monotonic increase in velocity led to a rise in temperature, a trend that did not fully align with the current parabolic results. On the other hand, the results of this study aligned with the findings from [14], which also highlighted the existence of an optimal point before cooling effects dominated.

The maximum recorded temperature for B40 was 1046°C, while B100 reached a maximum temperature of 1052°C. This small but consistent temperature difference of 6°C indicated that B100 produced a slightly higher flame temperature at the 300 mm point (see Fig. 3). The higher temperature was attributed to the greater oxygen content in pure biodiesel (B100), which enhanced combustion completeness and overall energy release.

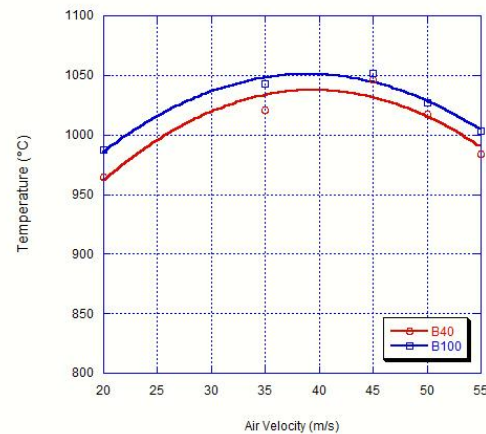


Fig. 3. Temperature distribution at thermocouple 2 (300 mm)

The subsequent decrease in temperature at air velocities above 45 m/s occurred due to the increased cooling effect caused by the higher airflow. Although higher air velocities accelerated the distribution of oxygen and the greater turbulence caused the air-fuel mixture to become more homogeneous, the residence time of the fuel in the combustion chamber was significantly reduced. While more efficient mixing took place, the shorter time available for complete reaction resulted in a lower observed temperature, underscoring the trade-off between mixing quality and reaction time in external combustion systems.

Overall, the B40 fuel produced lower combustion temperatures compared to B100, although both fuels exhibited a similar optimal trend in response to variations in air velocity. The

higher oxygen content in B100 enhanced combustion efficiency, thereby contributing to elevated temperatures at the measurement points, which implied a better thermal performance and potential operational benefit for pure biodiesel.

### 3.4 Temperature at $T_3$ (450 mm)

Flame temperature data were obtained using Type-K thermocouples installed at six distinct positions along the axial path of the burner flame. The thermocouples were mounted at specific distances from the burner nozzle to capture the longitudinal temperature distribution. The third measurement point ( $T_3$ ) was located 450 mm from the nozzle.

Figure 4 presented the variation in flame temperature at point  $T_3$  as a function of air velocity, comparing two fuel types: B40 and B100. The temperature increased with rising air velocity, peaking at 45 m/s, and subsequently decreased at higher velocities. This characteristic parabolic trend confirmed that 45 m/s represented the optimum air-to-fuel ratio for maximum heat release, even further downstream in the combustion chamber.

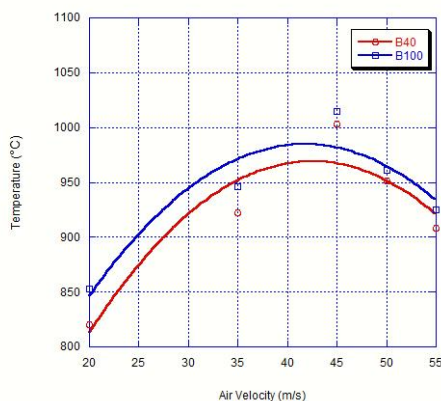


Fig. 4. Temperature distribution at thermocouple 3 (450 mm)

The maximum recorded temperature for B40 was 1037°C, while B100 reached a slightly higher peak of 1046°C. This difference indicated that at a distance of 450 mm from the nozzle, B100 produced a marginally higher flame temperature than B40 (see Fig. 4). This consistent superiority of B100 was attributed to its higher oxygen content and greater purity, which maintained a more complete combustion reaction even as the flame expanded.

The observed trend, where temperature tended to increase with rising air velocity up to a point, was reported in [12] and was also consistent with the results reported by [15], affirming the general behavior of oil burner flames under variable air flow.

The temperature decreased at air velocities above 45 m/s was attributed to the increased cooling effect caused by higher airflow rates. Although elevated air velocity enhanced oxygen distribution in the combustion chamber, promoting potentially more efficient mixing, the faster flow resulted in lower flame temperatures. This phenomenon was primarily due to the reduction in fuel residence time within the combustion zone and the increased mass flow rate acting as a heat sink. The observed temperature decline underscored the importance of optimizing air velocity (45 m/s) to maintain desirable flame temperatures and maximize thermal efficiency at this crucial distance of 450 mm from the burner nozzle for practical industrial applications.

### 3.5 Temperature at $T_4$ (600 mm)

Flame temperature data were acquired using Type-K thermocouples positioned at six different locations along the axial path of the burner flame. The thermocouples were installed at specified distances from the burner nozzle to capture the longitudinal temperature distribution. The fourth measurement point ( $T_4$ ) was located 600 mm from the nozzle.

Figure 5 illustrated the variation in flame temperature at point  $T_4$  as a function of air velocity, comparing two types of fuel: B40 and B100. As air velocity increased, flame temperature also rose, reaching a peak at 45 m/s before declining at higher velocities. This consistent parabolic trend at 600 mm reiterated that 45 m/s represented the optimal air-fuel mixing condition for maximizing heat release across the combustion length.

The maximum recorded temperature for B40 was 1003°C, while B100 achieved a slightly higher maximum of 1015°C. These findings indicated that at a distance of 600 mm, B100 produced a marginally higher flame temperature than B40. This sustained thermal superiority of B100 was directly linked to its higher inherent oxygen content and lack of inert fossil fuel components,

promoting a more thorough and hotter combustion process.

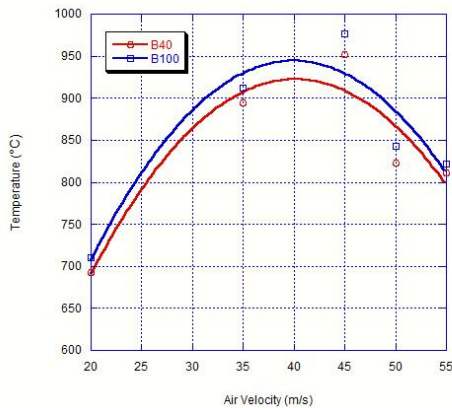


Fig. 5. Temperature distribution at thermocouple 4 (600 mm)

However, the temperatures observed at this point were generally lower compared to those recorded at earlier measurement positions (T1–T3) (see Fig. 5). This confirmed that the main heat release zone had passed, and the flame had begun to cool due to heat transfer to the surrounding environment and the entrainment of cold air.

The study conducted in [12] showed a direct relationship between the increase in velocity and the rise in temperature, a finding that differed from the parabolic optimal curve observed here. In contrast to these findings, the results of this study were consistent with the research conducted by [13], which supported the notion of a velocity threshold for maximum heat output.

The decrease in flame temperature at air velocities exceeding 45 m/s was attributed to the increased cooling effect induced by the stronger airflow. Although higher air velocity enhanced the distribution of oxygen within the combustion chamber, thereby accelerating the combustion process, this also led to a temperature decline due to the reduced residence time of the fuel in the combustion zone and the greater thermal sink provided by the excess air. The observed temperature reduction beyond 45 m/s highlighted the critical importance of optimizing air velocity to maintain combustion efficiency and flame temperature, particularly in the downstream section of the combustion system, for achieving stable and predictable thermal performance.

### 3.6 Temperature at T<sub>5</sub> (750 mm)

Flame temperature data were obtained using type-K thermocouples positioned at six different locations along the axial path of the burner flame. The thermocouples were installed at specific distances from the burner nozzle to capture the longitudinal temperature distribution. The fifth measurement point (T<sub>5</sub>) was located 750 mm from the nozzle. Figure 6 showed the variation in flame temperature at point T<sub>5</sub> as a function of air velocity, comparing two fuel types: B40 and B100.

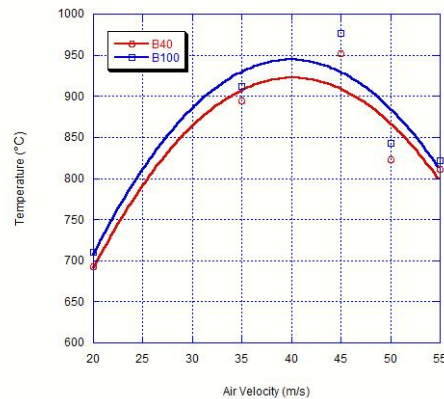


Fig. 6. Temperature distribution at thermocouple 5 (750 mm)

The temperature increased with rising air velocity, peaking at 45 m/s, and subsequently declined at higher velocities. This recurring parabolic trend re-established 45 m/s as the optimal operational velocity for maximizing thermal output across the length of the burner. The maximum temperature recorded for B40 was 951.4 °C, while B100 reached a slightly higher peak of 977 °C. These findings indicated that at a distance of 750 mm, B100 consistently produced a marginally higher flame temperature than B40—a characteristic attributed to its higher oxygen content promoting more complete late-stage combustion.

However, the temperatures measured at this point were significantly lower compared to those at the previous measurement locations (T<sub>1</sub>–T<sub>4</sub>). This reduction underscored the fact that the primary heat release zone had fully passed the T<sub>5</sub> location. Furthermore, the temperature reduction observed at T<sub>5</sub> relative to upstream points was attributed to the shortening of the flame at higher air velocities, which caused the measurement point to lie effectively beyond the main combustion envelope. Consequently, the thermocouple at T<sub>5</sub> recorded lower temperatures than those measured closer to the nozzle,

indicating a substantial drop in thermal intensity further downstream.

The decrease in flame temperature at air velocities above 45 m/s was attributed to the cooling effect caused by the stronger airflow. Higher air velocities enhanced the distribution of oxygen within the combustion chamber, accelerating the combustion process. However, this also resulted in a lower flame temperature due to the reduced residence time of the fuel in the combustion zone and the greater thermal sink provided by the excess air. This result contrasted with the findings of [12], which reported a direct correlation between increased air velocity and higher flame temperatures, but aligned more closely with the conclusions drawn by [14], which emphasized the existence of an optimal air flow threshold. The observed temperature drop beyond 45 m/s highlights the crucial need for air velocity optimization to maintain not only peak thermal output but also flame stability across the entire system length for effective energy utilization.

### 3.7 Temperature at T<sub>6</sub> (900 mm)

Flame temperature data were obtained using Type-K thermocouples installed at six distinct points (T<sub>1</sub>–T<sub>6</sub>) along the axial path of the burner flame, with measurement distances ranging from 150 mm to 900 mm from the nozzle. Figure 7 illustrated the variation in flame temperature at point T<sub>6</sub> as a function of air velocity, comparing two fuel types: B40 and B100.

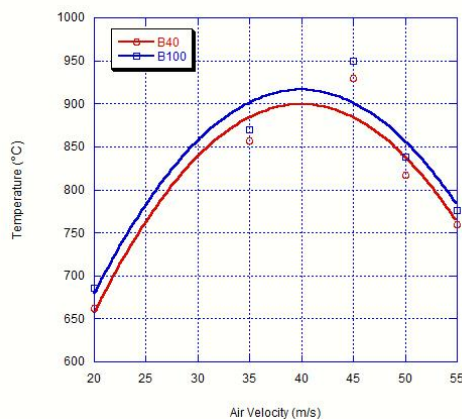


Fig. 7. Temperature distribution at thermocouple 6 (900 mm)

The flame temperature increased with rising air velocity, peaking at 45 m/s, followed by a decline at higher velocities. The maximum

recorded temperature for B40 was 930.1°C, while B100 reached a higher peak temperature of 950.1°C. These results indicated that at a distance of 900 mm from the nozzle, B100 consistently produced a higher flame temperature than B40. However, the temperatures at this location were lower compared to the upstream measurement points (T<sub>1</sub>–T<sub>5</sub>).

The decrease in temperature compared to earlier measurement points (T<sub>1</sub>–T<sub>4</sub>) was attributed to the shortened flame length at higher air velocities, which caused the thermocouple at T<sub>6</sub> to lie beyond the effective combustion zone. As a result, the recorded temperature was lower than that measured at closer distances to the nozzle.

The observed decline in flame temperature at air velocities above 45 m/s was primarily attributed to the cooling effect induced by the stronger airflow. Higher air velocities enhanced oxygen distribution within the combustion chamber, which improved combustion efficiency; however, they also resulted in reduced flame temperature due to the shortened residence time of fuel within the chamber.

Overall, the graphs showed a consistent trend where flame temperature increased with rising air velocity, peaking at 45 m/s before decreasing at higher speeds. The maximum temperatures recorded for B100 remained higher than those for B40 across all measurement points, indicating that B100 produced a hotter flame due to its higher oxygen and energy content. Flame temperature tended to decline as the distance from the burner nozzle increased.

## 4. Conclusions

The results of the study show that flame temperature increases with rising air velocity, peaking at 45 m/s, and then decreases at higher velocities. B100 fuel produces higher temperatures than B40 due to its higher oxygen content, which enhances combustion efficiency. The temperature drop beyond 45 m/s is caused by the cooling effect of stronger airflow. Increased air velocity also shortens the flame length, which affects the measured temperature. The reduction in maximum temperature at high velocities is primarily attributed to the decreased residence time of the fuel and uneven heat distribution. Proper control of air velocity is essential to

optimize flame temperature and combustion efficiency, with 45 m/s identified as the optimal operating point.

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