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The Effects of Pressure and Temperature on Flame Characteristics of Crude Palm Oil Combustion

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ABSTRACT

Using vegetable oil as a direct combustion fuel is an interesting energy development of lower emissions fuel. In this work, commercial cooking oil extracted from palm oil was burned using a typical nozzle having a diameter of 2 mm. Nozzle gage pressure and preheat temperature of palm oil were varied at 20, 40, 60 psi and 70, 90, 110 °C, respectively. Combustion oxidizer was air at room temperature. Equivalence ratio of ER= 1.1. To initiate combustion of the oil, a pilot flame from LPG with fixed firing rate was placed under the oil spray using a domestic stove. The experimental results shown that higher preheat temperatures and pressure accelerated combustion reactions of palm oil. The simulation also shown the same result as the experimental results. The higher preheat temperature and pressure led to high temperature, large size and long penetration of flame. The largest flame size was at 110 °C and 60 psi.

1. Introduction

Since the Industrial revolution, the energy mix of most countries across the world has become dominated by fossil fuels. The global greenhouse gas emissions 75% result from the burning of fossil fuels that are responsible for large amounts of air pollution and a health problem which leads to at least 5 million deaths each year. To reduce CO_2 emissions and air pollution, the world needs to rapidly shift towards low-carbon sources of energy – renewable energy [1-4].

Biomass energy, one of renewable energy sources, has played a significant role because it offers environmental and social benefits. Moreover, it can be converted into electricity and heat by the most common technique that is called direct combustion [5-7] and become a vital part of the global energy mix and account for an ever-growing share of electric capacity added worldwide [8].

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Several biofuels have been studied to solve emission problems. Hashimoto *et al.,* [9] studied the combustion characteristics compared 100% C-heavy oil with 50% C-heavy oil-crude jatropha oil (CJO) blending. The result shows that NO_x and SO_2 emissions of C-heavy oil-CJO blending were greatly decreased because the nitrogen and sulfur contents in CJO were significantly lower than C-heavy oil. Mahfouz *et al.,* [10] studied the effects of waste cooking - diesel oil blending: 0, 20, 40, 60, 80 and 100% on performance, emissions, and combustion characteristics of industrial oil burner. It was found that NO_x, SO_2 and CO emissions decrease when percentage volume of waste cooking oil increases. Muhammad *et al.,* [11] studied performance of sludge palm oil (SPO) combustion using waste oil burner compared with diesel. SPO was lower in CO, CO_2 and NO_x emissions during the combustion compared to diesel around 34%, 6% and 90 % reduction respectively.

According to some researcher, the results show that vegetable oil released fewer emissions compared with other oil, and blending fuel was less in emissions as well. So, this study focuses on using palm oil which is a high commercial value products in Southeast Asia.

Considering in Southeast Asia, palm oil production is estimated at 72.26 million ton in 2019. Indonesia is expected to produce the biggest share at 40.50 million ton, followed by Malaysia at 20.50 million ton. The two countries account for 84.4% of global production. Thailand ranks third, producing 2.90 million ton a year or 4% of global output [12-15].

According to the US Department of Agriculture data (USDA, 2020), in average, the palm oil harvested areas in Southeast Asia had grown a lot and led to a huge increase in palm oil production in the year 2018-2019 [16]. Due to the oversupply of palm oil, the market price of crude palm oil (CPO) went to a historic low. The governments try to lift the price up by using policies such as biodiesel and fuel in co-firing process [17].

Producing biodiesel from palm oil requires a great number of materials and energy. During the production process, several kinds of emissions are released and affect the environment [18]. Therefore, using crude palm oil as fuel for direct combustion such as in a boiler or industrial cooking process is another interesting development. It is not only to decrease emissions but also a way to help palm farmers.

This study focuses on using palm oil as fuel for direct combustion. Experiment and simulation of palm oil-air combustion were studied. An experiment attempts to investigate flame characteristics. Before entering a combustion chamber, palm oil is preheated 70, 90 and 110 ^{o}C with varied air pressure 20, 40 and 60 psi. Pilot flame is used for initial ignition of the fuel-air mixture. Flue gas analyzer, TESTO 350, is used to measure exhaust gas components. The simulation approach used to compare flame characteristics results and study additional result due to an experiment limitation. Computational fluid dynamics (CFD) ANSYS Fluent software is applied to investigate palm oil combustion simulation with same preheat temperature and air pressure conditions.

2. Methodology

2.1 Modelling

In this study, Computational fluid dynamics (CFD) ANSYS Fluent 2019 R3 software is used. Design modelling as shown in Figure 1. A 2 mm-diameter nozzle in the centre of a combustion chamber is used to introduces palm oil. Palm oil enters a combustion chamber with varied preheat temperature 70, 90 and 110 °C at 0.66 m/s. Ambient air enters a combustion chamber at 0.005 m/s. The overall equivalence ratio is 1.1.

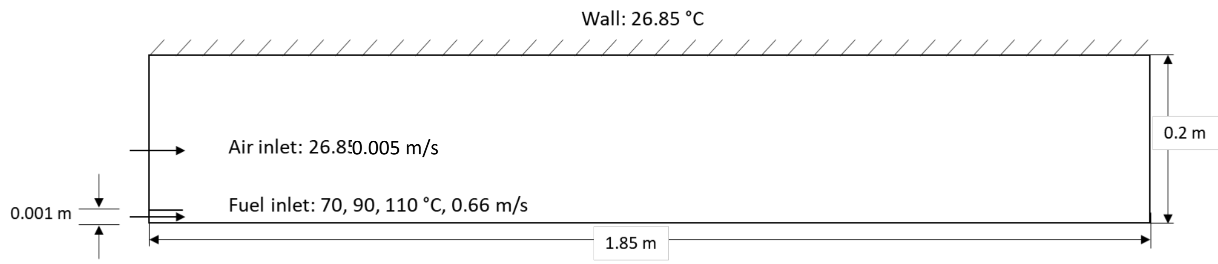


Fig. 1. Design Modelling

2.2 Mesh

Grid generation is shown in Figure 2. The grid-dependent test was varied in the element number of 5,000 – 15,000 elements. It was found that the saturated elements which were not changing the results significantly were 12,000 elements. These element numbers were selected to apply to all CFD runs.

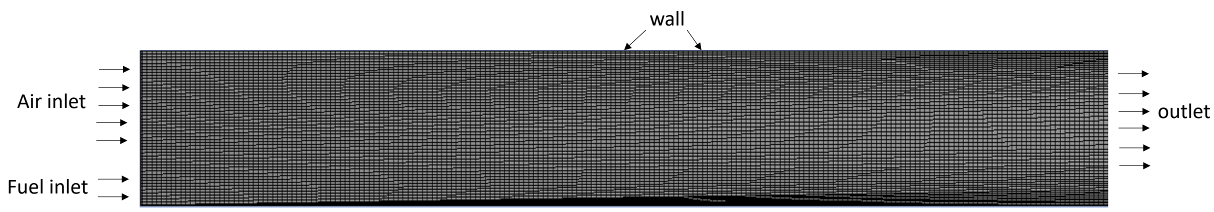


Fig. 2. Meshing

2.3 Solution Setup

Table 1 shows general and model setting. Palm oil-air combustion model was studied in axisymmetric 2D-space with energy equation and standard k-epsilon (2eqn). To simplify combustion investigation, the palm oil was given as gas phase. Species transport model was chosen to induce fuel to model. Table 2 shows boundary condition for fuel inlet and air inlet.

Table 1
General and model setting

Property	Value
2D space	Axisymmetric
Energy equation	On
Viscous	k-epsilon (2eqn)
Species	Species transport
Reactions	Volumetric
Mixture material	Palm oil-Air
Turbulence-chemistry Interaction	Eddy-Dissipation

Table 2
Boundary condition

Condition	Fuel inlet	Air inlet
Diameter (m)	0.002	0.4
Velocity (m/s)	0.66	0.005
Temperature (°C)	70, 90, 110	26.85
Materials	Palm oil	Air

Table 3 shows palm oil ultimate analysis. The palm oil sample was tested at Office of Scientific Instrument and Testing (OSIT), Prince of Songkla University (PSU), Thailand. CHNS/O Analyzer (Thermo Quest, FlashEA 2000 model, Italy) is used for analyzing the elements C, H, N, S and O in samples by the method of burning samples at high temperature into mixture gas. Then, enter the column to separate and measure the number of elements in the sample. Table 4 shows palm oil property, chemical formula, MW, density, etc., to study palm oil-air combustion [18]. To check convergence of results, define all absolute criteria in residual monitors 0.0001 and run calculation with number of Iteration 100000.

Table 3
Palm oil ultimate analysis

Sample	Unit	C	H	O	N
Palm oil	%wt	75.625±0.204	11.775±0.037	12.581±0.070	0.021±0.001

Table 4
Palm oil property [19]

Property	70 °C	90 °C	110 °C
Chemical formula	$C_{48}H_{90}O_6$	$C_{48}H_{90}O_6$	$C_{48}H_{90}O_6$
MW (kg/kmol)	744.38	744.38	744.38
Density (kg/m^3)	865.4	856.1	847.1
C_p (j/kg·K)	1988	2049	2113
Thermal cond. (w/m·k)	0.1683	0.1668	0.1653
Viscosity (kg/m·s)	0.01275	0.008087	0.005709

2.4 Experimental Setup

An experimental set up as shown in Figure 3. The fuel supply system is included of main tank for feeding fuel via a rotameter to control fuel flow rate. Then, heater with temperature controller is used to preheat palm oil 70, 90 and 110 ^oC. The air supply system consisted of air compressor, pressure regulator and an air rotameter to provide air with pressure 20, 40 and 60 psi. Palm oil and air enter a combustion chamber through 2-mm diameter nozzle. Pilot flame is used for initial ignition of the fuel-air mixture during start-up of combustion reaction. Flue gas analyzer, TESTO 350, is used to measure exhaust gas components in this experiment as shown in table 5.

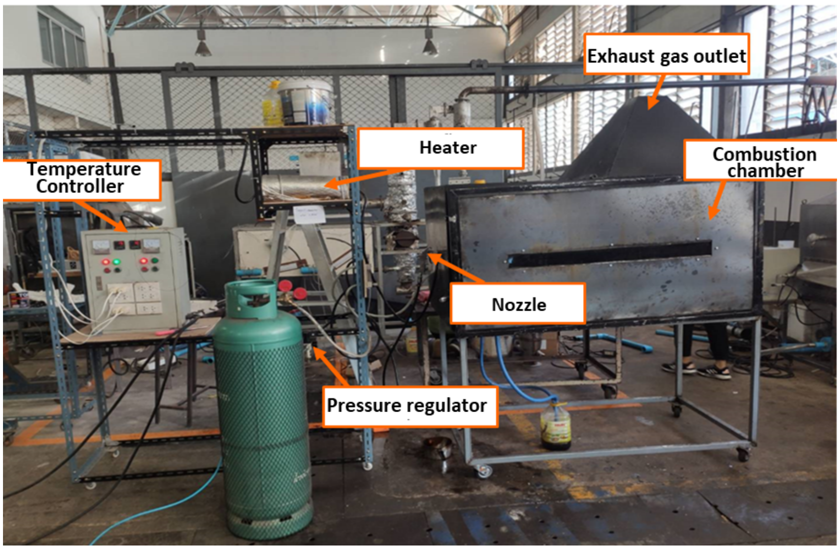


Fig. 3. An Experimental set up

Table 5
TESTO350 exhaust gas measurement [20]

Parameter		Accuracy
O_2	(0 to 25 vol.%)	± 0.8 vol.%
CO_2	(0 to 50 vol.%)	± 0.3 vol.%
CO	(0 to 10,000 ppm)	± 10 ppm
NO	(0 - 4,000 ppm)	± 5 ppm
NO_2	(0 - 500 ppm)	± 5 ppm
SO_2	(0 - 5,000 ppm)	± 5 ppm

3. Results

3.1 Flame Characteristics

Figure 4 shows the largest flame size was at preheat temperature 110 °C and pressure 60 psi. The higher preheat temperature and pressure can accelerate combustion reactions.

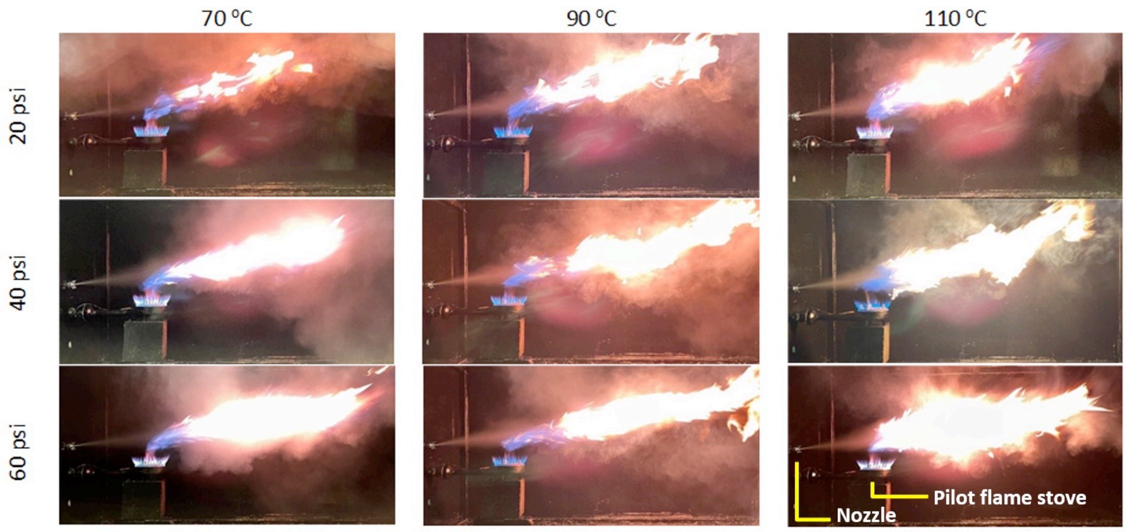


Fig. 4. Flame characteristics (experimental results)

Figure 5 shows the highest temperature was at preheat temperature 110 °C and pressure 60 psi. High temperature areas of the flame of CFD results (Figure 5) were similar to the flame size of experimental results (Figure 4). The higher preheat temperature and pressure led to high temperature, large flame size and long penetration of flame.

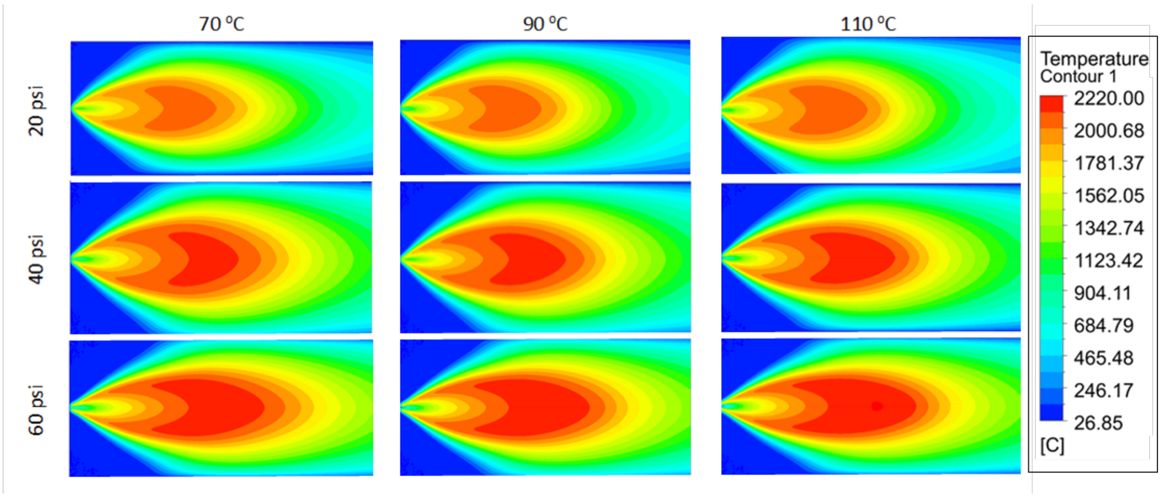


Fig. 5. Flame characteristics (CFD results)

3.2 Temperature Graph

The temperature along chamber length from an inlet increases rapidly and then begins to drop to the end of the chamber (185 cm). Figure 6(a) constant preheat temperature with varied pressure, the temperature start dropping at 60 cm. The highest temperature is at 60 psi and followed by 40 and 20 psi respectively. Figure 6(b) the highest temperature is at a chamber length 80, 90 and 100 cm for pressure condition 20, 40 and 60 psi respectively.

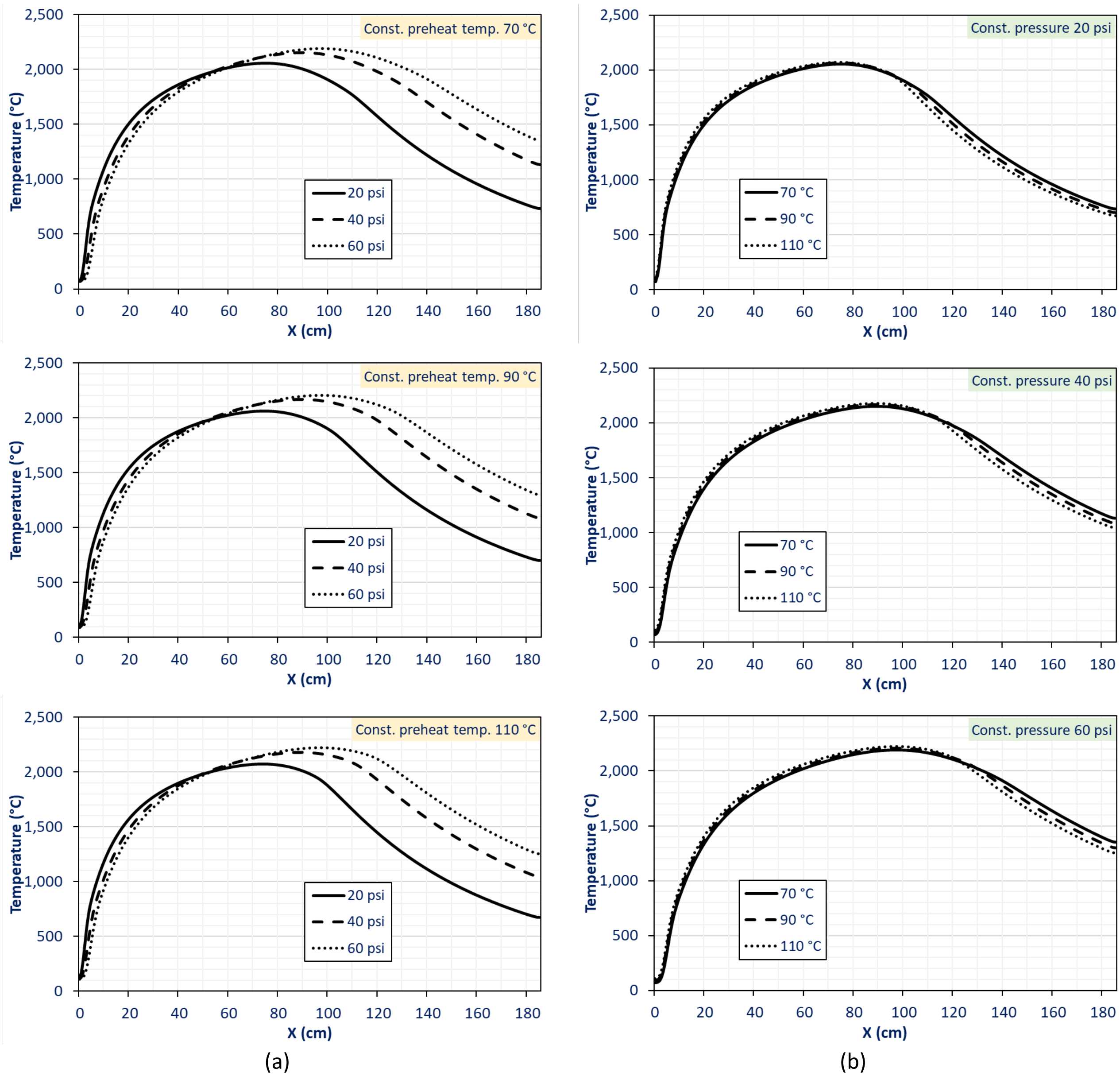


Fig. 6. Temperature graph along a combustion chamber length (a) constant preheat temperature, varied pressure, (b) constant pressure, varied preheat temperature (CFD results)

3.3 Palm Oil Graph

Considering Figure 7, palm oil is a reactant that used in combustion reaction. Therefore, palm oil mass fraction decreases rapidly and become 0 at a chamber length 100-120 cm. The higher preheat temperature, the faster palm oil mass fraction decreases as shown in Figure 7(a). For constant pressure varied preheat temperature, all the conditions show similar results as shown in Figure 7(b).

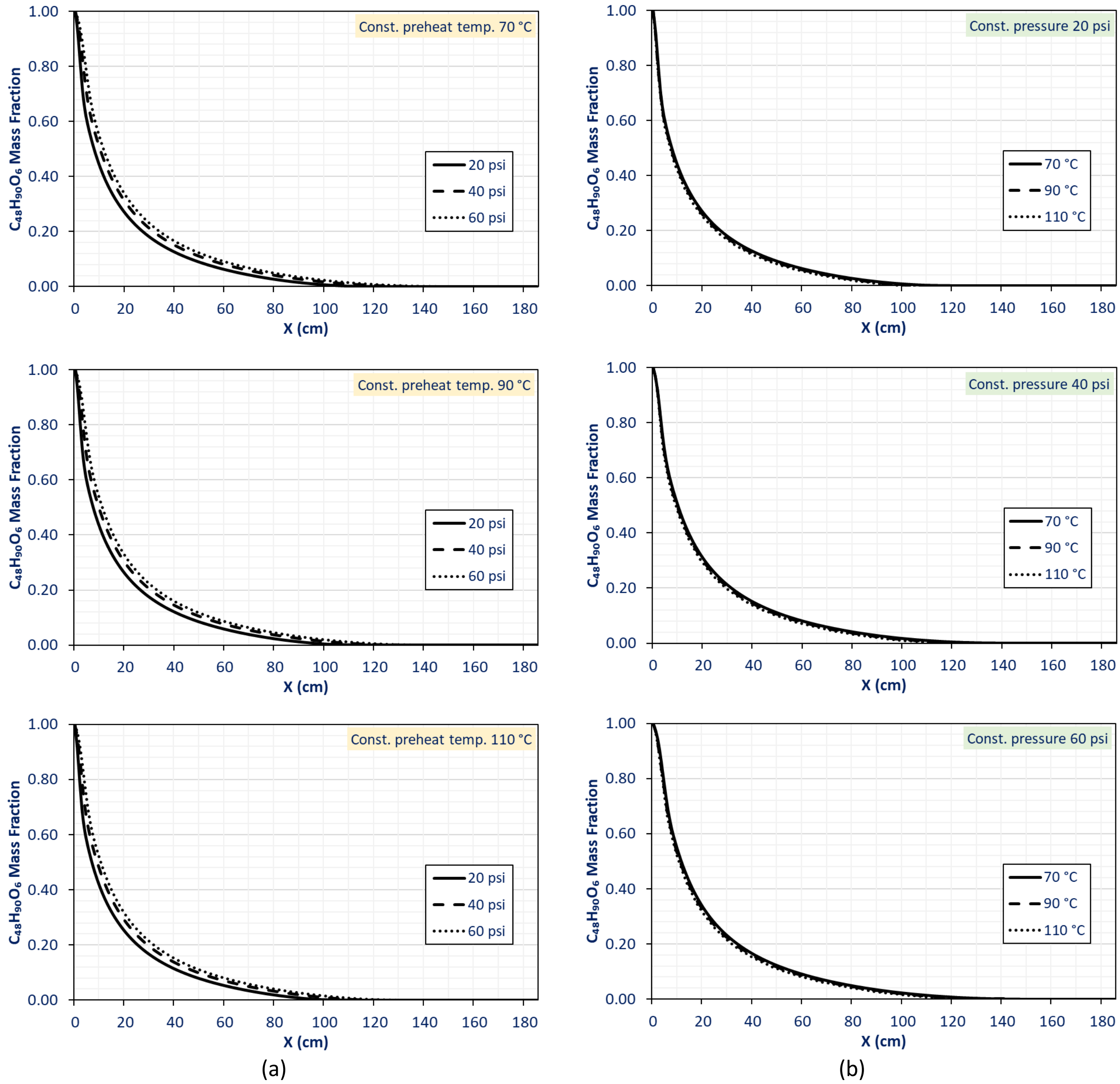
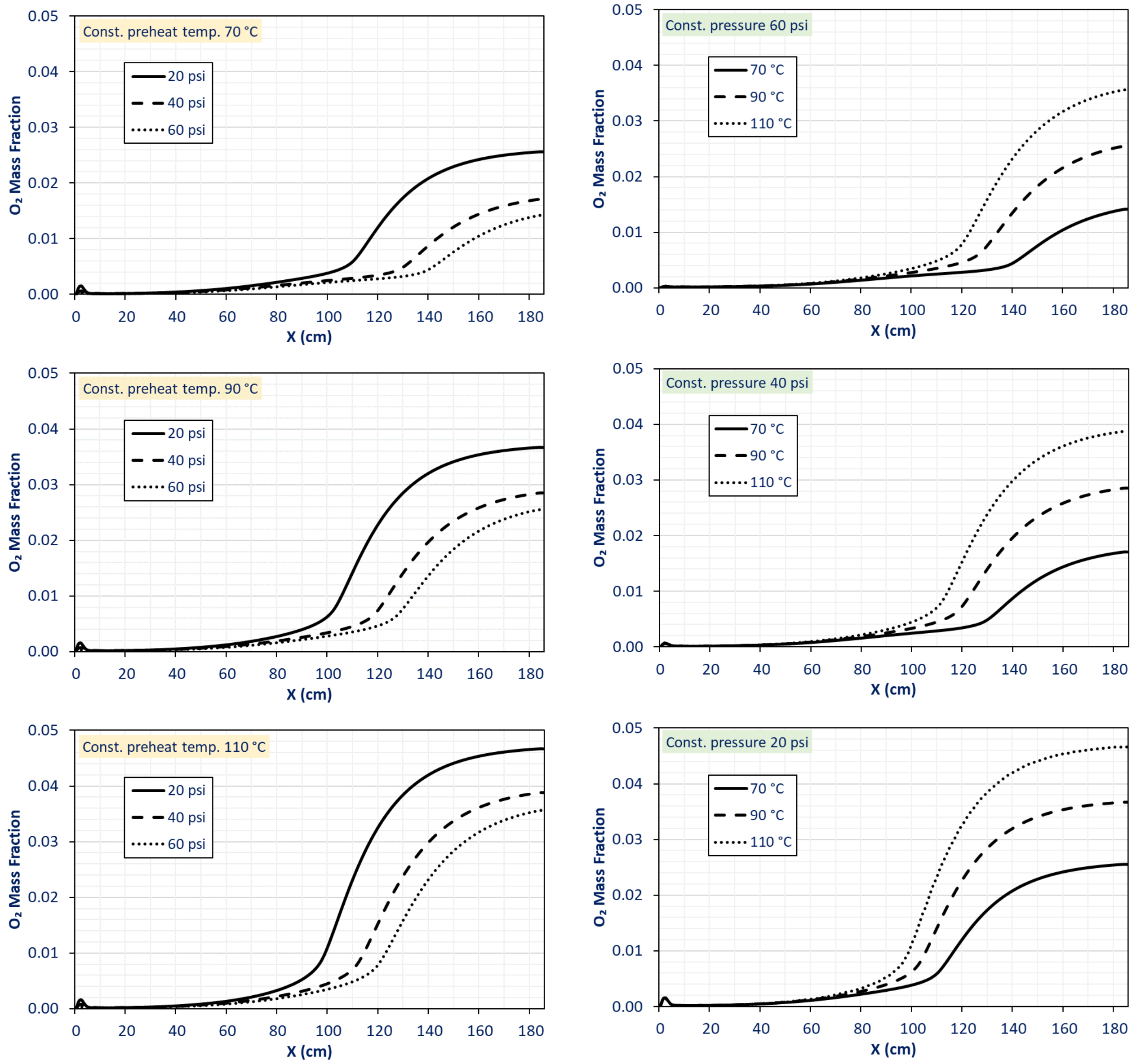


Fig. 7. Palm oil mass fraction along a combustion chamber length (a) constant preheat temperature varied pressure, (b) constant pressure varied preheat temperature (CFD results)

3.4 O_2 Graph

Considering Figure 8, O_2 is also a reactant that used in combustion reaction. When combustion reaction occurs, O_2 mass fraction increases slightly due to excess air in a chamber. Then, O_2 mass fraction rises rapidly at a chamber length 100-120 cm because there is not enough palm oil. So, air that enters a chamber is excess air.

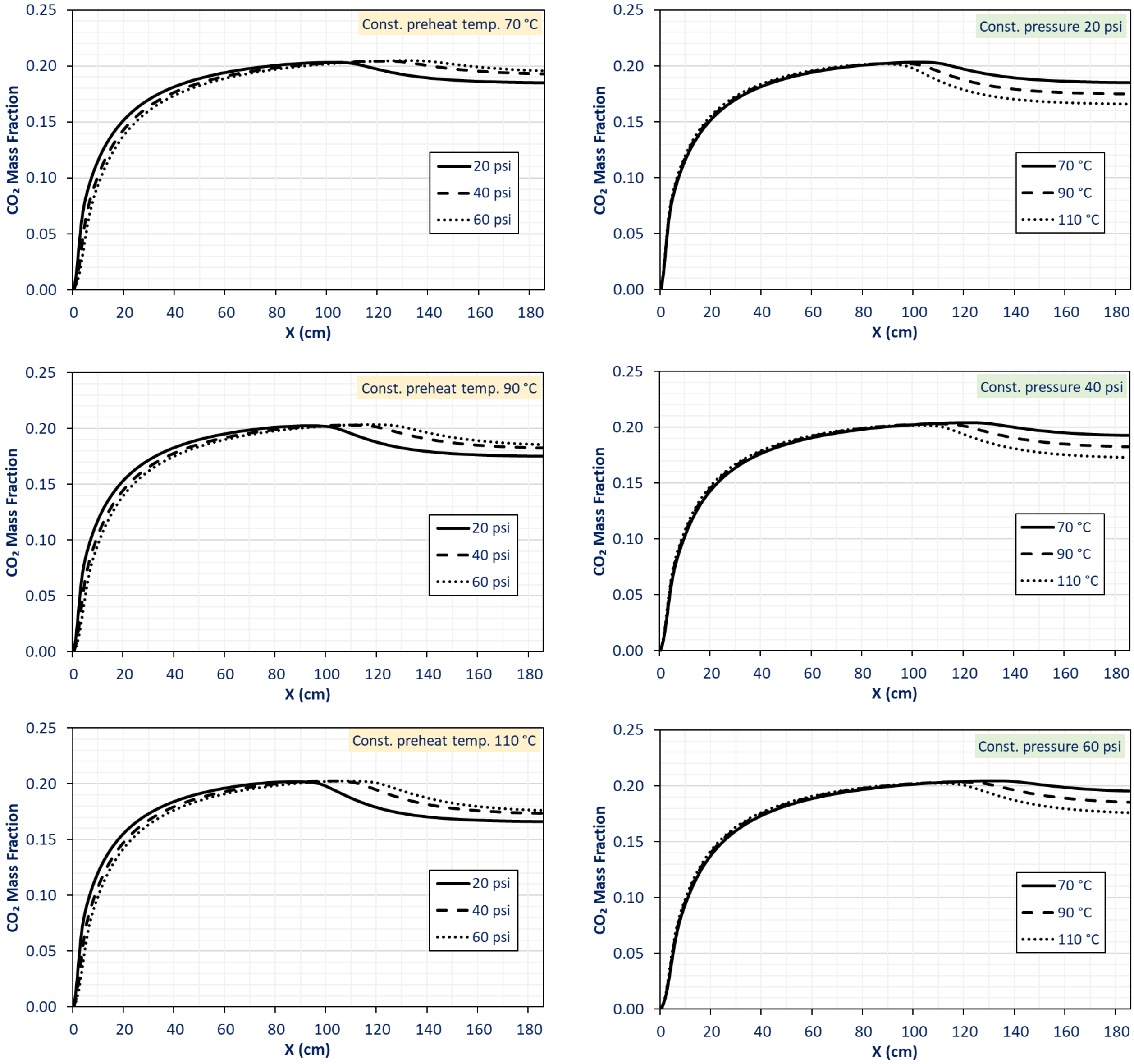


(a) (b)

Fig. 8. O_2 mass fraction along a combustion chamber length (a) constant preheat temperature varied pressure, (b) constant pressure varied preheat temperature (CFD results)

3.5 CO_2 Graph

Considering Figure 9, CO_2 mass fraction increases rapidly at a chamber length from an inlet to 40 cm because C is converted into CO_2 and CO, an increase in CO_2 showed better combustion and lower in CO. Then, CO_2 mass fraction keeps increasing slightly and starts to fall at a chamber length 100-120 cm due to no combustion reaction. Referring to Figure 7 palm oil mass fraction becomes 0 at 100-120 cm. So, there is no reactant to continue combustion reaction.



(a) (b)

Fig. 9. CO_2 mass fraction along a combustion chamber length (a) constant preheat temperature varied pressure, (b) constant pressure varied preheat temperature (CFD results)

4. Conclusion

This study focused on Palm oil-air combustion with species transport and compared with experimental results. The flam characteristics of simulation results were similar to the experimental results. The higher preheat temperature and pressure led to high temperature, large size and long penetration of flame. Moreover, the simulation results shown that the higher preheat temperature and pressure can accelerate combustion reaction. Temperature along a chamber length become higher and palm oil mass fraction decreases faster when palm oil-air combustion in high preheat temperature and pressure condition.

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References
[1] Hannah Ritchie, Max Roser, "Renewable Energy" 2020. [online] Available: https://ourworldindata.org/ renewable-energy.
[2] Omer, Abdeen Mustafa. "Energy use and environmental impacts: A general review." *Journal of renewable and Sustainable Energy* 1, no. 5 (2009): 053101. https://doi.org/10.1063/1.3220701
[3] Organization for Economic Cooperation and Development, "OECD Green Growth Studies: Energy" 2012.
[4] Hannah Ritchie, Max Roser. "Fossil Fuels" 2020.
[5] Dilip Ahuja, Marika Tatsutani, Daniel Schaffer, "Sustainable energy for developing countries" 2009.
[6] U.S. Department of Energy Federal Energy Management Program (FEMP), "Biomass For Electricity Generation" 2016.
[7] Eia. "Biomass-renewable energy from plants and animals" 2020.
[8] BioEnergy Consult, "Importance of Biomass Energy" 2020.
[9] Hashimoto, Nozomu, Hiroyuki Nishida, Masayoshi Kimoto, Kazuki Tainaka, Atsushi Ikeda, and Satoshi Umemoto. "Effects of Jatropha oil blending with C-heavy oil on soot emissions and heat absorption balance characteristics for boiler combustion." *Renewable Energy* 126 (2018): 924-932. https://doi.org/10.1016/j.renene.2018.04.018
[10] Mahfouz, Ahmed, Ahmed Emara, M. S. Gad, and Ahmed El Fatih. "Effect of waste cooking-diesel oils blends on performance, emissions and combustion characteristics of industrial oil burner." *Int. J. Res. Appl. Sci. Eng. Technol* 5 (2017): 1264-1274. https://doi.org/10.22214/ijraset.2017.9182
[11] Zuber, Muhammad Ahmar, Ahmad Muhsin Ithnin, Wira Jazair Yahya, Ahmad Danish Abd Wahab, and Mohamad Azrin Ahmad. "Performance of sludge palm oil combustion using waste oil burner." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 49, no. 1 (2018): 55-61.
[12] Phusadee Arunmas, Yuthana Praiwan, Pitsinee Jitpleecheep, "Palming off the problem" 2019.
[13] Alimalbari, Ameen, Sherly Hanifarianty, Anil Kumar, Thanet Khomphet, Theera Eksomtramage, and Makatar Wae-hayee. "Effects of pressed palm conditions on acceleration of palm drying rate and CPO quality." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 55, no. 1 (2019): 12-19.
[14] Husin, Akmal Hakim, Syahmil Hakim Hamzani, Shahrin Hisham Amirnordin, Mohd Faizal Mohideen Batcha, Rafiuddin Wahidon, and Makatar Wae-hayee. "Drying Studies of Oil Palm Decanter Cake for Production of Green Fertilizer." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 97, no. 2 (2022): 66-79. https://doi.org/10.37934/arfmts.97.2.6679
[15] Pakdeechot, Siravit, Makatar Wae-hayee, and Sherly Hanifarianty. "Effects of Sterilization Times of Palm Bunches on Fruit-Bunch Separation, Crude Palm Oil Yield and Quality Using Direct Steaming." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 82, no. 2 (2021): 39-46. https://doi.org/10.37934/arfmts.82.2.3946
[16] United States Department of Agriculture Foreign Agricultural Service, "data&analysis" 2019.
[17] Minchul, Suh. "World Palm Oil Supply Forecast", *Oil Palm Industry Economic Journal* 20, (2020): 21-27.
[18] Prapaspongsa, Trakarn, Charongpun Musikavong, and Shabbir H. Gheewala. "Life cycle assessment of palm biodiesel production in Thailand: impacts from modelling choices, co-product utilisation, improvement technologies, and land use change." *Journal of Cleaner Production* 153 (2017): 435-447. https://doi.org/10.1016/j.jclepro.2017.03.130
[19] Chempro "Technical Information Palm Oil Properties".
[20] TESTO "testo 350 · Flue gas analyzer Instruction Manual".