The properties of vegetable cooking oil as a fuel and its utilization in a modified pressurized cooking stove

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Abstract. Vegetable cooking oils (VCOs) and used vegetable cooking oils (UCOs) can be considered as alternative fuels which will provide the household with low price fuel and may solve the problem of getting rid of waste VCOs. Their utilization as cooking fuel can bring numerous benefits not only for urban but also for rural communities in Indonesia. The paper focuses on characterizing VCOs and UCOs as fuels for the household cooking application using a modified pressurized cooking stove. Physical properties such as auto-ignition point, auto-ignition time, flash point, density and viscosity of VCOs play the vital role in the combustion. Some properties of these oils were measured and characterized according to ASTM standards. The oil was used directly as a fuel using in a design modified pressurized cooking stove. Adjusting the temperature of vegetable cooking oils used as fuel, it is possible to improve their combustion performance, thus reducing ignition time and incomplete combustion. The main target of the research is to determine the quality and performances of these oils combustion. The auto-ignition point for the several oils was determined to be as follows: UCO: 460 ^{o}C, crude VCO: 406 ^{o}C, fresh VCO: 405 ^{o}C and the peanut cooking oil did not auto-ignite. Crude VCO gave the shorter auto-ignition time than other oils within 30 s. The efficiency of the pressurized stove using UCO, crude VCO and fresh VCO as fuel were observed 23.65%, 25.99%, and 31.57%, respectively. The highest flame temperature of 942^{o}C in these experiments was achieved by burning fresh VCO as fuel in this modified pressurized cooking stove. UCOs tended to produce luminous flames compared other oils.

1. Introduction

Indonesia is an agro based country and it has all the potential to produce vegetable cooking oil in huge quantities. Fuels of bio-origin such as vegetable cooking oils (VCOs) are a new alternative cooking fuel resource securing a sustainable and independent cooking energy supply. These alternative fuels can be produced from renewable energy sources such as soybean oil, sunflower oil, groundnut oil, palm kernels oil etc. Vegetable cooking oil (VCO) has the added safety advantage of having a much higher flash point than any other. Such fuels can be used directly as fuel for the household cooking application. The using of VCO has several advantages as combustion fuel due to relatively simple and low-cost technology for expelling and filtering, the VCO can be processed on the farm itself, thus saving the transport cost, time and energy [1].

Physical properties such as ignition point, of VCO, play the vital role in the combustion. It would be very beneficial to study the various factors surrounding the ignition of VCO. The properties of the oil would determine the auto-ignition temperature of the VCO due to different chemical compositions. Therefore different types of VCO would have different auto-ignition temperatures, resulting in different ignition times [2], [3].

1.1. Physical and thermal properties of fuel
Kerosene is commonly used as a liquid fuel where VCOs can be used as substitutes. Kerosene composed of hydrocarbon molecules. The kerosene fraction belongs to the group of hydrocarbon called paraffin, which has lower specific gravity than aromatic hydrocarbon of the same boiling point. The main components of kerosene are paraffin, cycloalkanes (naphtha) and aromatic compounds, where paraffin is the highest composition. VCO are tri-glycerol of fatty acids, with distinct chemical and physical properties, and different combustion characteristics than those of kerosene. VCO have a chemical composition that corresponds in most cases to a mixture of 95% triglycerides and 5% free fatty acids, sterols, waxes and various impurities [4]. The viscosity of VCO can be up to about 30 to 50 times higher than that of kerosene. The flash point of VCOs ranges from 180 to 300ºC, compared to 80ºC for kerosene, as shown in Table 1. [2], [3], [6-8]. This means the operating risks of kerosene are much higher due to its easy inflammation [5]. All properties of VCO are close to kerosene except the viscosity. High-value viscosity of the VCOs is considered to be the major constraint as combustion fuel, such as causing incomplete combustion and the formation of deposits on the burner nozzle [5].

Table 1. The properties of VCOs and kerosene

Fuel	Fuel ignition (^{o}C)	KinematicViscosity (cSt)	Gross calorific value (MJ/kg)
Kerosene	50-55	2.2	43.50
Palm oil	314	88.6	39.54
Coconut oil	270-300	51,9	37,54
Sunflower oil	316	65,8	39,81
Peanut oil	340	57,4	39,65
UCO	164	5.16	36,59

High ignition points of VCO in connection with extremely high viscosity require special adaptation mechanism of the cooking stoves. Many techniques have been developed to reduce the density and viscosity of VOC. Preheating of the VCO reduced the viscosity which resulted in improved atomization property [6]. Therefore these must be treated prior to the use of VCOs in the cooking stove. By adequately heating the VOC in the horizontal spiral coil before burning on burner spoiler, its physical parameters can reach values very close to that of kerosene. Consequently, by properly adjusting the temperature of VOC used as fuel, it is possible to improve their combustion performance, thus reducing ignition time and incomplete combustion.

1.2. Pressurized cooking stove
The cooking stove, in general, is classified in two main categories; vapor jet burner (pressurized) and wick burners. The thermal efficiency of kerosene stove is between 20–40 % depending on stove and cooking equipment design [8]. Since the viscosity of VCOs is higher than the viscosity of kerosene, directly usage of kerosene wick-type stoves is not suitable for the use with VCOs. Due to its high viscosity, VOC has difficulty to be used as direct fuel for cooking. Also, the presence of other component forming coke and higher ignition temperature of VCOs compared to kerosene make it difficult to ignite the fuel. Therefore, the straight use of VCO as fuel in pressurized cooking stove entails adjusting several physical properties of density and viscosity. Designs of stoves using were based on the methods to vaporize and spray under pressure into a specially designed stove [5]. In this experiment, VCO was used directly as a fuel using in a design of modified pressurized cooking stove equipped with the spiral coil as a preheater. Heating the VCO before injecting them into the combustion stove is one of the methods to reduce the viscosity number [6] and reducing the ignition

time. VCO was auto preheated before being burned to decrease its viscosity near to kerosene. Due to different chemical compositions, therefore different types of VCOs would have different auto-ignition temperatures, resulting in different ignition times. The results could give insight into safer VCOs to use that have higher auto-ignition temperatures. In this work, auto-ignition temperatures of these VCOs were measured and characterized according to ASTM standards.

The main objective of present study was to analyze the VCOs and UCO as fuel and to reduce the viscosity of oils by auto preheating in a modified pressurized stove.

2. Materials and methods

This work emphasizes the importance of the need to understand the vegetable cooking oil fires, especially the ignition characteristics of common VOCs. These experiments were researched to give insight into the temperatures ranges at which cooking oil will auto-ignite. The purpose of this research is to experimentally determine the combustion characteristics of three vegetable oils, namely VOC, UCO, crude VOC. To determine its usefulness as an alternative fuel, the combustion characteristics of vegetable oils are compared with kerosene.

The physical properties of VCOs and UCO were tested according to ASTM methods. An experiment was designed and several tests were conducted to determine the density, viscosity, auto-ignition temperatures, ignition time and smoke point of vegetable oils. To determine auto-ignition temperature, a small amount (5 mL) of cooking oil was heated in a small pan on a hot plate until the oil auto-ignited. The temperature of the oil in the pan was measured by using digital thermocouple Krisbow-KW06-283. The temperature of a smoke point was observed if enough volatile compounds emerge when a bluish smoke becomes clearly visible from the oil. The auto-ignition temperature and ignition time were measured when the minimum temperature at which an oil will start to burn without additional application of external heat (figure 1).

Figure 1. Test set up of ignition values

Three fairly common household cooking oils of UCO, crude VCO, fresh VCO and the peanut cooking oil were tested. The density measurements were performed gravimetrically at 30°C using volumetric glassware. Three test runs were taken to ensure the repeatability and accuracy of the data according to ASTM D1298 methods. The viscosity of household cooking oils was measured by using a Cannon-Fenske capillary viscometer immersed in a thermostatic bath. The measurements of viscosity were carried out at temperatures of 30°C, for a total of 3 measurements, each of which was obtained by averaging the values of three repetitions. The Cannon-Fenske type 200 viscometer with the viscosity range of 20-100 mm^2/sec. (centi-Stokes or cSt) was utilized to measure the viscosity of the oil using method suggested by ASTM D445. They allowed measuring the viscosity of all VCOs with flow times within the recommended range set by the standard ISO 3105:1994. The viscosity is obtained from the following equation (1) [9].

$$\upsilon = t c_0(T) \tag{1}$$

v is the kinematic viscosity in centistokes, t the flow time expressed in seconds and $c_0(T)$ the characteristic calibration constant of each viscometer measured at the working temperature.

The relationship between the chemical structure and composition of VCOs and heating value can be expressed by a mathematical equation [10]. In this case, heating values of various VCOs were estimated based on kinematic viscosity, v instead of chemical structure and composition effected by using equation (2) [11], [12].

$$HV = 37.946 + 0.0491\upsilon \quad (2)$$

HV being heating value in MJ/kg.

The main obstacle of using VCOs in cooking stoves is its high viscosity, which often leads to clogging of the fuel pipe or burner nozzle. The stove has been adapted to or modified for utilizing of VCOs. The design of stove using the VCOs was based on the method to utilize the VCOs, vaporized, auto preheated and sprayed under pressure. Several stoves which have been adapted to or specifically designed for vegetable oils, but it is not reported yet, the stove design with spiral pipe for auto preheating to produce good atomization and combustion [1], [2], [5-8], [13-15].

The modified stove consists of a fuel pressure vessel, a hand-pressure pump that develops a pressure of around 3 bar by keeping the fuel pressure vessel at higher levels for supplying the fuel, a spiral-shaped pipe that serves as oil preheating (vaporizer) and nozzle sprayer as burner tip with three different sizes of diameter. The diameter and height of modified pressurized stove were 20 cm and 30 cm, respectively. The dimensions of vegetable oil pressure vessel, which is 15 cm in diameter and 35 cm in height, while sprayer nozzle of 0.5 mm; 0.7 mm and 0.8 mm (figure 2). Due to the pressure in the tank, the fuel flows through the horizontal spiral oil pipeline. The flow of the fuel was regulated with a valve provided in the oil line.

The ignition was conducted by burning alcohol with variations in the amount of 10 mL, 15mL, and 20 mL, while the injecting VOC on horizontal spiral pipeline start to auto-preheat to vaporize and raise the temperature above the fire (ignition) point. The hot fuel mixes with the ambient air and gave out a yellow-blue flame. The ignition point, ignition time, flame temperature, thermal efficiency and fuel consumption rate were measured in these works based on ASTM 90-92D method. The ignition temperature and ignition time were measured when the oil started to burn. The flame temperature was measured as long as the burning oil.

During the experimentation, some observations of the amount of water evaporated and mass of fuel burned have been taken to calculate stove performance indicators as thermal efficiency. The thermal efficiency of the fuel/stove/pot combination were determined through calculations based on the modified version of the well-known water-boiling test (WBT) revised calculation procedure [13-17]. The test calculates this as the ratio of enthalpy change of the water in the pot to the maximum energy theoretically available from combustion. Thermal efficiency is calculated using the formula given below:

$$\eta_T = \frac{m_w \times 4.186(T_2 - T_1) + m_{cv} \times 2.257 \times 500(T_2 - T_1)}{m_f \times NHV} \quad (3)$$

where m_w is the initial mass of water in the vessel, (4.186 kJ/kg.°C) is the specific heat of water, (T_2-T_1) is the change in water temperature, m_{cv} is the mass of water evaporated from vessel, (2257 kJ/kg) is the latent heat of evaporation of water, m_v is the mass of vessel, (500 kJ/kg. °C) is the thermal conductivity of vessel, m_f is the mass of the fuel used, and LHV is the lower heating value of fuel.

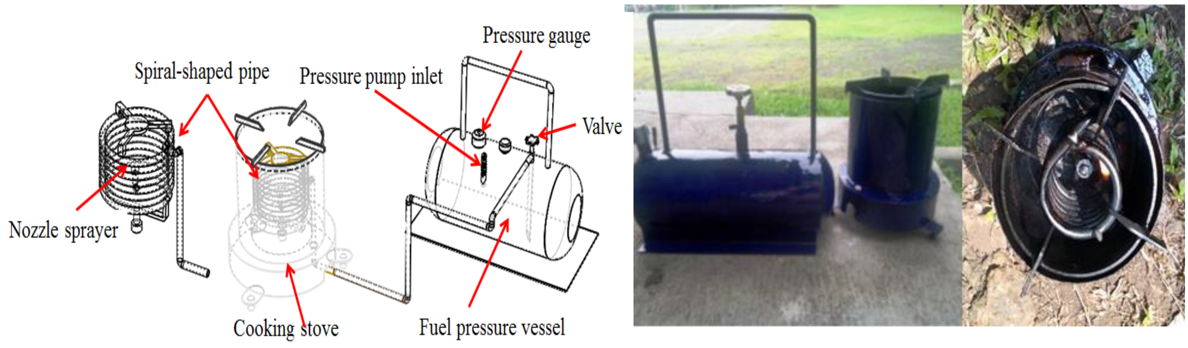

Figure 2. Sketch and photo of pressurized cooking stove with spiral pipe line as preaheater

3. Results and discussions

3.1. Density and viscosity

Among the VCOs properties as fuel are kinematics viscosity, density and heating value are the most important parameters that affect the combustion performance. The density of the VCOs as fuel is one of the important parameter since other performance parameters of combustion such as heating value have been correlated with it. The density values can also be used to measure the amount fuel in pressured vessel system by volumetric method. The variation of the density affects the power and the fuel spray characteristics during combustion in the pressurized cooking stove.

Table 2. Density and viscosity of VCOs and kerosene

Fuel	Auto-Ignition time (sec.)	Smoke Point (ºC)	Auto-Ignition temperature (ºC)
UCO	30	238	460
Crude VCO	45	215	412
Fresh VCO	54	200	405
Peanut cooking oil	-	182	-

The variation in density of vegetable oils is shown in table 2. Density is found to be more or less same for all vegetable oils, which is 50 % above that of kerosene (0.79 mg/mL). Since the density varies with composition and temperature and has a great influence on the atomization process. Thus the knowledge of the temperature dependence of this parameter is a highly important component of the process of the study. The fuel density required to be reduced more, in order to make it suitable for the pressurized cooking stove and makes it spray characteristics more like those of kerosene. From the different kinds of literature, it has been concluded that heating of the fuel which is the direct reduction of density [14,18].

Kinematic viscosity is also an important physical property affecting pressure drop in the fuel line of the pressurized cooking stove as well as the fuel atomization in nozzle sprayer. High VCOs viscosity can result in excessive pressure drop and produce spray with large droplets, which deteriorates the combustion performance. High VCOs viscosity also results in poor fuel atomization, incomplete combustion, deposits in the combustion vessel. In table 2. the kinematic viscosity of VCOs from this experiment is about 20-25 times higher than that of kerosene at 30 ºC. At this temperature kinematic viscosity of vegetable oils varies between 50-60 centistokes. Higher ranges of kinematic viscosity can clog fuel lines, affects the start of injection and adversely affect fuel atomization. The higher viscosity of VCOs than kerosene is directly related to the level of unsaturation and the length of the fatty acid chains. The viscosity tends to decrease when there is an increased presence of double bonds and grows with an increase in the length of the hydrocarbon chain and according to the level of polymerisation in the oil. The kinematic viscosity of these VCOs required to be reduced more, in order to make it suitable as kerosene in a pressurized cooking stove. From the different kinds of literature, it has been concluded that heating of the fuel makes it spray characteristics more like those of kerosene, which is the direct reduction of viscosity [18]. It was also reported that heating the vegetable oils to 140 ºC would reduce the viscosity to near that of kerosene at 20 °C and improve the spray characteristics [18]. There are several ways to reduce VCOs kinematic viscosity, and heating oil is one of them. Therefore an effort has been tried to reduce the kinematic viscosity by auto preheating the VCOs in a design pressurized cooking stove using horizontal spiral pipeline as a preheater.

Predicted heating values of VOCs using equation (3), as presented in table 2. shows a variation of the calorific value of kerosene with different VCOs. This may be due to the difference in the chemical composition or presence of oxygen molecule in the molecular structure of the oil. It can be explained that the viscosity increases when the presence of double bonds decreases and when the length of the hydrocarbon chain increases. The energy content (heating value) increases in accordance with the increase in the length of the chain, and therefore with the increase in carbon atoms, but decreases when the percentage of carbon decreases with respect to the oxygen. Moreover, the calorific content of the fuel decreases in accordance with the reduction in the hydrogen content, and therefore as the number of double bonds increases [18].

3.2. Fuel properties of VCOs

The liquid VCOs were tested to establish the auto ignition temperature. The VCO was heated, the temperature increase slows down before it reaches its boiling point, oil will start to emit smoke and pyrolysis. This is called the smoke point, at which the temperature of an oil under defined conditions, enough volatile compounds emerge from the oil that a bluish smoke becomes clearly visible. Then, once boiling begins, the temperature increases more rapidly as the boiling and smoke emission becomes more intense. When this is observed, the oil is becoming close to its auto-ignition temperature (without fire source).

Table 3. Specification of VCOs charaterization

Fuel	Auto-Ignition time (sec.)	Smoke Point (°C)	Auto-Ignition temperature (°C)
UCO	30	238	460
Crude VCO	45	215	412
Fresh VCO	54	200	405
Peanut cooking oil	-	182	-

Table 3 summarizes characteristics of some common vegetable cooking oil. The auto-ignition temperature of UCO, 460 °C is highest than other oils. It can be understood because during frying, vegetable cooking undergoes various physical and chemical changes, and many undesirable compounds are formed. These include free fatty acid and some polymerized triglycerides which increase the molecular mass and reduce the volatility of the oil. Therefore, fatty acid esters obtained from frying oil influences the fuel characteristics, such as the viscosity and burning characteristics [19], [20]. UCO is also full of bits of food and carbon that will reduce ignition time, the 30s shorter than three other oils. The lower auto-ignition temperature of crude VCO and fresh VCO were observed 412 °C and 405 °C, respectively, related to the level of double bonds and the length of the hydrocarbon chain on viscosity. The viscosity increases when the presence of double bonds decreases and when the length of the hydrocarbon chain increases. The increase in the viscosity of a vegetable oil subjected to rapid heating is determined by the breaking of the double bonds and a consequent reduction in the level of unsaturation [18]. The peanut cooking oil did not auto-ignite in this test. It was observed that peanut oil would vapor and dry without igniting due to unbroken of double bonds of fatty acid [21]. Results of this research could give an assumption that correlates to higher auto-ignition temperatures due to different chemical compositions. Therefore different types of oil would have different auto-ignition temperatures, resulting in different ignition times. The results could give insight into safer oils to use that have higher auto-ignition temperatures.

3.3 Performance of modified pressurized cooking stove

The main pressurized cooking stove design was manipulating the viscosity of the oil to make it behave like kerosene. This was done by auto preheating the oil on the horozontal spiral pipeline. At above room temperature (30 °C) VCOs have a theoretical viscosity of around 16-20 cSt, the same as kerosene. The viscosity of VCOs is closely dependent on temperature. An increase in temperature corresponds to a non-linear reduction in viscosity.

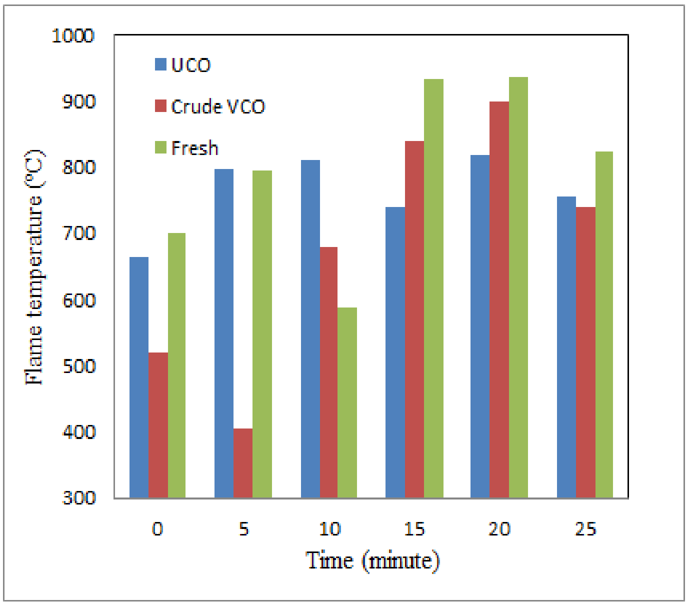

Figure 3. Flame temperature profile of VCOs burning

The water-boiling tests (WBT) were conducted to demonstrate the VCOs as potential cooking liquid fuels. The results show that the VCOs burnt transparent a yellow-blue flame. UCOs tended to produce luminous flames compared other oils. In these tests, the minimum temperature at which the vapors of a fuel catch fire if in contact with a flame was measured as ignition temperature. Figure 3 is the samples of flame temperature profile ignite by 20 mL of alcohol. The surface flame temperature different versus time was because of a little bit of pressure vessel changes. The highest surface flame temperature of 942ºC in these experiments was achieved by burning fresh VCO as fuel in this modified pressurized cooking stove. It is understood because of less fatty acid contained in fresh VCO rather than crude VCO and UCO. So that, the breaking of the chain in fatty acid become easier and faster [21]. The maximum temperature generated from combustion of VCOs an UCO using this pressurized cooking stove with horizontal pipe line preaheter is lower then than that of using a pressurized stove with vertical pipe line preaheter. The maximum surface flame temperatures of UCO, crude VCO and fresh UCO as fuel using the pressurized stove with vertical pipe line preaheter of 1100 °C, 1042 °C and 920 °C, respectively [22]. It is possible that the vertical spiral pipe provides greater heat transfer than the horizontal spiral pipe, since the surface of the heat transfer is larger.

A fuel/pressurized stove combination was characterized by a thermal efficiency. The following table 4 provides characteristics of VCOs. Auto preheating the oil in spiral coil pipeline will decrease viscosity and increases the mixing rate of air and vegetable oil due to increase the fuel mobility, assisting completion of combustion to produce higher flame temperature and increased the ignition temperature. The higher ignition of VCOs than kerosene is a beneficial safety feature, as the fuel can be safely stored and transported at the room temperature.

Table 4. Pressurizes of modified stove characterization

Fuel	Ignition temperature (^{o}C)	Fuel consumption (L/h)	Thermal efficiency (%)
UCO	478	4.10	23.65
Crude VCO	429	1.57	25.99
Fresh VCO	415	1.19	31.57
Kerosene	55	1.30	45.84

The specific fuel consumption seemed to be affected by the combined effects of fuel heating values and the viscosities. Low viscosity combined with the low-energy content of fuel resulted in much fuel consumption and time to boil. The thermal efficiency of all VCOs was found to be in the same range (23-32%) and about 1.3 times lower than thermal efficiency of kerosene.

Results of this research show that the VCOs require preheating to match the physical properties of kerosene. Heating of the VCOs to attain a lower viscosity has helped with the spraying (atomizing) of the oil on a pressurized stove. The reduced viscosity is not only to improve the combustion performance but is necessary for an even flow of the fuel through the fuel pipelines and nozzle spoiler.

4. Conclusion

It was found that VCOs and UCO as fuel had much higher ignition temperature (405 ^{o}C-478 ^{o}C) compare to kerosene whose ignition point only 55 ^{o}C. The VCOs and UCO utilization as fuel have several advantages as combustion fuel due to much safer to use than kerosene, little risk of fire hazards in the household application and other numerous ecological and sociological benefits.

The much higher kinematic viscosity of VCOs and UCO (50.14 cst-59.67cst) compare to kerosene (2.4 cSt) that affecting pressure drop in the fuel line of the pressurized cooking stove and the fuel atomization in nozzle sprayer could be manipulated to make it behave like kerosene by spiral pipe line as auto-preheater in the pressurized cooking stove.

It was observed that auto preheating the oil in a pressurized cooking stove and only a small amount of ethanol is needed for start-up, decreased the viscosity of VCOs and UCO by an indicator of higher flame temperature (about 900^{o}C) and increased the ignition temperature (415 ^{o}C-478 ^{o}C). The VCOs combustion produce transparent a yellow-blue flame. UCOs tended to produce luminous flames.

Generally, all VCOs fuel and kerosene showed average fuel consumption of ± 1.3 L/h, except UCO fuel consumption of 4.10 L/h. UCO is full of bits of food and carbon that will increase fuel consumption due to decreasing of heating value and density and viscosity.

The fuels tested using the standard water-boiling tests show that VCOs fuels have an average of thermal efficiency of around 23.65%-31.57%, which is ±30% lower than that of kerosene. Utilize UCO as fuel using this modified pressurized cooking stove with spiral pipe line auto-preaheater gives the thermal efficiency of 31.57% near to kerosene (45.84%).

Based on these findings, VCOs are a sustainable energy source as fuels have great potential to provide an alternative source of cooking energy supply not only for urban but also for rural communities in Indonesia. The introduction of a new design of prototype pressurized cooking stove with spiral pipe line auto-preaheater can be readily acceptable since its operation is similar to the well-known pressurized kerosene stoves.

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6. References

[1] Singh R N 2011 Straight Vegetable Oil: An Alternative Fuel for Cooking, Lighting and Irrigation Pump *IIOAB Journal* vol. **2** no. 7 pp. 44–49

[2] Ramkumar S and Kirubakaran V 2016 Review on Admission of Preheated Vegetable Oil in C.I. Engine *Indian J. Sci. Technol.* **9** (2) 1-11.

[3] Giuseppe Toscano and Eleonora Maldini 2007 Analysis of the Physical and Chemical Characteristics of Vegetable Oils as Fuel *J. of Ag. Eng. - Riv. di Ing. Agr.* 3 pp. 39-47

[4] Joel Blin, Christel Brunschwig, Arnaud Chapuis, Odilon Changotade, Sayon Sidibe, Eric Noumi and Philippe Girard 2013 Characteristic of Vegetable Oils for Use as Fuel in Stationary Diesel Engines-Towards Specifications for a Standard in West Africa *Renewable and Sustainable Energy Reviews* 22 pp. 580-597

[5] Ashok Yadav and Prakash Chandra Jha 2013 A Case Study On Biofuel Stove Technology: Jatropha As A Biofuel *Int. J. Tech. Enhancements and Emerging Engineering Research* vol.**1** no. 2 pp. 14-18

[6] Shahid E M, Jamal Y, Shah A N, Rumzan N and Munsha M 2012 Effect of Used Cooking Oil Methil Ester on Compression Ignition Engine *Journal of Quality and Technology Management* **8** (2) 91–100

[7] Sjaffriadi, B. Nurachman, N. A. Sasongko, and Masfuri Imron 2012 Waste Cooking Oil Pressurized Multifuel Stove *Proc. of National Seminar of chemical Engineering of Parahyangan Chatoclic University*

[8] Ejilah I R, Olorunnishola A A G and Enyejo L A 2013 A Comparative Analysis of the Combustion Behavior of Adulterated Kerosene Fuel Samples in a Pressurized Cooking Stove *Global Journal of Researches in Engineering Mechanical and Mechanics Engineering* vol.**13** no.6 pp. 35-43

[9] Bernat Esteban, Jordi-RogerRiba, Grau Baquero Antoni Rius and Rita Puig 2012 Temperature Dependence of Density and Viscosity of Vegetable Oils *Biomass, and Bioenergy* **4** pp.164-171

[10] DIN-V-51605 2006 Fuels for Vegetable Oil Compatible Combustion Engines–Fuel from Rapeseed Oil–Requirements and Test Methods 07

[11] A Demirbas 2000 A Direct Route to the Calculation of Heating Values of Liquid Fuels by Using their Density and Viscosity Measurements. Energy Convers Manage vol. **41**, pp.1609–14

[12] M. Kratzeisen, and J. Muller 2010 Influence of free Fatty Acid Content of Coconut Oil on Deposit and Performance of Plant oil Pressure Stoves *Fuel.* vol. **89** pp.1583–1589

[13] R. Natarajan, N.S.Karthikeyan, A. Agarwaal and K. Sathiyanarayanan 2008 Use of Vegetable Oil as Fuel to Improve the Efficiency of Cooking Stove *Renewable Energy* **33** pp. 2423–2427

[14] Wagutu, Agatha W, Thoruwa Thomas F N, Mahunnah R L A, Chhabra Sumesh, C Caroline, Thoruwa Lang'at and Mahunnah R L A 2010 Performance of a Domestic Cooking Wick Stove Using Fatty Acid Methyl Esters (FAME) from Oil Plants in Kenya *Biomass and Bioenergy*, pp.1250-1256

[15] Tafadzwa Makonese, Crispin Pemberton-Pigott, James Robinson, David Kimemia, and Harold Annegarn 2012 Performance Evaluation and emission Characterisation of Three Kerosene Utoves using a Heterogeneous Stove Testing Protocol (HTP) *Energy for Sustainable Development* vol.16 no. 3 pp. 344–351

[16] Gaurav Jambhulkar,Vibhor Nitnaware, Manisha Pal, Neha Fuke, Purva Khandelwal, Pallavi Sonule, Sneha Narnawre and V. P. Katekar 2015 Performance Evaluation of Cooking Stove Working on Spent Cooking Oil *Int. J. Emerging Sci. Eng.* **3** no. 4 pp. 26-31

[17] Suhartono, Bayu Dwi Prasetyo and Ikrimah Nur Azizah, 2016 Synthetic Gas (syngas) production in downdraft corncob gasifier and its application as fuel using conventional (LPG) domestic stove *J. Eng. Appl. Sci.* **11** no. 8 pp.5238-5243

[18] Giuseppe Toscano and Eleonora Maldini 2007 Analysis of the Physical and Chemical Characteristic of Vegetable Oils as Fuel *J. of Ag. Eng.-Riv. di Ing. Agr.* vol. **3**, pp. 39-47

[19] S. K. Acharya and M. K. Mohanty R. K. Swain 2009 Kusum Oil as a Fuel for Small Horse Power Diesel Engine *Int. J. Eng. Technol.* **1** 3 pp. 1793-8236

[20] K. Naima and A. Liazid 2013 Waste Oils as Alternative Fuel for Diesel engine: A review, *J. of Petroleum Technol. and Alternative Fuels* **4** no.3 pp. 30-43
[21] Krystyna Buda-Ortins. B.S. 2010 Auto-Ignition of Cooking Oil. Dept. of Fire Protection Engineering, University of Maryland
[22] Suhartono, Tiara Arini Putri, Lutfi Fauziah 2017 Performance Evaluation of a Pressurized Cooking Stove Using Vegetable Cooking Oils as Fuel *Int. J. on Advanced Science, Engineering and Information Technology* **7** no 4 pp. 1234-1241