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Research Article

Quality and Performance Evaluation of *Jatropha* Oil Blended with Kerosene for Cooking Stoves in Ethiopia

Lake Belete Adamu[1,2] and Kamil Dino Adem[3]

[1]*Wondo Genet College of Forestry and Natural Resources, Hawassa University, Shashamane, Ethiopia*
[2]*Ethiopia-Environment, Forest and Climate Change Commission (EFCCC), Addis Ababa, Ethiopia*
[3]*School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia*

Correspondence should be addressed to Kamil Dino Adem; kdadem@gmail.com

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In Ethiopia, the majority of rural household uses firewood with three-stone fire for cooking. Due to poor performance of the stove, there are major health issues created by indoor air pollution. To alleviate this problem, various efforts are undergoing such as the use of plant oil as an alternative fuel for cooking. This plant's oils are available in the rural areas with minimal effort and water. In this study, *Jatropha* oil was blended with kerosene to present it as an alternative fuel for the rural poor in Ethiopia. The blends of varying proportions of *Jatropha* oil and kerosene were prepared, analyzed, and compared with the fuel properties of kerosene. The viscosity of *Jatropha* oil was reduced in ranges 86.3% to 4.5% by heating the oil from 30°C to 100°C. In order to understand the value of the blended fuel, the blended fuel was used for the evaluation of the performance of a stove for its thermal efficiency and indoor air pollution. Thermal efficiency of the newly designed bio-oil stove (Jatrok stove) was 52–66% with its specific fuel consumption ranging from 30 to 37 g/L and the fire power of the stove ranging from 1398 to 1433 watt using 10% to 40% *Jatropha* oil in the blend. In the case of emission, the Jatrok stove showed 11.5 to 9.5 grams of carbon monoxide (CO) and 352 to 289 grams of carbon dioxide (CO_2) to boil 2.5 liters of water.The performance of the Jatrok stove using blended fuels was evaluated and compared with other domestic cooking stoves available in Ethiopia, making the stove comparable. A wider dissemination of such kind of plant oil blended with a kerosene-operated stove could reduce the environmental load in addition to lessoning the indoor air pollution in the kitchen.

1. Introduction

The growing concern on environmental protection and the severe climate change has made the attention on use of alternative energy sources to substitute the fossil fuel. Plant oils as alternative fuels have huge potential to be used as an energy source since they are renewable and could emit significantly less greenhouse gases with improving energy security [1]. Many countries developed energy crops based on the climate conditions of their country. In Ethiopia, *Jatropha curcas*, castor seed, and palm tree are dominant energy plants cultivated by the government for energy purpose [2]. *Jatropha curcas* is grouped in the family Euphorbiaceae and has the scientific denomination of *Jatropha curcas* L. It is a large shrub which has the maximum height not exceeding 5 meters and has been considered as a potential alternative fuel since it is nonedible and the most promising source of oil [3].

In Ethiopia, despite the opportunities for growing *Jatropha* as a biofuel crop, some barriers such as technical capacity and low awareness slowed down the utilization of the *Jatropha* plant oil [4, 5]. The calorific value of *Jatropha* oil is about 39.65 kJ/kg which is close to the calorific value of kerosene (43.50 kJ/kg); however, *Jatropha* oil has high viscosity (75.5 cSt) which is about 35-fold that of kerosene (2.2 cSt). This has a major impact on its utilization [6]. Various studies are trying to reduce the viscosity of vegetable oils using different techniques such as blending with alcohols or diesel fuels [7, 8], heating [8, 9], transesterification [10], and microemulsion with solvents (methanol and ethanol) [11]. In other studies for diesel engine applications, the blends of biodiesel with diesel showed lower smoke emissions and particulate matter than diesel fuel [12–17].

In parallel, some attempts have been made to develop cooking stoves for utilizing plant oils as a fuel source. However, the viscosity of plant oil is many times higher than that of kerosene where common wick-type cookstoves are not suitable to use plant oils as the cooking fuel [6]. Therefore, researchers have been focusing on utilization of plant oils on gravity [18] and pressure stoves [19].

In the pressure plant stove, the plant oil evaporates in a vaporizer and emitted through a nozzle to the combustion area and mixed with ambient air and burns. Its power is adjusted with a valve by regulating the fuel flow. It is a complex technology, and expensive [19]. In the gravity stove, the fuel tank is separated from stove, and the fuel is fed under gravity force. Placing the fuel tank above the burner helps to overcome the resistance encountered by the fuel during flow through wicks. The gravity stove tested with *Pongamia pinnata* (karanj) oil showed an efficiency of 11.81%, and the kerosene stove was also tested using karanj oil which showed 5.65% efficiency [18]. Previous studies reported that *Jatropha* oil can be blended with kerosene up to 30% for utilization in the pressure stove [6]. In the present study, a simple plant oil stove called the Jatrok stove was designed and manufactured in the workshop at the Ministry of Water, Irrigation, and Energy (MoWIE), and its performance and emission were tested and compared with the performance of domestic cooking stoves in Ethiopia. The thermal efficiency of domestic biomass cooking stoves such as the traditional wood stove, metal charcoal stove, and *Laketch* charcoal stove is 11.5%, 23%, and 38%, respectively [20]. The *Tikikil* wood stove has a thermal efficiency of 26%. Ethanol and kerosene stoves have a thermal efficiency 56% [21] and 60% [22], respectively. The specific fuel consumption (g/l) of stoves such as the traditional wood stove, metal charcoal stove, and Laketch charcoal stove is 190 g/l, 550 g/l, and 290 g/L, respectively [20]. Ethanol and kerosene stoves have a reduction in the specific fuel consumption from three-stone fire by 48% [21] and 4% [22], respectively. The fire power (watts) of ethanol and kerosene stoves is 1200 W [21] and 1300 W [22], respectively. The emission of the traditional wood stove to boil 2.5 liters of water in Ethiopia is 92 g/l and 681 g/l of carbon monoxide and carbon dioxide, respectively. *Lakech* has carbon monoxide and carbon dioxide emission of 79 g/l and 625 g/l, respectively, while *Merchaye* has 66 g/l and 531 g/l [23]. Ethanol has showed an emission of 2.12 g/l and 175 g/l of carbon monoxide and carbon dioxide, respectively [21].

The aim of this study is to investigate the effects of blending *Jatropha* oil with kerosene for cooking application. After studying the effects of heating and blending *Jatropha* with kerosene, the water boiling test was conducted to verify the possible use of the blend with various proportions.

2. Materials and Methods

In this study, *Jatropha* oil was extracted from dried *Jatropha* seeds using the Bielenberg ram oil press and purified through decantation. Blends of fuels were made by mixing *Jatropha* oil with kerosene. The viscosity of pure *Jatropha* and the blended fuels was measured by using the Brookfield DV2T viscometer, and calorific values were measured by using a calorimeter.

The materials used in this study were *Jatropha* oil, kerosene, the Brookfield DV2T, the Bielenberg ram oil press, balance, measuring cylinders, a calorimeter, a thermocouple, a hood system, a gas analyzer, aluminum pots, a stopwatch, and a data logger.

2.1. Development of the Plant Oil Stove. A simple plant oil stove was developed without wicks to solve problems associated to the difficulties of the plant oil going through wicks due to its high viscosity. To reduce the viscosity and improve the combustion of the oil, it was blended with kerosene. Since gravity plant stoves are not as such efficient [18] and pressures stoves are more complex and expensive, developing a simple and efficient stove for utilizing plant oils is of paramount importance. The stove designed for this study has 8 primary air holes with a diameter of 5 mm at 75 mm height of the stove. The total height of the stove is 155 mm, and its pot seat has a 6 mm height with a combustion diameter of 110 mm (Figure 1). The plant oil stove was developed at the work shop of the Ministry of Water, Irrigation, and Energy of Ethiopia.

2.2. Extraction of Jatropha Oil. In the present study, the Bielenberg ram oil press was used to extract the oil from the seeds. First, the seeds were fed into the hopper and then, crushed and milled in the chamber. Furthermore, the shaft of the screw was rotated forward manually to open the gap, and thus, oil flowed through the oil outlet and the cake was pressed through the plates. After extraction, the *Jatropha* oil was allowed to settle and decanted to remove residues. Blends were prepared by mixing the oil and kerosene in four different proportions (10 : 90, 20 : 80, 30 : 70, and 40 : 60 volume by volume ratios).

2.3. Viscosity Measurements. The viscosity of *Jatropha* oil was measured using the Brookfield viscometer model DV2T at temperatures of 20, 30, 40, 50, 60, 70, 80, 90, and 100°C. For viscosity measurements, 300 cm^3 of *Jatropha* oil was poured into a 600 cm^3 volumetric glass, and a spindle was screwed into the viscometer. The cup containing the sample was carefully locked into position so that the spindle cone can be completely immersed in the sample. The machine was switched on, and readings of viscosity, torque, and speed of rotation of the spindles were observed after about ten seconds of rotation of the spindle in the container. Viscosity

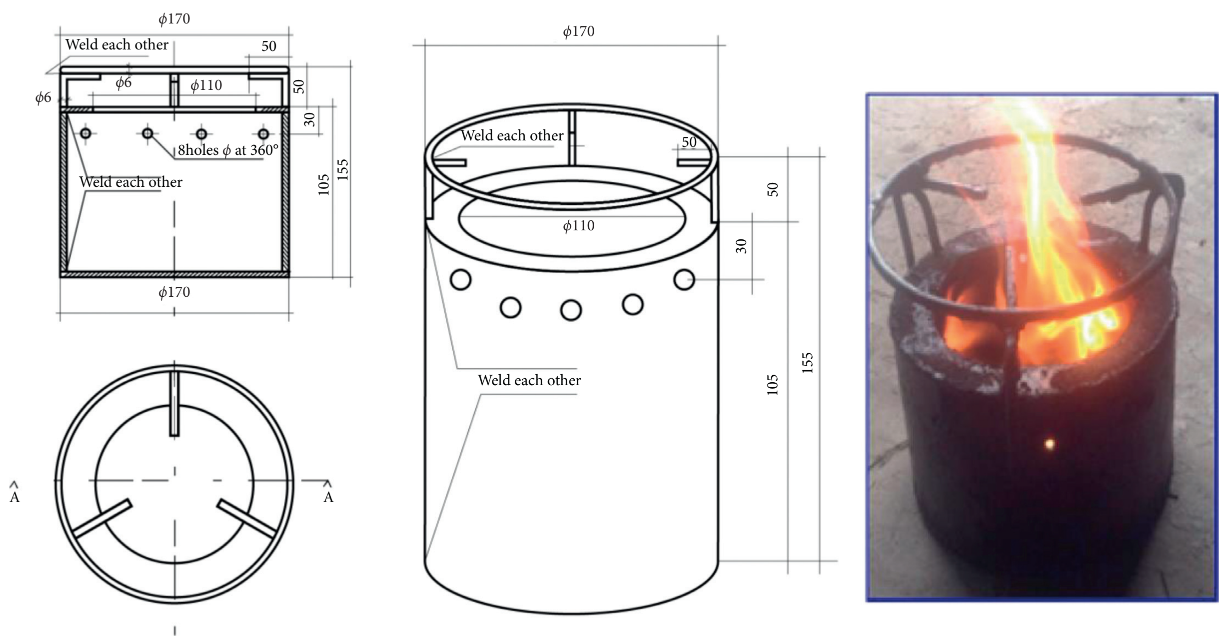

Figure 1: Design of the plant oil stove.

data were recorded when the torque was between 10% and 100%. If the torque was out of these values, the spindle type or speed of rotation of the spindle was adjusted to correct the reading [24].

2.4. Calorific Value Measurements. The calorific value of a fuel is the theoretical maximum amount of energy extracted from the combustion of fuel in a calorimeter. A calorimeter is an apparatus used to measure the amount of heat involved in a chemical reaction. In determining calorific values of fuels, the fuel was measured and placed in the calorimeter bomb using capsules and the cotton tread was fastened on the fuse wire and touching the fuel in the capsule. The bomb was closed and filled with oxygen at a pressure of 30 bars. After putting the samples in the bomb and filling the oxygen gas, a water bucket was filled with 2000 ml of water and inserted to the calorimeter jacket, and then, the bomb was inserted into the bucket. Finally, the calorimeter setting was turned on to start testing the calorific values of the fuel by combusting the fuel inside the bomb. The heating value was determined as the temperature rise in the water bucket [25].

$$H_c = \frac{W * T - e_1 - e_2 - e_3}{m}, \qquad W = \frac{H * m + e_4 + e_5 + e_6}{T}. \tag{1}$$

2.5. Performance Evaluation. The water boiling point test (cold and hot-start high power test) was conducted on the stove to determine the thermal efficiency, specific fuel consumption, and fire power of the stove using blended fuels in the cold-start high power phase. The test started with the stove at room temperature, using preweighted fuel (kerosene oil-blended fuels) to boil 2.5 kg water starting from room temperature. During the test, the ambient temperature and local boiling point were measured. The hot-start test followed a procedure same as that of the cold-start test, and the difference was that the hot-start test was started with a hot stove immediately after the cold-start test was completed. The thermocouple was inserted to the pot containing the water using a wooden fixture to measure the temperature. A hole was bored in the center of the wooden fixture to fit the thermocouple to the wooden fixture and prevent the water from escaping [26].

2.5.1. Thermal Efficiency. Thermal efficiency is a ratio of the work done by heating and evaporating water to the energy consumed by the burning fuel. It is an estimate of the total energy produced by the fire that is used to heat the water in the pot and calculated using the following equation [26]:

$$\text{Eff} = \frac{4.186\text{Ww}\left(T_f - T_i\right) + 2260 * \text{wv}}{f_m * \text{LHV}}. \tag{2}$$

2.5.2. Specific Fuel Consumption (SFC). Specific fuel consumption (SFC) : SFC is the parameter that calculates the fuel required producing a unit output, and it is a measure of the fuel required to produce one liter of boiled water starting with cold stove and calculated using the following equation [26]:

$$\text{SFC (g/L)} = \frac{\text{mass of fuel (g)}}{\text{mass of boild water (L)}}. \tag{3}$$

2.5.3. Fire Power. Fire power is a measure of fuel energy consumed to boil the water divided by the time to boil, and it tells the average power output of the stove in watts [19]. The fire power of the stove is calculated using the following equation [26]:

$$\text{Fire power (W)} = (\text{Mass of fuel (kg)} \times \text{LHV})/\text{Time (second.)}. \quad (4)$$

2.5.4. Emission Testing. The emission of the stove was collected in the emission hood, and it was calculated using the hood carbon balance method. Data on CO_2 and CO emissions were collected to boil 2.5 liter water following standard water boiling test method [26]. The hood method was used for determining the emissions with a Testo 330-LL flue gas analyzer [27]. The analyzer has an accuracy of ±20 ppm CO with a measuring range 0 to 4000 ppm CO and 1 ppm resolution, with a reaction time of approximately 40 seconds, and a measuring range 0–10,000 ppm and 1 ppm resolution, with a reaction time of 90 minutes for CO_2.

$$\text{Emission (g/kg)} = \frac{\text{Dry fuel collected in emissions}}{\text{Dry fuel consumed}}. \quad (5)$$

2.6. Statistical Analysis. The statistical analysis for the mean differences in viscosity, thermal efficiency, specific fuel consumption, and fire power of the Jatrok stove was performed using the T-test at 5% level of significance in SPSS statistical software version 20. The carbon monoxide and carbon dioxide data were analyzed using descriptive analysis.

2.7. Experimental Setup. The performance and emission test of the newly developed Jatrok stove using blended fuels were performed using water boiling test protocol. The stove tested was placed under a hood, and the gas analyzer probe was inserted into the hood so that emissions are automatically collected and analyzed by the instrument. Figure 2 shows the experimental setup for conducting the test.

3. Results

3.1. Effect of Temperature on the Viscosity of Jatropha Oil. Previous studies showed that many vegetable oils' viscosity is reduced on heating [9]. In the present investigation, the *Jatropha* oil viscosity was tested in temperatures ranging from 20°C to 100°C. The results showed that the viscosity of *Jatropha* oil reduced on heating. The viscosity of *Jatropha* oil at 20°C was between 42 and 46 cSt, and its viscosity at 100°C became 4.7 to 7 cSt with a 95% level of confidence (Table 1). The viscosity of *Jatropha* oil was reduced by 86.3% when the temperature increased from 20°C to 100°C.

An exponential decreasing relationship exists between viscosity and temperature showing functional dependence of viscosity on temperature. Figure 3 shows the regression coefficient value, (R^2), for temperature-viscosity relationships of 0.9466, which indicates that 94.66% of the total variation in the viscosity reduction is attributed to temperature.

3.2. Viscosities of Blended Fuels. Studies reported that blending of vegetable oil with other fuels such as alcohol or diesel fuel reduced the viscosity of vegetable oil [24]. In the present study, the *Jatropha* oil and kerosene were blended as J10, J20, J30, and J40, and their viscosity were measured and analyzed. The viscosity of *Jatropha* oil at room temperature (44 cSt) was taken as the baseline for comparing the effect of blending with kerosene on the viscosity of *Jatropha* oil. The viscosity of *Jatropha* oil reduced by 65% at 40% *Jatropha* oil in the blend and by 89% at 10% in the blend when compared with the viscosity of *Jatropha* at 20°C. The viscosity of the J10 (10% *Jatropha*- and 90% kerosene-blended fuel) was between 3.9609 and 5.7057 cSt and that of J40 (40% *Jatropha* oil and 60% kerosene blend fuel) was between 13.45 and 17.21 cSt with a 95% confidence level (Table 3).

The regression analysis indicates that the effect of blending *Jatropha* oil with kerosene on *Jatropha* oil viscosity was significant. The regression coefficient (R^2) value was 0.9479 indicating that 94.79% of the variation in the viscosity of the *Jatropha* oil is attributed to blending (Figure 4).

3.3. Calorific Value of Blended Fuels. The calorific values of the blended fuels were determined by following calorific value determination of combustible fuels steps described by the parr 6200 calorimeter (Table 5).

3.4. Stove Performance Testing

3.4.1. Thermal Efficiency. The thermal efficiency of the stove with J10, J20, and J40 fuel was 66%, 56%, and 52%, respectively (Tables 6–8). The reason for lower thermal efficiency with increased *Jatropha* oil in the blend was due to higher viscosity, poor volatility, and low combustibility of the oil.

3.4.2. The Specific Fuel Consumption. The specific fuel consumption of the stove increased with increasing *Jatropha* oil in the blend due to its low combustibility, and the specific fuel consumption of the stove with J10, J20, and J40 fuels was 30 g/L, 35 g/L, and 38 g/L, respectively (Tables 6–8). The lower combustion resulted in more consumption of the fuel to generate enough heat. Increasing the oil ratio in the blend caused low combustion due to poor volatility and lower ability of the fuel to mix with oxygen.

3.4.3. Fire Power. The fire power of the Jatrok stove decreased with increasing *Jatropha* oil in the blend. The fire power of the stove with J10, J20, and J40 blended fuels was 1433 W, 1404 W, and 1399 W, respectively (Tables 6–8). The reason for reducing the fire power as the oil ratio increased in the blend was the explanation same as that given above for the fuel consumption. Fire power is the fuel energy consumed to complete some task, such as cooking divided by the time it takes to cook. As the combustion of the fuel reduced, enough energy could not be generated and the rate of energy delivered to the stove is reduced. In this study, as the Jatropha oil increased in the blend, the rate of energy

(a) (b)

Figure 2: Hood-type experimental setup for stove testing.

Table 1: The change in viscosity of *Jatropha* oil with temperature increment.

	Viscosity (cSt)								95% confidence level	
Temp (oc)	Test 1	Test 2	Test 3	Mean	SD	Std. error	*T*-test	*P* value	Lower	Upper
20	45	43.5	44	44	0.76	0.44	100	0.001	42.26	46.06
30	43	41.5	42	42	0.76	0.440	95.6	0.001	40.26	44.06
40	36.5	37.2	38.5	37.5	1.01	0.58	63.8	0.001	34.87	39.92
50	29.5	31.5	29.5	30	1.15	1.66	45.2	0.001	27.3	33.03
60	23	25.5	26.5	25	1.80	1.04	24.0	0.002	20.52	29.47
70	18	19.5	17.85	18.5	0.91	1.52	35.0	0.001	16.18	20.71
80	13	14	13.5	13.5	0.5	1.28	46.7	0.001	12.25	14.74
90	10	11	10.5	10.5	0.5	1.28	36.3	0.001	9.25	11.74
100	5.5	6	6.5	6.0	0.5	1.28	20.7	0.002	4.75	7.24

The overall viscosity reduction by heating was statistically significant as tested by the *T*-test ($P < 0.001$) (Table 2).

Table 2: Statistical test of viscosity of *Jatropha* oil and temperature.

	T-test	*P* value	Std. error mean	Std. deviation
Viscosity	5.39	0.001	4.68	14.04
Temperature	6.58	0.001	9.12	27.38

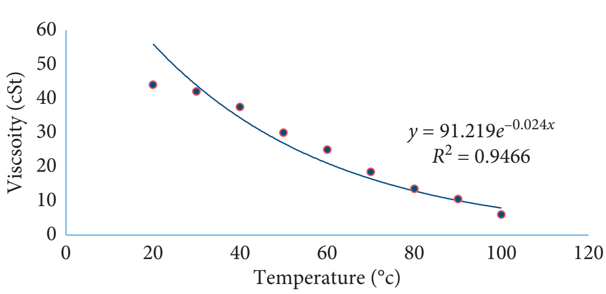

Figure 3: Approximate graph for the temperature-viscosity relationship.

delivered to the stove was reduced due to the oil's low combustibility.

3.5. Emission Test Results of the Jatrok Stove Using Blended Fuels. The carbon monoxide and carbon dioxide emissions of the Jatrok stove were measured during the cold-start high power test of the water boiling test procedure, and the results are presented in Table 9. CO emissions of the Jatrok stove were 11.5 g/L, 11.3 g/L, and 9.5 g/L using J10, J20, and J40 fuels, respectively (Table 9), and its CO_2 emissions were 352 g/L, 334 g/L, and 289.2 g/L using J10-, J20-, and J40-blended fuels, respectively (Table 9).

4. Discussion

The viscosity of vegetable oils (avocado, canola, rapeseed, macadamia nut, olive, peanut, rice bran, safflower, sunflower, and soybean) has been shown to reduce on heating [9]. The viscosity of the oil was reduced by 86.3% when the

Table 3: Effect of blending on the viscosity of the *Jatropha* oil.

Fuel	Viscosity (cSt)									
	Test 1	Test 2	Test 3	Ave.	SD	Std. error	*T*-test	*P* value	95% confidence level	
									Lower	Upper
J100	45	43.5	44	44.2	0.50	0.28	129.9	0.001	36.2	38.7
J10	4.8	5.2	4.5	4.8	0.35	0.20	23.83	0.002	3.96	5.70
J20	7.8	8.5	7.5	7.9	0.51	0.29	26.77	0.001	6.65	9.20
J30	13.5	12.8	13.5	13.2	0.40	0.23	56.85	0.001	12.2	14.27
J40	14.8	16.2	15	15.3	0.75	0.43	35.07	0.001	13.45	17.21

Viscosity of *Jatropha* oil showed a statistically significant reduction due to blending with kerosene fuel ($P < 0.023$) (Table 4).

Table 4: Statistical test of the effect of blending on *Jatropha* oil viscosity.

	T-test	*P* value	Std. error mean	std. deviation	95% confidence interval of the difference	
					Lower	Upper
Fuel type	3.87	0.030	6.45	12.90	0.44	4.55
Viscosity (cSt)	4.28	0.023	2.40	4.81	2.64	17.95

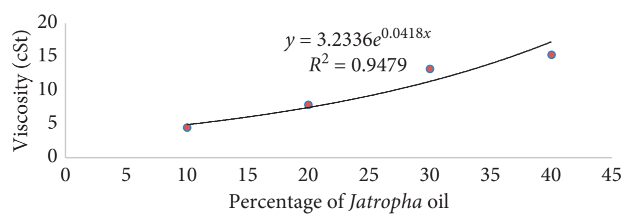

Figure 4: Effect of blending of kerosene on the viscosity of *Jatropha* oil.

Table 5: Calorific values of blended fuels.

Fuel	Calorific values (kJ/kg)					
	Test 1	Test 2	Test 3	Ave.	Mean	SD
J10	42925	43225	42559	42903	42903	333.3
J20	42312	41985	42703	42333	42333	359.4
J40	41863	40803	40860	41175	41175	596.2

Table 6: Performance of the Jatrok stove using J10 fuel.

Parameters		High power (cold-start test result)					High power (hot-start test result)				
	Units	Test 1	Test 2	Test 3	Mean	Stdv.	Test 1	Test 2	Test 3	Mean	Stdv.
Time to boil	Min	31	30	35	32	2.6	26	29	28	27.7	1.52
Temp-corrected time to boil	Min	31	30	35	32	2.6	27	29	29	28.3	1.15
Burning rate	g/min	2	2	2	2	0	2	2	2	2.2	0
Thermal efficiency	%	65%	69%	59%	65%	5%	69%	68%	63%	66%	3%
Specific fuel consumption	g/liter	31	28	32	30.3	2.1	29	29	31	29.7	1.15
Temp-corrected specific fuel consumption	g/liter	31	28	32	30.3	2.08	30	29	32	30.3	1.52
Temp-corrected specific energy cons.	kJ/liter	1,259	1,164	1,291	1238	66%	1,190	1,207	1,289	1228.7	53
Fire power	Watts	1,398	1,357	1,276	1344	62	1,538	1,452	1,571	1521	61

Table 7: Performance of the Jatrok stove using J20 fuel.

Parameters		High power (cold-start test results)					High power (hot-start test results)				
	Units	Test 1	Test 2	Test 3	Mean	Stdv.	Test 1	Test 2	Test 3	Mean	Stdv.
Time to boil	Min	42	36	38	38.7	3.1	30	34	32	32	2
Temp-corrected time to boil	Min	42	36	39	38.7	3.2	31	34	33	32.4	1.4
Burning rate	g/min	2	2	2	1.9	0.2	3	2	2	2.3	0.2
Thermal efficiency	%	57%	53%	55%	55%	2%	55%	55%	59%	56%	2%
Specific fuel consumption	g/liter	33	34	36	34.4	1.4	36	35	32	34.3	1.9
Temp-corrected specific consumption	g/liter	33	34	37	34.6	1.8	37	35	33	35.1	1.9
Temp-corrected specific energy cons.	kJ/liter	1,330	1,414	1,460	1401.3	65.8	1486	1468	1335	1429.6	82.8
Fire power	Watts	1,111	1,403	1,316	1277	150.0	1667	1507	1417	1530	126.6

Table 8: Performance of the Jatrok stove using J40 fuel.

		High power (cold-start test results)					High power (hot-start test results)				
	Units	Test 1	Test 2	Test 3	Mean	Stdv.	Test 1	Test 2	Test 3	Mean	Stdv
Time to boil	min	38	40	35	37.7	2.5	40	41	35	38.7	3.2
Temp-corrected time to boil	min	38	39	35	37.6	2	41	40	36	39.3	2.8
Burning rate	g/min	2	2	2	2.1	0.3	2	2	2	2	0.2
Thermal efficiency	%	52	53	47	51	3	54	50	51	52	2
Specific fuel consumption	g/liter	38	36	40	38.3	2.2	36	37	36	36.3	0.6
Temp-corrected specific consumption	g/liter	38	36	41	38.3	2.7	37	37	37	37	0.3
Temp-corrected specific energy cons.	kJ/liter	1535	1498	1642	1558.1	74.6	1479	1547	1497	1507.6	35.1
Fire power	watts	1404	1316	1619	1446	156.1	1250	1335	1467	1351	109.2

Table 9: Emission test result of the Jatrok stove using blended fuels.

Fuel	Parameters	Test 1	Test 2	Test 3	Mean	Stdv.
J10K90	CO (ppm)	368	378	298	348	43.5
	CO_2 (ppm)	9700	10900	12500	11033	1404.7
	Fuel consumed (gm)	77.5	70	80	75.8	5.2
	CO emission (g/kg)	11.8	13.5	9.3	11.5	2.1
	CO_2 emission (g/kg)	313	352	391	352	39
J20K80	CO (ppm)	478	362	326	388.6	79.4
	CO_2 (ppm)	13500	10700	10300	11500	1743.5
	Fuel consumed (gm)	82.5	85	92.5	86.6	5.2
	CO emission (g/kg)	14.5	10.6	8.8	11.3	2.9
	CO_2 emission (g/kg)	409	314.7	278.3	334	67.4
J40K60	CO (ppm)	429	341	307	359	62.9
	CO_2 (ppm)	12300	11400	9100	10933	1650
	Fuel consumed (gm)	95	90	100	95	5
	CO emission (g/kg))	11.3	9.5	7.7	9.5	1.8
	CO_2 emission (g/kg)	323.7	316.8	227.5	289.2	53.6

temperature increased from 20°C to 100°C. The viscosity of *Jatropha* oil reduced by 65% and 89% at 40% and 10% oil, respectively, compared to the oil's viscosity at 20°C. In the present study, the viscosity of *Jatropha* oil reduced significantly on heating. This exponential decreasing pattern in viscosity with increasing temperature is similar with Eryilmaz and Yesilyurt's [8] research on safflower oil-diesel research.

The Jatrok stove was compared with the previous works on the cookstoves in terms of thermal efficiency, specific fuel consumption, and fire power and emission characteristics of the stoves. The thermal efficiency of the Jatrok stove using J10, J20, and J40 fuels was of 66%, 56%, and 52%, respectively. The stove using up to 40% *Jatropha* oil is more efficient than the thermal efficiency of the traditional stove [20], metal charcoal stove [20], Lakech [20], and rocket stoves [20]and comparable with the thermal efficiency of ethanol [21] and kerosene stoves [22]. The conventional kerosene and gravity stoves with plant oil (karanj) have a thermal efficiency of 5.65% and 11.81%, respectively [18]. In the present study, the Jatrok stove using blended fuels up to 40% oil has thermal efficiencies more than 50%. The specific fuel consumption of the Jatrok stove using J10, J20, and J40 is less than that of the traditional stove [20], metal stove [20], Lakech [20], rocket [20], and ethanol stove [21]; however, it is more than that of the kerosene stove [22]. The fire power of the Jatrok stove power using J10, J20, and J40 fuels was comparable with the fire power of the ethanol stove [21] and kerosene stove [22]. CO and CO_2 emissions of the Jatrok stove using J10, J20, and J40 are comparable with the CO emission of the ethanol stove [21] but much less than that of the traditional [23], *Lakech*, and Merchaye cookstoves [23]. In addition, CO emission decreases when increasing the percentage of blending *Jatropha* oil with kerosene, and this is similar with the decreasing trend seen when blending biodiesel with diesel fuel [12–17].

5. Conclusions

In this study, effects of temperature and blending of the *Jatropha* oil with kerosene on the viscosity of *Jatropha* oil were investigated. The results showed that viscosity of *Jatropha* oil is significantly reduced on heating and blending with kerosene. In addition, the Jatrok plant stove using *Jatropha*- and kerosene-blended fuel was also investigated in this study to see its effect on the stove performance on this blended fuel. A summary of the study is presented below:

The viscosity of *Jatropha* oil was reduced by 86.3% when the temperature increased from 20°C to 100°C. This is the effect of temperature on *Jatropha* oil.

When blending 40% *Jatropha* oil with kerosene, the viscosity of the blend reduced by 65%. At 10% *Jatropha* oil blend, the viscosity reduced by 89%. This makes the reduction in viscosity suitable for the cooking stove.

The calorific value reduced as the blending increased from 10% *Jatropha* to 40% *Jatropha* from 42,903 kJ/kg to 41,175 kJ/kg.

The stove performance indicators, thermal efficiency, specific fuel consumption, and fire power, were investigated to understand the effect of blending *Jatropha* oil with kerosene. The thermal efficiency decreased from 66% to 52% when the *Jatropha* oil blend increased from 10% to 40%. The specific fuel consumption increased from 30 g/L to 38 g/L when blending *Jatropha* oil from 10% to 40%. The fire power of the stove reduced from 1433 W to 1399 W when *Jatropha* oil was blended in the ratio of 10% to 40% with kerosene. The reduction in the stove performance is not much compared to the price of kerosene in the rural area.

The carbon monoxide and carbon dioxide emissions of the stove when using blended *Jatropha* oil with kerosene from 10% to 40% *Jatrohpa* oil was a CO emission reduction from 11.5 g/L to 9.5 g/L. In the case of carbon dioxide, it was reducing from 352 g/L to 289 g/L. The reduction in carbon monoxide has a reduction in indoor air pollution load in the kitchen.

The abovementioned conclusion suggests that *Jatropha* oil blended with kerosene could be an alternative fuel for biomass cooking stoves replacing the poor efficiency stoves in the rural areas.

Nomenclature

cSt: Centistokes
e_1: Heat produced by burning the nitrogen portion of the air trapped in the bomb to form nitric acid
e_2: Heat produced by the formation of sulfuric acid from the reaction of sulfur dioxide, water, and oxygen
e_3: Heat produced by the heating wire and cotton thread
e_4: Correction for the heat of formation of nitric acid (kJ/kg)
e_5: Correction for sulfur which is usually 0
e_6: Correction for heating wire and combustion of the cotton thread (kJ/kg)
Eff: Thermal efficiency (%)
f_m: Fuel consumed (g)
H: Heat of combustion of the standard benzoic acid sample (kJ/kg)
H_c: Gross heat of combustion
LHV: Lower heating value for the fuel (J/kg)
M: Mass of the sample (g)
SFC: Specific fuel consumption (g/L)
T: Temperature rise
T_i, T_f: Initial and final temperature (°C)
W: Energy equivalent of the calorimeter being used
wv: Water vaporized from the pot (g)
Ww: Mass of water remaining in the pot (g).

Data Availability

The raw and analyzed data can be obtained on reasonable request from the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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