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Biodiesel-Petrodiesel Blends Physicochemical Characterization and Economic Assessment of Designing a Plant in Iran

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ABSTRACT

Introduction: By substituting conventional fossil fuels, biofuel can emerge as a potential sustainable energy source with favorable environmental outcomes. Biodiesel, in particular, is increasingly attracting attention due to its high potential to increase the consumption of biofuel and contributing to sustainable development. Experimental studies have revealed that biodiesel can play a considerable role of biodiesel in improving petroleum-based characteristics.

Materials and Methods: Physicochemical properties of pure biodiesel produced through esterification and transesterification, petroleum diesel, and biodiesel-diesel blends were experimentally measured. Ninety percent of the filtered and dried waste cooking oil (WCO) was converted to biodiesel, and it was shown that cetane index, flash point, and fire point increased by applying B10 (10% biodiesel + 90% petrodiesel) instead of petrodiesel.

Results: B10 exhibited an adequate depression in pour point and cloud point by 6°C and 3°C at low temperature, respectively. Also, in this study, an economical study and a sensitivity analysis of a biodiesel production plant from WCO with a capacity of 90 tons per day was carried out, using COMFAR III software. The highest proportion of operating cost belonged to WCO (75%) followed by methanol (10%) and machinery, service, and maintenance expense (5%).

Conclusion: Biodiesel showed a positive influence on petrodiesel characteristics, in which the desired green fuel contributed to save the environment. Eventually, economic analysis provides the possibility of running a plant in Iran as a sustainable solution to energy issues.

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Introduction

Humans have been dealing with environmental pollution as a major problem in the 21st century[1, 2]. One of the greatest challenges that scientists have faced globally is a gradual increase in conventional fossil-fuel-related pollution and cost, which can be solved by using renewable energy resources [3, 4]. Various renewable energy sources such as solar energy, wind, biofuels (biodiesel, bioethanol), and waste heat have been developed to efficiently harvest energy [5-7]. Fossil fuel pollution brings about many detrimental effects on human health, such as exhaust emissions containing particle matters (PM), nitrogen oxides (NO_x), carbon

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monoxide (CO) and unburned hydrocarbons (HC), which can cause lung cancer, lung oedema, fatal effects on fetuses, and morbidity promotion [8-10].

Biodiesel production from waste cooking oil (WCO) is an effective strategy for decreasing the cost of raw material, as well as solving the waste oil disposal problem [11-14]. It is noticed that low price and availability of waste oil make it more preferable than vegetable oil, either edible or non-edible. High viscosity of the waste oil is the main deterrent to using it directly in combustion systems. Three different methods of thermal cracking, pyrolysis, and trans-esterification have been suggested to reduce viscosity [15, 16]. Low cost and high conversion efficiency have made trans-esterification more desirable for practical purposes [17].

Several advantages of biodiesel over fossil fuel such as biodegradability, non-toxicity, greenhouse gasses reduction, similarity to petroleum-based diesel structure, and the ability to mix with petrodiesel at different portions are principal reasons for its rising consumption. Moreover, lack of sulfur and aromatics, and less pollution due to the existence of oxygen in its chemical structure turns it into an environmentally friendly fuel [18, 19].

Biodiesel contains mono-alkyl ester of a long-chain saturated and unsaturated fatty acids, and its composition consists of 75% C, 13% H, and 12% O by weight, in which the presence of oxygen influences the performance of engine [20-22]. The fewer C-H bonds as a consequence of high concentration of oxygen leads to lower CO and HC emissions. Besides, burning smoothly and high evaporation rate can be counted as the advantages of using biodiesel [23, 24]. Cloud point and pour point can be considered significant advantages of biodiesel, which improve the cold-flow properties of the fuel[25]. Therefore, biodiesel has a good potential to use in the transportation sector as an alternative fuel and also in power plants[26].

Recently, biodiesel is drawing the attention of south-east Asian countries. In this area, B5 biodiesel blend taken from palm oil is used for transportation as well as power generation and in the industrial sectors. Malaysia is a country that has reached high levels in biodiesel production by using jatropha and palm oil, and is currently attempting to formulate a richer blend ratio [27].

Currently, studies are focused on cheaper feedstock for biodiesel production, such as WCO, waste animal fat, and sewage sludge. Capodaglio and Callegari concluded that waste sewage sludge can be a suitable raw material for biodiesel production, which has a much lower cost by using pyrolysis[28]. Moecke et al. evaluated economic, environmental and social aspects of biodiesel, reporting that the produced biodiesel can be used as fuel in the artisanal fishing boats. Trans-esterification process was applied for biodiesel production from WCO in a batch reactor with a capacity of 200 (L/day) [29]. In addition, based on life cycle assessment (LCA) studies, socioeconomic advantages and environmental effects of biodiesel were analyzed using a pilot plant for required processes in order to produce biodiesel from WCO gathered in Brazil[30]. However, comparing laboratory and large-scale data, LCA studies have provided good information on the cultivation and harvesting of algae. Results have demonstrated favorable environmental outcomes regarding particulate matter, global warming, and total NO_x and SO_x emissions [31].

In Iran, replacing conventional fuel with renewable energy from biomass sources such as citrus waste products gives a higher benefit and has a great potential for biodiesel production, bioethanol, and biogas [32, 33]. It should also be noted that biodiesel production has been studied technically and economically by authors in Iran, who considered waste oil to be an affordable resource [34-37].

Biofuel has great potential in Iran, since about 7% of the territory is covered with forests, which can produce valuable resources such as lipids. Algae, fish oil, as well as plant oil sources such as jatropha, castor plant, and palm. These are suitable sources for biodiesel production, especially WCO, of which 0.3 million tons is produced annually. Therefore, this appealing setting provides strong evidence that it is quite enough to forecast blending ratios up to B10 by 2026 [38].

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China, USA, India, and Russia are the leading CO_2 producers in the world[39]. Iran emitted 3.6 tons CO_2 per capita in 1990, which reached 5.3 tons in 2000. This amount of pollution rate has grown in recent years to reach 7.56 tons per capita in 2015[40].

The objective of this study is to evaluate the specification of WCO methyl ester (biodiesel, B100) and conventional petrodiesel fuel (B0) as well as biodiesel blends. WCO as a low-cost raw material was used experimentally to produce biodiesel. Moreover, B10 in Iran, as an alternative to petrodiesel, is anticipated to be highly promoted by 2035. Due to its enormous potential to expand the consumption of biofuel and contribute to sustainable development, biodiesel is gaining more and more attention. Moreover, a factory with a capacity of 90 tons per day was examined economically.

Materials and Methods

Methodology

WCO was obtained from several local restaurants and then mixed in order to make feedstock for biodiesel production process. Figure 1 shows the biodiesel production apparatus for both esterification and trans-esterification, which consists of 6 items. The pilot of desired reaction process was equipped with a reflux condenser, 500 ml three-necked flask, heater stirrer, magnetic stirrer, water bath, and a thermometer. The reagents applied in the experiment conditions of biodiesel production are presented in Table 1. The yield of fatty acid methyl ester (FAME) was calculated by equation (1), which is mentioned below [41]:

$$\text{yield}\ (\%) = [\text{weight of biodiesel}\ (g)/\text{weight of lipid}\ (g)] \times 100 \quad (1)$$

Biodiesel production

Biodiesel production process is performed in four steps:

1. Waste oil filtering and preparation

Gathered waste oil needs an impurity separation process. To this end, as shown in Figure 2 (a), suspended food particles should be separated by filtering through filter paper. Absence of water results in the prevention of soap production, which is undesirable for biodiesel production. The reaction of water and alcohol reduces process yield and makes the final separation difficult. Hence, it was placed on a hot plate at a temperature above 100 °C stirring for an hour to eliminate water content in the waste oil.

2. Esterification and transesterification reactions

Heating oil decomposes the long carbon chain to create free fatty acids [42]. The reaction of free fatty acids with alkali catalyst produces soap, and water which decreases the outcome of reaction and forms the emulation [43, 44]. An acid-catalyzed technique was used in biodiesel production to decrease the content of free fatty acid (FFA) to less than 1% in order to convert FFA into methyl ester until WCO was prepared for the trans-esterification process by base-catalyst [45-47]. A titrimetric method was applied to determine the FFA content representing an amount of 5.37 wt. %. In the acid-catalyzed process, 100 ml filtered oil with 8:1 molar ratio of methanol (purity 98%) to oil and 1% (v/v) of H_2SO_4 (98%) were applied to the crude oil. As shown in Figure 2 (b), the reaction was carried out at 75 °C and 800 rpm. After 2 hours, a separating funnel was used to separate the acid, impurity, and methanol. After 10 hours, the lower layer (esterified oil) was separated and entered into a rotary evaporator. It can eliminate almost all water and alcohol excess after 1 hour. Then, to perform transesterification reaction, processed waste oil (at 50 °C) again was poured into three neck-round flasks equipped with a reflux condenser and a thermometer (Digital thermometer (KT-300) 240x30x30 mm, accuracy -50 to 300 Celsius) to avoid alcohol vaporization, then a combination of 25 ml of methanol and 0.5% w/w (of oil) sodium hydroxide (99%) was added to the flask. The reaction was allowed to proceed at 70 °C (± 2) with continuous stirring at 600 rpm for 1.5 hours and refluxing by a water-cooled condenser. According to the color change and return of alcohol from the condenser in the first 45 minutes, it seems that most of the conversions took place in this period.

3. Separation of biodiesel and glycerol:

When the reaction was complete, the mixture

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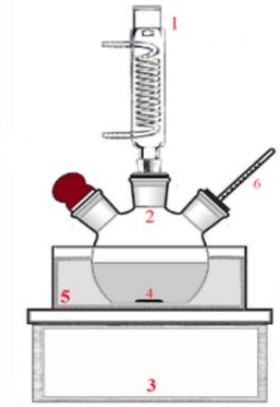
was passed through to the separating funnel for a day to separate the rich phase of glycerol from biodiesel. There might be some excess impurities in the lower layer which has to be removed. It can be seen in Figure 2 (c).

4. Post-treatment process

It was probable that the biodiesel still contains glycerol, alcohol, and impurities. Therefore, as shown in Figure 2 (d), the sample was heated up to 75 °C with continuous stirring for half an hour to vaporize alcohol, and then it was washed with warm distilled water at least three times until the outlet water became slightly clear. In the next stage, excess water and methanol were eliminated by a rotary evaporator. Finally, the remaining water was taken from biodiesel by heating and using granular Na_2So_4. Eventually, a filter paper (150 mm diameter, no.1) was employed to filter the final product which was prepared for blending with ordinary diesel.



No.	Equipment name
1	reflux condenser
2	500 ml three necked flask
3	heater stirrer
4	magnetic stirrer
5	water bath
6	thermometer

Figure 1: Schematic diagram of biodiesel production setup

Table 1: Summary of processes of biodiesel production from WCO

Parameter			Specification
	Esterification	**Transesterification**	
Source	WCO		
Alcohol used	Methanol		98 % purification Merck
Catalyst used	H_2SO_4	NaOH	Acidic catalyst: 98% Alkali catalyst: 99%
Reaction temperature	75 °C	70 °C	-
Reaction time	2 h	1.5 h	-
Stirring speed	800 rpm	600 rpm	-

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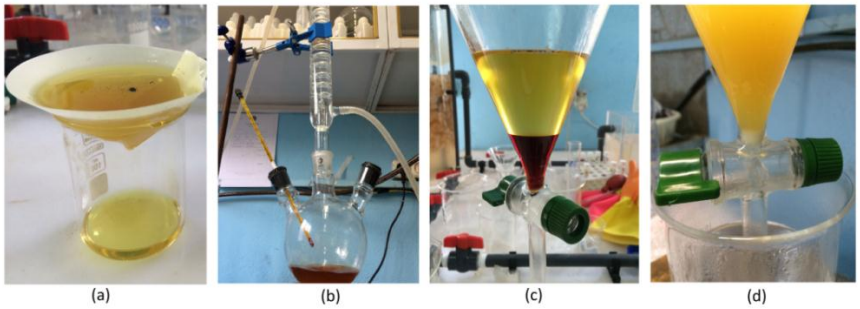

Figure 2: (a) Waste oil filtering, (b) Reaction system, (c) Separating funnel, and (d) Purification

Blending of biodiesel

It is not common to use neat biodiesel because of economic disadvantages, incompatibility with engines, and physicochemical issues, such as low energy content, oxidation stability, higher kinematic viscosity, and density. Petro-diesel can be completely miscible to biodiesel at different portions [48, 49]. Biodiesel blend at different ratios is a suitable choice to improve the quality of conventional petrodiesel. Therefore, these blends were supplied to verify the effect of blending on petrodiesel based on ASTM D6751 standard procedure.

Petro-diesel was prepared from Tehran refinery based on Euro 5 standard. In order to make blends at three different ratios including B5, B10, and B20 by volume fraction, they were mixed under following appropriate conditions and are shown in Figure 3. To make these blends, a 500 ml neck-round flask was used and biodiesel was added to petroleum-based diesel at 45 °C. The flask was fixed with a clamp on a vertical stand with continuous stirring at a speed of 700 rpm for 1 hour.

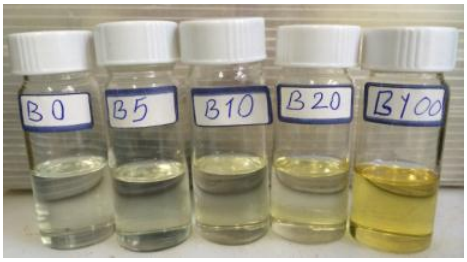

Figure 3: Biodiesel Blends: B0, B5, B10, B20, and B100

Physicochemical analysis

Physical and chemical characteristics of biodiesel and biodiesel/petro-diesel blends were analyzed using ASTM D6751 method.

Economic analysis

The production steps of biodiesel on a laboratory scale and chemical parameters in its characteristics are described in the previous section. Then, a WCO biodiesel plant was evaluated economically with a capacity of 90 tons per day. Economic estimates of factory construction and internal rate of return (IRR) sensitivity analysis were performed by COMFAR III software on a variety of parameters.

COMFAR software has been designed by the United Nations Industrial Development Organization (UNIDO) to evaluate economic projects. The software makes it easy to organize and calculate financial reports. The advantages of COMFAR software include high flexibility, user-friendliness, low error, and high level of sensitivity.

Results

Characterization of fuel properties

The percentage of biodiesel yield (lipid conversion efficiency) obtained from optimum reactions was 90% after eliminating glycerol from separating funnel. Table 2(a), (b) shows the properties of produced biodiesel (B100) in comparison to other studies and demonstrates the chemical and physical properties of the blends such as kinematic viscosity at 40 °C, density, pour point, cloud point, flash point, fire point sulfur content, cetan index, and calorific value. These results are in accordance to the standard test method ASTM D6751, and the data depicted in Table 2 are expressed as an average of three values in each test.

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Table 2(a): Biodiesel obtained from WCO characterization

Properties	Unit	Test method	ASTM-BD D6751	N. Yilmaz et al. [50]	Z. Al-Hamamre, A. Al-Salaymeh [51]	A.N. Phan, T.M. Phan [52]	Sadaf et al. [53]	Produced Biodiesel (this study)
Kinematic viscosity at 40 °C	mm^2/s	D445	1.9 - 6.0	4.57	5.86	4.89	5.83	5.8
Density at 15 °C	kg/m^3	D4052	860 to 900	855	877	880	874	870
Pour point	°C	D97	-15 to 10			0	1	9
Cloud point	°C	D2500				3	10.5	21
Flash point	°C	D93	130 min	126	150	120		144
Fire point	°C	D92						198
Cetan index		D976						59.7
Sulfur content	ppm	D4294	15 ppm					12
Calorific value (HHV)	MJ/kg	D240	> 35	40.5	35.66	41.84	37.2	45.11

Table 2(b): Physicochemical fuel properties of biodiesel in comparison to petrodiesel and its blends

Properties	Unit	Test method	B0 (Petrodiesel)	B5 (5 % v/v)	B10 (10 % v/v)	B20 (20 % v/v)	B100 (Biodiesel)
Kinematic viscosity at 40 °C	mm^2/s	D445	2.75	2.83	3.04	3.1	5.8
Density at 15 °C	kg/m^3	D4052	821	823	827	834	870
Pour point	°C	D97	-6	-8	-12	-12	9
Cloud point	°C	D2500	2	0	-1	-2	21
Flash point	°C	D93	63	63.5	64.5	66	144
Fire point	°C	D92	91	92	93	94.5	198
Cetan index		D976	55.9	56.1	56.4	57.1	59.7
Sulfur content	ppm	D4294	56	55	52	48	12
Calorific value (HHV)	MJ/kg	D240	45.98	45.91	45.89	45.79	45.11

Fuel properties analysis

The following section discusses the properties of blending pure biodiesel with conventional petroleum-based diesel.

Density

Density is an important property of fuel atomization and affects the energy content, air-fuel ratio within the diesel engine and cetan number [54, 55]. Figure 4 presents the variation in density with volumetric percentage of biodiesel-petro diesel. The foregoing density for petro-diesel goes up from 821 to 823, 827, and 834 (kg/m^3) for B0, B5, B10, and B20, respectively. Thus, it can be seen that blend density increased slightly by increasing the biodiesel percentage.

Kinematic viscosity at 40 °C

One of the fuel properties affecting the fuel injection system is kinematic viscosity. Fuel fluidity and atomization are important characteristics of fuels measured by kinematic viscosity [56, 57]. Unsuitable fuel injection and pumping can cause incompetency at low temperatures due to higher kinematic viscosity [58]. The kinematic viscosity of biodiesel was measured at 5.8 (mm^2/s), and the recommended range of kinematic viscosity is 1.9- 6.0 (mm^2/s) according to ASTM test method [57]. It was observed experimentally that the kinematic viscosity at 40 °C of petro-diesel increased when the biodiesel portions in petro-diesel rose (Figure 4). The kinematic viscosity changed from 2.75(B0) to 2.83, 3.04, and 3.10 (mm^2/s) for B5, B10, and B20, respectively.

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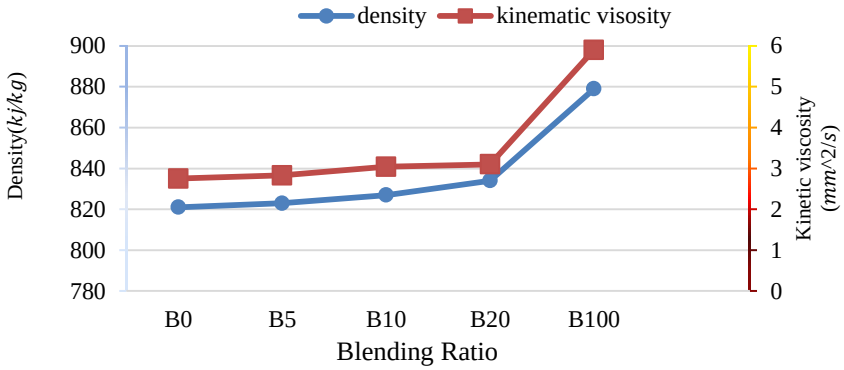

Figure 4: Density and kinematic viscosity of blends

Calorific value *(MJ/kg)*

The energy content of biodiesel is known as the potential energy contained in a given biodiesel fuel influencing the engine power, which depends on the energy content of the oil as a feedstock [42, 59]. In this investigation, the energy content known as higher heating value (HHV) of methyl ester was measured and the results are presented in Table 2. Figure 5 shows blended biodiesel energy is slightly less than petrodiesel. An increase in biodiesel-diesel blend ratios marginally decreased the calorific value of the blends. The calorific value of the biodiesel was measured 45.115 (MJ/kg) which was 98.11 % of the petro-diesel (B0) and the energy quantity of B5, B10, and B20 were found 0.13%, 0.18%, and 0.4% less than petro-diesel, respectively, as reported in Table 2(b). Therefore, considering the final cost of biodiesel blends, HHV is an important characteristic of a fuel, which indicates the upper limit of the available thermal energy produced by a complete combustion of fuel. It may not be reasonable to mix higher amounts of biodiesel to maintain the adequate expected energy content; therefore, B0 to B10 would be logical options.

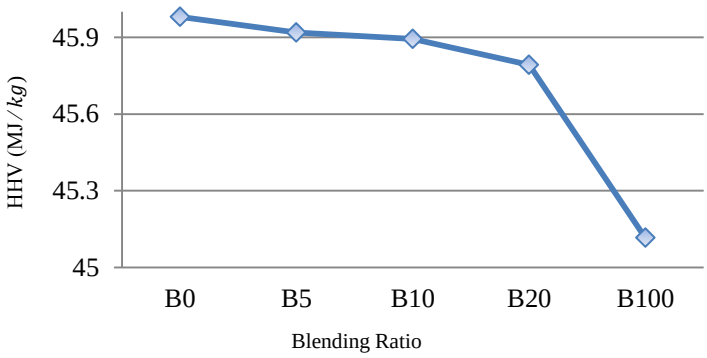

Figure 5: Calorific value (HHV) of biodiesel blends

Cetane index

In another experimental investigation, cetane value of fuel was evaluated to measure the ignition quality. The ignition delay time is the period that fuel is injected and began to combust. During this time the fuel evaporates and is dispersed with the compressed air in the combustion chamber. If all conditions are available, the fuel will spontaneously begin to combust. The ignition time depends on the composition of the fuel, operational parameter, and engine design. Cetane is the speed of fuel combustion and an indicator of fuel quality. The lower cetane values have a longer ignition delay compared to the higher ones. Cetan index is an essential property since biodiesel affects the petrodiesel cetan index. The recommended cetane index range for biodiesel/petrodiesel blends is at least 40 [60]. In this study, B0 cetan index was found

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55.9 and attained 56.1, 56.4, and 57.1 for B5, B10, and B20, respectively (Table 2 and Figure 6).

Sulfur content

Due to the lower sulfur content in biodiesel compared to petrodiesel, lower amount of SO_2 is produced [61]. Sulfur content of diesel fuel depends on fuel types and varies from one engine to another. Sulfur is known as an emission causing acid rain, and affects PM emissions to the extent that has convinced the scientists to limit diesel sulfur content more than ever. Sulfur subtraction needs to be taken into account because it can increase ecosystem damage and cause lots of losses in the country. As a result, new technologies of emission control and heavy processing have been performed at Tehran refinery to reduce sulfur content in recent years.

The biodiesel sulfur content was measured 12 ppm, while the proposed value of the sulfur-based fuel on ASTM D6751 standard is reported less than 15 ppm[62]. The results show that biodiesel as an additive can reduce the sulfur content of petrodiesel from 56 ppm (B0) to 52 ppm (B10). Sulfur content reduction trend is given in Table 2 and it can be seen in Figure 6.

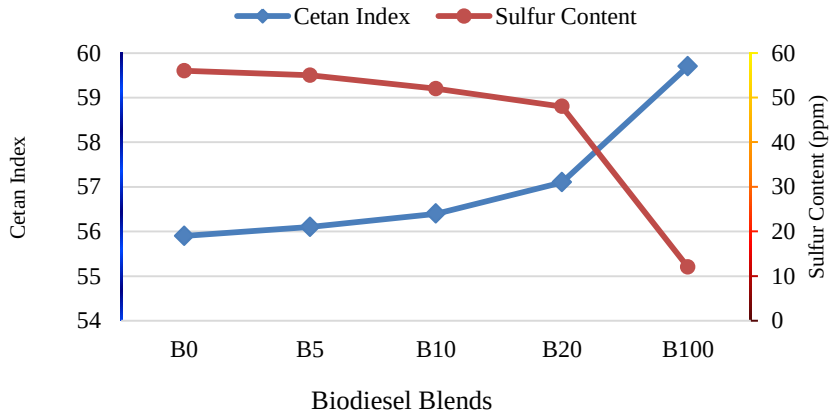

Figure 6: Cetan index and sulfur content of biodiesel blends

Flash point and Fire point (°C)

The flash point shows the minimum temperature at which fuel vaporizes enough to get ignited, and is known as the safety measure of fuels for transportation and storage. The fire point is the lowest temperature at which the vapor of fuel continues to burn for at least 5 seconds after ignition [63, 64]. Table 2 demonstrates a slight increase in several percentages of biodiesel in the blends and a drastic two-fold rise in 100% biodiesel compared to ordinary fuel. The flash point and fire point of petrodiesel were measured 63 and 91°C, respectively. Figure 7 demonstrates that the flash point and fire point increase as the blend ratios increase. The flash point of 100% biodiesel complied with ASTM D6751, and it had the highest flash point indicating low volatility of this fuel [65]. Mixing biodiesel with petro-diesel can increase the flash point of the blends and is a suitable choice in terms of safety, since higher flash point of biodiesel decreases flammability hazard providing more safety in transferring and shipping. So, increasing the rate of biodiesel positively enhances the safety regulation of introduced fuel.

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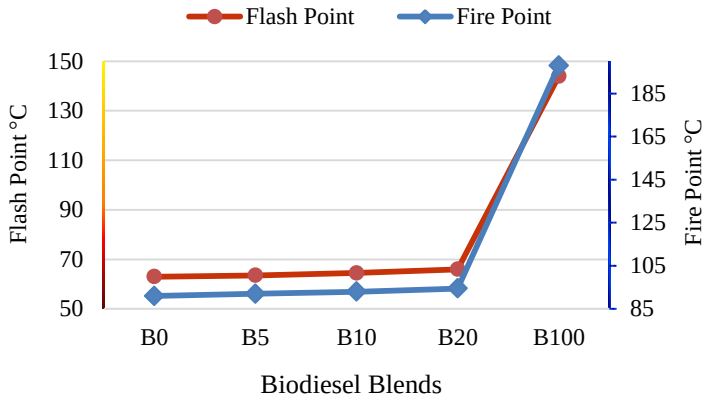

Figure 7: Flash point and fire point of biodiesel blends

Pour point and cloud point (°C)

Fuel constraints under cold weather are generally determined by factors such as cloud point, pour point, and cold filter plugging point. Cloud point shows the temperature at which the cluster of wax crystal can be seen, and the temperature at which fuel flow reduces due to gel formation during fuel cooling is known as the pour point of fuels [66]. The pour point and cloud point of WCO methyl ester were measured at different mixing portions as represented in Figure 8 and Table 2. Biodiesel (B100) had a higher pour point and cloud point in comparison with petrodiesel (B0), 9°C, and 21°C, respectively. It is important to notice that biodiesel can decrease these characteristics by making blends; in other words, both cloud point and pour point of biodiesel blends were lower than conventional petrodiesel. According to Table 2, B10 had lower pour point and cloud point than petro-diesel enabling higher compatibility with vehicles.

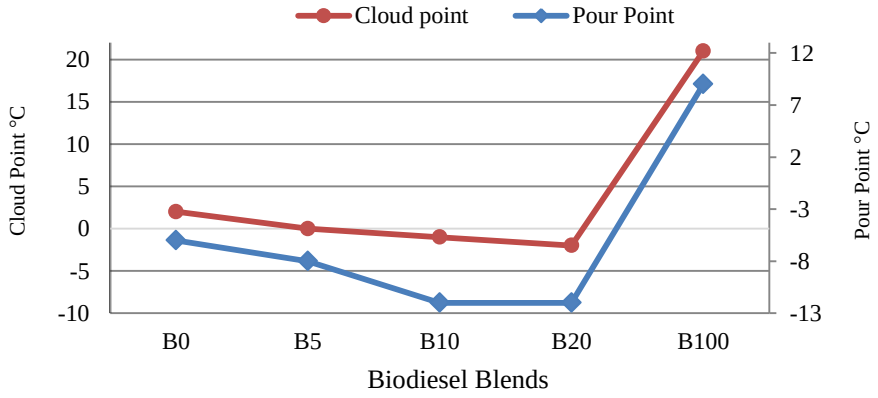

Figure 8: Pour point and cloud point of biodiesel blends

***Distillation curve** (°C)*

Fuel tendency to form smoke and soot is evaluated by distillation curve [67]. Fuel distillation significantly impacts fuel safety and performance, since volatility has a profound effect on fuel tendency to vaporize, especially initial boiling point (IBP), which influences fuel vapor pressure [68]. According to Table 3 and Figure 9, the distillation curve is the temperature change as a function of distillation percentage from IBP to final boiling point (FBP), performed at the atmospheric pressure of fuel.

In this survey, ASTM D86 was used for obtaining experimental distillation, because at different percentages of recovery, biodiesel has the highest distillation temperature. The obtained

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results showed that the percentage of biodiesel had direct relationship with IBP and FBP. The IBP of biodiesel was measured at 261 °C, while conventional diesel had the lowest value of 175 °C. IBP was measured at 170.5, 171, and 172 °C for B5, B10, and B20, respectively. According to Table 3, boiling point at 10% to 95% recovery of each sample was higher in contrast to petrodiesel (B0). It can be demonstrated that at the IBP and FBP the samples temperatures converge, while they diverge as they reach an equal content of each fuel in blends.

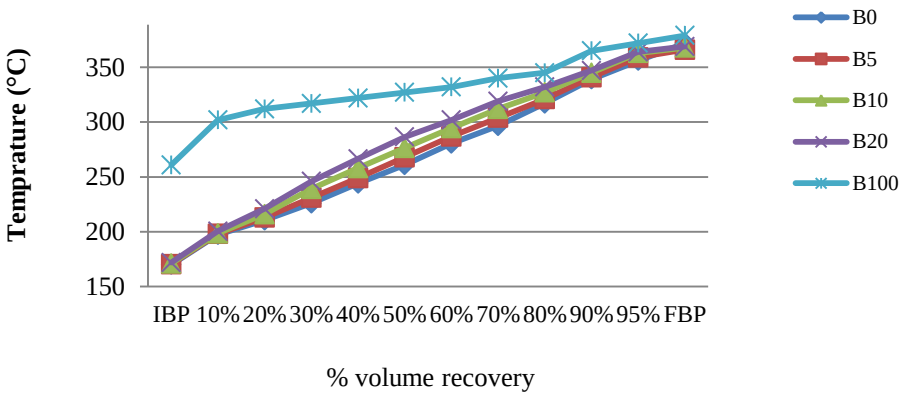

Figure 9: Distillation curve of biodiesel, diesel, and the blends

Table 3: Distillation temperature for biodiesel, petrodiesel, and the blends

Vol. %	B0	B5	B10	B20	B100
IBP*	170	170.5	171	172	261
10	197.4	198	198.5	200.5	302
20	210.5	213	216	221	312
30	226	231	239	246	317
40	244	249	258	266.5	322
50	261	268	276.5	286.5	327
60	280.5	287	294.5	302	332
70	296.5	304	312	319	340
80	317	321	327	332	345
90	339	341	345	347	365
95	356	359	363	364	372
FBP**	372	366	368	369	379

***** Initial Boiling Point
****** Final Boiling Point

Economic assessment of biodiesel production

From an economic viewpoint, WCO is the best raw material in contrast to the utilization of imported fresh edible oil, when only 10-15% of consumed edible oil in Iran is produced by domestic production and the rest is imported [69]. It is not reasonable to neglect this large amount of purchased edible oil. According to results, biodiesel production includes the expenses of raw materials, energy, human labor, services, and maintenance.

Not only would the daily consumption of 80 million liters of petrodiesel in Iran be reduced by 10%, but also it can be replaced by an alternative fuel. Therefore, biodiesel would potentially own an 8 million litter market per day. Regarding the capacity of producing biodiesel from WCO, B10 can be produced in order to be consumed in big cities that are receiving the most exposure to pollution (Tehran, Mashhad, Karaj, Esfahan, Shiraz, etc.). For instance, the amount of WCO in Tehran has come to 60000 kg per day only by the food service industry and food manufacturing. As a result, this amount of waste oil is an indigenous

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threat to ecosystem of Tehran. Regarding the potential of Tehran as a sources of raw material and operationalization, this city can be a suitable option for launching biofuel production. Therefore, B10 is anticipated to be highly promoted as a substitute for petrodiesel by the year 2035 in Iran.

For the economic evaluation, a discount rate of 18% (tax rate = 9%) was assumed for the survey. According to oil conversion efficiency to biodiesel of 90% and biodiesel density of 870kg/m^3, the annual increase rate of operating costs, the annual increase rate of biodiesel price, and the annual increase rate of glycerol price were considered 17%, 2%, and 17% respectively, as inputs to the COMFAR III software. Operational costs and distribution expenses of biodiesel production from WCO are presented in Table 4 and Figure 10, respectively. According to Table 4, unit cost of biodiesel production in Iran is anticipated to be 0.412$/L$. Figure 10 indicates that the highest share of expenses belongs to WCO (75%), followed by methanol (10%), machinery, services, and maintenance (5%). Moreover, Table 5 shows the total investment costs, and Table 6 demonstrates the revenues from the sale of biodiesel and glycerol. As shown in Figure 11, the largest share of total investment costs belongs to process equipment (62 %), followed by contingencies fees (15%) and utility (9%), respectively. According to economic calculations performed by COMFAR III software, Net Present Value (NPV) of Total Capital Invested (at 18%) was obtained 11,722,000 $, and the IRR on investment was assessed 20.21 % with a 5-year normal payback. Overall, positive net present value (NPV) ($11,722,000) and IRR indexes of more than 18% (21.20 %) can be found, which indicates that the process would be financially feasible.

Table 4: Operating costs for a 90 t/d WCO-biodiesel plant

Item	Unit	Price ($/unit)	Quantity	Total cost ($)
Direct Costs				
WCO[a]	Tone	300[b]	33000	9900000
Methanol[a]	Tone	215	6005	1291075
H_2SO_4[a]	Tone	270	341.2	92129
NaOH[a]	Tone	1370	37.95	51991
H2O[a]	M^3	0.18	39930	7187
Electricity[a]	Kwh	0.07	1724910	120744
Machinery, service and maintenance (10% of process equipment utility		equipment, building and		676900
Royality				425000
Labor[c]	Person	9240	9	83160
Depreciation				486554
Total direct costs				13134740
Indirect costs				
Insurance				88160
Marketing (2% of total revenue from biodiesel and crude glycerol sale)				837390
Total indirect costs				925550
Total operating costs				14060290
Unit cost of biodiesel production				0.412$/L

[a] All given prices are based on Iran market data (2020 April).
[b] 25 % of fresh vegetable oil price.
[c] Including basal labor payment and other expenses based on Iran ministry of labor laws.

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Table 5: Total capital cost for a 90 t/d WCO-biodiesel plant

Item	Cost (Thousand USD)
Equipment	
Process equipment[a]	5198
Utility equipment	806
Total equipment cost	6004
Civil and construction[a]	
Land acquisition	55
Building and structure	161
Total civil cost	216
Installation[b]	600
Contingencies fee[c]	1283
Pre-production expenditures	302
Total capital cost	8405

a All given prices are based on Iran market data – 2020 April.
b 10% of equipment costs including engineering design cost, construction labor, piping, electrical. and control instruments and their programing and other expenses.
c 18% of total equipment cost and civil and construction cost (expect land expense)

Table 6: Total revenue from crude biodiesel and glycerol sales

Quantity (tone)	Price ($/ton)	Sale($)
Biodiesel: 29700	1065/8	31654260
Glycerol: 4300	240	1032000

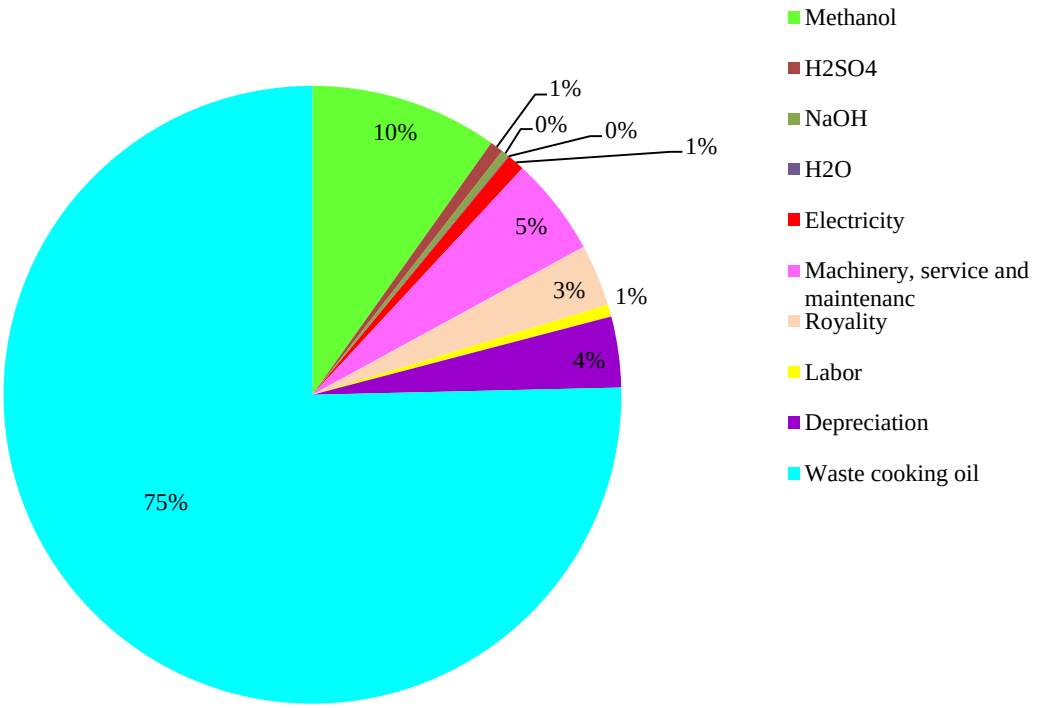

Figure 10: Distribution of expenses in biodiesel production

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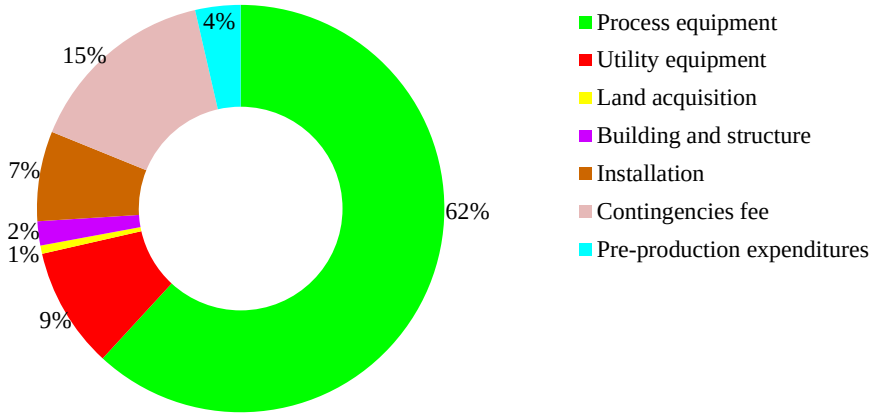

Figure 11: share of different items in total investment costs

Sensitivity analysis

COMFAR III was used for sensitivity analysis. Results indicated that the increase in the internal rate of return had the greatest effect on sales revenues, so that with an increase of 20% in IRR, sales revenues attained 35.57% (Figure 12). Also, it can be seen that the growth in IRR has resulted in a slight increase in fixed assets and led to an extreme decrease in operating costs.

Scope for further research

Authors have recently focused on modern technologies to reduce energy consumption, increase efficiency, and use environmentally-friendly reagents. Accordingly, the mechanochemical approach would be a promising technique, due to improving the reaction conditions in lower temperatures and consuming less time. Therefore, one of the main goals of sustainable development can be reached through mechanochemical processes in biodiesel production.

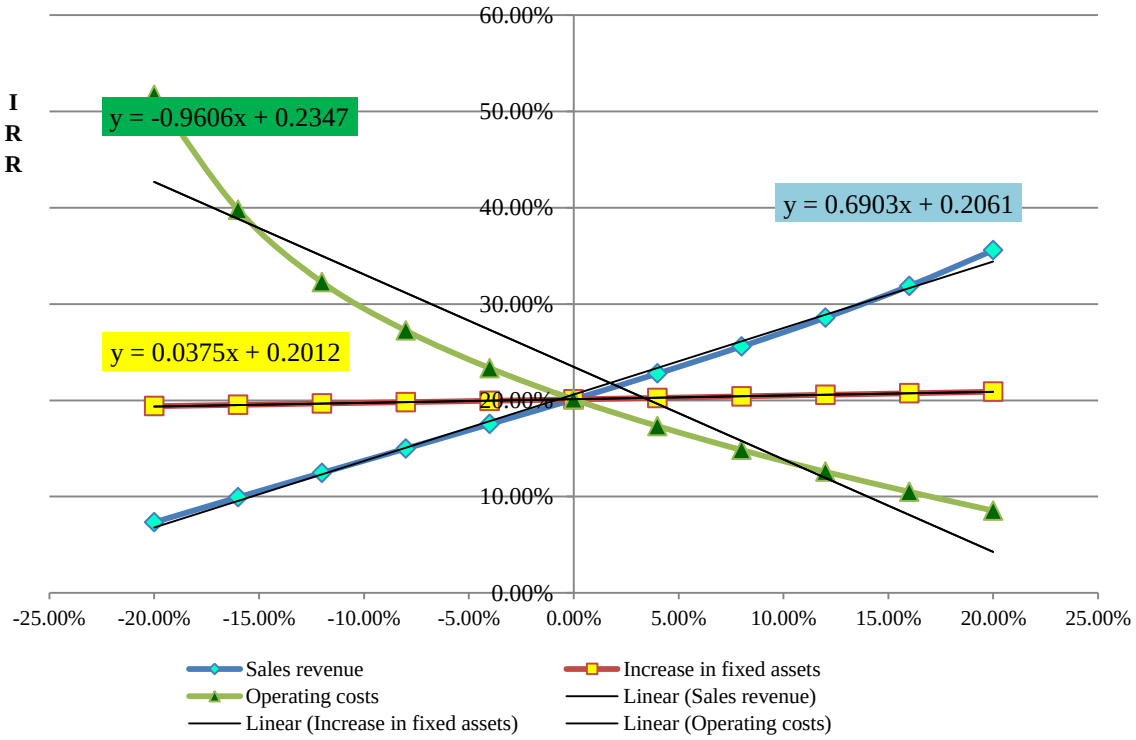

Figure 12: Sensitivity of the IRR on the sales revenue, operating costs and increase in fixed assets

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Discussion

In the present study, the production of biodiesel was conducted on laboratory scale, and it was shown that the evaluated properties of the biodiesel conform to the American Society test method standard (ASTM D6751) which is similar to a study conducted by Sadaf, et al. [53]. From a technical viewpoint, it is noticed that both the density and viscosity of petrodiesel increase when the blends percentage ratio rises; however, energy content of higher-biodiesel-ratio fuel shows an insignificant decrease which can still provide enough energy in engines. On the other hand, the increased cetane index can play a positive role to enhance the quality of burning, which is achieved by adding more biodiesel in petrodiesel. Higher content of biodiesel in conventional fuel improves the quality by decreasing sulfur content and safety parameters, which are flash point and fire point, making it a favorable fuel in harsh conditions. Furthermore, it was evidenced that the improved pour point and cloud point can work positively in cold conditions to keep the fuel from forming wax crystals as can be seen in Atabani et al. investigation[66].

The ever-increasing greenhouse gas (GHG) rate, which is considered a threat to the environment, is an important issue. In the Iranian national document of the knowledge-based development of renewable energy, biodiesel consumption is a part of the renewable energy domain in the 1404 outlook. One of the macro policies of Iran in the exhibition of bioenergy fuels is the consumption of bioethanol and biodiesel in upcoming years. Also, reducing at least 10 million tons of greenhouse gas emissions in comparison with 2015 is expected by increasing the renewable energy share. Therefore, biofuel, as a prerequisite for economic activities, has become one of the most essential elements in global policies in Iran toward sustainable development. Using WCO as raw material for biodiesel production has been considered not only as a progressive step in reducing environmental pollution, but also as a viable measure to improve human safety [25,30].

Conclusion

Due to the growing environmental concerns over the past years, decisions have been made to achieve sustainable development. While developed countries have made considerable progress in controlling environmental pollution, developing countries (e.g. Iran) are still facing different challenges. Waste cooking oil as a cheaper alternative reduces GHG emissions and prevents waste accumulation[19]. Biodiesel blends are beneficial from an environmental perspective to improve the fuel's physicochemical properties; hence, biodiesel blends in Iran have advantages including less consumption of conventional fuel, carbon marketing and reducing environmental pollutants. Moreover, it decreases the dependence on imported oil, due to agricultural development, and creates more occupations in the country, leading to new green policies and sustainable development. The ten percent blend of biodiesel with petrodiesel (B10) improves most of the conventional diesel fuel properties, which can be used without any engine modification. Lowering the amount of sulfur can improve environmental health as a result of using biofuels, to meet one of the fundamental objectives of sustainability.

Economic estimation of factory construction and the IRR sensitivity analysis were conducted on a variety of terms. They indicate that the cost of producing biodiesel in Iran reaches 0.412$/L. The highest proportion of operating costs respectively belong to WCO (75%) followed by methanol (10%) and machinery, services and maintenance expenses (5%). Moreover, the largest proportion of total investment costs relates to processing equipment (62 %), followed by contingencies fees (15%) and utility (9%).

Sensitivity analysis results show that the increase in the IRR has the greatest effect on sales revenue, while the increasing trend in IRR has resulted in a slight increase in fixed assets, and eventually it leads to an extreme decrease in operating costs. Ultimately, the IRR of more than 18% (21.20 %) and positive NPV indexes ($11,722,000) can be concluded that the project would be economically feasible.

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Abbreviations

GHG: Green House Gases
B0: 0% Biodiesel + 100% Petrodiesel
B5: 5% Biodiesel + 95% Petrodiesel
B10: 10% Biodiesel + 90% Petrodiesel
B20: 20% Biodiesel + 80% Petrodiesel
B100: 100% Biodiesel + 0% Petrodiesel
WCO: Waste Cooking Oil
PM: Particle Matters
NO_x: Nitrogen Oxides
CO2: Carbon Dioxide
CO: Carbon Monoxide
HC: Hydro Carbons
LCA: Life Cycle Assessment
Sox: Sulfur Oxides
FAME: Fatty Acid Methyl Ester
FFA: Free Fatty Acid
IRR: Internal Rate Of Return
HHV: Higher Heating Value
IBP: Initial Boiling Point
FBP: Final Boiling Point
NPV: Net Present Value
UNIDO: United Nations Industrial Development Organization

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Conflict of interest

The authors declare there is no conflict of interest.

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