PERSPEKTIVE DERIVATA BILJNIH ULJA ZA ENERGETSKE POTREBE SEOSKE POLJOPRIVREDE U INDIJI

PROSPECTS OF VEGETABLE OIL DERIVATIVES FOR RURAL AGRICULTURAL ENERGY IN INDIA

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Svijet je suočen s dvojnom krizom: krizom nestajanja fosilnih goriva i krizom degradacije okoliša. Alternativna goriva, očuvanje i upravljanje energijom, energetska učinkovitost i zaštita okoliša posljednjih su godina dobili na značenju. Kao alternativa dizel gorivu dosta obećavaju esterificirana biljna ulja koja su ekološki vrlo pogodna. U ruralnoj Indiji 90 %potreba za naftom otpada na poljoprivrednu mehanizaciju poput traktora i vršilica. Poljoprivrednici koji posjeduju marginalna i velika zemljišta mogu ispuniti zahtjeve dizel goriva tako da siju uljarice na vlastitoj zemlji. U ovom radu procjenjuje se isplativost lokalne proizvodnje biljnih ulja u jednom malom oglednom selu u središnjoj Indiji. Analiziraju se metilni esteri masnih kiselina iz ulja pamukovog sjemena, sojinog ulja, ulja balanitesa i jatrofina ulja da bi se ustanovila njihova svojstva i radni učinak u dizel motoru, a procjenjuje se i potrebna površina zemljišta za uzgoj tih uljnih kultura kako bi se udovoljilo potrebama seoske poljoprivrede za gorivom. Rezultati pokazuju da kalorična vrijednost metilnih estera iznosi 93 % dizela, a i druga su svojstva posve usporediva s dizelom. Analiza radnog učinka metilnih estera u motoru pokazuje neznatno smanjenje toplinske učinkovitosti od oko 3,23 %, dok su emisije smanjene za 8 % do 10 % u usporedbi s dizelom. Izvršena je i ekonomska analiza te je ustanovljeno da je korištenje derivata biljnih ulja kao zamjene za dizel gorivo skuplje od korištenja mineralnog dizela.

The world is confronting the twin crises of fossil fuel depletion and environmental degradation. Alternative fuels, energy conservation and management, energy efficiency and environmental protection have become increasingly import in recent years. Among alternative fuels, esterified vegetable oils hold good promise as eco-friendly alternatives to diesel fuel. In rural India, 90 % of the petroleum diesel requirement is for agricultural equipment such as tractors and threshers. Marginal farmers and large landholders can meet their diesel requirement by sowing oil yielding crops on their own lands. This paper evaluates the feasibility of the local production of vegetable oil for a small representative village in central India. Fatty acid methyl esters of cottonseed oil, soybean oil, balanites oil and jatropha oil were analyzed for their properties and performance in diesel engines. The land required to grow these oil crops in order to meet rural agricultural diesel requirements was estimated. The results indicate that the calorific value of these methyl esters is 93 % that of diesel and the other properties are quite comparable with diesel. Engine performance analysis of these methyl esters indicates that there is a slight decrease in thermal efficiency of approximately 3,23 %, while emissions are reduced by 8 % to 10 % as compared to diesel. Economic analysis was also performed and it was found that vegetable oil derivatives as diesel fuel substitutes are costlier than mineral diesel.

Ključne riječi: biodizel; esteri; transesterifikacija; biljna ulja
Keywords: biodiesel; esters; transesterification; vegetable oils

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1 UVOD

Dizel goriva imaju bitnu ulogu u gospodarstvu pojedine zemlje. Ona se koriste za pogon teških kamiona, autobusa u gradskom prijevozu, lokomotiva, električnih generatora, poljoprivredne mehanizacije, rudarske opreme, itd. Rastuće cijene dizel goriva i sve manje rezerve nafte potiču nas na traženje alternativnih goriva. Alternativna goriva trebaju biti lako dostupna, neškodljiva za okoliš te tehnološki i ekonomski konkurentna. Jedno od takvih goriva su trigliceridi (biljna ulja/životinjske masti) i njihovi derivati [1]. Biljna ulja imaju oko 88 % energijskog sadržaja naftnog dizela [2]. I biljna ulja i njihovi esteri obećavajuće su alternative kao goriva za dizel motore.

Problemi povezani s biljnim uljima za vrijeme ispitivanja motora mogu se svrstati u dvije velike skupine i to u probleme radne naravi i probleme izdržljivosti. Radni problemi odnose se na pokretanje motora, paljenje, izgaranje i radni učinak. Problemi izdržljivosti odnose se na formiranje naslaga, pougljenjivanje vrha sapnica za ubrizgavanje, zapinjanje prstena i razrjeđivanje ulja za podmazivanje. Primijećeno je da čista biljna ulja, kad se rabe puno sati, mogu zagušiti filtar goriva zbog visoke viskoznosti i netopljivosti svojstvene čistim biljnim uljima. Visoka viskoznost, višestruko nezasićeni karakter i veoma niska hlapljivost biljnih ulja odgovorni su za radne probleme i probleme izdržljivosti u njihovu korištenju kao goriva u dizel motorima. Visoka viskoznost biljnih ulja uzrok je slabog raspršivanja goriva, velike veličine kapljica i time velike penetracije sprej mlaza. Mlaz ima tendenciju postati kruta struja umjesto sprej sitnih kapljica. Stoga se gorivo ne distribuira, odnosno ne miješa za zrakom potrebnim za izgaranje u komori izgaranja. Posljedica je toga slabo izgaranje popraćeno gubitkom snage i ekonomičnosti [3].

Različiti načini smanjenja ovih parametara uključuju razrjeđivanje, mikroemulziju, pirolizu, katalitičko krekiranje i transesterifikaciju. Zbog jednostavnosti postupka i glicerola koji se dobiva kao komercijalno vrijedan nusproizvod, postupku transesterifikacije daje se prednost pred ostalima [4]. Postupak transesterifikacije je reakcija triglicerida iz masti ili ulja s bioalkoholom, čime se formiraju esteri (biodizel) i glicerol [5]. Najbolji način korištenja biljnih ulja kao goriva jest njegova pretvorba u biodizel. Biodizel se definira kao monoalkilni esteri dugolančanih masnih kiselina dobivenih iz obnovljivih sirovina, kao što su biljna ulja ili životinjske masti za uporabu u motorima na kompresiju i paljenje [6]. Za izgaranje biodizela navodi se u više izvora da ima niže emisije u usporedbi s naftnim dizelom, odnosno niže emisije SO_2, čađe, ugljičnog monoksida (CO) i ugljikohidrata (HC). Za emisije NOx iz biodizela navodi se da imaju raspon

1 INTRODUCTION

Diesel fuels have an essential function in the industrial economy of a country. They are used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment etc. The increasing prices of diesel fuel and decreasing reserves prompt us to search for alternative fuels. Alternative fuels should be easily available, environment friendly and techno-economically competitive. Such fuels include triglycerides (vegetable oils/animal fats) and their derivatives [1]. Vegetable oils have about 88 % of the energy content of petroleum diesel [2]. Both vegetable oils and their esters are promising alternative fuels for diesel engines.

The problems associated with vegetable oils during engine tests can be classified into two broad groups, operational and durability. Operational problems are related to starting ability, ignition, combustion and performance. Durability problems are related to deposit formation, carbonization of the injector tip, ring sticking and lubricating oil dilution. It has been observed that when straight vegetable oils are used for long hours, they tend to clog the fuel filter because of their high viscosity and insolubility. The high viscosity, polyunsaturated character and extremely low volatility of vegetable oils are responsible for the operational and durability problems associated with their utilization as fuels in diesel engines. The high viscosity of vegetable oils causes poor fuel atomization, large droplet size and thus high spray jet penetration. The jet tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed or mixed with the air required for burning in the combustion chamber. This results in poor combustion accompanied by decreased power and economy [3].

Various means to reduce these parameters include dilution, microemulsion, pyrolysis, catalyst cracking and transesterification. Because of the simple process and glycerol obtained as a by-product, which has commercial value, the transesterification process is preferred over others [4]. The tranesterification process is the reaction of the triglycerides of the fat or oil with bioalcohol to form esters (biodiesel) and glycerol [5]. The best way to use a vegetable oil as fuel is to convert it into biodiesel. Biodiesel is defined as the mono-alkyl esters of long-chain fatty acids derived from renewable feedstock, such as vegetable oils or animal fats, for use in compression-ignition engines [6]. The combustion of biodiesel has been reported in a number of works to have lower emissions than petroleum diesel, with lower emission of SO_2, soot, carbon monoxide (CO) and hydrocarbons (HC). NOx emissions from biodiesel are reported između plus ili minus 10 % u usporedbi s petrodizelom [7], [8] i [9].

U ovom se radu nastoji dati pregled mogućnosti korištenja čistih biljnih ulja i biodizela za ruralne energetske potrebe, raspoloživih postupaka i karakteristika goriva, te analiza učinka i ekonomska analiza proizvodnje biodizela.

2 ZNAČAJKE SELA I NJEGOVE ENERGETSKE POTREBE

U ovoj studiji ocjenjuje se isplativost biodizela za poljoprivredne namjene za jedno selo u ruralnom području Indije. Riječ je o selu Shivar u kotaru Amravati pokrajine Vidarbha države Maharashtra. Selo ima 1 500 jutara zemlje i 1 250 stanovnika (400 domaćinstava). Poljoprivreda je glavna gospodarska djelatnost (pamuk, soja i bijeli grah). Veliki i srednji zemljoposjednici posjeduju 80 % poljoprivrednog zemljišta, oko 25 do 30 jutara, dok mali i sitni zemljoradnici posjeduju od 1 do 7 jutara. Zastupljenost pojedinih kultura prikazana je u tablici 1.

to have a range of 10 % in comparison to petrodiesel [7], [8] and [9].

The present paper is an attempt to review the possibilities for using neat vegetable oils and biodiesel for rural energy requirements, the processes available, fuel characteristics, performance analysis and an economic analysis of biodiesel production.

2 VILLAGE CHARACTERIZATION AND ENERGY DEMAND

In the present study, the feasibility of biodiesel for agricultural applications is evaluated for a rural Indian village, Shivar, in the Amravati District, Vidarbha Region of the State of Maharashtra. This village has 1 500 acres of land and 1 250 people (400 households). The primary economic activity is agriculture (cotton, soy and gram). Large and medium-size landholders occupy 80 % of the agricultural land, owning about 25 acres to 30 acres each, while small and marginal farmers possess about 1 to 7 acres. The land occupied by various crops in the village is presented in Table 1.

Tablica 1 – Postotak zemlje zasađen različitim kulturama
Table 1 – Percentage share of land occupied by various crops

Kultura / Crop	[%] korištene zemlje / of land occupied
Mahunarke (azijski grah, slanutak/bijeli grah) / Pulses (Mung, Tur/Gram)	40
Pamuk / Cotton	35
Soja / Soybean	20
Suncokret / Sunflower	5

Kako se obrađivana zemlja ne navodnjava, opterećenje navodnjavanja iznosi nula. Stambeno korištenje odnosi se uglavnom na rasvjetu i radio/televiziju, dok se ostale energetske potrebe odnose na poljoprivredu, tj. na traktore i vršilice. U tablici 2 dan je sažetak procijenjenih energetskih potreba sela.

Since 100 % of the land under cultivation is non-irrigated, the irrigation load is nil. Residential uses are mostly for lighting and radio/television. Other energy uses involve energy required for agriculture, such as for powering tractors and threshers. Table 2 summarizes the estimated power requirement for the village.

Tablica 2 – Procjena potreba za energijom u kontekstu potrošnje dizela za rasvjetu i poljoprivredu
Table 2 – Estimated energy demand in terms of diesel for lighting and the agricultural sector

Rasvjeta stambena / Lighting Residential	0,08 kW/kućanstvo / house x 400	4 h/d / 4 h/d	128 kWh/d / 128 kWh/d	70 l dizela/d (25 550 l/god. / 70 l of diesel/d (25 550 lit/year)
Rasvjeta ulična / Lighting streetlights	0,06 kW/rasvjeta / light x 100	4 h/d / 4 h/d	24 kWh/d / 24 kWh/d	15 l dizela/dan (5 475 l/god.) / 15 l of diesel/d (5 475 l/year)
Poljoprivreda: Traktori / Agricultural: Tractors	3,75 l/jutro po / smjeni x 1 500 / 3,75 l/acre per shift x1 500	6 smjena/god. / shift/year		33 750 l dizela/god. / 33 750 l of diesel/year
Poljoprivreda: Vršilice / Agricultural: Threshers	5 l/jutro kulture x 1 500 / 5 l/acre of crop x 1 500	Srednja vrijednost / Mean value		7 500 l dizela/god. / 7 500 l of diesel/year

Odgovarajuće potrebe za dizelom za rasvjetu izračunavaju se uzimajući u obzir da toplinska učinkovitost motora iznosi 25 %. Poljoprivredne potrebe za dizelom evidentiraju se putem terenskih proba i zatim se izračunavaju tako da se uzima prosjek radova obavljanih traktorima i vršilicama. Budući da se dio poljoprivrednih djelatnosti obavlja pomoću volovske zaprege, opterećenje traktora razmjerno se smanjuje. Energetska potreba iznosi oko:

31 025 l (rasvjeta) + 41 250 l (poljoprivreda)
= 72 275 l dizela.

Kad se doda 5 % s obzirom na niže toplinske vrijednosti biodizela i 6 % na eventualno dodatno opterećenje, potražnja za biodizelom doseže 80 000 litara godišnje.

The equivalent diesel requirement for lighting purposes is calculated, assuming the thermal efficiency of the engine to be 25 %. The agricultural diesel requirement is recorded by conducting field trials and then calculated by taking the average of the work performed by tractors and threshers. Since part of the agricultural activity is shared by bullock-drawn implements, the tractor load is reduced somewhat to the said value. The energy required is about

31 025 l (lighting) + 41 250 l (agricultural)
= 72 275 l of diesel.

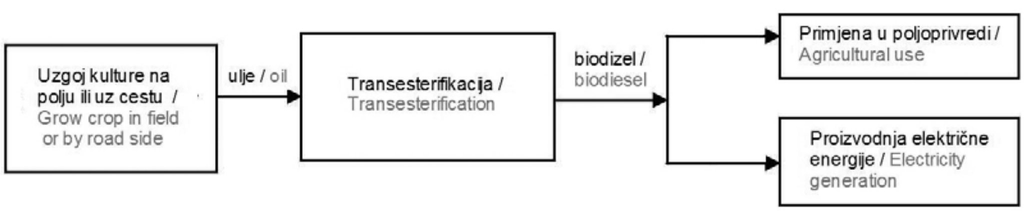
Adding 5 % due to the lower heating values of biodiesel and 6 % for the additional load, if any, the biodiesel requirement reaches 80 000 l/year.

3 BIODIZELSKI SUSTAV

Ruralni biodizelski sustav obuhvaća uzgoj uljarica, prešanje sjemenki u ulje, obradu ulja u biodizel transesterifikacijom, uporabu tog biodizela za pogon poljoprivrednih strojeva i proizvodnju električne energije pomoću agregata, kao što je prikazano na slici 1.

3 BIODIESEL SYSTEM

The rural biodiesel system involves growing oil crops, pressing the seeds into oil, processing the oil into biodiesel by transesterification, using this biodiesel to powr agricultural equipment and employing generators for electricity generation as shown in Figure 1.



Slika 1 — Opći dijagram protoka za ruralnu proizvodnju biodizela
Figure 1 — General flow diagram for rural biodiesel production

3.1 Ulja za proizvodnju biodizela

Glavni resursi biljnih ulja koji se uzgajaju u dotičnom području jesu pamuk, suncokret i soja, dok je ulje balanitesa potpuno neiskorišteni prirodni resurs. Balanites ili hingan je višenamjensko drvo poznato po svojoj mnogostrukoj uporabi kao ogrjevno drvo, drveni ugljen, građevno drvo, krma i dr. Plodovi su mu jestivi, a sjeme se drobi za proizvodnju ulja. U suhom stanju koštica teži 15 % do 18 % težine ploda, te sadrži 45 % do 47 % ulja [10]. U dotičnom području toga drveta ima u izobilju uz ceste. Prosječni prinos ulja od različitih uljnih sjemenki u tom području zajedno s jatrofom izračunava se putem istraživanja provedenih u selu, a podaci o prinosu uzimaju se kao prosjek prinosa zadnje tri godine. Sastav masnih kiselina tih ulja naveden je u tablici 3.

3.1 Oils for biodiesel production

The primary resources of vegetable oil cultivated in the said area are cotton, sunflower and soy, whereas balanites oil is a natural resource that is totally unutilized. Balanites or hingan is a multipurpose tree known for its many uses as fuel wood, charcoal, timber, fodder etc. The fruits are edible and the seeds are crushed to produce oil. On a dry basis, the kernel weight is 15 % to 17 % of the fruit, which contains 45 % to 47 % oil [10]. It is abundantly available in the said area along the roadside. The average oil yields from various oil seeds available in the said area along with jatropha were calculated by conducting a survey in the village and the data for the yield were taken as the average of the last three years' yield. The fatty acid compositions of these oils are given in Table 3.

Tablica 3 – Sastav masnih kiselina sirovog pamukovog sjemena, sojinog ulja, ulja suncokreta i ulja balanitesa
Table 3 – Fatty acid compositions of crude cottonseed, soybean, sunflower and balanites oils

Sastav masnih kiselina (težinski %) / Fatty acid Composition (wt %)	Ulje pamukovog sjemena / Cotton seed oil	Sojino ulje / Soybean oil	Ulje suncokreta / Sunflower oil	Ulje balanitesa / Balanites oil	Jatrofino ulje / Jatropha oil
Palmitinska kiselina / Palmitic ($C_{16:0}$)	11,67*	11,75	6,0	17	14,2
Palmitolinska kiselina / Palmitolic ($C_{16:1}$)	–	–	–	4,3	1,4
Stearinska kiselina / Stearic ($C_{18:0}$)	0,89**	3,15	3,0	7,8	6,9
Oleinska kiselina / Oleic ($C_{18:1}$)	13,27	23,26	17,0	32,4	43,1
Linolna kiselina / Linoleic ($C_{18:2}$)	57,51***	55,53	74,0	31,3	34,4
Linolinska kiselina / Linoleic ($C_{18:3}$)	–	6,31	–	7,2	–
Zasićena / Saturated	12,56	14,9	26,0	24,8	21,1
Nezasićena / Unsaturated	87,44	85,1	74,0	75,2	78,9

* 2002.: 22 – 28 [2]
** 2002.: 1 – 2 [2]
*** 2002.: 58 –59 [2]

Budući da je udio uzgoja ricinusa i suncokreta u dotičnom području manji zbog neizvjesnosti uroda, ta se ulja ne uzimaju u obzir za proizvodnju biodizela. Biodizel ulja pamukovog sjemena, sojinog ulja, ulja balanitesa i jatrofina ulja izrađen je i ispitan kako bi se ustanovile osobine i učinske karakteristike u dizel motoru. Izračunat je trošak proizvodnje biodizela s obzirom na tržišnu cijenu ulja pamukovog sjemena, sojinog ulja, ulja balanitesa i jatrofina ulja (tablica 4 i tablica 5).

Since the cultivation share of castor and sunflower in the said area is lower due to the uncertainty of the yield, these oils are not considered for biodiesel production. Biodiesels of cottonseed oil, soybean oil, balanites oil and jatropha oil were prepared and tested for properties and performance analysis of a diesel engine. The costs of making biodiesel, taking into account the market prices for cottonseed oil, soybean oil, balanites oil and jatropha oil, are calculated (Tables 4 and 5).

Tablica 4 – Trošak biodizela proizvedenog iz različitih ulja s obzirom na tržišnu cijenu ulja u rupijama [INR]
Table 4 – Costs of biodiesel produced from various oils, taking into account the market prices of oils in [INR]

Pojedinosti / Perticulars	**Soja** / Soyabean	**Pamukovo sjeme** / Cottonseed	**Balanites** / Balanites	**Jatrofa** / Jatropha
Trošak ulja (90 % prinosa estera / yield of ester) / Oil cost/l [INR/l]	55,00	45,00	45,00	50,00
Metanol / Methanol	4,05	4,05	4,05	4,05
Reagensi / Reagents	0,85	0,85	0,85	0,85
Električna energija / Electricity	0,20	0,20	0,20	0,20
Pročišćavanje / Purification	0,35	0,35	0,35	0,35
Radna snaga / Labor	1,20	1,20	1,20	1,20
Ukupno / Sub total	61,65	51,65	51,65	56,65
Dohodak od prodaje nusproizvoda (glicerola) / Revenue from by-product (glicerol) sales	4,35	4,35	4,35	4,35
Sveukupno (trošak minus dohodak po litri biodizela u rupijama / (Total (cost less revenue)/ litre of biodiesel in [INR/l]	57,3	47,30	47,30	52,3
Sveukupno (trošak minus dohodak po litri biodizela / Total (cost less revenue)/ litre of biodiesel [USD/l]	1,32	1,09	1,09	1,21

Tablica 5 – Prinos ulja po jutru za razne sorte uljnog sjemena u dotičnom području
Table 5 – Oil yields per acre for various oil seeds in the said area

Kultura / Crop	Prinos ulja / Oil yield [kg/ha]	Biodizel[a] / Biodiesel (BD) [kg/ha]	Prinos BD-a u l/jutro / BD yields l/acre[b]	Jutra zemlje potrebna za 80 000 l BD-a / Acres needed per 80 000 l of BD
Pamuk / Cotton	325	309	138	580
Soja / Soybean	446	424	188	426
Suncokret / Sunflower	952	904	401	200
Ricinus / Castor	1413	1342	596	134
Balanites / Balanites	1800	1710	760	106
Jatrofa* / Jatropha*	1892	1798	799	100

*još nema izvješća o sadnji iste u navedenom području, a – za 95 % iskorištenja, b – pretpostavlja se 0,9 kg/l /
*No plantation reported yet in the said area, a – 95 % recovery, b – 0,9 kg/l assumed

4 POKUSI

Ova studija podijeljena je na tri dijela, kako slijedi: prvo, esterifikacija, drugo, utvrđivanje svojstava i treće, analiza radnog učinka u motorima na kompresiju i ubrizgavanje i isplativosti u ruralnom području.

4.1 Transesterifikacija

Najčešći derivati poljoprivrednog ulja za gorivo jesu metilni esteri. Oni se formiraju transesterifikacijom ulja s metanolom ili etanolom u prisutnosti nekog baznog katalizatora da bi se dobili metilni ili etilni esteri i glicerol. U ovoj studiji koristi se

4 EXPERIMENTAL

The present study is divided into three basic parts: esterification, property determination, performance analysis of a CI engine and feasibility in a rural area.

4.1 Transesterification

The most common derivative of agricultural oil for fuel is methyl esters. These are formed by the transesterification of the oil with methanol or ethanol in the presence of a base catalyst to yield methyl or ethyl esters and glycerol. In the present study, a simple alkaline transesterification projednostavni postupak alkalne transesterifikacije da bi se proizveo metilni ester od ulja pamukovog sjemena, sojinog ulja i ulja balanitesa. Katalizator koji se koristi u toj reakciji jest kalijev hidroksid (KOH). Kemijska reakcija postupka transesterifikacije [11] prikazana je pomoću donjih triju konsekutivnih i reverzibilnih jednadžbi:

cess as discussed in [tobacco] is used to prepare methyl ester from cottonseed oil, soybean oil and balanites oil. The catalyst used in the reaction is potassium hydroxide (KOH). The chemical reaction of the transesterification process [11] is represented by the three consecutive and reversible equations below:

$$\text{Triglyceride} + \text{ROH} \xrightleftharpoons{\text{catalist}} \text{Diglyceride} + \text{R}^{I}\text{COOR}$$

$$\text{Diglyceride} + \text{ROH} \xrightleftharpoons{\text{catalist}} \text{Monoglyceride} + \text{R}^{II}\text{COOR}$$

$$\text{Monoglyceride} + \text{ROH} \xrightleftharpoons{\text{catalist}} \text{Glycerol} + \text{R}^{III}\text{COOR}$$

$$\text{Triglicerid} + \text{ROH} \xrightleftharpoons{\text{katalozator}} \text{Diglicerid} + \text{R}^{I}\text{COOR}$$

$$\text{Diglicerid} + \text{ROH} \xrightleftharpoons{\text{katalozator}} \text{Monoglicerid} + \text{R}^{II}\text{COOR}$$

$$\text{Monoglicerid} + \text{ROH} \xrightleftharpoons{\text{katalozator}} \text{Glicerol} + \text{R}^{III}\text{COOR}$$

4.2 Utvrđivanje gorivih svojstava estera i dizela

Metilni ester ulja pamukovog sjemena (CSOME), metilni ester sojinog ulja (SOME), metilni ester jatrofina ulja (JOME) i metilni ester ulja balanitesa (BOME) ispituju se kako bi se ustanovile njihove učinske i emisijske karakteristike u četverotaktnom dizel motoru s jednim cilindrom i to usporedilo sa standardnim podacima za dizel gorivo. Gustoća različitih goriva mjerila se pomoću boce za određivanje specifične težine. Kinematička viskoznost mjerila se pomoću Redwoodovog viskozimetra broj 1. Kalorična vrijednost i palište mjerili su se pomoću kalorimetrijske bombe, odnosno Pensky-Martensovog uređaja za određivanje temperature paljenja u zatvorenoj posudi. Dean-Starkov aparat korišten je za mjerenje sadržaja vode. Sadržaj koksa mjeren je Conradsonovim ispitivačem udjela ugljika. Za mjerenje sadržaja pepela u lonac za taljenje stavljen je uzorak goriva od 10 g i grijan na 600 °C u Muffleovoj peći u trajanju od dva sata. Pepeo koji se formirao nakon grijanja i izgaranja vagan je da bi se utvrdio sadržaj pepela u gorivu. Uređaj za određivanje stiništa korišten je za mjerenje stiništa različitih goriva. U tablici 6 prikazana su razna svojstva utvrđena za estere i dizel.

4.3 Analiza učinka motora

S obzirom na specifične značajke dizel motora, tj jedan cilindar, konstantan broj okretaja (1 500 o/min), vodeno hlađenje, direktno ubrizgavanje uz nominalnu snagu od 3,7 kW, za ovo istraživanje odabran je motor na kompresiju i ubrizgavanje koji je u širokoj uporabi u poljoprivrednom

4.2 Determination of the fuel properties of esters and diesel

Cottonseed oil methyl ester (CSOME), soybean oil methyl ester (SOME), jatropha oil methyl ester (JOME) and balanites oil methyl ester (BOME) were studied for the performance and emission characteristics of a single-cylinder four-stroke diesel engine and compared with baseline data for diesel fuel. The densities of the fuels were measured using a relative density bottle. Kinematic viscosity was measured using a No. 1 Redwood viscometer. Calorific value and flash point were measured using a bomb calorimeter and Pensky-Martens closed cup flash point apparatus, respectively. A Dean & Stark apparatus was used to measure water content. Carbon residue was measured using a Conradson carbon residue tester. To measure ash content, a 10 g sample of fuel was taken in a crucible and heated at 600 °C in a Muffle furnace for 2 h. The ash formed after heating and combustion was weighed to determine the ash content of the fuel. A pour point apparatus was used to measure the pour points of the various fuels. Table 6 presents the properties determined for the esters and diesel.

4.3 Engine performance analysis

Considering the specific features of a diesel engine, i.e. single cylinder, constant speed (1 500 rpm), water cooled and direct injection with a rated output of 3,7 kW, a CI engine that is widely used in the agricultural sector was selected for this investigation. The engine was coupled to an electrical generator. The major pollutants in the exhaust of a diesel engine are smoke and nitrogen oxides. A sektoru. Motor je spojen s agregatom. Glavni zagađivači u ispuhu dizel motora jesu dim i dušični oksidi. Nissan-Boschov mjerač dima korišten je za mjerenje gustoće ispušnog dima iz dizel motora.

Motor je radio najprije na dizel, potom na metilne estere biljnih ulja. Učinski podaci analizirani su zatim temeljem grafičkih prikaza toplinske učinkovitosti, omjera potrošnje goriva i proizvedene snage, te gustoće dima za sva goriva.

4.4 Prinos ulja za različite kulture u dotičnom području

Što se tiče uljnog prinosa pamuka, ricinusa, suncokreta i balanitesa, provedeno je detaljno ispitivanje u dotičnom području te je u svrhu proračuna razmatran prosječan prinos u posljednje tri godine, pri čemu su podaci o prinosu jatrofina ulja preuzeti iz dostupne literature.

5 REZULTATI I RASPRAVA

5.1 Transesterifikacija:

Izvedena transesterifikacijska reakcija pokazuje da, kad molarni omjer metanola i ulja iznosi oko 6:1 uz 1 do 1,25 težinskog postotka katalizatora KOH, dobiva se prinos estera veći od 95 %: bilanca mase za transesterifikaciju izvedenu za sva tri ulja na prosječnoj osnovi dana je u donjoj jednadžbi:

Nissan Bosch smoke meter was used to measure the smoke density of the exhaust from the diesel engine.

The engine was first operated on diesel and then on vegetable oil methyl esters. The performance data were analyzed from graphs recording the thermal efficiency, brake-specific fuel consumption and smoke density for all the fuels.

4.4 Oil yield for various crops in the region

To determine the oil yields of cotton, soybean, castor, sunflower and balanites, a detailed survey was conducted in the said area and the average yields of the last three years were used for calculation purposes. The jatropha oil yield was taken from the available literature.

5 RESULTS AND DISCUSSION

5.1 Transesterification

The transesterification reaction performed shows that methanol to oil in the molar ratio around 6:1 together with 1 wt % to 1,25 wt % of catalyst KOH results in an ester yield of over 95 %. The average mass balance for the transesterification of all three oils is given in the equation below:

$$\text{100 kg ulja + 20 kg metanola + 1,5 kg KOH} \Longrightarrow \text{96 kg biodizela + 25 kg glicerina}$$

$$\text{100 kg oil + 20 kg methanol + 1,5 kg KOH} \Longrightarrow \text{96 kg biodiesel + 25 kg glycerine}$$

5.2 Svojstva estera:

Značajna svojstva estera CSOME, SOME, JOME i BOME u usporedbi s dizelom prikazana su u tablici 6. Svojstva metilnih estera sojinog ulja, ulja pamukovog sjemena i ulja balantinesa posve su usporediva s dizelom.

5.2 Properties of esters:

The important properties of CSOME, SOME, JOME and BOME in comparison to diesel are given in Table 6. The properties of the methyl esters of CSO, SO and CBO are quite comparable to diesel.

Tablica 6 – Fizikalno-kemijska svojstva različitih metilnih estera
Table 6 – Physico-chemical properties of various methyl esters

Svojstvo / Property	CSOME	SOME	JOME	BOME	Dizel / Diesel
Gustoća / Density, [kg/m³]	882[1]	885	879	860	850
Viskoznost[a] / Viscosity[a], Cst [mm²/s]	4,0	4,08[2]	4,4	3,98	2,60
Kalorična vrijednost / Calorific value [MJ/kg]	40,32	39,76	39,85	39,65	43,5
Kiselost / Acid value [mgKOH/g]	0,32	0,15	0,28	0,34	–
Palište / Flash point [⁰C]	70[3]	145[4]	163	75	52
Stinište / Pour point [⁰C]	–3[5]	–16[6]	–10	–2,5	–17
Sadržaj vode / Water content [%]	0,03	0,04	0,02	0,04	–
Sadržaj pepela / Ash content [%]	0,02	0,012	0,014	0,017	0,01
Ostatak koksa / Carbon residue [%]	0,1	0,1[7]	0,1	0,19	0,15

a – mjereno pri 40 °C
1 – 873 (2001); 2 – (3,05 – 4,08); 3 – 110 (2001); 4 – (141 – 171) (2001); 5 – (–4); 6 – [(–3) – (–1)] (2001); 7 – 0,3 (2001)

5.3 Analiza učinka i emisije motora:

Pokusi na motoru obavljeni su uz različita opterećenja. Variranje različitih parametara motora i emisije grafički je prikazano u odnosu na primijenjeno opterećenje u kW.

5.3.1 Omjer potrošnje goriva i proizvedene snage (BSFC)

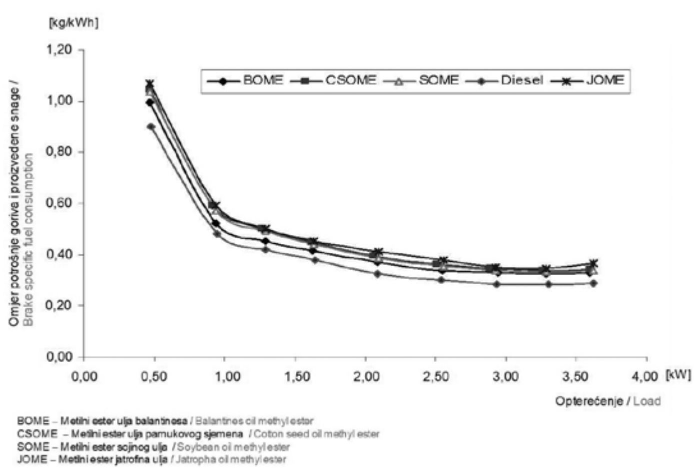
Variranje omjera potrošnje goriva i proizvedene snage s primijenjenim opterećenjem za različite estere prikazano je na slici 2. Trendovi su posve slični za sva goriva. Omjer potrošnje goriva i proizvedene snage (BSFC – Brake-Specific Fuel Consumption) za sve je metilne estere malo viši nego kod dizela u odnosu na primijenjeno opterećenje. To je zbog činjenice što esteri imaju manju kaloričnu vrijednost u usporedbi s dizelom i stoga treba nešto malo više goriva na bazi estera da bi se održala snaga.

5.3 Performance and emission analysis on an engine:

Engine experiments were conducted at various loads. The variation of the engine and emission parameters is plotted against the applied load in kW.

5.3.1 Brake-specific fuel consumption (BSFC)

Variations in brake-specific fuel consumption with applied load for various esters are shown in Figure 2. The trends are quite similar for all the fuels. The brake-specific fuel consumption for all the methyl esters is slightly higher than diesel, corresponding to the applied load. This is due to the fact that the esters have lower calorific values than diesel. Therefore, slightly more ester-based fuel is needed to maintain power.



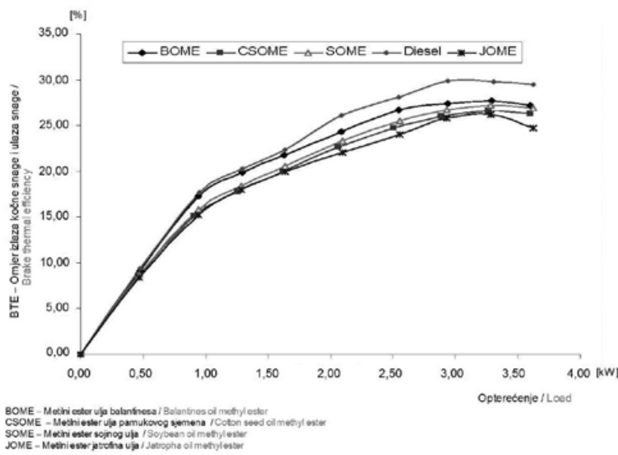
Slika 2 — Variranje BSFC-a s primijenjenim opterećenjem za različite estere
Figure 2 — Variation of BSFC with applied load for various esters

5.3.2 Omjer izlaza kočne snage i ulaza snage (BTE)

Variranje omjera izlaza kočne snage i ulaza snage (BTE - Brake Thermal Efficiency) s opterećenjem za CSOME, SOME, BOME, JOME i dizel prikazano je na slici 3. BTE jednog motora ovisi o više faktora osim toplinske vrijednosti, a specifična težina određenog goriva igra značajnu ulogu u poboljšanju tog omjera. BTE ima tendenciju porasta s porastom primijenjenog opterećenja. Na slici se jasno vidi da je do 20 % opterećenja BTE dizela i raznih estera isti, no kako se opterećenje povećava, krivulje BTE svrstavaju se prema donjoj strani. Glavni razlog nižeg BTE-a u slučaju estera jest porast potrošnje goriva i njegova niža kalorična vrijednost u usporedbi s dizelom. Maksimalni BTE od 27,12 % uočava se na opterećenju od 80 % za estere, što je 3,45 % manje nego kod dizela u istim uvjetima opterećenja. No, u cjelini esteri se ponašaju slično kao i dizel gorivo.

5.3.2 Brake Thermal Efficiency (BTE)

Variations in brake thermal efficiency (BTE) with load for CSOME, SOME, BOME, JOME and diesel are shown in Figure 3. The brake thermal efficiency of an engine depends on a number of factors but the heating value and specific gravity of a particular fuel play an important role in improving it. The BTE has a tendency to increase with an increase in the applied load. It can be clearly seen from the figure that at up to 20 % load conditions the BTEs of diesel and various esters are the same but as the load increases the brake thermal efficiency curves diversify toward the lower side. A prominent reason for lower BTE in the case of esters is the increase in fuel consumption and its lower calorific value in comparison to diesel. The maximum BTE of 27,12 % is observed at a load of 80 % for esters, which is 3,45 % lower than that of diesel for the same load conditions. However, overall the esters behave similarly to diesel fuel.



Slika 3 — Variranje BTE-a s primijenjenim opterećenjem za različite estere
Figure 3 — Variation of BTE with applied load for various esters

5.3.3 Dim

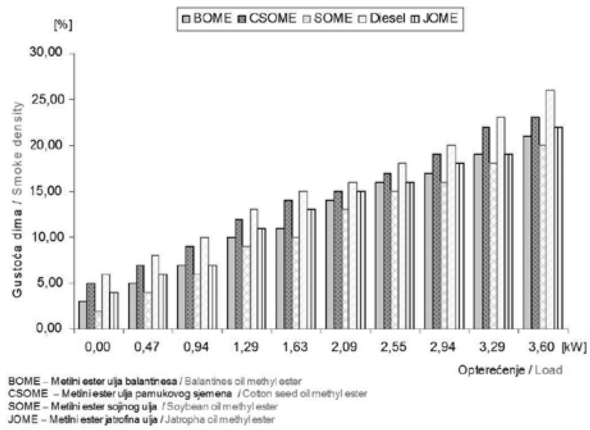
Dim iz motora funkcija je opterećenja motora. Na slici 4 vidljivo je da u istim uvjetima opterećenja esteri proizvode manje dima od dizela. Razlog je tome prisutnost molekula kisika u lancu estera, što pojačava ukupno izgaranje u usporedbi s dizelom.

Iz gornjih je rezultata posve jasno da esteri biljnih ulja mogu zamijeniti dizel kao gorivo.

5.3.3 Smoke

The smoke from an engine is a function of the engine load. From Figure 4, it can be seen that esters produce less smoke than diesel for the same load conditions. This is due to the presence of oxygen molecules in the esters chain, which enhances its complete combustion as compared to diesel.

From the above results, it is very clear that esters of vegetable oils can replace diesel as fuel.



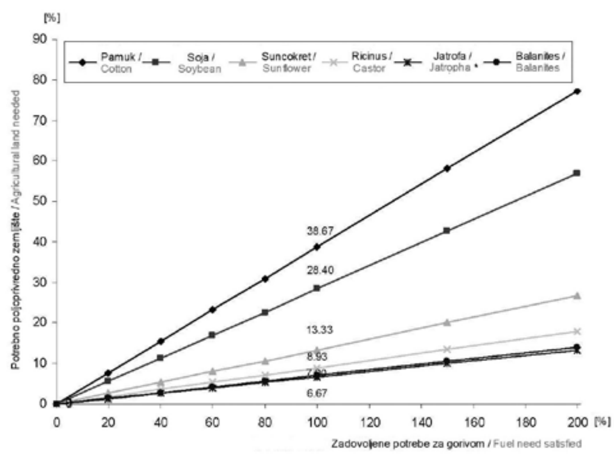
Slika 4 — Emisija dima u usporedbi s primijenjenim opterećenjem za različite estere
Figure 4 — Smoke emission in comparison to applied loads for various esters

5.4 Trošak ulja i korištenje zemlje radi zadovoljenja potreba sela za dizelom

U tablici 4 prikazan je trošak raznih metilnih estera proizvedenih prema tržišnoj cijeni ulja koja se mogu nabaviti u Indiji. Trošak biljnih ulja nešto je veći od dizela zbog rascjepkanosti tržišta biljnih ulja. Potrebe za zemljištem kako bi se 100 % ispunile potrebe za energijom dane su u tablici 5 zajedno s budućim povećanjem potreba za istom površinom, te procentualno korištenje zemlje grafički prikazano na slici 5 pokazuje da su potrebe za zemljom za različite kulture uljarica različite, i to najveće za pamuk, a najmanje za jatrofu. Premda su potrebe za zemljom pamuka, soje i balanitesa veće, te nam kulture daju jednako važne nusproizvode, pa je ukupna cijena ulja za iste nešto manja u usporedbi s jatrofom koja se sadi samo zbog ulja.

5.4 Oil cost and land utilization to meet village biodiesel demand

Table 4 shows the cost of various methyl esters produced as per the market price of the oils available in India. The cost of vegetable oils is slightly higher than diesel because of the fragmented nature of the vegetable oil market. The land required to meet 100 % of the energy requirement is given in Table 5 along with the future increase in demand for the same area. The percentage of land utilization plotted in Figure 5 shows the land required for various oil crops varies, the most for cotton and the least for jatropha. Although more land is required for cotton, soybean and balanites, these crops give us important by-products and hence their total oil cost is somewhat lower than for jatropha, which is planted only for the oil.



Slika 5 — Potrebe za poljoprivrednim zemljištem u odnosu na postotak zadovoljene potrebe za gorivom
Figure 5 — Agricultural land required against the % fuel requirement met

6 ZAKLJUČCI

Rezultati analize u ovom prilogu navode na zaključak da esteri biljnih ulja dobiveni od lokalno uzgajanih uljarica u ruralnom području mogu zamijeniti naftni dizel primjenom jednostavne tehnologije. Odabir ulja za proizvodnju biodizela ovisi o raspoloživosti i prinosu uljarica u dotičnom području. Cijena proizvedenog biodizela iznosi oko 1,17 USD, što iznosi više od 0,85 USD koliko stoji dizel. Potrebe za zemljom više su za pamuk u usporedbi s drugim uljaricama, no kako je pamuk značajna kultura u dotičnom području i uzgaja se uglavnom radi pamučnog vlakna, uzima se u obzir kao uljarica od interesa za ovo područje. Ima, međutim, značajnih koristi od biodizela, koje se ne smiju ispustiti iz vida. Biodizel se može smatrati klimatski neutralnim, jer ugljični dioksid koji se oslobađa u izgaranju prethodno se odvaja tijekom uzgoja kulture. Isto je tako značajna lokalna gospodarska djelatnost temeljena na uzgoju i obradi.

6 CONCLUSIONS

The results of the analyses presented in this paper demonstrate that esters of vegetable oils from locally grown oil crops in the rural region can be substituted for petroleum-based diesel using simple technology. The selection of the oil for biodiesel preparation depends on the availability and yield of the oil crops in the region of interest. The price of the biodiesel produced is about 1,17 USD, which is higher than 0,85 USD for diesel. More land is required for cotton than for the other oil yielding crops. However, since cotton is the major crop in the given region and is cultivated mainly for the cotton fiber, it is considered to be the oil of interest for this region. Nonetheless, there are important benefits from biodiesel that should not be overlooked. Biodiesel can be considered climate neutral because the carbon dioxide released during combustion was sequestered previously during crop growth. The local economic activity resulting from local growth and processing is important as well.

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