Vijeće Pomorskog fakulteta Kotor na sjednici održanoj dana 7.07. 2023. godine, na osnovu čl.31a. Pravila doktorskih studija razmatrajući godišnji izvještaj mentora, donijelo je sljedeću

O D L U K U

-I-

Usvaja se Godišnji izvještaj (drugi) o napredovanju doktoranda i radu studenta na sprovedenim istraživanjima i postignutim rezultatima, za mr Nadu Marstijepović, studenta doktorskih studija na studijskom programu Pomorske nauke.

Izvještaj je podnio mentor prof.dr Danilo Nikolić, red. prof. Pomorskog fakulteta Kotor Univerziteta Crne Gore.

-II-

Ova odluka stupa na snagu danom donošenja.

VIJEĆE POMORSKOG FAKULTETA KOTOR

Kotor, 7.07. 2023. godine

Broj 01-

Predsjedavajući Vijeća

DEKAN

Prof.dr Špiro Ivošević

GODIŠNJI IZVJEŠTAJ MENTORA O NAPREDOVANJU DOKTORANDA

Akademska godina za koju se podnosi izvještaj	2014/15 – 2022/23		
OPŠTI PODACI O DOKTORANDU			
Titula, ime, ime roditelja, prezime	mr Nada Marstijepović		
Fakultet	Pomorski fakultet Kotor		
Studijski program	Postdiplomske doktorske studije Pomorske nauke		
Broj indeksa	3/2011		
MENTOR/MENTORI			
Prvi mentor	Prof. dr Danilo Nikolić	Univerzitet Crne Gore – Pomorski fakultet Kotor	Naučna oblast motoru i vozila
Drugi mentor	-	-	-
EVALUACIJA DOKTORANDA*			
Koliko ste zadovoljni kvalitetom održanih susreta sa doktorandom?	[ ] 1 [ ] 2 [ ] 3 [ ] 4 [x] 5		
(Ako je prethodni odgovor „1“ ili „2“ dati obrazloženje i prijedloge za poboljšanje)			
Da li je definisan plan rada sa doktorandom?	[x] DA [ ] NE		
Da li je doktorand ostvario napredak prema predviđenom planu rada?	[x] DA [ ] NE		
(Ako je prethodni odgovor „ne“ dati obrazloženje i prijedloge za poboljšanje)			
Kvalitet napretka doktorandovog istraživačkog rada u periodu između dva izvještaja je:	[ ] 1 [ ] 2 [ ] 3 [x] 4 [ ] 5		
(Ako je prethodni odgovor „1“ ili „2“ dati obrazloženje i prijedloge za poboljšanje)			
Dati ocjenu doktorandove spremnosti za konsultacije.	[ ] 1 [ ] 2 [ ] 3 [ ] 4 [x] 5		
Dati ocjenu planiranja i izvršavanja godišnjih istraživačkih aktivnosti i stručnog usavršavanja doktoranda.	[ ] 1 [ ] 2 [ ] 3 [ ] 4 [x] 5		
Dati ocjenu napretka u savladavanju metodologije naučno-istraživačkog rada.	[ ] 1 [ ] 2 [ ] 3 [x] 4 [ ] 5		
Dati ocjenu o aktivnostima sprovedenim na pisanju i objavljivanju naučnih radova.	[ ] 1 [ ] 2 [ ] 3 [x] 4 [ ] 5		
Dati ocjenu doktorandovog generalnog odnosa prema studijama.	[ ] 1 [ ] 2 [ ] 3 [x] 4 [ ] 5		
Dati ocjenu ukupnog kvaliteta doktorandovog rada.	[ ] 1 [ ] 2 [ ] 3 [x] 4 [ ] 5		
(Ako je prethodni odgovor „1“ ili „2“ dati obrazloženje i prijedloge za poboljšanje)			

* Ocjene su: 1 – nedovoljan, 2 – dovoljan, 3 – dobar, 4 – vrlo dobar, 5 – odličan

SAGLASNOST ZA NASTAVAK STUDIJA	
Može li doktorand nastaviti studije?	☒ Da ☐ Da, uz određene uslove ☐ Ne
(Ako je prethodno dat odgovor pod „b)“ ili „c)“ dati obrazloženje i prijedloge za poboljšanje)	
Napomene	
(Popuniti po potrebi)	

IZJAVA MENTORA

U prethodnom periodu mr Nada Marstijepović je bila uključena kao aktivni istraživač u trogodišnjem 2012 -2015 nacionalnom naučno-istraživačkom projekatu "Mogućnosti proizvodnje tečnih biogoriva iz obnovljivih izvora i njihove primjene za pogon dizel motora na brodovima pomorske privrede i Mornarice Vojske Crne Gore" - BIOPOWER kojim je rukovodio mentor prof. dr Danilo Nikolić. Kao dodatak ovom prilogu je priložen Izvještaj o realizaciji ovog projekta za treću završnu godinu.

Kao rezultat prethodnih istraživanja na BIOPOWER projektu objavljeno je više naučno-istraživačkih radova tokom 2016. godine od kojih izdvajam one koji su objavljene u časopisu na SCI listi i u monografiji izdatoj od renomiranog izdavača, u kojim je mr Nada Marstijepović koautor:

1. Nikolić D., **Marstijepović Nada,** Cvrk S., Gagic R., Filipovic I. (2016) Evaluation of pollutant emissions from two-stroke marine diesel engine fueled with biodiesel produced from various waste oils and diesel blends. Brodogradnja/Shipbuilding: Theory and Practice of Naval Architecture, Marine Engineering and Ocean Engineering, Vol.67 No.4 December 2016. (online), pp 81-90. ISSN 0007-215X, eISSN 1845-5859. (https://doi.org/10.21278/brod67406)
2. Nikolić D., Cvrk S., **Marstijepović Nada**, Gagic R., Filipovic I., Influence of Biodiesel Blends on Chracteristics of Gaseous Emissions From Two Stroke, Low Speed Marine Diesel Engines. Advances in Application of Industrial Biomaterials pp 49 - 63. Print ISBN 978-3-319-62766-3, online ISBN 978-3-319-62767-0. Izdavač: Springer. 2017 (https://doi.org/10.1007/978-3-319-62767-0_3)

Kako su u međuvremenu izmijenjena Pravila studiranja na doktorskim studijama UCG, više nije bilo dovoljan uslov da doktorand bude koautor već isključivo prvi autor, pristupilo se izradi dodatnog naučno-istraživačkog rada u cilju zadovoljenja novonastale situacije. Rad u kojem je mr Nada Marstijepović prvi autor je objavljen 2022. godine u časopisu Thermal Science:

3. **Marstijepović Nada**, Cvrk S., Gagic R., Filipovic I., Nikolić D., Application of Biodiesel Derived From Olive Oil Production Wastes at Marine Diesel Engine and Evaluation of Gasseous Emission Trends, Thermal Science, 2022, https://doi.org/10.2298/TSCI220707218M (https://thermalscience.vinca.rs/online-first/5094) ;

U Kotoru, 15/5/2023

Ime i prezime prvog mentora

Prof. dr Danilo Nikolić

Prilog dokumenta sadrži:

- Objavljeni rezultati rada na izradi doktorske disertacije (za drugi izvještaj mentora)

Crna Gora
Ministarstvo nauke

Broj: 01-
Podgorica, 2015. godine.

I Z V J E Š T A J
o radu na nacionalnom naučnoistraživačkom projektu za treću– završnu istraživačku godinu

Naziv projekta

"Mogućnosti proizvodnje tečnih biogoriva iz obnovljivih izvora i njihove primjene za pogon dizel motora na brodovima pomorske privrede i Mornarice Vojske Crne Gore"

Rukovodilac projekta

Prof. dr Danilo Nikolić

Ustanova – nosilac istraživanja

Univerzitet Crne Gore – Fakultet za pomorstvo Kotor

Datum početka projekta: _01.04.2012 _
Datum završetka projekta: _30.12.2015 _
***Vrsta istraživanja** (1 - osnovna, 2 – primijenjena, 3 – razvojna)* _2_

M.P. **Rukovodilac ustanove**

Rimski trg 46, 81000 Podgorica, Crna Gora
Tel: (+382) 20 482 145; Fax: (+382) 20 234-168; E-mail: kabinet@mna.gov.me;
Web:www.mna.gov.me

1. Izvještaj o radu na projektu za III godinu istraživanja

1.1 Ukratko opisati sadržaj istraživanja realizovanih u izvještajnoj godini

U trećoj godini istraživanja obrađeni su rezultati dobijeni tokom prve i druge godine istraživanja.

U ovoj istraživačkoj godini je nabavljen uređaj za određivanje oksidacione stabilnosti biodizela, te su dodatna ispitivanja vršena na ovom uređaju.

Jedan dio prethodnih laboratorisjkih istraživanja je ponovljen u cilju potvrđivanja rezultata.

Održavana je radionica iz tematske oblasti alternativnih goriva i njihove primjene u transportu – u Okviru **IV SIMPOZIJUMA LABORATORIJA ZA NAFTU I NAFTNE DERIVATE U REGIONU** održanog 28.-29. maja 2015 na Fakultetu za pomorstvo u Kotoru.

Članovi radnog tima su bili gosti na Nor-Shipping najvećem sajmu pomorstva u Oslu, Norveška, od 2 do 5 juna 2015.godine, na kojem su uspostavljeni kontakti sa proizvođačima biogoriva za upotrebu u pomorstvu, kao i potencijalnim korisnicima.

Nakon potvrde svih rezutata urađena je njihova statistička obrada.

Rezultati istraživanja su predstavljeni na radionici posvećenoj biogorivima i napisani naučnoistraživački radovi koji će biti objavljeni kao dio monografije i u časopisu na Sci listi.

(max. 3 strane)

2. Postignuti ciljevi istraživanja u izvještajnoj godini

2.1 Očekivani rezultati (navedeni u prihvaćenoj prijavi projekta):

U trećoj godini istraživanja, planirane su sledeće aktivnosti:

- Objavljivanje rezultata istraživanja u međunarodnim časopisima i konferencijama;

- Održavanje okruglog stola ili konferencije iz tematske oblasti alternativnih goriva i njihove primjene u transportu;

- Doktorska disertacija doktoranta – saradnika na istraživanju mr. sci. Nade Marstjepović. Pismeni oblik Disertacije bi trebao biti priveden kraju do polovine 2015. godine na Fakultetu za pomorstvo (tematska oblast – inovativne tehnologije proizvodnje tečnih biogoriva);

- Doktorska disertacija doktoranta – saradnika na istraživanju Pukovnika mr. sci. Seada Cvrka. Pismeni oblik Disertacije bi trebao biti priveden kraju do polovine 2015. godine na Fakultetu za pomorstvo (tematska oblast – primjena biogoriva kao pogonskog goriva za dizel motore brodova Mornarice Vojske Crne Gore);

2.2 Ostvareni rezultati (sumarno):

- Objavljivanje rezultata istraživanja u međunarodnim časopisima – Napisana su i predata na recenziju dva naučnoistraživačka rada u knjizi **Advances in Application of Industrial Biomaterials** kojij je izdavač SPRINGER, kao I jedan u časopisu **Atmospheric Pollution Research** koji se nalazi na SCi listi (vidjeti prilog)

- Održavanje okruglog stola ili konferencije iz tematske oblasti alternativnih goriva i njihove primjene u transportu – u Okviru **ČETVRTI SIMPOZIJUM LABORATORIJA ZA NAFTU I NAFTNE DERIVATE U REGIONU** održanog 28.-29. maja 2015 na Fakultetu za pomorstvo u Kotoru održana je radionica u vezi potencijala primjene tečnih biogoriva u transportu (u prilogu dostavljen program simpozijuma). Takođe, prof.dr Danilo Nikolić i doc. Dr Špiro Ivošević su bili gosti na Nor-Shipping najvećem sajmu pomorstva u Oslu, Norveška, od 2 do 5 juna 2015.godine, na kojem su uspostavljeni kontakti sa proizvođačima biogoriva za upotrebu u pomorstvu, kao i potencijalnim korisnicima. (ove aktivnosti su kofinansirane od strane Fakulteta za pomorstvo)

2.3 Obrazložiti ukoliko nijesu postignuti očekivani rezultati:

- Doktorska disertacija doktoranta. Kako je Pravilima doktorskih studija na Univerzitetu Crne Gore predviđeno da prilikom formiranja komisije za ocjenu doktorskog rada kandidat mora imati objavljen minimum jedan rad iz oblasti istraživanja u časopisu na SCI listi, to će se procedura oko doktorskog rada nastaviti sa objavljivanjem članaka koji su već poslati i čekaju recenzije.

(max. 3 strane)

3. Postignuti rezultati projekta u izvještajnoj godini

3.1.Navesti naučne radove i druge postignute rezultate projekta u izvještajnoj godini

**** razvrstati radove pojedinačno za Rukovodioca projekta i svakog aktivnog istraživača po kategorijama i izvršiti obračun koeficijenta K u skladu sa Pravilnikom - preuzmi (str. 4-6);***

**** navedene radove priložiti kao dokaz u elektronskoj formi, uz Izvještaj;***

Aktivni istraživači koji su angažovani u trećoj godini projekta su:

1. Prof dr Danilo Nikolić, rukovodilac projekta
2. Prof dr Slavica Perović
3. Prof dr Ivan Filipović
4. Docent dr Radoje Vujadinović
5. Docent Aleksandar Ivanović

Napomena: Broj angažovanih aktivnih istraživača za III godinu je ograničen na 6

Aktivni istraživač red. br. 1 (Rukovodilac projekta)

1. **Danilo Nikolic**, Nada Marstijepovic, Sead Cvrk, Radmila Gagic, An investigation of using biodiesel/diesel blends on the exhaust emission of a marine diesel engine, a paper is to be published in a book/monography **Advances in Application of Industrial Biomaterials** by SPRINGER (to be published)
2. **Danilo Nikolic**, Sead Cvrk, Nada Marstijepovic, Radmila Gagic, Ivan Filipovic, gaseous emission evaluation of two stroke marine diesel engine fueled with biodiesel produced from various waste oils and diesel blends, paper is submitted in **Atmospheric Pollution Research** (to be published).
3. Castells Marcella, Francesc Xavier Martínez de Osés, Ordás Santiago; Borén Clara, **Nikolic Danilo**, "Modernizing And Harmonizing Maritime Education In Montenegro And Albania" Proceedings, 16th IAMU Annual General Assembly, Opatija, Croatia, 2015
4. **Nikolić Danilo** "Cruise ship and environmental issues", Međunarodna konferencija Montenegro Sustainable Maritime Competence Development Initiative, Kotor, 2014.
5. **Nikolić Danilo** "Stanje voznog parka lakih motornih vozila u vezi sa emisijama CO_2 i potrošnjom goriva", Konferencija "Ekonomična potrošnja goriva u Crnoj Gori", Podgorica, novembar 2015.

Aktivni istraživač red. br.2

1. **S.M. Perovich**, M. Djukanovic, T. Dlabac, **Danilo Nikolic** and M. Calasan, Concerning an Analytical Improvement of the Solar Cell Junction Ideality Factor Estimation, Applied Mathematical Modelling, ISSN:0307-904X, 13. Nov.2014.
2. **Slavica M. Perovich** and Martin P. Ćalasan, The Special Trans Functions Theory For The Degree Of The Nuclear Fuel Burn-Up Estimation, The Third International Conference On Radiation And Applications In Various Fields Of Research, RAD, June 2015, Budva, Montenegro.
3. Martin P. Ćalasan, Rada Dragović Ivanović and **Slavica M. Perovich**, Determining the STFT Exact Formulae to the Transistor Thermal Sensitivity Estimations, 4nd Mediterranean Conference on Embedded Computing MECO - 2015 Budva, Montenegro.

Aktivni istraživač red. br.3

1. **Filipović I.**, Pikula B., Kepnik G.: "Impact of Physical Properties of Mixture od Diesel and Biodiesel Fuels on Hydrodynamic Characteristics of Fuel Injection System", Journal Thermal Science, Vol. 14, No. 1 , pp.143-153
2. Bibić Dž., **Filipović I.**, Hribernik A., Pikula B.: "Heat Release Characteristic in IC Engines With M-tipe Fuel Injection Procedure", 47th International Symposium FUELS 2014, Šibenik

Aktivni istraživač red. br.4

1. Bošković Lj., Stanojević M., Drašković I., Karadžić U., **Vujadinović R.**, Iskustvo u procesu razvoja ideje, projektovanja i realizacije MHE „Vrelo“, CIGRE 2015, Budva, 2015
2. **Vujadinović R.**, Petrovic S.:"Use of models for the calculation of CO2 emissions for passenger cars in Montenegro", 17th Symposium on Thermal Science and Engineering of Serbia “Energy – Ecology – Efficiency” SIMTERM 2015, Sokobanja, 2015. pp 1100=1114
3. **Vujadinović R**.:"Activities of the Administration of Montenegro’s Capital City, Podgorica, for Energy More Efficient Road Traffic", 17th Symposium on Thermal Science and Engineering of Serbia “Energy – Ecology – Efficiency” SIMTERM 2015, Sokobanja, 2015. pp 1089=1099
4. **Vujadinović R**., Karadžić U.:”Education of local governments as a way towards sustainable development of the countries of the Western Balkans - Case Study of Montenegro”, International Conference on Sustainable Development – ICSD2015, Belgrade, 2015, CD Proceedings.

Aktivni istraživač red. br.5

1. **A. B. Ivanovic** and A. R. Ivanovic, Pravci Razvoja Forenzike U Državama Evrope, časopis PRAVNE TEME, Godina 1, Broj 2, str. 170-184
2. **Aleksandar B. Ivanovic** i Aleksandar R. Ivanovic, Evropski Dokazni Nalog i Evropski Nalog Za Istragu u Krivičnim Stvarima, Pravne teme No 5/2015
3. **A. B. Ivanovic** and A. R. Ivanovic, Method of selection of forensic experts in the countries of Europe, European academy of Forensic Sciences 2015 (Zbornik radova)
4. Ivana Bjelovuk, **Aleksandar Ivanovic**, Milan Zarkovic, Gunshot Residues In Determining a Shooting Distance In Forensics, The Days of Archibald Rais Zbornik radova Tom 3 / Conference Proceedings Vol. 3, (Medjunarodni skup u organizaciji Kriminalisticko policijske akademije u Beogradu),
5. **Aleksandar B. Ivanovic**, Pravni Aspekt Prihvatanja Forenzickih Metoda, Savremene tendecije u obrazovanju pravnika, Zbornik radova
6. **Aleksandar B. Ivanović**, Aleksandar R. Ivanović, Forenzika Kao Naučna Disciplina, PERJANIK No 32 (izdavac Policijska Akademija Crne Gore)

3.2 Popuniti tabelu za Rukovodioca projekta i sve aktivne istraživače angažovane na projektu u prvoj godini (u skladu sa navedenim koeficijentima)

I godina projekta	Oznaka koef. K	K 1.1	K 1.2	K 2.1	K 2.2	K 2.3	K 2.4	K 3.1	K 3.2	K 3.3	K 4.1	K 4.2	K 5.1	K 5.2	K 6.1	K 7.1	K 8.1	K 8.2	UKUPNO
istraživač red. Br.1	Broj radova			1				1			2	1							
	Ukupno K			(5)				(5)			2.5	0.5							13
istraživač red. Br.2	Broj radova							1			2								
	Ukupno K							5			3								8
istraživač red. Br.3	Broj radova							1			1								
	Ukupno K							5			0.6								5.6
istraživač red. Br.4	Broj radova										4								
	Ukupno K										6.5								6.5
istraživač red. Br.5	Broj radova								3	1	2								
	Ukupno K								12	1	2								15

3.3 Navesti indikatore produktivnosti rada na projektu ostvarene u toku treće istraživačke godine

Naziv	Oznaka	Vrsta rezultata	Broj ostvarenih radova / rezultata *(upisati ostvareni broj jedinica u polja)*
K 1. Monografija	K 1.1.	Međunarodnog značaja	
	K 1.2.	Nacionalnog značaja	
K 2. Poglavlja i pregledni radovi	K 2.1.	Poglavlje u monografiji međunarodnog značaja	1
	K 2.2.	Pregledni rad u časopisumeđunarodnog značaja	
	K 2.3.	Poglavlje u monografijinacionalnog značaja	
	K 2.4.	Pregledni rad u časopisu nacionalnog značaja	
K 3.Objavljeni radovi	K 3.1.	U vodećem časopisumeđunarodnog značaja	3
	K 3.2.	U časopisu međunarodnog značaja	3
	K 3.3.	U časopisu nacionalnog značaja	1
K 4. Radovi na naučnim skupovima	K 4.1.	međunarodnog značaja štampan u cjelini	11
	K 4.2.	nacionalnog značaja štampan u cjelini	1
K 5. Uvodno predavanje na naučnom skupu	K 5.1.	Međunarodnog značaja	
	K 5.2.	Nacionalnog značaja	
K 6. Disertacija iTeza (odbranjena)	K 6.1.	Doktorska disertacija	
	K 6.2.	Magistarska teza	
K 7. Patenti	K 7.1.	Realizovan patent	
K 8. Inovativno rješenje	K 8.1.	Novi proizvod ili tehnologija u proizvodnji, programski sistem, sorta, linija, rasa, soj	
	K 8.2.	Bitno poboljšanje postojećeg proizvoda i tehn,prototip nove metode, nove genetske potrebe, mikroorganizmi	

Napomena: Cjelovitu tabelu sa objašnjenjima vrste rezultata vidjeti u Pravilniku (str. 4-6)

3.4 Mobilnost istraživačkog tima

(M*obilnost se odnosi na boravak crnogorskihistraživača van Crne Gore*, *kao i boravak inostranih istraživača u Crnoj Gori, koja je finansirana sa projekta)*

- Broj članova projektnog tima koji su učestvovali u mobilnosti 5
- Broj dana članova projektnog tima u inostranstvu - ukupno 2
- Broj inostranih istraživača koji su došli u Crnu Goru u okviru projekta 0
- Broj dana inostranih istraživača u Crnoj Gori - ukupno 0
- Ostalo (navesti)

3.5 Saradnja sa poslovnim sektorom

3.5.1. Da li je projektom bila predviđena saradnja sa poslovnim subjektima

Da +

Ne

3.5.2. Da li je kroz projekat ostvarena saradnja sa poslovnim subjektima

Da

Ne +

3.5.3. Ukoliko je saradnja ostvarena, navedite njene glavne rezultate:

3.5.4. Ukoliko saradnja nije ostvarena, a bila je planirana, navedite razloge njenog izostanka:

U okviru projekta je bila predviđena saradnja između Fakulteta i institucija koje se bave pomorskim transportom putnika u teritorijalnim vodama Crne Gore. Saradnja je predviđala ukazivanje na mogućnost upotrebe biodizela za pogon plovila. Međutim, usljed pada cijena dizel goriva na tržištu i činjenice da su rezerve otpadnih materija za proizvodnju biodizela u Crnoj Gori ograničene kao i da cijena proizvodnje litra biodizela veća od tržišne cijene dizel goriva, dovelo je do odustajanja od saradnje za neko vrijeme. Što se tiče saradnje sa Ministarstvom odbrane, Mornaricom Vojske Crne Gore pokazana je velika zainteresovanost za upotrebu biodiezela za pogon svojih plovila, ali je za to neophodno obezbijediti bezbjedne zalihe ovog goriva. U svakom slučaju, u ovim institucijama su predstavljeni benefiti upotrebe biodizela proizvedenog od otpadnih materija koja se nalaze u Crnoj Gori.

3.5.5. Navedite (ukoliko je bilo) pojedinačne partnere iz poslovnog sektora:

- -

3.5.6. Ukoliko ste imali saradnju, navedite probleme na koje ste naišli u toku rada, kao i Vaše prijedloge kako bi se oni mogli prevazići:

3.6 Ostalo (navesti po slobodnom izboru)

4. Finansijski izvještaj o utrošku sredstava za realizaciju projekta u trećoj istraživačkoj godini

4.1. Izvještaj o ukupno odobrenim sredstvima za realizaciju projekta

	Planirana sredstva za realizaciju cijelog projekta	Sufinansiranje ministarstava	Sufinansiranje ustanove/trećih strana
Odobreno sufinansiranje od strane ministarstava	57.109,47 €	39.976,63 €	17.116,49 €
Sufinansiranje ustanove	0 €	0 €	0 €
Sufinansiranje trećih strana	0 €	0 €	0 €
Ukupno	57.109,47 €	39.976,63 €	17.116,49 **€**

4.2 Izvještaj o utrošku sredstava projekta za treću istraživačku godinu

	NAKNADE ZA RAD NA PROJEKTU	MATERIJALNI TROŠKOVI	REŽIJSKI TROŠKOVI	UKUPNO
Planirano za treću godinu	9.262,38 €	3.400,00 €	924,24 €	13.558,62 €
Utrošeno u trećoj godini	11.294,49 €	28.974,00 €	0	40.268,49 €
Sufinansiranje ministarstava u III godini	9.346,99 €	2.646,00 €	0	11.992,99 €
Sufinansiranje ustanove / trećih strana u III godini	1.947,50 €	26.328,00 €	0	28.275,50 €
Preostala uplaćena sredstva ministarstava				

Navesti sufinansijere projekta u trećoj godini – tj.treće strane (pored ministarstava i ustanove)

- UCG, Fakultet za pomorstvo FZP (naknade, materijalni troškovi)
- UCG, Fakultet za pomorstvo FZP (rancimat, uređaj za određivanje oksidacione stabilnosti biodizela)
- Putni troškovi na prostoru Crne Gore su plaćani iz sopstvenih sredstava članova radnog tima
- Putni troškovi van Crne Gore (Norshipping 2015) su plaćeni iz drugih sredstava koji nijesu prikazani u ovom obračunu

4.3 Materijalni troškovi – Iznos troškova prema specifikaciji

Putni troškovi realizovani sa projekta	Popuniti podatke o posjeti - mjesto, datum, red.br. istraživača i troškovi po pojedinačnom putovanju, realizovani sa projekta	Ukupnitroškovi
Crna Gora		*0*
Zemljeregiona (Zapadni Balkan)		*0*
Evropa		*0*
Ostalezemlje		*0*
	Ukupno	*0*

Oprema, materijal, usluge, ostalo	Specifikacija nabavki u toku izvještajne godine	Iznos
Troškovinabavkeopreme		27.194,00 €
Materijali i hemikalije		
usluge		330,00 €
Ostalitroškovi		1.450,00 €
	Ukupno	28.974,00 €

Napomena:
Dio materijalnih troškova je raspoređen po Odluci br. 01-3277 od 30.01.2015.g na telefonske račune pojedinih članova radnog tima (Danilo Nikolic, Sead Cvrk, Nada Marstijepovic), administracije Fakulteta (sekretar Vera Popovic, sef racunovodstva Dana Vujic, racunovodja Katarina Saranovic) i sistem inženjera (Zeljko Pekic) na Fakultetu za pomorstvo Kotor, kao vid telefonskih troškova tokom realizacije projekta (Odluka priložena).

****

NAPOMENA 1:

Potrebno je Ministarstvu nauke dostaviti sljedeće:

1. ***Izvještaj o radu na nacionalnom naučnoistraživačkom projektu za treću istraživačku godinu***
2. ***Finansijski izvjestaj - III godina***
3. ***Kopije računa i putnih naloga realizovanih sa sredstava projekta (u štampanoj ili elektronskoj formi)***
4. ***CD/DVD/USB u prilogu Izvještaja, na kojem će se nalaziti:***
   - ***Dokumenta navedena pod 1,2,3 (1. u Word-u a 2. U Excel-u)***
   - ***Kopije računa i putnih naloga (ukoliko se ne dostave u štampanoj formi) i***
   - ***Objavljene naučne radove i druge realizovane rezultateprojekta, kao dokaz***
5. ***Jedan štampani primjerak i jedan elektronski primjerak (u Word-u) Završnog elaborata.***

ROK ZA DOSTAVLJANJE Izvještaja o radu na nacionalnom naučnoistraživačkom projektu za treću – završnu istraživačku godinu: 30. decembar 2015. godine do 16 časova.

ROK ZA DOSTAVLJANJE ZAVRŠNOG IZVJEŠTAJA / ELABORATA*:* 01. februar 2016. do 16 časova

PRILOG: Predati radovi za objavljivanje iz oblasti istraživanja (2)

GASEOUS EMISSION EVALUATION OF TWO STROKE MARINE DIESEL ENGINE FUELED WITH BIODIESEL PRODUCED FROM VARIOUS WASTE OILS AND DIESEL BLENDS

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GASEOUS EMISSION EVALUATION OF TWO STROKE MARINE DIESEL ENGINE FUELED WITH BIODIESEL PRODUCED FROM VARIOUS WASTE OILS AND DIESEL BLENDS

Abstract

Shipping represents a significant source of diesel emissions, which affect global climate, air quality and human health. Around two-thirds of these emissions occur within 400 km of coastlines, leading to reduced air quality in coastal areas and harbours. Biofuels could be one of the options to realize lower carbon intensity in shipping and also reduce its impact on environment. Biofuels have attracted much attention as they are renewable and can be produced locally. The main drawbacks of biofuels are the limitation of raw materials and production costs. In Southern Europe, some wastes, such as used frying oils and waste from olive oil production, appear to be attractive candidates for second generation of biodiesel production. This study investigates the influence of biodiesel blends on the characteristics of gaseous emissions from two stroke marine diesel engine. The engine was fuelled with diesel fuel and blends containing 7 % and 20 % of three types of second generation biodiesel from olive husk oil, waste frying sunflower oil, and waste frying palm oil. According the results, for different engine speeds, emissions of NOx, SOx, CO and CO_2 are lower when using blended fuels than diesel fuel.

Key words: Olive husk oil; Waste frying oils; Biodiesel; Two stroke marine diesel engine; Gaseous emission;

1. Introduction

The shipping sector has become a key component of the world's economy. The world fleet of sea going merchant ships comprises of over 104000 ships (International Maritime Organization, IMO, 2012). At the same time, ships are responsible for 13 %, 15 % and 2,2 % on annual average basis (from 2007 - 2012) of global sulfur oxide (SOx), nitrogen oxides (NOx) and carbon dioxide (CO_2) emissions, respectively (IMO, 2014). Air pollution from shipping is regulated by IMO through its International Convention for the Prevention of Pollution from Ships, MARPOL, and its Annex VI. Annex VI of this Convention sets limits on NOx and SOx emissions from ship exhaust, prohibits deliberate emissions of ozone depleting substances, regulates shipboard incineration, and emissions of volatile organic compounds VOC from tankers. Recently, IMO also adopted measures to reduce greenhouse gas emissions from ships through new chapter to MARPOL Annex VI entitled "Regulations on energy efficiency for ships" which includes a suite of mandatory technical and operational measures, with the aim of improving the energy efficiency of new ships through improved design and propulsion technologies, and for all ships by improving operational measures (IMO, 2015).

As a renewable source of energy, biofuels have favourable impact on the environment and can replace in some extent fossil fuels. The main drawbacks of biofuels are limitation of raw materials and production costs. Biodiesel could be one option in reducing emission of pollutants and greenhouse gasses in shipping sector. Nowadays, there are very little practical experiences with the use of biodiesel in the shipping. The implementation of biodiesel as marine fuel was tested in few research programs, where some advantages of biodiesel over fossil fuels were noted (Florentinus et al., 2011): blending can be made up to 100% of biodiesel, reduction of particulate emissions, no adverse effects detected in marine engines, no bacterial formations were not detected in tanks of biofuels during storage for more than 6 months. These programs noted also some potential problems (Florentinus et al., 2011): biodiesel acts as a solvent and tends to soften and degrade certain rubber and elastomer compounds that are often used in older engines, and biodiesel can easily remove deposits remained after diesel fuel in the system and thus to clog filters. The IMO study (IMO, 2007) concluded that low blends of biodiesel up to 20% (B20) could be used without any fuel system degradation. Previously mentioned studies were conducted on 4-stroke medium speed marine diesel engines.

In this study, influence of biodiesel (FAME) and diesel fuel blends on the characteristics of exhaust emissions from marine diesel engine was investigated. For this study, a reversible two-stroke, low speed, cross-flow scavenging, 4 cylinder marine diesel engine was used. The engine was fuelled with pure low sulphur diesel fuel and blends containing 7 % and 20 % of three types of biodiesel. Three types of biodiesel were produced in lab conditions, using olive husk oil, waste frying sunflower oil, and waste frying palm oil. Base-catalysed trans-esterification was implemented for biodiesel production.

2. Experimental procedure

For this study, a marine diesel engine was employed. It is a reversible 2-stroke, 4 - cylinder, marine diesel engine with cross-flow scavenging, model ALPHA 494 R produced by LITOSTROJ Ljubljana (Slovenia) under Burmeister licence, Table 1. Engine was installed on ship Jadran. The engine can be regarded as a low speed because the maximum engine speed is 320 min^{-1}, making maximum power of 390 kW. Since it is an old type of marine diesel engine, there are no any after-treatment devices installed, neither engine control technology for reducing pollutant emission. Such situation is preferable for investigation of direct influence of biodiesel on exhaust emission from marine diesel engines.

The direct propulsion system of the ship makes the engine, propeller shaft that is connected to the output coupling, and fixed pitch propeller. Tests were conducted when the ship was berthed in the harbour, on the same day in order to have the same atmospheric conditions. Running the engine when the ship is berthed is called a heavy propeller condition. Tests were carried out on three regimes of engine speeds, 150 rpm, 180 rpm and 210 rpm.

Table 1 Marine diesel engine specifications

Engine producer	Engine model	Working principle	Max power	Cyl. No.	Stroke/Bore

Burmeister	Alpha 494-R	2-stroke	390 kW @ 320 rpm	4	490mm/290mm

During operation of the engine, power is constantly changing depending on the connected consumer. In the conditions of operation of the vessel, engine power which is transmitted to the fixed pitch propeller depends on the number of revolutions, pitch and propeller diameter. The resistance that provides fixed pitch propeller is proportional to the square of the propeller speed:

$$M = k \cdot n^2 \qquad (1)$$

Effective power that is delivered to the propeller can be expressed via the torque which is transmitted from engine crankshaft via coupling to the propeller shaft and propeller, where it reverses the angular velocity ω. The recorded average torque and shaft speed data are used for engine effective power estimation in accordance to the formula (Borkowski et al., 2011):

$$P_e = M \cdot \omega = M \frac{\pi \cdot n}{30} [kW] \qquad (2)$$

where:

M - mean measured torque [kNm],

n - mean engine-propeller rotational speed [rpm].

For the set of engine speeds and different testing fuels, measurements of propeller shaft torque and power are conducted by means of strain gauges. This method establishes a functional connection between the elastic angular deformation of the propeller shaft and engine torque/power. Experimental measurements of propeller shaft torque and power is set so as onto propeller shaft are installed two pairs of strain gauges type XY21-6/350, connected in Wheatstone bridge. The strain gauges are mounted at an angle of 180° relative to one another. Power is delivered to strain gauge from source of AC voltage of 9 V. Measuring signal from the Wheatstone bridge is delivered to the radio transmitter allowing transfer of data to the receiver. A power source, transmitter and antenna are mounted on a ringed disc which is made of plastic in order to eliminate noise, and is placed on the propeller shaft. Next to the shaft a signal receiver and speed sensor are placed. The signal receiver and speed sensor are connected to an electronic measuring device Spider 8. Spider 8 is connected to a personal computer. Software for data processing is "Catman 3.0". Listed equipment is produced by Hottinger Baldwin Messtehnik (HBM).

Hourly fuel consumption was measured for each engine speed and fuel type. The volumetric method of fuel consumption measurement was employed for fuel mass flow estimation according to the formula (Borkowski et al., 2011):

$$B = \frac{V_p \cdot \rho_p}{t} [kg/h] \qquad (3)$$

where:

B	- fuel mass flow [kg/h],
V_p	- fuel volume consumed during the measurement time [m^3],
ρ_p	- fuel gravity [kg/m^3],
t	- time of measurement [h].

Exhaust emission analyser by Testo, model 350-MARITIME, was used in the experiment for measuring SO_2, CO, NOx and CO_2 concentrations in the engine exhaust. Testo model 350-MARITIME has type approval by GL, Germanisher Lloyd. Instrument itself was located on the gallery in the engine room about two meters above the engine. The probe was posed into an opening of the exhaust gases collector (which was designed for such experiments) above the engine. A lower part of the exhaust gasses collector from the engine exhaust to the point of probe insertion was not cooled. Between each regime of engine speeds exhaust gas tests were conducted after parameters of the engine, such as coolant and oil temperature, were stabilized. The schematic of the exhaust emission tests is shown in Figure 1.

The engine was fuelled with pure diesel fuel and blends containing 7 % and 20 % of three types of biodiesel (FAME). The diesel fuel was a representative fuel used by the fleet of Montenegrin vessel boats in territorial waters with flash point being above 60 ºC. Three types of biodiesel were produced in lab conditions, using waste frying sunflower oil, waste frying palm oil and olive husk oil. Waste frying oils were collected from hotel restaurants while olive husk oil was collected from a local olive oil producer in Montenegro. Base-catalysed transesterification was used for biodiesel production. Basic test fuel properties are given in Table 2, where letter D stands for pure diesel fuel without any biodiesel addition, DS for blends of diesel fuel and biodiesel made of waste frying sunflower oil, DP for blends of diesel fuel and biodiesel made of waste frying palm oil, and DO for blends of diesel fuel and biodiesel made of olive husk oil. For blended fuels, to initial letters a percentage of biodiesel is added. The tests were conducted during summer period, so poor low-temperature properties of biodiesel were avoided. Also, biodiesel was used in experiment a couple days after it was produced in laboratory, so poor stability properties of biodiesel were avoided.

Table 2 Test fuels basic properties

Parameters	Units	1 D	2 DS7%	3 DS20%	4 DP7%	5 DP20%	6 DO7%	7 DO20%
Density @ 15°C	kg/m^3	833.4	837.2	843.7	836.37	842.3	837.7	843.65
Viscosity @ 40°C	mm^2/s	2.92	2.95	3.12	3.00	3.19	3.31	3.46
Cetane number		51.3	53.5	54.9	52.5	54.1	53.8	55.1
Distillation								
% (v/v) recovered @ 250°C	% (v/v)	29	28	27	26	25	26	27
% (v/v) recovered @ 350°C	% (v/v)	91	91	89	92	92	91	89
95% (v/v)	º C	354	357	359	356	357	355	358

Sulfur content	mg/kg	8.6	7.8	6.2	7.9	6.1	7.8	6.0
Water content	mg/kg	40.94	79.99	153.42	71.93	128.23	56.52	111.44
Net calorific value (calculated)	MJ/kg	43.98	41.77	41.59	43.77	42.65	42.52	42.25
Total aromatics	% m/m	22.8	22.3	20.3	22.5	20.9	22.4	20.3
FAME content	v/v	0	7	20	7	20	7	20

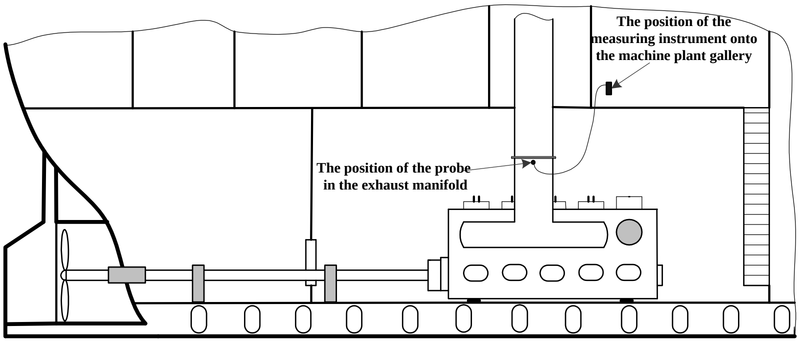

Fig. 1 Position of exhaust emission testing equipment

Tests were conducted under identical conditions. Fuel was supplied to the engine by an outside tank. For every fuel change, the fuel lines were cleaned, and the engine was left to run for at least 20 minutes to stabilize on the new conditions. Fuel samples were prepared separately and poured into separate tanks connected to the suction side of the engine fuel pump. Excess fuel was returned into the same tank. The tank was located on the gallery in the engine room about two meters above the engine, so that the fuel came to the fuel pump by the force of gravity. A glass burette of known volume was also attached in parallel to this tank and was used for fuel consumption measurements.

3. Results and discussion

3.1 Engine parameters

With increase of engine speed a torque and effective shaft power increase as well, table 3. Fuel consumption increases with increase of biodiesel share in fuel, Table 3, which is due to lower calorific value of biodiesel comparing to diesel fuel.

Table 3 Dependence of engine speed on torque, effective power and fuel consumption

Engine speed, rpm	Torque, Nm	Effective power (propeller), kW	Fuel consumption, kg/h						
			1 D	2 DS7%	3 DS20%	4 DP7%	5 DP20%	6 DO7%	7 DO20%
150	4267	67	15.30	16.00	16.10	15.30	15.70	15.85	16.05
180	5609	105	23.20	24.45	24.55	23.35	23.95	24.00	24.20
210	7643	168	36.20	38.10	38.25	36.35	37.30	37.40	37.75

3.2 Exhaust emission

3.2.1 Oxides of Nitrogen, NOx

It can be observed from Figure 2 that amount of NOx increases with increase of engine speed. The reason for this is increased combustion temperature, since formation of NOx inside engine cylinder is temperature dependent (Heywood, 1988).

Emission of NOx from biodiesel blends fueled engine is significantly lower than NOx emission from diesel fueled engine, at all engine speeds. This reduction ranges from 26 % (in case of diesel fuel blended with biodiesel made of waste frying palm oil) to 72 % (in case of diesel fuel blended with biodiesel made of olive husk oil), and is increasing with increased biodiesel content in blends and engine speed. Following only blended fuels, with increase of biodiesel content from 7% to 20% there is NOx emission reduction regardless of engine speed. Possible reasons for the decrease in NOx, are higher cetane numbers and lower aromatic contents of the biodiesel blends than that of the diesel fuel. Higher cetane numbers of the biodiesel blends than that for the diesel fuel is usually associated with lower NOx emissions (Kalligeros et al., 2003; Monyem and Gerpen, 2001). Increasing cetane number reduces the size of the premixed combustion by reducing the ignition delay. This results in lower NOx formation rates since the combustion pressure rises more slowly, giving more time for cooling through heat transfer and dilution and leading to lower localized gas temperatures (Kalligeros et al., 2003; Lee et al., 1998).

Furthermore, aromatic and poly-aromatic hydrocarbons are responsible for higher NOx emissions (Kalligeros et al., 2003; Takahashi et al., 2001; Spreen et al., 1995; Martin et al., 1997). This is probably due to the higher flame temperatures associated with aromatic compounds. By reducing aromatics the fame temperature will drop, leading to a lower NOx production rate. As a result, the addition of biodiesel which does not contain the above classes of compounds, reduces the NOx emissions from the engines. The aromatics have high carbon–hydrogen ratios and thus fuels with lower aromatics will lead to a smaller amount of CO_2 and larger amount of H_2O being formed compared to high aromatic fuels. Since H_2O has a lower tendency to dissociate at high temperatures will lead to low aromatic fuels having lower concentrations of $O^{\bullet}$ radicals which will further reduce the kinetic production of NO (Kalligeros et al., 2003). This trend was also reported by Kalligeros et al. (2003), Dincer (2008) and Dorado et al. (2003). Others reported increase of NOx emission with increase of biodiesel proportion in blended fuels mostly due to increased oxygen content of biodiesel fuels (Gumus and Kasifoglu, 2010; Godiganur et al., 2010).

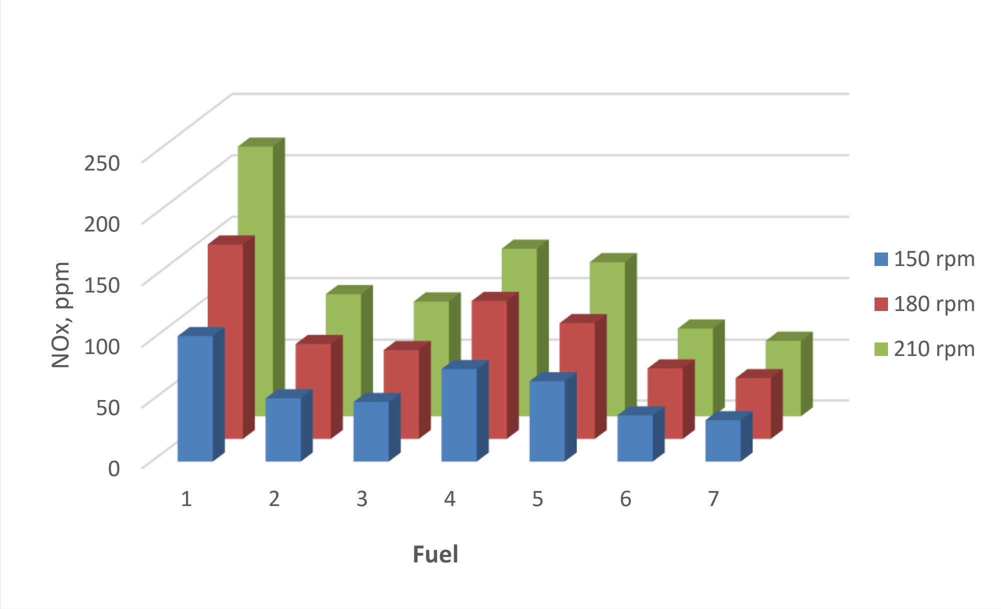

Fig. 2 Exhaust emission of NOx for different fuels and engine speeds, ppm

Comparing biodiesel feedstock type, biodiesel blends made of waste frying oils show somewhat higher NOx emission from biodiesel made from olive husk oil, which could be due to their higher poly-aromatic and total aromatics content.

3.2.2 Sulfur dioxide, SO_2

Exhaust emission of SO_2 is strongly dependent on fuel sulfur content. Since biodiesel has almost no sulfur content, the blending of diesel fuel with biodiesel can reduce the sulfur content and thus reduce the emission of SO_2. Diesel fuel used in this experiment was standard fuel used for yachts and vessels sailing in territorial waters in Montenegro, Table 2.

It can be observed from Figure 3 that SO_2 emission is increasing with increase of engine speed. The reason for this increase is more fuel is consumed, therefore more sulfur in fuel combusted.

Further, emission of SO_2 from biodiesel fueled engine is lower from 33 % (in case of diesel fuel blended with biodiesel made of waste frying palm oil) to 70 % (in case of diesel fuel blended with biodiesel made of waste frying sunflower oil) from diesel fueled engine. Sulfur in diesel fuel helps in lubricating moving parts of the engines. Hence, the reduction of the fuel sulfur content in fuels decreases its lubricity (Muñoz et al., 2011). Addition of, as little as, 2% biodiesel into marine diesel fuel significantly improves the lubricity of the moving parts of a marine engine (NREL and DoE, 2009). Therefore, adding biofuels in diesel fuel improves SO_2 emission and fuel lubricity, with last to be very important for older two stroke slow speed engines, such is an engine used in this experiment.

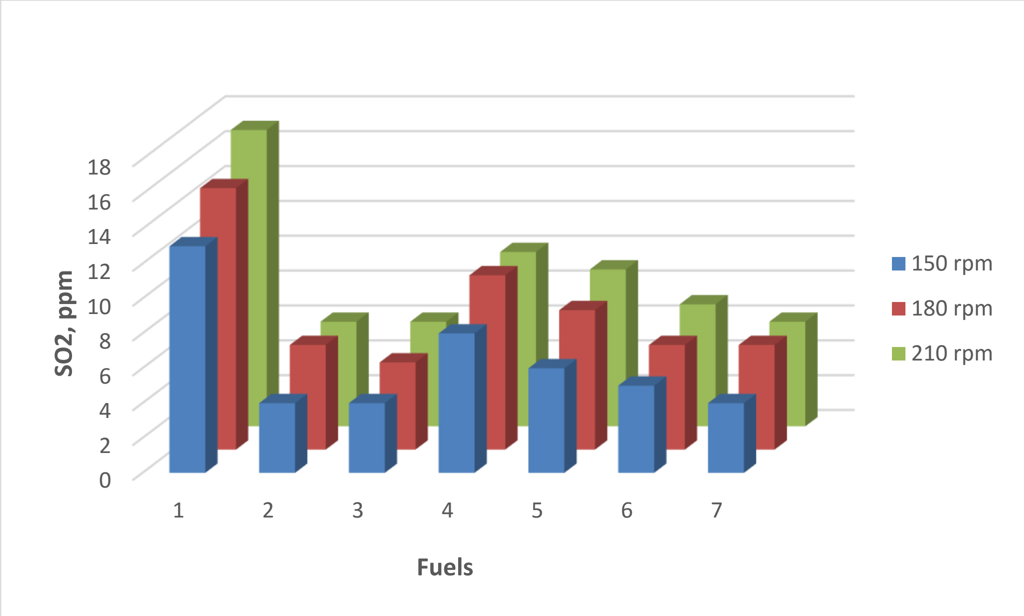

Fig. 3 Exhaust emission of SO_2 for different fuels and engine speeds, ppm

3.2.3 Carbon monoxide, CO

CO emissions are controlled primarily by the air/fuel ratio. For fuel rich mixtures, CO concentration in the exhaust increase with decreasing air/fuel ratio, as the amount of fuel increases. For fuel lean mixtures, CO concentration in the exhaust vary little with air/fuel ratio. Diesel engines always operate well on the leaner side of stoichiometric (Bhardwaj and Abraham, 2008).

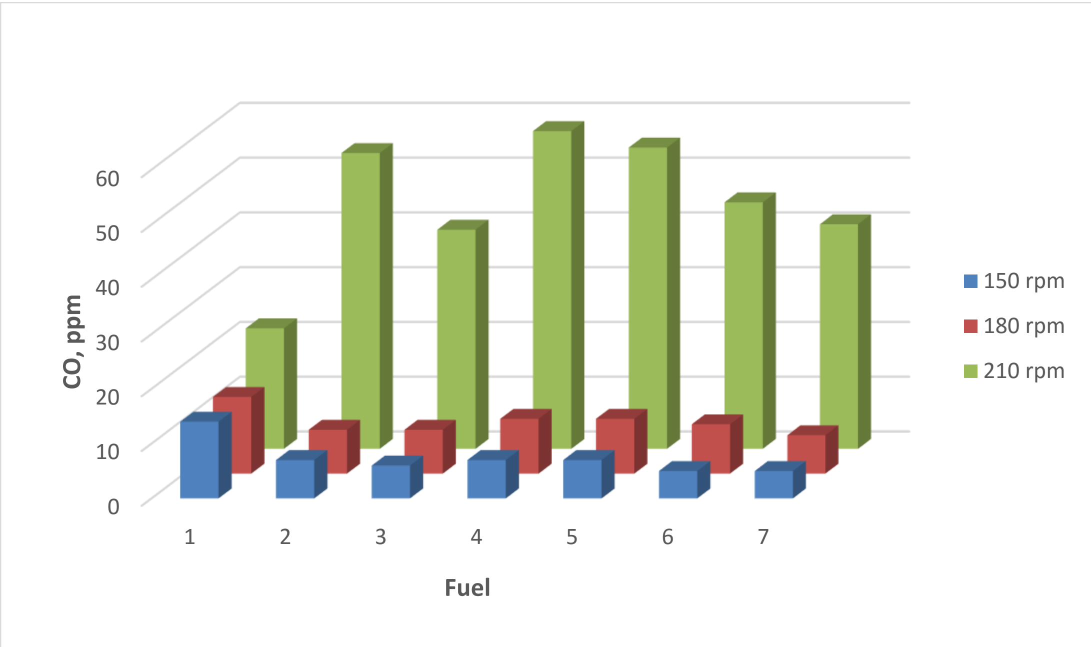

Fig. 4 Exhaust emission of CO for different fuels and engine speeds, ppm

CO emission is increasing slightly with increase of engine speed from 150 rpm to 180 rpm, while increases significantly with increase of engine speed from 180 rpm to 210 rpm, Figure 4. The reason for latter is because air/fuel ratio significantly decreases with this increase of engine speed. Similar trends have been reported by Gumus and Kasifoglu (2010), Usta et al. (2005) and Lertsathapornsuka et al. (2008).

Further, emission of CO from biodiesel fueled engine is lower from 28 % (in case of diesel fuel blended with biodiesel made of waste frying palm oil) to 64 % (in case of diesel fuel blended with biodiesel made of olive husk oil) from diesel fueled engine at low and medium engine speeds. This might be possible because of oxygenated nature of biodiesel fuel. When biodiesel blends are utilized, owing to the inbuilt oxygen in the fuel the local air/fuel ratio during the combustion becomes leaner which results in the reduction in the CO from biodiesel blends. This trend was also reported by Gumus and Kasifoglu (2010) and Ramadhas et al. (2005). However, applying maximum engine speed there is evident increase of emitted CO when using biodiesel blends, and is higher for up to 62 % comparing to CO emitted when using diesel fuel. At this highest engine speed, with local air/fuel rations becoming richer, poor combustion and other biodiesel properties minimize influence of its higher oxygen content. This trend was reported also by Lujan et al. (2009) and Fontaras et al. (2009). Comparing biodiesel feedstock type, biodiesel made of waste frying palm oil shows somewhat higher CO emission from other biodiesel blends, regardless of engine speed. This could be due to its higher carbon content.

3.2.4 Carbon dioxide, CO_2

It can be observed from Figure 5 that CO_2 emission is increasing with increase of engine speed, due to higher fuel consumption.

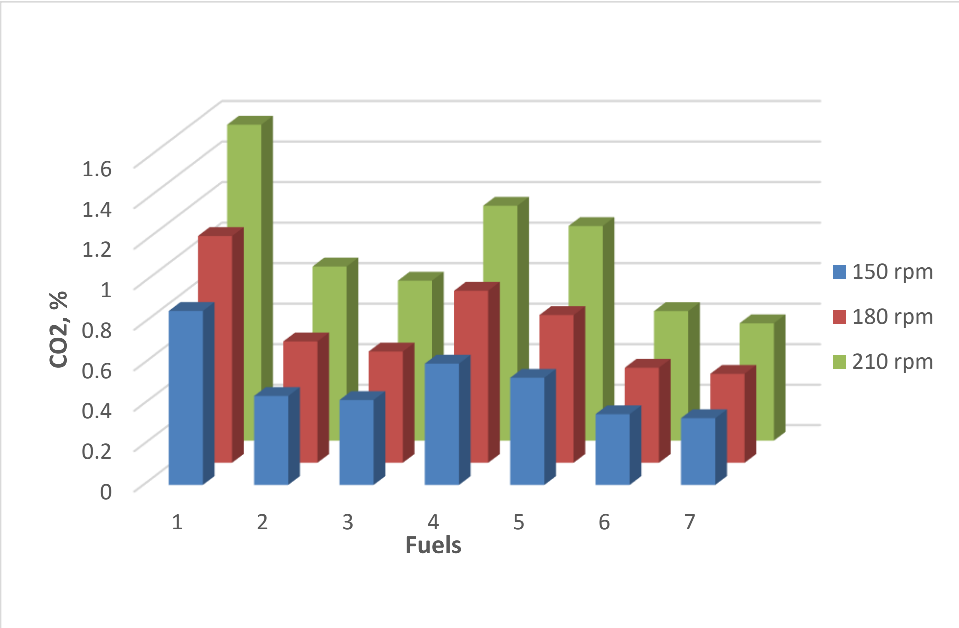

Fig. 5 Exhaust emission of CO_2 for different fuels and engine speeds, %

Emission of CO_2 from biodiesel fueled engine is lower than CO_2 emission from diesel fueled engine at all engine speeds, and this is more evident for higher contents of biodiesel in blended fuels. Emission is lower from 24 % (in case of diesel fuel blended with biodiesel made of waste frying palm oil) to 63 % (in case of diesel fuel blended with biodiesel made of olive husk oil) from diesel fueled engine, Figure 5. The reason is that biodiesel blends have lower carbon to hydrogen ratio than diesel fuel, hence the combustion of these fuels produces less CO_2. This trend was also reported by Ozsezen et al. (2009), and Utlu and Kocak (2008).

Comparing biodiesel feedstock type, biodiesel blends made of waste frying oils show somewhat higher CO_2 emission from biodiesel made from olive husk oil, which could be due to its higher carbon content.

4. Conclusion

Influence of biodiesel (FAME) blends with low sulphur diesel fuel on the characteristics of exhaust emissions from two stroke marine diesel engine were investigated. A reversible two-stroke, low speed, cross-flow scavenging, 4 - cylinder marine diesel engine was used. The engine was fuelled with pure low sulphur diesel fuel and blends containing 7 % and 20 % of three types of biodiesel, made of waste frying sunflower oil, waste frying palm oil and olive husk oil. The experimental results may lead to the following conclusions:

- NOx emission is reduced using biodiesel blends which is mostly attributed to its higher cetane number and lower aromatic content.
- SO_2 emission is reduced using biodiesel blends which is attributed to its lower sulfur content.
- CO emission is reduced using biodiesel blends which is mostly attributed to its oxygenated nature making leaner combustion.
- CO_2 emission is reduced using biodiesel blends which is attributed to its lower carbon to hydrogen ratio than diesel fuel.
- Emissions of NOx, SO_2, CO and CO_2 increase with increase of engine speed.
- Biodiesel made of olive husk oil showed better emission performances from biodiesel made from waste frying palm and sunflower oil.

ACKNOWLEDGMENTS

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REFERENCES

IMO International Maritime Organization, 2012. International Shipping Facts and Figures – Information Resources on Trade, Safety, Security, Environment.

IMO, 2014. Third IMO GHG Study 2014 – Final Report, MEPC 67/INF.3.

IMO, 2015. Note by the International Maritime Organization to the forty-third session of the Subsidiary Body for Scientific and Technological Advice (SBSTA 43) Paris, France, 1 to 4 December 2015. Agenda item 10(c) Emissions from fuel used for international aviation and maritime transport. Update on imo's work to address emissions from fuel used for international shipping.

Anouk Florentinus at al., 2011. Potential of biofuels for shipping – Final Report, Ecofys 2011 by order of: European Maritime Safety Agency (EMSA)

IMO, 2007. Feasibility study into the use of biofuels in the Norwegian domestic fleet, Marine Environment Protection Committee, 57th session, Agenda item 4.

Tadeusz Borkowski, Lech Kasyk, Przemyslaw Kowalak, 2011. Assessment Of Ship's Engine Effective Power Fuel Consumption And Emission Using The Vessel Speed, Journal of KONES Powertrain and Transport, Vol. 18, No. 2.

John B. Heywood, 1988. Internal Combustion Engine Fundamentals, McGraw Hill, ISBN 0-07-100499-8.

S. Kalligeros, F. Zannikos, S. Stournas, E. Lois∗, G. Anastopoulos, Ch. Teas, F. Sakellaropoulos, 2003. An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine, Biomass and Bioenergy 24, 141–149.

Monyem A, Gerpen JH, 2001. The effect of biodiesel oxidation on engine performance and emissions. Biomass and Bioenergy 20, 317–325.

Lee R, Pedley J, Hobbs Ch., 1998. Fuel quality impact on heavy duty diesel emissions - a literature review. SAE Paper No. 982649, SAE, Warrendale, PA.

Takahashi S, Nikolic D, Wakimoto K, and Iida N, 2001. Effects of Aromatics Contents and 90% Distillation Temperature of Diesel Fuels on Flame Temperature and Soot Formation, SAE Paper No. 2001-01-1940, SAE, Warrendale, PA.

Spreen KB, Ulman TL, Mason RL., 1995. Effects of cetane number, aromatics and oxygenates on emissions from a 1994 heavy duty diesel engine with exhaust catalyst. SAE Paper No. 950250, SAE, Warrendale, PA.

Martin B, Beckman D, Aakko P, De Giacomo N, Giavazzi F., 1997. Infuence of future fuel formulations on diesel engine emissions—a joint European study. SAE Paper No. 972966, SAE, Warrendale, PA.

Dincer K., 2008. Lower emission from biodiesel combustion. Energy Source Part A 2008; 30:963–8.

Dorado MP, Ballesteros E, Arnal JM, Gomez J, Lopez FJ., 2003. Exhaust emissions form a diesel engine fuelled with transesterified waste olive oil. Fuel 2003; 82:1311–5.

Gumus M, Kasifoglu S., 2010. Performance and emission evaluation of a compression ignition engine using a biodiesel (apricot seed kernel oil methyl ester) and its blends with diesel fuel. Biomass Bioenergy 2010;34:134–9.

Godiganur S, Murthy CHS, Reddy RP, 2010. Performance and emission characteristics of a Kirloskar HA394 diesel engine operated on fish oil methyl esters. Renewable Energy 2010;35:355–9

Muñoz, M.; Moreno, F.; Monné, C.; Morea, J.; Terradillos, J., 2011. Biodiesel improves lubricity of new low sulphur diesel fuels. Renew. Energy 2011, 36, 2918–2924.

National Renewable Energy Laboratory (NREL) and U.S. Department of Energy, 2009. Biodiesel Handling and Use Guide, 4th ed.; Report Number NREL/TP-540-43672; Office of Scientific and Technical Information: Oak Ridge, TN, USA,.

Bhardwaj, O. and Abraham, M., 2008. A comparative study of Performance and Emission Characteristics of a CRDe SUV fueled with Biodiesel blends & Diesel fuel. SAE Technical Paper 2008-28-0075, SAE, Warrendale, PA.

Usta N, Ozturk E, Can O, Conkur ES, Nas S, C¸ on AH, et al, 2005. Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a diesel engine. Energy Conversion and Management 2005; 46:741–55.

Lertsathapornsuka V, Pairintrab R, Aryusukb K, Krisnangkura K, 2008. Microwave assisted in continuous biodiesel production from waste frying palm oil and its performance in a 100kW diesel generator. Fuel Process Technology 2008; 89:1330–6.

Ramadhas AS, Muraleedharan C, Jayaraj S., 2005. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 2005; 30:1789–800.

Lujan JM, Bermudez V, Tormos B, Pla B., 2009. Comparative analysis of a DI diesel engine fuelled with biodiesel blends during the European MVEG-A cycle: Performance and emissions (II). Biomass and Bioenergy 2009; 33:948–56.

Fontaras G, Karavalakis G, Kousoulidou M, Tzamkiozis T, Ntziachristos L, Bakeas E, 2009. Effects of biodiesel on passenger car fuel consumption, regulated and non-regulated pollutant emissions over legislated and real-world driving cycles. Fuel 2009; 88:1608–17.

Ozsezen AN, Canakci M, Turkcan A, Sayin C, 2009. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. Fuel 2009; 88:629–36.

Utlu Z, Kocak MS., 2008. The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions. Renewable Energy 2008; 33:1936–41.

APPLICATION OF BIODIESEL/DIESEL BLENDS IN TWO STROKE MARINE DIESEL ENGINES

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Abstract

As a renewable sources of energy, biofuels have favourable impact on the environment and can replace to some extent fossil fuels. Biodiesel is one option in reducing emission of pollutants and GHG in shipping sector. By 2030, Lloyd Register predicts global demand for about 100 million tons of biofuels in shipping, mostly biodiesel. This study investigates the influence of biodiesel blends on the characteristics of gaseous emissions from two-stroke, low speed marine diesel engine. The engine was propelled with low sulfur diesel fuel and blends containing 7 % and 25 % of two types of biodiesel, produced in lab conditions using waste frying sunflower oil and waste frying palm oil. Biodiesel blends show better emission performance of NOx, SO_2, CO, and CO_2 than diesel fuel.

Keywords: Used frying oils; Biodiesel; Two-stroke marine diesel engine; Exhaust emission;

Article I. Introduction

The continuous increase of the international maritime traffic has increased marine fuel consumption from about 250 million to 325 million tonnes over the period 2007–2012 [1]. As a consequence, ships were responsible for 13 %, 15 % and 2,2 % (on annual average basis) of global sulfur oxide (SOx), nitrogen oxides (NOx) and carbon dioxide (CO_2) emissions, respectively [1]. Ship's exhaust emission could be transported hundreds of kilometres inland. Median transport velocity of SOx and NOx is 400 around kilometres per day, while mean residence time is 1-3 days, indicating mean transport distances of 400 to 1200 km [2].
International Maritime Organization IMO recognizes the importance and need to limit the emission of pollutants and greenhouse gases that originate from marine diesel engines. IMO's Marine Environment Protection Committee MEPC adopted International Convention for the Prevention of Pollution from Ships - MARPOL 73/78. On September 27th 1997, the MARPOL Convention has been amended by the Protocol which includes Annex VI titled "Regulations for the

Prevention of Air Pollution from Ships". MARPOL Annex VI sets limits on NOx and SOx emissions from ship exhaust, and prohibits deliberate emissions of ozone depleting substances. MARPOL Annex VI also regulates shipboard incineration, and the emissions of volatile organic compounds from tankers. This Protocol entered into force on May 19th 2005, and applies to all engines over 130 kW of power. MEPC revised MARPOL Annex VI with the aim of significantly strengthening the emission limits and strengthened the requirements for the permitted sulfur levels in marine fuels in light of technological improvements and implementation experience. The amendments entered into force on July 1st 2010. Furthermore, in July 2011, IMO adopted measures to reduce greenhouse gas emissions from ships. A new Chapter 4 to MARPOL Annex VI entitled "Regulations on energy efficiency for ships" was adopted, which includes a suite of mandatory technical and operational measures, with the aim of improving the energy efficiency of new ships through improved design and propulsion technologies, and for all ships by improving operational measures, which could help to reduce CO_2 emissions between 45 and 50 million tons on annual basis by 2020 [4]. These regulations entered into force on January 1st 2013 and apply to all ships over 400 gross tonnage.
Biofuels could be one of the options to realize lower carbon intensity in shipping and also possibly reduce the effect of its emissions on air quality. Biofuels have attracted much attention as they are renewable and can be produced locally. The main drawbacks of biofuels are the limitation of raw materials and production costs. In general, the first generation of biofuels is produced from grains, oil crops and sugar crops. These resources for production of biofuels are limited. There is a threshold beyond which there could not be produced enough biofuels that not jeopardize food supplies and biodiversity. Since the first generation of biofuels have certain limitations, second and third generation of biofuels are already under development worldwide. The basic raw material for production of second generation of biofuels is biomass, which consists of remains of non-food parts of crops and other crops that are not used for food purposes, and industrial waste such as wood chips, bark and pulp from fruit processing and many others. The third generation of biofuels covers production from microalgae. Price of biofuels is another key factor that limits the widespread use because of the higher cost of production than of fossil fuels.
There is very little practical experience with the use of biofuels in the shipping sector. Several companies have tested biofuels in mostly cargo and passenger ships engines. Most projects are performed by shipping companies, and sometimes in cooperation with classification societies. Tests were conducted mostly using FAME (fatty acid methyl esters - biodiesel), vegetable oils and BioLNG [5]. The implementation of biodiesel as marine fuel was tested in several

research programs (RCCL Project Royal Caribbean - Cruises testing on biodiesel, MAERSK/LR Project, BV energy Project, Earthrace), where some advantages of biodiesel over fossil fuels were noted: blending can be made up to 100% of biodiesel, reduction of particulate emissions, no adverse effects were detected in marine engines, no bacterial formations were detected in tanks of biofuels during storage for more than 6 months. The potential problems are: biodiesel acts as a solvent and tends to soften and degrade certain rubber and elastomer compounds that are often used in older engines, and biodiesel can easily remove deposits remained after diesel fuel in the system and thus clog filters [5]. The IMO study [6] concluded that low blends of biodiesel up to 20% (B20) could be used without any fuel system degradation. The application of smaller biodiesel blends at marine fuels distillates could be introduced relatively easily. This compound could be prepared at the time of bunkering. These studies were conducted on 4-stroke marine diesel engines.

The used frying oils, generated from the fried food, could be candidate for biodiesel production in regions with negligible vegetable oil production. Wastes containing oils are products of decomposition that impair the oil quality causing reduction in productivity in the trans-esterification reaction and may also generate undesirable by-products which hurt the final product. For these reasons, it is important to refine the used frying oils for the biodiesel production. For the treatment of adequacy of used frying oils, the operations that can be applied are filtration, de-acidification or neutralization and whitening.

In this study influence of biodiesel (FAME) blends with low sulfur diesel fuel on the characteristics of exhaust emissions from marine diesel engine were investigated. For this experiment, a reversible two-stroke, low speed, cross-flow scavenging, 4 cylinder marine diesel engine was used. The engine was fuelled with pure low sulfur diesel fuel and blends containing 7 % and 25 % of two types of biodiesel. Two types of biodiesel were produced in lab conditions, using waste frying sunflower and waste frying palm oils. Base-catalysed trans-esterification is used in this research.

Article II. Experimental procedure

For this study, a marine diesel engine was employed, Table 1. It is a reversible 2-stroke, 4 - cylinder, marine diesel engine with cross-flow scavenging, model “ALPHA 494 R” produced by LITOSTROJ Ljubljana (Slovenia) under Burmeister licence. Engine was installed on motor/sailing ship „Jadran” in 1969. The engine can be regarded as a low speed because the maximum engine speed is 320 min^{-1}, making maximum power of 390 kW. Since it is an old type of marine diesel engine, there are no any aftertreatment devices installed, neither engine control technology for reducing pollutant emission. Such situation is preferable for investigation of direct influence of biodiesel on exhaust emission from marine diesel engines.

Table 2 Marine diesel engine specifications

Engine producer	Engine model	Working principle	Max power	Cyl. No.	Stroke/Bore
Burmeister	Alpha 494-R	2-stroke	390 kW @ 320 rpm	4	490mm/290mm

The direct propulsion system of the ship makes the engine, propeller shaft that is connected to the output coupling, and fixed pitch propeller. Measurements were made when the ship was berthed in the harbour. Running the engine when the ship is berthed is called a heavy propeller condition. For this reason the measurement were carried out only on three regimes of engine speeds, 150 min^{-1}, 180 min^{-1} and 210 min^{-1}.

During operation of the engine, power is constantly changing depending on the connected consumer. In the conditions of operation of the vessel, engine power which is transmitted to the fixed pitch propeller depends on the number of revolutions, pitch and propeller diameter. The resistance that provides fixed pitch propeller is proportional to the square of the propeller speed:

$$M = k \cdot n^2 \quad (1)$$

Effective power that is delivered to the propeller can be expressed via the torque which is transmitted from engine crankshaft via coupling to the propeller shaft and propeller, where it reverses the angular velocity ω. The recorded average torque and shaft speed data are used for engine effective power estimation in accordance with the formula [7]:

$$P_e = M \cdot \omega = M \frac{\pi \cdot n}{30}[kW] \quad (2)$$

where:

M - means measured torque [kNm],
n - means engine-propeller rotational speed [rpm].

For the set of engine speeds of 150 min^{-1}, 180 min^{-1} and 210 min^{-1} and different fuels, measurements of propeller shaft torque and power are conducted by means of strain gauges. This method establishes a functional connection between the elastic angular deformation of the propeller shaft and engine torque/power. Experimental measurements of propeller shaft torque and power is set so as onto propeller shaft are installed two pairs of strain gauges type XY21-6 / 350, connected in Wheatstone bridge. The strain gauges are mounted at an angle of 180˚ relative to one another. Power is delivered to strain gauge from source of AC voltage of 9 V. Measuring signal from the Wheatstone bridge is delivered to the radio transmitter allowing transfer of data to the receiver. A power source, transmitter and antenna are mounted on a ringed disc which is made of plastic in order to eliminate noise, and is placed on the propeller shaft. Next to the shaft a signal receiver and speed sensor are placed, Figure 2. The signal receiver and speed sensor are connected to an electronic measuring device „Spider 8”. The “Spider 8” is connected to a personal computer. Software for data processing is ''Catman 3.0''. Listed equipment is produced by Hottinger Baldwin MESSTEHNIK (HBM).

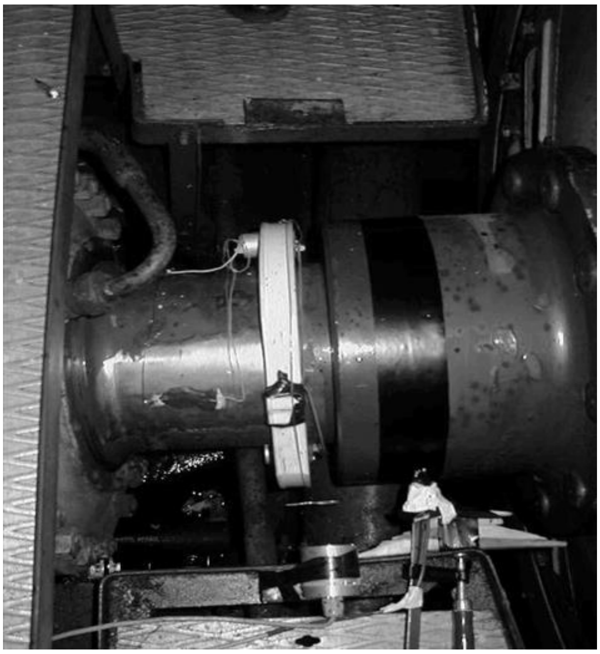

Fig. 2 Strain gauges mounted on the propeller shaft

Hourly fuel consumption was measured for each engine speed and fuel. The volumetric method of fuel consumption measurement was employed for fuel mass flow estimation according to the formula [7]:

$$B = \frac{V_p \cdot \rho_p}{t} \left[kg/h \right] \qquad (3)$$

where:

B - fuel mass flow [kg/h],
V_p - fuel volume consumed during the measurement time [m^3],
ρ_p - fuel gravity [kg/m^3],
t - time of measurement [h].

Exhaust emission analyser Testo, model 350-MARITIME, was used in the experiment for measuring SO_2, CO, NOx and CO_2 concentrations in the engine exhaust. Testo model 350-MARITIME has type approval by GL, Germanisher Lloyd. The specifications of the emissions analyser are cited in Table 2. Instrument itself was located on the gallery in the engine room about two meters above the engine. The probe was posed into an opening of the exhaust gases collector (which was designed for such experiments) above the engine. A lower part of the exhaust gasses collector from the engine exhaust to the point of probe insertion was not cooled. Between each regime of engine speeds exhaust gas tests were conducted after parameters of the engine, such as coolant and oil temperature, were stabilized. The schematic of the exhaust emission tests is shown in Figure 3.

Table 2 Specification of exhaust emission analyser Testo, model 350-MARITIME

Parameter	Measuring range	Accuracy
°C, flue gas	-40 up to 1000°C	max ±5K
O_2	0… 25 vol%	
CO	0 … 3000 ppm	
NO	0 … 3000 ppm	
NO_2	0 … 500 ppm	
SO_2	0 … 3000 ppm	
CO_2	0….. 40 vol%	
Pabs	600 … 1150 hPa	±5 hPa at 22°C ±10 hPa at -5°C up to 45°C

The engine was fuelled with pure diesel fuel and blends containing 7 % and 25 % of two types of biodiesel (FAME). The diesel fuel was a representative fuel used by the fleet of Montenegrin vessel boats in territorial waters with flash point being above 60 ºC. Two types of biodiesel were produced in lab conditions, using waste frying sunflower oil and waste frying palm oil and olive husk oil. Waste frying oils were collected from hotel restaurants. Base-catalysed transesterification was used for biodiesel production. Test fuel basic properties are given in Table 3, where letter DF stands for pure diesel fuel without any biodiesel addition, DS for blends of diesel fuel and biodiesel made of waste frying sunflower oil and DP for blends of diesel fuel biodiesel made of waste frying palm oil. For blended fuels, to initial letters a percentage of biodiesel is added. The tests were conducted during summer period, so poor low-temperature properties of biodiesel were avoided. Also, biodiesel was used in experiment a couple days after it was produced in laboratory, so poor stability properties of biodiesel were avoided.

Tests were conducted under identical conditions. Fuel was supplied to the engine by an outside tank. For every fuel change, the fuel lines were cleaned, and the engine was left to run for at least 20 minutes to stabilize on the new conditions. Fuel samples were prepared separately and poured into separate tanks connected to the suction side of the engine fuel pump. Excess fuel was returned into the same tank. The tank was located on the gallery in the engine room about two meters above the engine, so that the fuel came to the fuel pump by the force of gravity. A glass burette of known volume was also attached in parallel to this tank and was used for fuel consumption measurements.

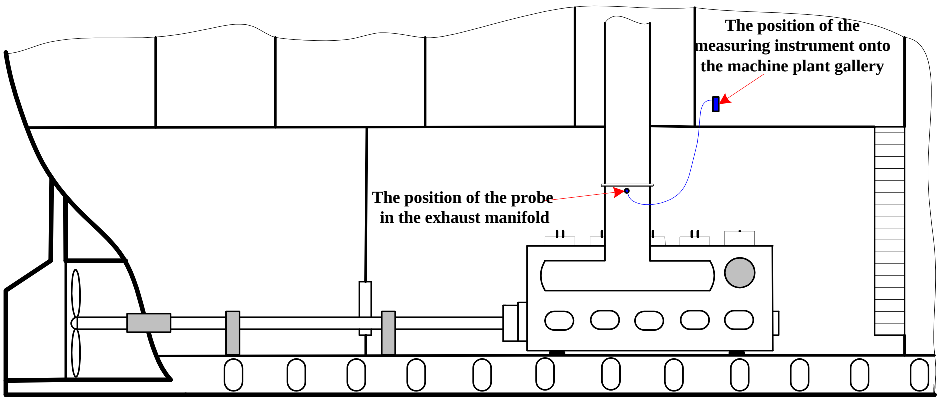

Fig. 3 Position of exhaust emission testing equipment

Table 3 Test fuels basic properties

Parameters	Units	Fuel 1 DF	Fuel 2 DP7%	Fuel 3 DP25%	Fuel 4 DS7%	Fuel 5 DS25%
Density @ 15°C	kg/m³	833.4	836.37	844.8	837.2	846.6
Viscosity @ 40°C	mm²/s	2.92	3.00	3.21	2.95	3.23
Cetane number		51.3	52.5	53.9	53.5	54.2
Distillation						
% (v/v) recovered @ 250°C	% (v/v)	29	26	20	28	19
% (v/v) recovered @ 350°C	% (v/v)	91	92	92	91	89
95% (v/v)	°C	354	356	360	357	361
Sulfur content	mg/kg	8.57	7.91	5.68	7.79	5.64
Water content	mg/kg	40.94	71.93	153.65	79.99	177.42
Net calorific value (calculated)	MJ/kg	43.98	43.77	42.14	41.77	40.94
Total aromatics	% m/m	22.8	22.5	20.5	22.3	19.8
FAME content	v/v	0	7	25	7	25

Article III. Results and discussion

Section 3.01 Engine/propeller parameters

With increase of engine speed a torque and effective shaft power increase as well, table 4. Fuel consumption increases with increase of biodiesel share in fuel, Table 4, which is due to lower calorific value of biodiesel comparing to diesel fuel.

Table 4 Dependence of engine speed on torque, effective power and fuel consumption

Engine speed, rpm	Torque, Nm	Effective power (propeller), kW	Fuel consumption, kg/h				
			Fuel 1 DF	Fuel 2 DP7%	Fuel 3 DP25%	Fuel 4 DS7%	Fuel 5 DS25%
150	4267	67	15.30	15.30	15.90	16.00	16.35
180	5609	105	23.20	23.35	24.25	24.45	24.95
210	7643	168	36.20	36.35	37.80	38.10	38.85

Section 3.02 Exhaust emission

(a) Oxides of Nitrogen, NOx

Different types of oxides of nitrogen (NOx) are produced when oxygen reacts with nitrogen from air and fuel at high temperatures [8]. This means that formation of NOx inside engine cylinder is temperature dependent.

It can be observed from Figures 3 and 4 that amount of NOx increases with increase of engine speed. The reason is very simple i.e. the engine combustion temperature increases due to the increase of engine speed. The trend in the increase of NOx is smooth.

Emission of NOx from biodiesel blends fueled engine is significantly lower than NOx emission from diesel fueled engine, at all engine speeds. This reduction ranges from 26 % to 60 %, and is increasing with increased biodiesel content in fuels and engine speed. Following only blended fuels, with increase of biodiesel content from 7 to 25%, there is evident NOx emission reduction regardless of engine speed. Possible reasons for the decrease in NOx, are higher cetane numbers and lower aromatic contents of the biodiesel blends comparing to the diesel fuel.

Higher cetane numbers of the biodiesel blends than that for the diesel fuel is usually associated with lower NOx emissions [9, 10]. Increasing cetane number reduces the size of the premixed combustion by reducing the ignition delay. This results in lower NOx formation rates since the combustion pressure rises more slowly, giving more time for cooling through heat transfer and dilution and leading to lower localized gas temperatures [9, 11]. Furthermore, aromatic and poly-aromatic hydrocarbons are responsible for higher NOx emissions [9, 12, 13, 14]. This is probably due to the higher flame temperatures associated with aromatic compounds. By reducing aromatics the flame temperature will drop, leading to a lower NOx production rate. As a result, the addition of biodiesel which does not contain the above classes of compounds, reduces the NOx emissions from the engines. The aromatics have high carbon–hydrogen ratios and thus fuels with lower aromatics will lead to a smaller amount of CO_2 and larger amount of H_2O being formed comparing to high aromatic fuels. Since H_2O has a lower tendency to dissociate at high temperatures, this will lead to low aromatic fuels having lower concentrations of $O^{\bullet}$ radicals which will further reduce the kinetic production of NO [9]. This trend was also reported in [9, 15, 16]. Others reported increase of NOx emission with increase of biodiesel proportion in blended fuels mostly due to increased oxygen content of biodiesel fuels [17, 18].

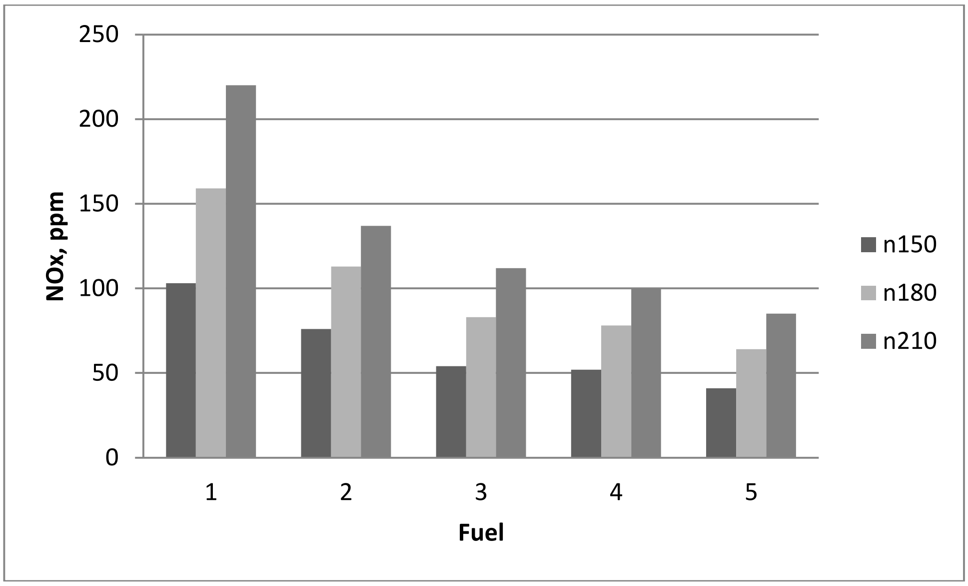

Fig. 3 Exhaust emission of NOx for different fuels, %.

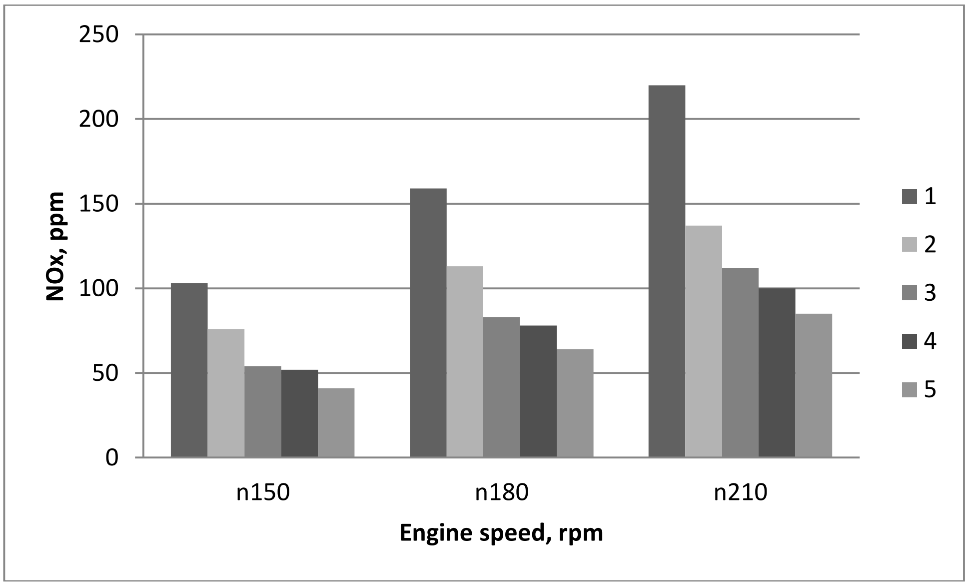

Fig. 4 Exhaust emission of NOx for different engine speeds, %.

(b) Sulfur dioxide, SO_2

Exhaust emission of SO_2 is strongly dependent on fuel sulfur content. Since biodiesel has almost no sulfur content, the blending of diesel fuel with biodiesel can reduce the sulfur content and thus reduce the emission of SO_2. Diesel fuel used in this experiment was standard low sulfur diesel fuel used for naval vessels in Montenegro (sailing ship Jadran is used for training of naval cadets as well as students of Maritime Faculty), Table 3.
It can be observed from Figures 5 and 6 that SO_2 emission is increasing with increase of engine speed. The reason for this increase is that more fuel is consumed, therefore more sulfur in fuel is combusted. Also, emission of SO_2 is decreasing with decreasing sulfur level in fuels for same engine speed, and it is lowest for blends with 25 % of biodiesel, Figure 5.
Fuel sulfur also lubricates the moving parts of engines. Hence, the reduction of the fuel sulfur content which is accompanied with reduction of aromatic hydrocarbons in diesel fuels

decreases its lubricity [19]. According to [20], the addition of as little as 2% biodiesel into marine diesel fuel significantly improves the lubricity of the moving parts of a marine engine. Therefore, adding biofuels in diesel fuel improves SO_2 emission and fuel lubricity, the latter to be very important for older two stroke slow speed engines using low sulfur fuels, such is an engine used in this experiment.

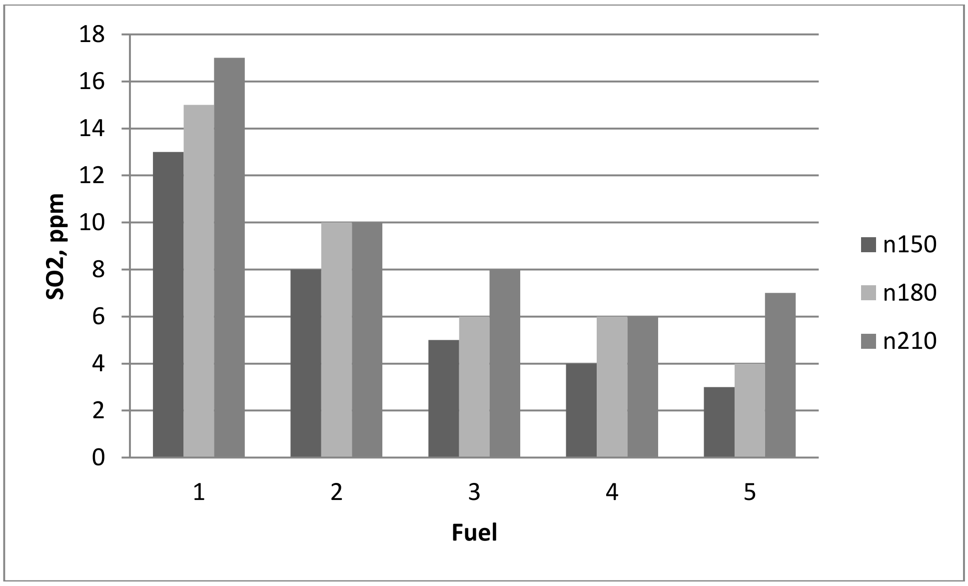

Fig. 5 Exhaust emission of SO_2 for different fuels, %

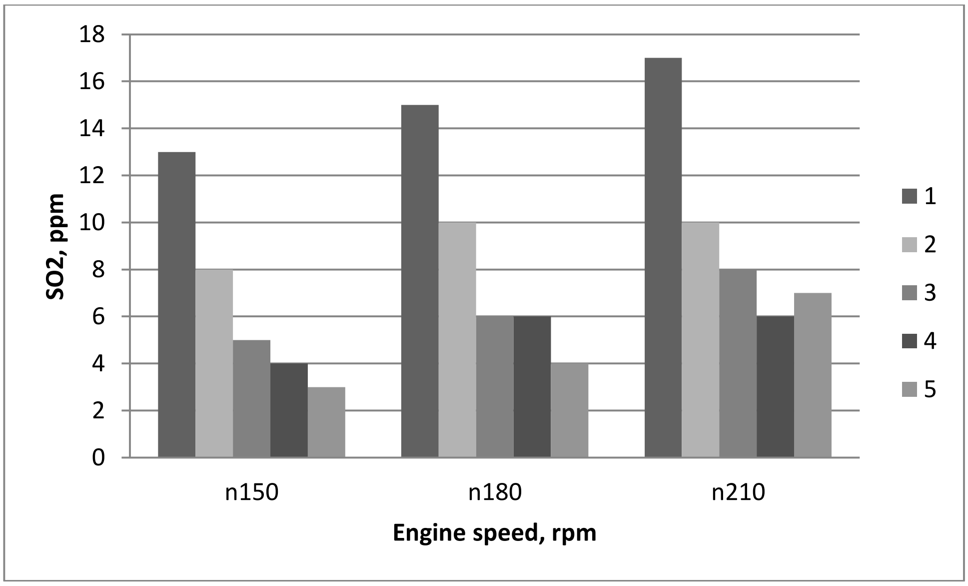

Fig. 6 Exhaust emission of SO_2 for different engine speeds, %

(c) Carbon monoxide, CO

CO emissions from internal combustion engines are controlled primarily by the air/fuel ratio. For fuel rich mixtures, CO concentration in the exhaust increase steadily with decreasing air/fuel ratio, as the amount of fuel increases. For fuel lean mixtures, CO concentration in the exhaust varies little with air/fuel ratio. However, diesel engines always operate well on the leaner side of stoichiometric [21].

It can be observed from Figures 7 and 8 that CO emission is increasing with increase of engine speed. The reason for this increase is because air/fuel ratio decreases with increase of load. Similar trends have been shown by [17, 22, 23].

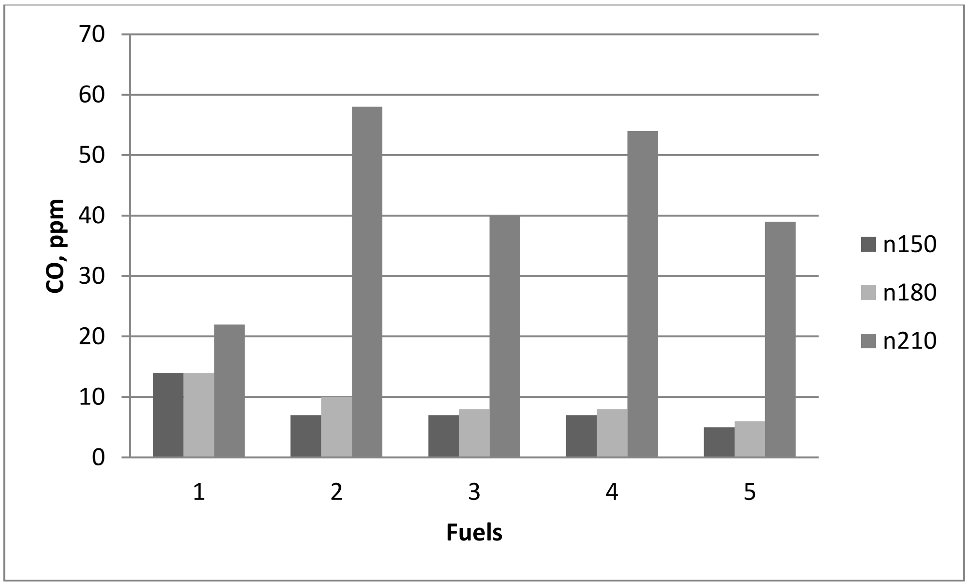

Fig. 7 Exhaust emission of CO for different fuels, %

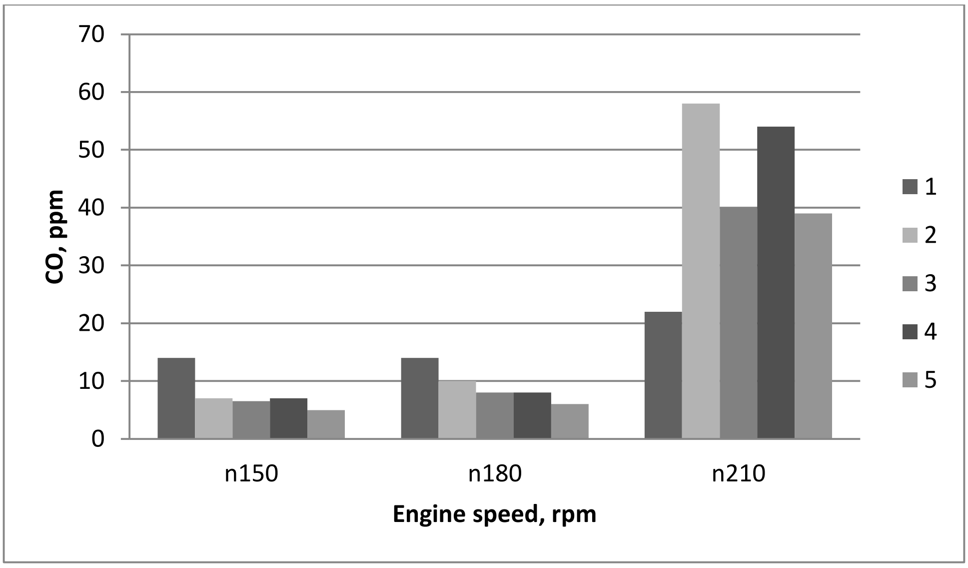

Fig. 8 Exhaust emission of CO for different engine speeds, %

Further, emission of CO from biodiesel fueled engine is lower more than 50% of the CO emission from diesel fueled engine at low and medium engine speeds. Following only biodiesel blends, with increase of biodiesel content from 7% to 25% there is CO emission reduction regardless of engine speed, being most evident for maximum engine speed. This might be possible because of oxygenated nature of biodiesel fuel. When biodiesel blends are utilized, owing to the inbuilt oxygen in the fuel the local A/F ratio during the combustion becomes leaner which results in the reduction in the CO from biodiesel blends. This trend was also reported in [17, 24]. However, when applying maximum engine speed there is notable increase of emitted CO when using biodiesel blends. At this high engine speeds, poor combustion and other fuel characteristics annul influence of biodiesel's higher oxygen content. This trend was reported also in [25, 26].

(d) Carbon dioxide, CO_2

It can be observed from Figures 9 and 10 that CO_2 emission is increasing with increase of engine speed. The reason for this increase is that more fuel is consumed for higher power.

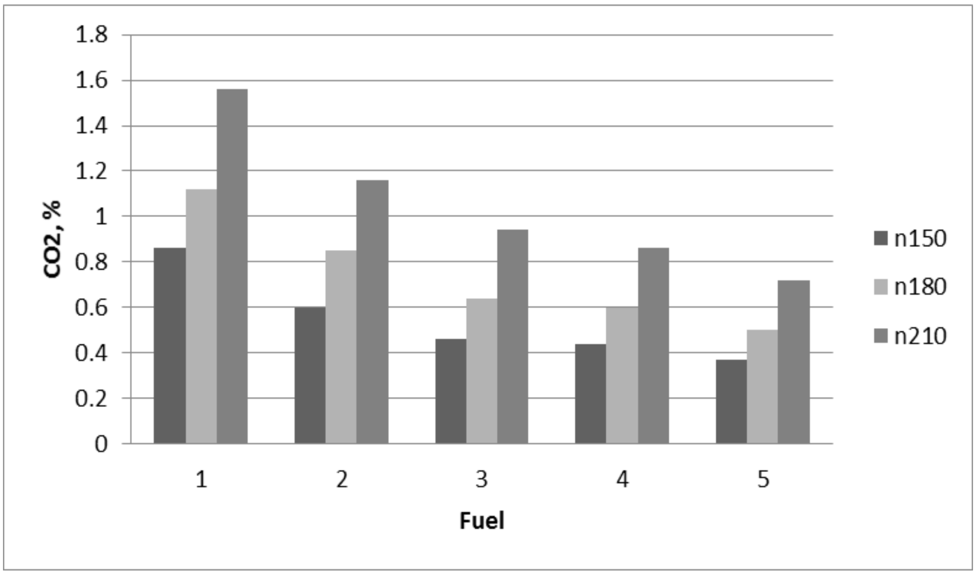

Fig. 9 Exhaust emission of CO_2 for different fuels, %

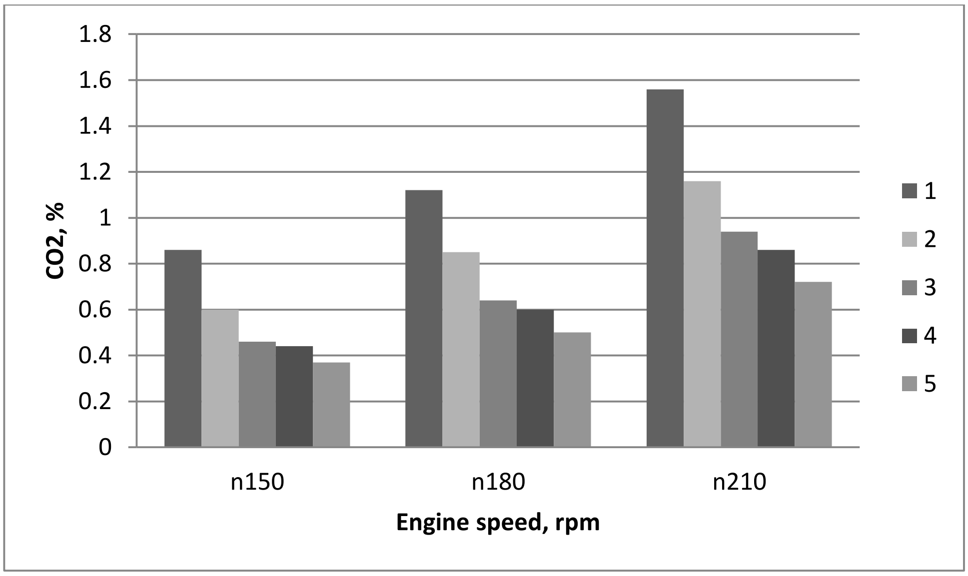

Fig. 10 Exhaust emission of CO_2 for different engine speeds, %

Emission of CO_2 from biodiesel fueled engine is lower than CO_2 emission from diesel fueled engine at all engine speeds, and this is more evident for higher contents of biodiesel in blended fuels. The reason is that biodiesel blends have lower carbon to hydrogen ratio than diesel fuel, hence the combustion of these fuels produces less CO_2. This trend was also reported in [27, 28].

Article IV. Conclusion

In this study influence of biodiesel (FAME) blends with low sulfur diesel fuel on the characteristics of exhaust emissions from marine diesel engine were investigated. A reversible two-stroke, low speed, cross-flow scavenging, 4 -cylinder marine diesel engine was used. The engine was fuelled with pure low sulfur diesel fuel and blends containing 7 % and 25 % of two types of biodiesel, made of waste frying sunflower and waste frying palm oils. The experimental results may lead to the following conclusions:

- NOx emission is reduced using biodiesel which is mostly attributed to its higher cetane number and lower aromatic content.
- SO_2 emission is reduced using biodiesel which is attributed to its lower sulfur content.
- CO emission is reduced using biodiesel which is mostly attributed to its oxygenated nature making leaner combustion.
- CO_2 emission is reduced using biodiesel which is attributed to its lower carbon to hydrogen ratio than diesel fuel.
- Emissions of NOx, SO_2, CO and CO_2 increase with increase of engine speed.

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REFERENCES

[1] IMO International Maritime Organization, Third IMO GHG Study 2014 – Final Report, MEPC 67/INF.3, 25 July 2014.

[2] M.I.Lamas and C.G.Rodriguez, Emissions from marine engines and NOx reduction methods, Journal of Maritime Research, Vol IX, No. I (2012), ISSN 1697-4040

[3] Doug Woodyard, Pounder's Marine Diesel Engines and Gas Turbines, ISBN 978-0-7506-8984-7, 9th Edition, 2009.

[4] IMO International Maritime Organization, www.imo.org.

[5] Anouk Florentinus at al., Potential of biofuels for shipping – Final Report, Ecofys 2011 by order of: European Maritime Safety Agency (EMSA)

[6] IMO 2007, Feasibility study into the use of biofuels in the Norwegian domestic fleet, Marine Environment Protection Committee, 57th session, Agenda item 4

[7] Tadeusz Borkowski, Lech Kasyk, Przemyslaw Kowalak, ASSESSMENT OF SHIP'S ENGINE EFFECTIVE POWER FUEL CONSUMPTION AND EMISSION USING THE VESSEL SPEED, Journal of KONES Powertrain and Transport, Vol. 18, No. 2 2011.

[8] John B. Heywood, Internal Combustion Engine Fundamentals, McGraw Hill, ISBN 0-07-100499-8, 1988.

[9] S. Kalligeros, F. Zannikos, S. Stournas, E. Lois∗, G. Anastopoulos, Ch. Teas, F. Sakellaropoulos, An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine, Biomass and Bioenergy 24 (2003) 141 – 149.

[10] Monyem A, Gerpen JH. The effect of biodiesel oxidation on engine performance and emissions. Biomass and Bioenergy 20 (2001) 317–325.

[11] Lee R, Pedley J, Hobbs Ch. Fuel quality impact on heavy duty diesel emissions - a literature review. SAE Paper No. 982649, SAE, Warrendale, PA, 1998

[12] Takahashi S, Nikolic D, Wakimoto K, and Iida N, Effects of Aromatics Contents and 90% Distillation Temperature of Diesel Fuels on Flame Temperature and Soot Formation, SAE Paper No. 2001-01-1940, SAE, Warrendale, PA, 2001.

[13] Spreen KB, Ulman TL, Mason RL. Effects of cetane number, aromatics and oxygenates on emissions from a 1994 heavy duty diesel engine with exhaust catalyst. SAE Paper No. 950250, SAE, Warrendale, PA, 1995.

[14] Martin B, Beckman D, Aakko P, De Giacomo N, Giavazzi F., Infuence of future fuel formulations on diesel engine emissions—a joint European study. SAE Paper No. 972966, SAE, Warrendale, PA, 1997.

[15] Dincer K. Lower emission from biodiesel combustion. Energy Source Part A 2008; 30:963–8.

[16] Dorado MP, Ballesteros E, Arnal JM, Gomez J, Lopez FJ. Exhaust emissions form a diesel engine fuelled with transesterified waste olive oil. Fuel 2003; 82:1311–5.

[17] Gumus M, Kasifoglu S. Performance and emission evaluation of a compression ignition engine using a biodiesel (apricot seed kernel oil methyl ester) and its blends with diesel fuel. Biomass Bioenergy 2010; 34:134–9.

[18] Godiganur S, Murthy CHS, Reddy RP. Performance and emission characteristics of a Kirloskar HA394 diesel engine operated on fish oil methyl esters. Renewable Energy 2010;35:355–9

[19] Muñoz, M.; Moreno, F.; Monné, C.; Morea, J.; Terradillos, J. Biodiesel improves lubricity of new low sulfur diesel fuels. Renew. Energy 2011, 36, 2918–2924.

[20] National Renewable Energy Laboratory (NREL) and U.S. Department of Energy. Biodiesel Handling and Use Guide, 4th ed.; Report Number NREL/TP-540-43672; Office of Scientific and Technical Information: Oak Ridge, TN, USA, 2009

[21] Bhardwaj, O. and Abraham, M., "A comparative study of Performance and Emission Characteristics of a CRDe SUV fueled with Biodiesel blends & Diesel fuel," SAE Technical Paper 2008-28-0075, 2008

[22] Usta N, Ozturk E, Can O, Conkur ES, Nas S, C¸ on AH, et al. Combustion of biodiesel fuel produced from hazelnut soapstock/waste sunflower oil mixture in a diesel engine. Energy Conversion and Management 2005; 46:741–55.

[23] Lertsathapornsuka V, Pairintrab R, Aryusukb K, Krisnangkura K. Microwave assisted in continuous biodiesel production from waste frying palm oil and its performance in a 100kW diesel generator. Fuel Process Technology 2008; 89:1330–6.

[24] Ramadhas AS, Muraleedharan C, Jayaraj S. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy 2005; 30:1789–800.

[25] Lujan JM, Bermudez V, Tormos B, Pla B. Comparative analysis of a DI diesel engine fuelled with biodiesel blends during the European MVEG-A cycle: Performance and emissions (II). Biomass and Bioenergy 2009; 33:948–56.

[26] Fontaras G, Karavalakis G, Kousoulidou M, Tzamkiozis T, Ntziachristos L, Bakeas E,. Effects of biodiesel on passenger car fuel consumption, regulated and non-regulated pollutant emissions over legislated and real-world driving cycles. Fuel 2009; 88:1608–17.

[27] Ozsezen AN, Canakci M, Turkcan A, Sayin C. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. Fuel 2009; 88:629–36.

[28] Utlu Z, Koc¸ ak MS. The effect of biodiesel fuel obtained from waste frying oil on direct injection diesel engine performance and exhaust emissions. Renewable Energy 2008; 33:1936–41.

ELABORAT

O nacionalnom naučnoistraživačkom projektu

"Mogućnosti proizvodnje tečnih biogoriva iz obnovljivih izvora i njihove primjene za pogon dizel motora na brodovima pomorske privrede i Mornarice Vojske Crne Gore"

2012-2015

Finansiralo Ministarstvo Nauke Crne Gore

Kotor, februar 2016.

Realizovana istraživanja

Početak aktivnosti na projektu je protekao u pronalaženju otpadnih materija u Crnoj Gori koja se mogu upotrijebiti za proizvodnju biodizela II generacije. Nakon analize tržišta, i sakupljenih podataka, utvrđeno je da postoje značajne zalihe otpadnog jestivog ulja. Otpadno jestivo ulje se uglavnom nalazi i sakuplja u ugostiteljskim objektima kao nuzproizvod pripremanja hrane (hoteli i restorani). U ovim objektima se uglavnom upotrebljavaju palmino i suncokretovo ulje. Zbog činjenice da su ova dva ulja najraprostranjenija na crnogorskom tržištu, to se za ovo istraživanje uzelo u obzir otpadno suncokretovo i otpadno palmino ulje. Nakon prikupljanja određene količine otpadnog suncokretovog i palminog ulja, pristupilo se njihovom prečišćavanju od primjesa (vode, grubih i finih prljavština, i dr). Nakon odstranjivanja nečistoća ustanovio se kvalitet otpadnih ulja putem analize u akreditovanoj laboratoriji. Tek nakon što je utvrđen potreban kvalitet ulja, pristupilo se pripremi za proces njegovog pretvaranja u biodizel II generacije. Proces transesterifikacije, kojim se otpadno ulje transformiše u biodizel je ponavljan više puta, sve dok se nije proizveo biodizel zadovoljavajućeg kvaliteta, što se utvrđivalo ispitivanjima u akreditovanoj laboratoriji. Samo biodizel dobrog kvaliteta se može dalje miješati sa fosilnim dizel gorivom i kao takvo primjenjivati za pogon postojećih brodskih motora na brodovima Mornarice Crne Gore. Takođe, s obzirom da je u Crnoj Gori zastupljena proizvodnja maslinovog ulja, posjetilo se više proizvodnih pogona ovog tipa u okolini Bara i Ulcinja. Ustanovljeno je da postoje više potencijalno korisnih otpadnih materija, različitih gustina, sadržaja masnoća, primjesa i sl. Međutim, nakon analize utvrđeno je da samo jedna od njih se može iskoristiti za proizvodnju biodizela II generacije. Treba napomenuti da su palmino i suncokretovo ulje prethodno termički obrađena, dok ovo maslinovo nije. Iz ulja su potpuno odstranjene nečistoće, i pristupilo se pripremi ovog ulja za proces transesterifikacije. Nakon više postupaka, biodizel iz otpadnog maslinovog ulja se nije mogao proizvesti, što se ogledalo u neizdvajanju glicerina. To nas je navelo da utvrdimo što je razlog tome. Na kraju se utvrdilo da je razlog to što takvo maslinovo ulje, tj. otpadno ulje pri proizvodnji jestivog ulja, ima previsoke masne kiseline. Neophodno je pronaći način kako da se smanje ove kiseline i tek onda prići proizvodnji biodizela. S obzirom da je razlog otkriven pri kraju prve godine projekta, to će se rješenje ovog problema naći početkom realizacije druge godine projekta.

U drugoj godini istraživanja, nakon proizvedenog biodizela II generacije od otpadnog palminog, suncokretovog i maslinovog ulja, prišlo se miješanju istog sa fosilnim dizel gorivom. Za miješanje sa biodizelom upotrijebilo se standardno eurodizel gorivo koje se koristi za potrebe brodova Mornarice Crne Gore. Udjeli biodizela u dizel gorivu su od 7%, 20% i 25%. Izbor ovih udjela je utvrđen nakon literaturnog pregleda sličnih eksperimenata. Naime, 7% udjela biodizela u dizel gorivu je maksimalna dozvoljena koncentracija predviđena evropskim standardom kvaliteta dizel goriva EN 590, 20% udjela biodizela je maksimalni udio biodizela u dizel gorivu prilikom ispitivanja na brodskim motorima, dok je 25% izabran kao pretpostavljeni najveći mogući udio biodizela za bezbjedan pogon brodskog dizel motora smještenog na školskom brodu Jadran. Na taj način je korišteno 8 vrsta smješa biodizel/dizel gorivo kao i čisto dizel gorivo kao referentno, kao što slijedi:

1. Dizel (B0)
2. Dizel 93% : 7% biodizela od palme = 28 L+2.1L (BP7%)
3. Dizel 80% : 20% biodizela od palme = 24 L+6 L (BP20%)
4. Dizel 75% : 25% biodizela od palme = 22,5 L+7.5 L (BP25%)
5. Dizel 93% : 7% biodizela od suncokreta = 28 L+2.1 L (BS7%)
6. Dizel 80% : 20% biodizela od suncogreta = 24 L+6 L (BS20%)
7. Dizel 75% : 25% biodizela od suncokreta = 22,5 L+7.5 L (BS25%)
8. Dizel 93% : 7% biodizela od masline = 28 L+2.1L (BM7%)

Mjerenje sastava emisije izduvnih gasova izvršeno je na prekretnom dvotaktnom brodskom dizel motoru sa poprečnim ispiranjem tip ''ALPHA 494 R'' proizvođača LITOSTROJ Ljubljana, fabrički broj 64361, godina proizvodnje 1968 a godina ugradnje na motorni jedrenjak Jadran 1969. Mjerenje je izvršeno kada je brod bio na vezu u luci. Motor se može smatrati da je sporohodni pošto postiže maksimalni broj obrtaja radilice motora od 320 min-1 (pri tome postiže maksimalnu snagu od 390 kW). Pogoski sistem broda čini motor, propelerno vratilo koje je spojeno na izlaznu spojnicu motora i dvokrilni propeler sa fiksnim krilima. Rad motora, kada je brod na vezu, predstavlja vožnju sa ''teškim propelerom''. Zbog toga je mjerenje emisije izduvnih gasova, izvršeno za svaki uzorak goriva samo na tri režima u rasponu od 150 min-1 (minimalni broj obrtaja) do 210 min-1 radilice motora (propelernog vratila). Prvi broj obrtaja radilice motora na kome se mjerio sastav emisije izduvnih gasova bio je 150 min-1, drugi 180 min-1 i treći 210 min-1. Na broju obrtaja radilice motora od 210 min-1 ostvarena su dva režima i to prvi sa kormilom u nultom položaju (u sredini) i kormilom zakrenutim sasvim lijevo.

Mjerenje je izvršeno za osam uzoraka različitih goriva tako što su se uzorci pripremali posebno i sipali u posebnu posudu koja se spajala na usisnoj strani pumpe goriva motora. Povratno gorivo se dovodilo u istu posudu. Posuda se nalazila na galeriji mašinskog prostora iznad motora na visini oko dva metra, tako da je gorivo slobodnim padom dolazilo do pumpe goriva. Prvo mjerenje izvršeno je na uzorku čistog dizel goriva B0 a zatim na uzorcima mješavina.

Mjerenje emisije izduvnih gasova vršilo se sa instrumentom ''TESTO 350-MARITIME''. Sonda instrumenta postavljala se u otvor sabirnog kolektora izduvnih gasova (koji je predviđen za ovakva mjerenja) iznad motora.

U trećoj godini istraživanja obrađeni su rezultati dobijeni tokom prve i druge godine istraživanja.

U ovoj istraživačkoj godini je nabavljen uređaj za određivanje oksidacione stabilnosti biodizela, te su dodatna ispitivanja vršena na ovom uređaju. Jedan dio prethodnih laboratorisjkih istraživanja je ponovljen u cilju potvrđivanja rezultata.

Održavana je radionica iz tematske oblasti alternativnih goriva i njihove primjene u transportu – u Okviru IV SIMPOZIJUMA LABORATORIJA ZA NAFTU I NAFTNE DERIVATE U REGIONU održanog 28.-29. maja 2015 na Fakultetu za pomorstvo u Kotoru.

Članovi radnog tima su bili gosti na Nor-Shipping najvećem sajmu pomorstva u Oslu, Norveška, od 2 do 5 juna 2015.godine, na kojem su uspostavljeni kontakti sa proizvođačima biogoriva za upotrebu u pomorstvu, kao i potencijalnim korisnicima.

Rezultati istraživanja su predstavljeni na radionici posvećenoj biogorivima i napisani naučnoistraživački radovi koji će biti objavljeni kao dio monografije i u međunarodnim časopisima.

Ostvareni rezultati

Realizacijom projekta su ostvareni sledeći rezultati:

- Poboljšanje tehnologije proizvodnje biodizela od otpadnog jestivog ulja. Veoma uspješno je proizveden biodizel od otpadnog suncokretovog i otpadnog palminog ulja (VIDJETI PRILOG 1);
- Održan okrugli sto pojedinih predstavnika distributera goriva u Crnoj Gori i članova radnog tima projekta iz tematske oblasti alternativna motorna goriva i njihove primjene u transportu, tokom konferencije II International Symposium on corrosion, material and environmental protection, održanoj u Baru 20.10.2012.g.;
- Ispitivanjem primjene smješe biodizela II generacije sa dizel gorivom u brodskim dizel motorima potvrđene su mogućnost njegove primjene (VIDJETI PRILOG 2);
- Ispitivanjem je utvrđeno da se u brodskom dvotaktnom sporohodnom dizel motoru može bez problema koristiti smješa goriva koja sadrži do 25% biodizela;
- Ispitivanjem je potvrđeno da se sa povećanjem udjela biodizela u smješi sa dizel gorivom ekološki parametri brodskih dizel motora poboljšavaju.
- Objavljivanje rezultata istraživanja u međunarodnim časopisima – Napisana su i predata na recenziju dva naučnoistraživačka rada:
    - Danilo Nikolic, Nada Marstijepovic, Sead Cvrk, Radmila Gagic, An investigation of using biodiesel/diesel blends on the exhaust emission of a marine diesel engine, a

paper is to be published in a book/monography Advances in Application of Industrial Biomaterials by SPRINGER.

  - Danilo Nikolic, Sead Cvrk, Nada Marstijepovic, Radmila Gagic, Ivan Filipovic, gaseous emission evaluation of two stroke marine diesel engine fueled with biodiesel produced from various waste oils and diesel blends, paper is submitted in Atmospheric Pollution Research.

- Odbranjena polazna istraživanja doktoranta mr Nade Marstijepović na Fakultetu za pomorstvo Kotor pod nazivom "Ekološki aspekti primjene biodizela II generacije u pomorstvu", 24.12.2012.g.
- Odbranjena polazna istraživanja doktoranta mr Seada Cvrka na Fakultetu za pomorstvo Kotor pod nazivom "Mogućnosti poboljšanja ekoloških performansi brodskog dizel motora optimizacijom regulacije opterećenja", 25.12.2012.g.
- Održana je radionica iz tematske oblasti alternativnih goriva i njihove primjene u transportu – u Okviru ČETVRTI SIMPOZIJUM LABORATORIJA ZA NAFTU I NAFTNE DERIVATE U REGIONU održanog 28.-29. maja 2015 na Fakultetu za pomorstvo u Kotoru održana je radionica u vezi potencijala primjene tečnih biogoriva u transportu.

Finansijski aspekt projekta

Za realizaciju projekta utrošena su finansijska sredstva prikazana u tabeli:

Odobreno sufinansiranje od strane ministarstava	39.976,63 €
Sufinansiranje ustanove i trećih strana	48.275,50 €
Ukupno	88.252,68 €

Radni tim na projektu

Istraživači koji su dali doprinos realizaciji projekta su:

1. dr Nikolić Danilo, vanr. prof.
2. dr Vujadinovic Radoje, docent
3. dr Vujović Lazo, red. prof.
4. dr Filipović Ivan, red. prof.

5. dr Ivanović Aleksandar, docent
6. dr Nikolić Božidar, red. prof.
7. dr Slavica Perović, red. prof.
8. pukovnik mr Cvrk Sead, saradnik doktorant
9. mr Marstjepović Nada, saradnik doktorant
10. mr Kovač Drasko, stručni saradnik
11. mr Sekulović Danilo, stručni saradnik
12. Gačević Vesko, stručni saradnik
13. mr Ivošević Spiro, stručni saradnik
14. Petrović Miroslav, tehnički saradnik

PRILOG 1:

PROIZVODNJA BIODIZELA II GENERACIJE

Prije opisivanja tehnologije proizvodnje biodizela u labolatorijskim uslovima opisat će se proces transesterifikacije, i dati prikaz o osnovnim hemikalijama koje se koriste u samom procesu.

Jestivo biljno ulje (novo ili korišćeno) ima previsok viskozitet da bi se bez prerade koristilo u današnjim dizel motorima. Da bi se jestivo ulje pretvorilo u biodizel potrebno mu je smanjiti viskozitet. To se postiže hemijskim putem kojim se razbijaju molekuli masti i na taj način smanjuje viskozitet. Taj postupak se naziva transesterifikacija.

Molekul masti je triglicerid što znači da se sastoji iz tri lanca masnih kisjelina (estera) koje su povezane sa molekulom glicerola. Glicerol ima udio u ulju oko 20%. Procesom transesterifikacije lanci masnih kisjelina se odvajaju od molekula glicerola i vežu sa metanolom. Glicerol tone na dno, čineći nuz-produkt glicerin. Na mjesto glicerola dolazi metanol.

Hemikalije potrebne za postupak transesterifikacije su:

- Metanol;
- Kaustična soda ili natrijum hidroksid (NaOH).

Metanol je dodavan u razmjeri 20% u odnosu na ulje i bio je velike čistoće 99,5% jer voda ometa proces transesterifikacije. Metanol je izuzetno opasna materija koja, ako se proguta, može izazvati sljepilo, a u većim količinama je smrtonosna. Zato je izuzetno važno ne udisati pare metanola i naravno ne progutati metanol pri radu. Pri radu su korišćene gumene rukavice i zaštitna odjeća.

Od jednog molekula triglicerida, dobijana su tri molekula alkilnog estra koji nazivamo biodizel. Da bi se razbio molekul triglicerida , dodavan je katalizator NaOH, takođe opasna materija vrlo nagrizajućih svojstava. Kaustična soda je izrazito toksična hemikalija koja može oštetiti kožu , oči i pluća, a može biti i smrtonosna ako se proguta. Korišćena je kaustična soda 96% čistoće. Kaustična soda je korišćena da se molekuli masnih kisjelina odvoje od glicerola kako bi se oslobođene spojile sa alkoholom. Kaustična soda se spojila sa glicerolom i padala na dno posude u kojoj je proizvođen biodizel. Kaustična soda je mjerena u gramima, zato je korišćena precizna vaga, osjetljivu već od 1 grama. U samom procesu proizvodnje miješani su metanol i kaustična soda i dobijen natrijum-metoksid, koji je obezbjeđivao odvajanje masnih kisjelina od glicerola. Natrijum-metoksid je opasan i ima sva opasna svojstva i jedne i druge hemikalije. Pri radu su korišćene isključivo plastične, polietilenske, staklene, emajlirane ili inoks posude, koje su bile potpuno suve. Nusproizvod proizvodnje biodizela je glicerin. Glicerin koji je dobijen nakon proizvodnje nije opasan i toksičan, i može se koristiti za proizvodnju sapuna.

Kako je biodizel proizveden od otpadnog palminog jestivog ulja i od otpadnog suncokretovog jestivog ulja, najvažnije je bilo uklanjanje takozvanih slobodnih masnih kisjelina u otpadnom ulju. Količina masnih kisjelina je određena procesom titracije. Ukoliko se ne uklone slobodne masne kisjeline, one mogu zaustaviti proces proizvodnje biodizela. Slobodne masne kisjeline su neutralisane dodavanjem kaustične sode. Procesom titracije određuje se koliko sode treba za ovaj postupak. Titracija je najkomplikovaniji dio ovog procesa.

1. Oprema i hemikalije

Na slikama 1., 2., 3, i 4. je prikazan laboratorijski pribor, zaštitna oprema, laboratorijska vaga E2 klase kao i bormašina sa nastavkom za miješanje, koji su korišćeni pri proizvodnji biodizela.

Slika 1. Laboratorijski pribor

Slika.2. Zaštitna-oprema

Slika 3. Precizna vaga

Slika 4. Bormašina sa mješalicom

Za dobijanje biodizela korišćeno je :

- otpadno palmino jestivo ulja (Slika 6. i 7.);
- otpadno suncokretovo jestivo ulja (Slika 8. i 9.)
- natrijum hidroksid (96% čistoće);
- metanol (99,5% čistoće);
- vinski bijeli ocat;
- destilovana voda i
- lakmus papir (Slika 5.).

Slika 5. Hemikalije za transesterifikaciju

Slika 6. Korišćeno palmino ulje

Slika 7. Korišćeno palmino ulje

Slika 8. Korišćeno suncokretovo ulje

Slika 9. Korišćeno suncokretovo ulje

2. Prečišćavanje korišćenog ulja

2.1. Grijanje i filtriranje

Kao sirovinu za dobijanje biodizela korišćeno je otpadno palmino jestivo ulja **(uzeto iz ---Danilo zna**) i otpadno suncokretovo jestivo ulja (uzeto iz Hotela Perla u Herceg Novom). Zato što su korišćena otpadna jestiva ulja, ulja su zagrijavana i filtrirana kako bi uklonili ostatke od prženja. Za filtriranje je korišćena gaza i gusta tkanina sa više slojeva. Grijanjem ulja olakšavano je filtriranje jer toplo ulje teče brže (Slika 10., 11. i 12.).

Slika 10. Korišćeno suncokretovo ulje

Slika 11. Zagrijavanje ulja

Slika 12. Filtriranje ulja

2.2. Uklanjanje vode

Kao što je već rečeno, voda smeta procesu transesterifikacije jer se veže sa kaustičnom sodom i pretvara ulje u sapun. U najgorem slučaju može da se desi da umjesto biodizela proizvedemo gel, koji je po sastavu sapun ali neupotrebljiv. Kako je u otpadnom palminom i suncokretovom ulju bilo vode, ulja su zagrijana na 100ºC, kako bi voda isparila (Slika 11.).

3. Analiza otpadnog jestivog ulja

Posle filtriranja i uklanjanja vode izvršena je analiza otpadnog palminog i suncokretovog jestivog ulja u laboratoriji pri čemu su dobijeni sljedeći rezultati za pojedine parametre otpadnih ulja (Tabela 1 i 2).

Tabela 1. Karakteristike otpadnog palminog jestivog ulja

Veličina	Jedinica	Metoda	Korišćeno ulje
Gustina	kg/m³	MEST EN ISO 3675	919,6
Tačka paljenja	ºC	EN ISO 2719	140
Sadržaj sumpora	mg/kg	ISO 8754	0
Kinematska viskoznost na 40 ºC	mm²/s	MEST ISO 3014	41,26
Sadržaj vode i sedimenata	%V/V	ASTM D2709	0,075
Korozivnost na 100 ºC	ºC	ISO2160	1a

Tabela 2. Karakteristike otpadnog suncokretovog jestivog ulja

Veličina	Jedinica	Metoda	Korišćeno ulje
Gustina	kg/m³	MEST EN ISO 3675	926,87
Tačka paljenja	ºC	EN ISO 2719	226
Sadržaj sumpora	mg/kg	ISO 8754	0
Kinematska viskoznost na 40 ºC	mm²/s	MEST ISO 3014	40,7
Sadržaj vode i sedimenata	%V/V	ASTM D2709	0,015
Korozivnost na 100 ºC	ºC	ISO2160	1a

4. Postupci proizvodnje biodizela

4.1. Postupak titracije

Pošto koristimo palmino otpadno ulje i otpadno suncokretovo ulje, potrebno je dodavanjem dodatne količine hemikalija korigovati pH vrijednost korišćenog palminog ulja i suncokretovog ulja. Optimalna pH vrijednost korišćenih ulja je između 8 i 9. Zbog toga se tačna količina reaktanta određuje postupkom titracije.

Ovo je najteži i najkritičniji dio postupka u kojem treba biti što precizniji. Proces titracije nam daje odgovor koliko kaustične sode je potrebno za proces. Zato se koristila suva soda koja nije bila u kontaktu sa vodom. Kod postupka titracije prvo je vršeno miješanje 1 gr kaustične sode (Slika 13.) i 1 litar destilovane vode, pri čemu se soda potpuno otopila u destilovanoj vodi (označimo to kao 0,1 % NaOH rastvor) (Slika 14.). Dobijeni rastvor se za dalji tok postupka koristi i za palmino ulje i za suncokretovo ulje.

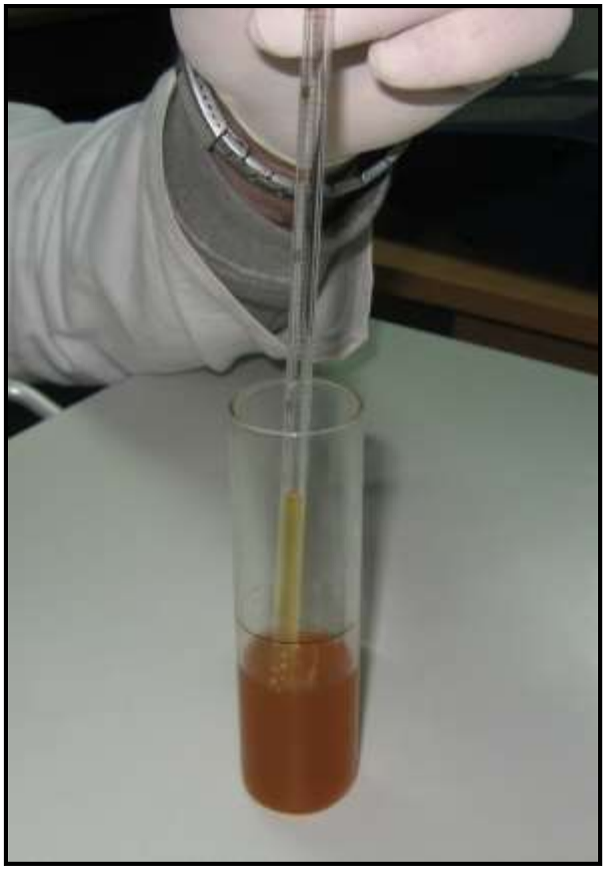
Slika 13. 1 gr kaustične sode

Slika 14. 0,1% NaOH rastvor

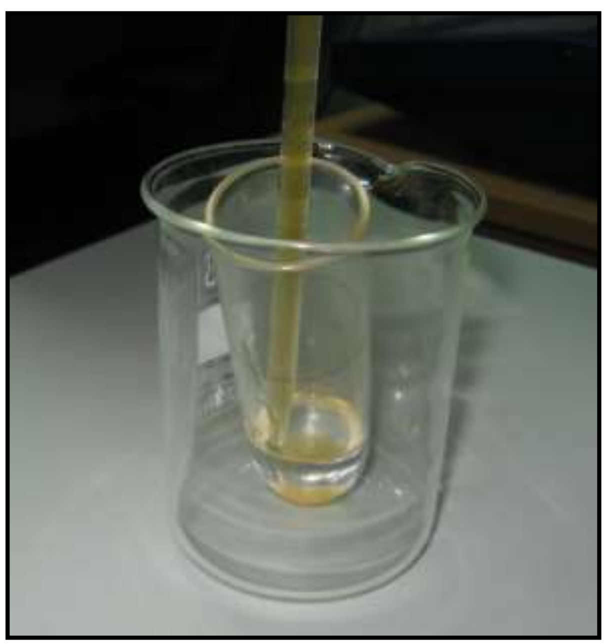
Nakon toga je izvršeno miješanje 10 ml izopropil alkohola (izopropanola) (Slika 16.) sa 1 ml otpadnog palminog ulja i suncokretovog ulja od kojeg pravimo gorivo(Slika 15., 17. i 18.). Zatim su se rastvori palminog i suncokretovog ulja lagano zagrijavali i miješali dok se svo ulje nije rastopilo u izopropanolu(Slika 19. i 20.).

Slika 15. 0,1% NaOH rastvor

Slika 16. Uzimanje 10ml izopropanola



Slika 17. Uzimanje 1ml palminog ili suncokretovog ulja



Slika 18 . Dodavanje ulja izopropanolu

Slika 19. Zagrijavanje smješe

Slika 20. Miješanje smješe

Pomoću lakmus papira je izmjerena pH vrijednost rastvora palminog ulja i suncokretovog ulja u izopropanolu, pri čemu je pH vrijednost za oba ulja bila 5**.** Nakon toga je izmjeren 1 ml rastvora NaOH i dodat u rastvor palminog ulja i 1 ml rastvora NaOH i dodat u rastvor suncokretovog ulja(Slika 23. i 24.), pri čemu su ponovo izmjerene pH vrijednosti oba rastvora. Nakon toga je vršeno dodavanje po 1ml rastvora NaOH u oba rastvora i nakon svakog dodavanja izmjerena je pH vrijednost rastvora ulja. Cilj je postići pH rastvora oko 8 do 9 i tada je titracija završena (Slika 21. i 22.).

Slika 21. Titracija

Slika 22. Mjerenje pH rastvora ulja

Slika 23. Mjerenje 1 ml rastvora NaoH

Slika 24 . Mjerenje pH rastvora ulja

Važno je zapamtiti koliko je ukupno mililitara rastvora NaOH dodato u rastvor ulja. Dakle potrebna količina NaOH za potpunu transesterifikaciju je: 3,5 gr plus onoliko grama koliko je mililitara rastvora NaOH dodavano tokom titracije. Za palmino ulje i suncokretovo ulje u procesu titracije dva puta dodavan po 1ml vodenog rastvora NaOH, tako da je ukupna potrebna količina NaOH za palmino ulje i suncokretovo ulje 3,5+2=5,5 grama, za 1 litar otpadnog ulja.

4.2. Priprema natrijum-metoksida

Prvo je izmjerena potrebna količina metanola. Potrebna količina je 20% od količine ulja. To znači pošto je rađeno sa 3 litra palminog ulja i 3 litra suncoktretovog ulja potrebno je po 0,6 litara (600 ml) metanola i za jednu i drugu vrstu ulja(Slika 27. i 28.). Nakon toga je izmjerena potrebna količina kaustične sode, pošto je titracijom određeno da je potrebno 5,5 grama po litri oba ulja, za količinu od 3 litra palminog ulja i 3 litra suncokretovog ulja izmjereno je po 16,5 gr kaustične sode (Slika 25. i 26.).


Slika 25. i 26. Mjerenje težine kaustične sode

Nakon toga je vršeno dodavanje kaustične sode metanolu(Slika 29.). Miješanjem NaOH i metanola dobijen je natrijum-metoksid (Slika 30.), posebno za palmino ulje a posebno za suncokretovo ulje. Nakon toga posude u kojima je pripreman natrijum-metoksid su dobro protresene da bi se kaustična soda otopila u metanolu. Zatim su rastvori ostavljeni da odstoje 24 časa da bismo bili sigurni da je sva kaustična soda otopljena u metanolu. Nakon 24 časa na dnu posuda uočeni su nerastopljeni kristali kaustične sode, pri čemu postupak nije nastavljen jer se sva soda nije otopila u metanolu. Kako se kaustična soda kad je hladnije vrijeme slabije rastvara u metanolu, zbog toga je za miješanje upotrijebljena mehanička mješalica koja je znatno ubrzala proces, to jest korišćena je ručna bušilica sa nastavkom za miješanje.

Slika 27. i 28. Mjerenje potrebne količine metanola

Slika 29. Dodavanje NaOH metanolu **Slika 30. Smješa NaOH i metanola**

4.3. Grijanje i miješanje

Kako je palmino ulje i suncokretovo ulje bilo hladno, vršeno je zagrijavanje ulja na 60ºC, a zatim je još jednom provjereno dali se sva kaustična soda rastopila u metanolu, a kako je sva soda bila rastopljen u metanolu, tada su ulja dolivena dobijenom natrijum-metoksid (Slika 31.). Da bi reakcija bila uspješna, dobijene mješavine su izmiješane sa bušilicom i nastavkom za miješanje. Miješanje je trajalo oko jedan čas (Slika 32.).

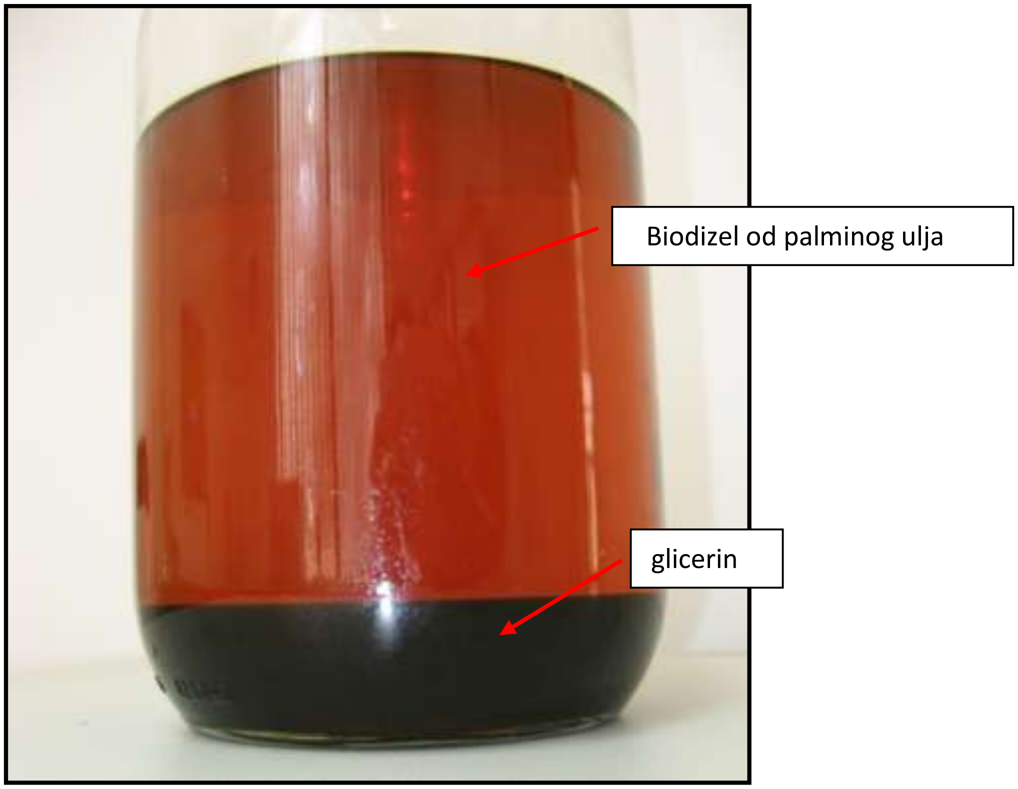
Slika 31. Miješanje smješe metanol i NaOH **Slika 32. Miješanje smješe metanol i NaOH**

Nakon miješanja dobijena je mješavina natrijum-metoksida i ulja (Slika 33.).

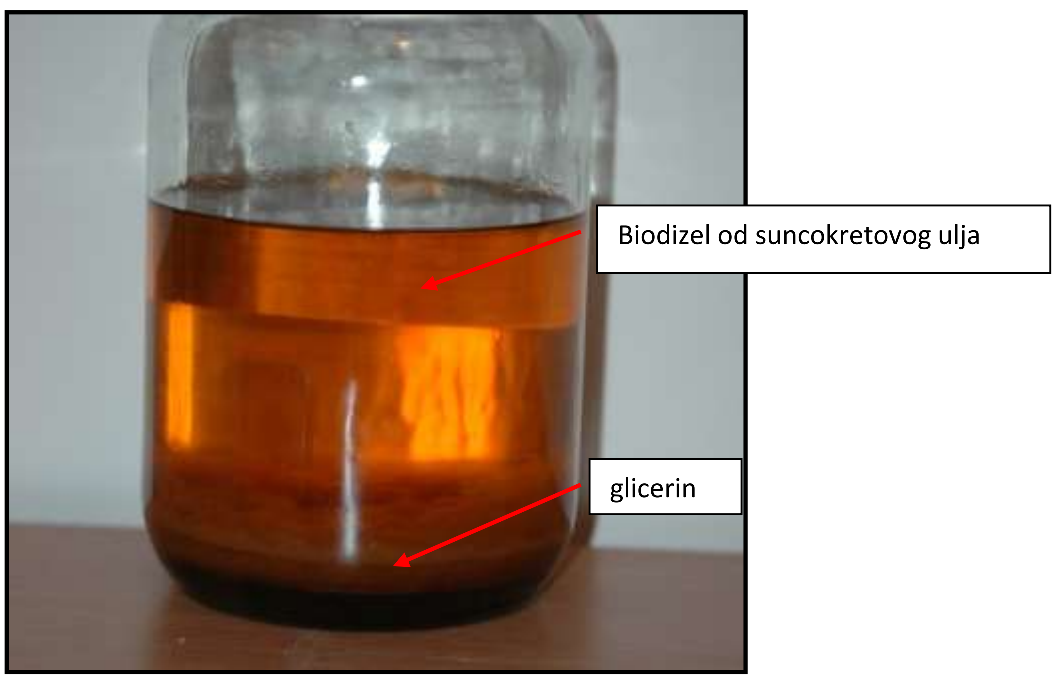
Slika 33. Smješa natrijum-metoksid ulje

4.4. Taloženje i separacija

Poslije miješanja ostavljene su mješavine palminog ulja i suncokterovog ulja da odstoje najmanje 8 sati, pri čemu je glicerin u obije mješavine pao na dno, a svjetliji prozirni biodizel je ostao iznad (Slika 34. i 35.). Proizvedeni biodizel od otpadnog palmonog ulja i suncokretovog ulja je ostavljen da ostoji još oko sedam dana kako bi bili sigurni da se glicerin nataložio.



Slika 34. Taloženje i separacija palminog ulja



Slika 35. Taloženje i separacija suncokretovog ulja

Nakon sedam dana izdvojio se biodizel od palminog i suncokretovog otpadnog ulja koji se koristio u daljem eksperimentu (Slika 36.).

Slika 36. Proizvedeni biodizel

Provjera fiziko-hemijskih karakteristika dobijenih biodizela vršena je po važećim standardima za ove vrste goriva pri čemu su dobijeni rezultati koji su dati u tabelama 3 i 4.

Tabela 3. Karakteristike proizvadenog biodizela od palminog otpadnog ulja

Veličina	**Jedinica**	**Metoda**	**Korišćeno ulje**
Gustina	kg/m³	MEST EN ISO 3675	885,1
Tačka paljenja	ºC	EN ISO 2719	120
Sadržaj sumpora	mg/kg	ISO 8754	0
Kinematska viskoznost na 40 ºC	mm²/s	MEST ISO 3104	5,23
Cetanski indeks	**-**	**MEST EN ISO 4264**	**54,65 ili 46.57**
Sadržaj vode i sedimenata	%V/V	ASTM D2709	0,03
Korozivnost na (50 ºC 3h)	ºC	ISO 2160	1a
Destilacija Početak destilacije 5% 10% 50% 90% 95%	ºC	ISO 3405	 312 324 325 332 355 357

Tabela 4. Karakteristike proizvadenog biodizela od suncokretovog otpadnog ulja

Veličina	Jedinica	Metoda	Korišćeno ulje
Gustina	kg/m³	MEST EN ISO 3675	893,9
Tačka paljenja	ºC	EN ISO 2719	170
Sadržaj sumpora	mg/kg	ISO 8754	0
Kinematska viskoznost na 40 ºC	mm²/s	MEST ISO 3104	5,52
Cetanski indeks	**-**	**MEST EN ISO 4264**	**51,83 ili 44,52**
Sadržaj vode i sedimenata	%V/V	ASTM D2709	0,015
Korozivnost na (50 ºC 3h)	ºC	ISO 2160	1a
Destilacija Početak destilacije 5% 10% 50% 90% 95%	ºC	ISO 3405	 315 324 328 335 356 358

PRILOG 2:

EXPERIMENTALNO ODREĐIVANJE EMISIJE IZDUVNIH GASOVA IZ BRODSKOG MOTORA KORIŠĆENJEM DIZEL GORIVA I SMJEŠA SA BIODIZELOM NAPRAVLJENIM OD OTPADNOG JESTIVOG ULJA (SUNCOKRET, PALMA, MASLINA)

Nakon proizvedenog biodizela II generacije od otpadnog palminog, suncokretovog i maslinovog ulja, prišlo se miješanju istog sa fosilnim dizel gorivom. Za miješanje sa biodizelom upotrijebilo se standardno eurodizel gorivo koje se koristi za potrebe brodova Mornarice Crne Gore. Udjeli biodizela u dizel gorivu su od 7%, 20% i 25%. Izbor ovih udjela je utvrđen nakon literaturnog pregleda sličnih eksperimenata. Naime, 7% udjela biodizela u dizel gorivu je maksimalna dozvoljena koncentracija predviđena evropskim standardom kvaliteta dizel goriva EN 590, 20% udjela biodizela je maksimalni udio biodizela u dizel gorivu prilikom ispitivanja na brodskim motorima, dok je 25% izabran kao pretpostavljeni najveći mogući udio biodizela za bezbjedan pogon brodskog dizel motora smještenog na školskom brodu Jadran. Na taj način je korišteno 8 vrsta smješa biodizel/dizel gorivo kao i čisto dizel gorivo kao referentno, kao što slijedi:

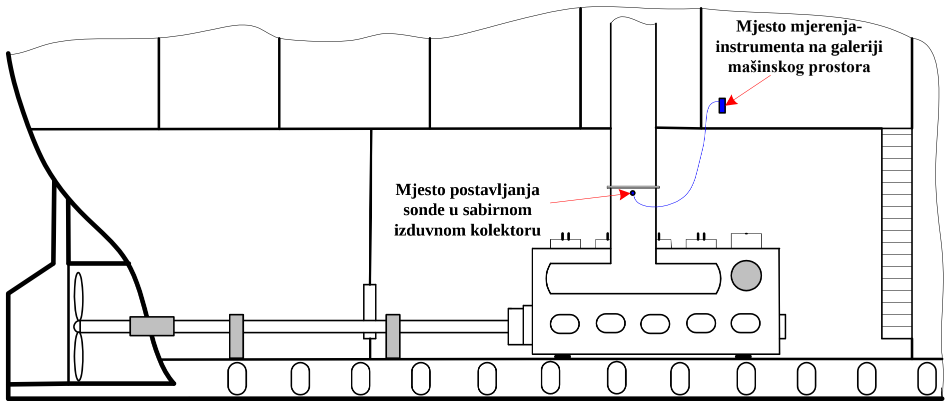
1. Ekodizel (B0)
2. Ekodizel 93% : 7% biodizela od palme = 28 L+2.1L (BP7%)
3. Ekodizel 80% : 20% biodizela od palme = 24 L+6 L (BP20%)
4. Ekodizel 75% : 25% biodizela od palme = 22,5 L+7.5 L (BP25%)
5. Ekodizel 93% : 7% biodizela od suncokreta = 28 L+2.1 L (BS7%)
6. Ekodizel 80% : 20% biodizela od suncogreta = 24 L+6 L (BS20%)
7. Ekodizel 75% : 25% biodizela od suncokreta = 22,5 L+7.5 L (BS25%)
8. Ekodizel 93% : 7% biodizela od masline = 28 L+2.1L (BM7%)

U dojnoj tabeli data su osnovna svojstva korištenih goriva:

Parametri		1 B0%	2 BP7%	3 BP20%	4 BP25%	5 BS7%	6 BS20%	7 BS25%	8 BM7%
Density @ 15°C	kg/m3	833,4	836,37	842,3	844,8	837,2	843,7	846,65	837,7
Viscosity @ 40°C	mm2/s	2,92	3,00	3,19	3,21	2,95	3,12	3,23	3,31
Flash point	°C	62,0	71,5	79,5	81,5	71,3	79,3	81,3	71,2
Corrosion, Cu, 1h, 40 °C		1a	1a	1a	1a	1a	1a	1a	1a
Cetane index		55,27	55,14	55,32	55,66	55,41	55,72	55,32	54,07
Distillation % (v/v) recovered @ 250°C % (v/v) recovered @ 350°C	 % (v/v) % (v/v)	 29 91	 26 92	 25 92	 20 92	 28 91	 21 89	 19 89	 27 89

95% (v/v)	ºC	362	357	356	360	362	362	363	365
CFPP	ºC	- 18	-18	-16	-16	-18	-16	-16	-16
Sulfur content	mg/kg	85,73	79,10	61,30	54,82	77,90	61,51	56,37	79,96
Water content	mg/kg	40,94	71,93	128,23	153,65	79,99	153,42	177,42	26,52
FAME content	v/v	0	7	20	25	7	20	25	7

Mjerenje emisije izduvnih gasova vršilo se sa instrumentom ''TESTO 350-MARITIME''. Sonda instrumenta postavljala se u otvor sabirnog kolektora izduvnih gasova (koji je predviđen za ovakva mjerenja) iznad motora. Više o instrumentu se može naći na http://www.testo350.com/downloads/350-maritime/Brochure_350_Maritime.pdf .



Sl. Shema brodskog pogona

Dio sabirnog kolektora od motora do mjesta mjerenja nije hlađen (nije predviđeno hlađenje kolektora). Sam instrument se nalazio na galeriji mašinskog prostora iznad motora na visini oko dva metra. Mjerenje emisije za svaki uzorak goriva vršilo se na istim režimima rada motora. Između svakog režima rada motora vršilo se mjerenje kada se stabilizuju parametri mjerenja kao i drugi parametri rada motora (temperature rashladne tečnosti i ulja).

Rezultati izmjerenih parametara dati su u donjim tabelama.

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	1,25	19,61	169	14	13	0,2	2,7	32	34	30	40	112,6
N 180	1,12	19,69	159	14	15	0,3	2,0	34	36	32	40	118,2

N 210	1,56	19,13	220	22	17	0,2	2,9	36	38	34	44	156,9
N 210 km	1,77	18,81	205	155	11	0,1	3,1	40	44	36	50	224,1

Rezultati izmjerenih parametara za B0 gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	0,6	20,38	76	7	8	0,3	2,1	38	42	38	56	129,1
N 180	0,85	20,07	113	10	10	0,3	2,3	40	44	38	48	158,1
N 210	1,16	19,64	137	58	10	0,2	2,0	40	44	38	46	211,5
N 210 km	1,17	19,63	140	67	10	0,2	2,6	40	44	38	50	220,7

Rezultati izmjerenih parametara za BP7% gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	0,53	20,40	66	7	6	0,3	2,0	40	46	38	58	129,7
N 180	0,73	20,23	95	10	8	0,2	2,2	40	46	36	46	157,8
N 210	1,06	19,79	126	55	9	0,2	2,3	40	46	36	46	214,4
N 210 km	0,99	19,87	118	55	8	0,2	2,2	40	46	36	50	220,3

Rezultati izmjerenih parametara za BP20% gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	0,46	20,58	54	7	5	0,2	1,8	40	50	38	52	133,9
N 180	0,64	20,36	83	8	6	0,2	1,9	42	50	36	48	161,0
N 210	0,94	19,97	112	40	8	0,2	2,2	42	50	36	48	215,2
N 210 km	0,90	20,03	107	46	7	0,2	2,2	42	50	36	48	219,7

Rezultati izmjerenih parametara za BP25% gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	0,44	20.65	52	7	4	0,2	1,8	42	50	36	48	134,1
N 180	0,60	20,44	78	8	6	0,2	1,9	42	50	36	48	161,4
N 210	0,86	20,09	100	54	6	0,2	2,1	42	48	36	48	217,5
N 210 km	0,84	20,11	100	49	6	0,2	2,1	42	48	36	48	222,2

Rezultati izmjerenih parametara za BS7% gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova

								ulja u motor				
N 150	0,42	20,68	49	6	4	0,2	1,7	42	50	38	50	138,2
N 180	0,55	20,51	73	8	5	0,2	1,9	44	50	38	48	163,5
N 210	0,79	20,20	94	40	6	0,2	2,1	44	50	38	48	218,2
N 210 km	0,75	20,24	92	39	6	0,2	2,1	46	52	38	52	222,8

Rezultati izmjerenih parametara za BP20% gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	0,37	20,75	41	5	3	0,2	1,7	42	50	38	48	133,1
N 180	0,5	20,57	64	6	4	0,2	1,8	42	50	38	48	161,7
N 210	0,72	20,22	85	39	7	0,2	2,0	42	50	36	48	217,0
N 210 km	0,70	20,25	83	42	7	0,2	2,0	44	52	38	52	221,4

Rezultati izmjerenih parametara za BP25% gorivo

Režim i br. obr. min^{-1}	CO_2 %	O_2 %	NO_x ppm	CO ppm	SO_2 ppm	Stepen korisnosti %		Temperature º C				
						Neto	Bruto	Ulaznog ulja u motor	Izlaznog ulja iz motora	Ulazne vode u motor	Izlazne vode iz motora	Izduvnih gasova
N 150	0,35	20,71	38	5	4	0,3	1,7	44	50	38	48	130,1
N 180	0,47	20,54	58	9	6	0,3	1,8	44	50	38	48	161,1
N 210	0,64	20,32	72	45	6	0,2	2,0	44	50	38	50	211,1

N 210 km	0,67	20,28	74	55	5	0,2	2,0	44	52	38	52	224,1

Rezultati izmjerenih parametara za BM7% gorivo

Na sljedećim fotografijama su prikazani detalji sa postupka mjrerenja izduvne emisije iz brodskog motora.



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