



Faculty of Engineering
University of Kragujevac



Ministry of Science, Technological
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**11th International Congress
Motor Vehicles & Motors 2026
ECOLOGY -
VEHICLE AND ROAD SAFETY
- EFFICIENCY
Proceedings**



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FOREWORD

For 47 years, a traditional international gathering - originally known as a Symposium and, since 2006, as the "Motor Vehicles and Motors" Congress - has been held biennially at the Faculty of Engineering (formerly the Faculty of Mechanical Engineering) of the University of Kragujevac. This year, the 11th International Congress "Motor Vehicles and Motors" took place in Kragujevac on October 8th–9th, 2026, under the traditional motto: "Ecology – Vehicle and Road Safety – Efficiency".

A large number of authors from both the country and abroad responded to the organizers' invitation, resulting in numerous high-quality submissions across the event's core areas: "Power Train Technology," "Vehicle Design and Manufacturing," "Vehicle Dynamics and Intelligent Control Systems," "Driver/Vehicle Interface, Information Systems, and Assistance Systems," and "Transport Challenges in Emerging Economies." Additionally, two topics were officially introduced for the first time: "Artificial Intelligence in Automotive Technology" and "Autonomous Vehicles".

A total of 63 papers were accepted for presentation following a rigorous peer-review process. The presentations were organized into sessions, including a newly introduced poster session dedicated to students and young researchers.

The Congress organizers extend their special gratitude to the distinguished scientists in the fields of motor vehicles and transportation who agreed to deliver three inspiring introductory lectures addressing the heart of contemporary issues in the sector: prof. dr Ralph Putz (Landshut University of Applied Sciences, Germany), prof. dr Aleksandar Stevanović (University of Pittsburgh, USA), and prof. dr. Isak Karabegović (Academy of Sciences and Arts of Bosnia and Herzegovina, Bosnia and Herzegovina).

We extend our sincere gratitude to the esteemed members of the Congress Scientific Committee—who also served as reviewers for the papers submitted for presentation—for their significant contribution to the overall quality of the accepted papers.

The organization of the Congress was once again supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, the Faculty of Engineering of the University of Kragujevac, and the International journal "Mobility & Vehicle Mechanics" and we sincerely thank them for their support.

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PREDGOVOR

Već 47 godina, svake druge godine, na Fakultetu inženjerskih nauka (nekada Mašinskom fakultetu) Univerziteta u Kragujevcu održava se tradicionalan međunarodni skup, nekada nazivan Simpozijum, a od 2006. godine - Kongres „Motorna vozila i motori“. Ovogodišnji, 11. Međunarodni kongres „Motorna vozila i motori“ održan je u Kragujevcu od 8. do 9. oktobra 2026. godine, uz tradicionalni moto „Ekologija – Vozilo i bezbednost na putu – Efikasnost“.

Na poziv organizatora odazvao se veliki broj autora iz zemlje i inostranstva, što je donelo veliki broj prijavljenih kvalitetnih radova iz glavnih oblasti skupa: „Tehnologija pogonskog sistema“, „Dizajn i proizvodnja vozila“, „Dinamika vozila i inteligentni upravljački sistemi“, „Interfejs vozač/vozilo, informacioni sistemi i sistemi za pomoć“, „Transportni izazovi ekonomija u usponu“, uz prvi put zvanično promovisane teme – „Veštačka inteligencija u automobilskoj tehnologiji“ i „Autonomna vozila“.

Ukupan broj od 63 radova je prihvaćen za prezentaciju posle rigoroznog procesa recenziranja. Rad je organizovan po sekcijama, uz prvi put promovisanu poster sekciju namenjenu za studente i mlade istraživače.

Organizatori Kongresa su posebno zahvalni istaknutim naučnicima iz oblasti motornih vozila i saobraćaja koji su pristali da održe tri inspirativna uvodna predavanja koja zadiru u srž savremenih pitanja vezana za vozila i saobraćaj, a to su: prof. dr Ralph Putz (Landshut University of Applied Sciences, Nemačka), prof. dr Aleksandar Stevanović (University of Pittsburgh, SAD) i prof. dr Isak Karabegović (Akademija nauka i umjetnosti Bosne i Hercegovine, Bosna i Hercegovina).

Veliku zahvalnost dugujemo našim dragim članovima Naučnog odbora Kongresa, ujedno i recenzentima radova prijavljenih za prezentaciju na Kongresu, koji su mnogo doprineli ukupnom kvalitetu konačno prihvaćenih radova.

Organizaciju Kongresa i ovog puta su podržali: Ministarstvo nauke, tehnološkog razvoja i inovacija Republike Srbije, Fakultet inženjerskih nauka Univeziteta u Kragujevcu i Međunarodni časopis „Mobility & Vehicle Mechanics“, na čemu im se iskreno zahvaljujemo.

Naučni odbor i Organizacioni odbor Kongresa MVM2026

CONTENT

INTRODUCTORY LECTURES

MVM2026-IL1	Ralph Pütz	OPERATING COSTS OF PUBLIC TRANSPORT BUSES WITH DIFFERENT PROPULSION SYSTEMS AND VARIOUS TYPES OF RENEWABLE ENERGY OVER TIME – WHERE IS THE JOURNEY HEADING?	3
MVM2026-IL3	Isak Karabegović	COLLABORATIVE ROBOTICS AND ARTIFICIAL INTELLIGENCE IN THE AUTOMOTIVE INDUSTRY: SMART ASSEMBLY AND AUTOMATED QUALITY CONTROL	13

SECTION A Power Train Technology

MVM2026-003	Ivan Grujic Aleksandar Davinic Zeljko Djuric Jovan Doric Milan Eremija Attila Kiss Sunny Narayan	THE INVESTIGATION OF THE COMBUSTION PROCESS OF THE BLEND OF THE CONVENTIONAL DIESEL FUEL AND BIODIESEL MADE FROM THE WASTE GRAPE SEEDS	35
MVM2026-008	Željko Đurić Ivan Grujić Nadica Stojanović Snežana Petković Jelena Adžić Milan Eremija	EXPERIMENTAL INVESTIGATION OF THE COMBUSTION PROCESS AND EFFICIENCY OF A DIESEL ENGINE IN THE CASE OF BIODIESEL FUEL APPLICATION	41
MVM2026-011	Milan Eremija Ivan Grujić Danijela Miloradović Željko Đurić Svetko Milutinović Nadica Stojanović	EXPERIMENTAL ANALYSIS OF EXHAUST GAS TEMPERATURE DURING THE USE OF BIODIESEL FUEL	53
MVM2026-013	Krasimir Markov Hristo Stanchev	INVESTIGATION OF THE FUEL CONSUMPTION AND EMISSIONS OF A DIESEL ENGINE RUNNING ON DIESEL WITH AN ADDITIVE	61
MVM2026-015	Milan Eremija Zoran Ristikić Svetko Milutinović Mesud Ajanović	EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF TIRE PRESSURE ON THE ROLLING RESISTANCE COEFFICIENT OF COMMERCIAL VEHICLES	67
MVM2026-025	Marko Lučić Mirjana Grdinić-Rakonjac Radoje Vujadinović Vladimir Pajković Ivan Grujić	ENERGY USE IN MONTENEGRO'S ROAD TRANSPORT SECTOR: TRENDS, FUEL STRUCTURE AND DEPENDENCE ON PETROLEUM-BASED FUELS	77

MVM2026-030	Vladimir Kočović Živana Jovanović Pešić Miloš Pešić Jelena Đusić Dragan Džunić	TRIBOLOGICAL PERFORMANCE OF BRASS SURFACES LUBRICATED WITH NEW AND USED ENGINE OILS	85
MVM2026-034	Mihailo Đuković Saša Milojević Slobodan Savić Blaža Stojanović Horia Abaitancei	APPLICATION OF A RADIAL HYDRAULIC MOTOR IN ALTERNATIVE VEHICLE DRIVE SYSTEMS	91
MVM2026-036	Marko Kitanović Slobodan Popović Nenad Miljić Predrag Mrđa	EFFECTIVE MIXTURE COMPOSITION IN THE ANGULAR DOMAIN IN SUPERCHARGED DISI ENGINE WITH MULTIPLE INJECTIONS	111
MVM2026-037	Petar Markov Radivoje Pušara Dragan Peruničić	A SINGLE-RANGE POLYNOMIAL MODEL FOR TEMPERATURE-DEPENDENT MIXTURE PROPERTIES IN COMBUSTION ENGINES WITH VARIABLE EGR RATES	125
MVM2026-038	Dragan Peruničić Petar Markov Radivoje Pušara	MODELING OF SPECIFIC HEAT RATIO FOR DISI ENGINES WITH COMPLEX MIXTURE FORMATION AND HIGH EGR RATES	139
MVM2026-041	Predrag Mrđa Slobodan Popović Nenad Miljić Marko Kitanović	EXPERIMENTAL AND CFD-BASED INVESTIGATION OF VAPOUR POCKET FORMATION IN AN INTERNAL COMBUSTION ENGINE COOLING SYSTEM	155
MVM2026-042	Nenad Miljić Predrag Mrđa Slobodan J. Popović	QUANTIFYING IMEP EVALUATION ERROR INDUCED BY PIEZOELECTRIC PRESSURE SENSOR AGEING IN INTERNAL COMBUSTION ENGINE INDICATION	165
MVM2026-051	Saša Milojević Marija Rafailović Michal Loman Branislav Šarkan Ján Vrábel Slobodan Savić	SAFETY AND OPERATIONAL CONSIDERATIONS FOR COMPOSITE HYDROGEN AND CNG STORAGE CYLINDERS IN VEHICLES	175
MVM2026-068	Mitar Mišić Stjepan Galamboš Boris Stojić Jovan Dorić Luka Sekicki	DEVELOPMENT OF AN ELECTRONIC MEASUREMENT SYSTEM FOR TURBOCHARGER WASTEGATE ACTUATOR RESPONSE-TIME TESTING	185
MVM2026-071	Mitar Mišić Stjepan Galamboš Jovan Dorić Boris Stojić Luka Sekicki	DESIGN AND IMPLEMENTATION OF A TEST BENCH FOR EVALUATING THE DYNAMICS OF PNEUMATIC WASTEGATE ACTUATORS	193

SECTION B

Vehicle Design and Manufacturing

MVM2026-006	Gordana Bogdanović Aleksandar Radaković Dragan Čukanović Petar Knežević Aleksandar Nešović	VARIATIONAL SHEAR CONTROL IN ESL–HSDT LAMINATES FOR AUTOMOTIVE STRUCTURES	203
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MVM2026-007	Gordana Bogdanović Aleksandar Radaković Petar Knežević Dragan Čukanović Marko Milošević	FATIGUE ANALYSIS OF MATERIALS AND METHODS FOR CYCLE COUNTING UNDER ARBITRARY LOAD HISTORIES	211
MVM2026-009	Julija Boskovic Ivan Grujic Stefan Djuric Nadica Stojanovic Bogdan Zivkovic Milan Ivkovic Suzana Petrovic Savic	DEVELOPMENT OF AN EXPERIMENTAL FIVE-AXIS CNC SYSTEM USING STEPPER MOTORS	219
MVM2026-012	Saša Vasiljević Jasna Glišović Slobodan Vasiljević	ANALYSIS OF EXPERIMENTAL METHODOLOGIES FOR TESTING INNOVATIVE BRAKE SOLUTIONS	235
MVM2026-016	Ljubica Spasojević Zorica Djordjević Sonja Kostić Saša Jovanović	MODAL ANALYSIS OF A COMPOSITE CRANKSHAFT FOR AN INTERNAL COMBUSTION ENGINE (ICE)	245
MVM2026-017	Zvonko Petrović Suzana Petrović Savić Milica Tufegdžić Nikola Kostić Milena Petrović	MATHEMATICAL MODELING OF HYDRAULIC DRIVE FOR THE MITSUBISHI RV-2FRL INDUSTRIAL ROBOT: INFLUENCE OF MOMENT OF INERTIA ON SERVO VALVE RESPONSE TIME	253
MVM2026-022	Marko Delić Vesna Mandić Nada Ratković Nikola Komatina Dušan Arsić Nikola Kastratović	ANALYSIS OF THE INFLUENCE OF IMPORTANT FORMING PARAMETERS IN SHEET METAL STAMPING IN AUTOMOTIVE INDUSTRY USING FEA	267
MVM2026-024	Milan Simonović Dragan Adamović Đorđe Ivković Marko Simonović	ANALYSIS OF THE POSSIBILITY OF PREDICTING THE TENSILE STRENGTH OF ADVANCED STRUCTURAL STEELS USED IN THE AUTOMOTIVE INDUSTRY USING ARTIFICIAL NEURAL NETWORKS WITH DIFFERENT NUMBERS OF NEURONS IN THE HIDDEN LAYER	275
MVM2026-026	Nenad Petrović Živana Jovanović Pešić Dragan Džunić Vladimir Kočović Strahinja Milenković	CREATING CURVED MESHES BY HEAT-FORMING 3D-PRINTED PARTS	287
MVM2026-050	Danijela Tadić Jasna Glišović Nikola Komatina	COMPARATIVE ANALYSIS OF OBJECTIVE CRITERIA WEIGHTING METHODS FOR ELECTRIC VEHICLE EVALUATION	293
MVM2026-052	Dragan Čukanović Gordana Bogdanović Aleksandar Radaković Petar Knežević	APPLICATION, MODELLING AND BENDING ANALYSIS OF COMPOSITE LAMINATES IN MODERN VEHICLES	303
MVM2026-053	Mihajlo Jevtić Aleksandra Obradović Bogdan Todorović Nebojša Hristov Damir Jerković	FINITE ELEMENT ANALYSIS OF STRUCTURAL SUPPORT REACTIONS IN WHEELED MOBILE PLATFORM UNDER HIGH-INTENSITY IMPULSIVE LOADING	311

MVM2026-059	Dušan Milojević Nikola Kotorčević Đorđe Damljanović Nikola Živčević Dušan Arsić Fatima Živić	EFFECTS OF UNIT CELL GEOMETRY AND STRUT THICKNESS ON THE COMPRESSIVE BEHAVIOR OF 3D-PRINTED MECHANICAL METAMATERIALS	321
MVM2026-060	Nebojša Arsić Nenad Kostić Nenad Petrović Nenad Marjanović	APPLICATION OF 3D SCANNING AND CAD DEVIATION ANALYSIS AS A BASIS FOR PRESS TOOL OPTIMISATION IN THE AUTOMOTIVE INDUSTRY	325
MVM2026-061	Sandra Gajević Slavica Miladinović Nikola Mitrović Zorica Djordjević Saša Milojević Blaža Stojanović	APPLICATION OF LAMINATED COMPOSITES IN THE AUTOMOTIVE, AVIATION AND MARINE INDUSTRY	333
MVM2026-067	Luka Milić Ilija Vidović Matija Simanić Momir Drakulić Aleksandar Đurić	ADDITIVE MANUFACTURING AS A FABRICATION METHOD FOR A LIGHTWEIGHT TRACKED ROBOT PLATFORM	345
MVM2026-070	Dobrivoje Čatić Vladimir Čatić	A COMBINED FTA-FMEA PROCEDURE FOR PRODUCT DEVELOPMENT	355
MVM2026-073	Milan Blagojević Milan Bojović Živče Šarkočević	REVERSE ENGINEERING OF A COMPLETE VEHICLE FOR THE DEVELOPMENT OF A MODULAR VEHICLE PLATFORM	363
MVM2026-076	Nenad Miloradović Rodoljub Vujanac Mirjana Piskulić	WAREHOUSE SYSTEMS IN THE AUTOMOTIVE INDUSTRY: A COMPARATIVE STUDY OF STORAGE SYSTEMS, HANDLING EQUIPMENT AND SAFETY CLEARANCE	369

SECTION C

Vehicle Dynamics and Intelligent Control Systems

MVM2026-001	Miroslav Demić Mikhail P. Malinovsky Andrija Vujičić	THEORETICAL-EXPERIMENTAL APPROACH TO THE DEVELOPMENT OF A METHOD FOR IDENTIFYING THE HEAT DISSIPATION RATE OF MOTOR VEHICLE SHOCK ABSORBERS	379
MVM2026-002	Aleksandar Jovanović Katarina Kukić Ana Uzelac Dušan Teodorović	DEEP Q-LEARNING ALGORITHM FOR TRAFFIC CONTROL AT A DISPLACED LEFT-TURN INTERSECTION	393
MVM2026-014	Boris Stojić Nebojša Nikolić Luka Sekicki	A FLEXIBLE COMPUTATIONAL MODEL FOR FUEL CONSUMPTION ESTIMATION IN ARBITRARY VEHICLE DRIVING CYCLES	403
MVM2026-018	Dušan Opsenica Ivan Blagojević Saša Mitić	THE INFLUENCE OF ELECTRIC VEHICLE CONFIGURATION ON VEHICLE DYNAMIC CHARACTERISTICS	413
MVM2026-023	Snežana Petković Valentina Golubović Bugarski Jelena Adžić Milan Eremija	ANALYSIS OF PARAMETERS INFLUENCING ROAD TANKER ROLLOVER	425

MVM2026-028	Momir Drakulić Aleksandar Đurić Sreten Perić	SENSITIVITY ANALYSIS OF A TERRAMECHANICS MODEL OF TRACK- TERRAIN INTERACTION WITH RESPECT TO VEHICLE DESIGN PARAMETERS	435
MVM2026-031	Marko Simonović Dragan Adamović Đorđe Ivković Milan Simonović	SELECTION OF MATERIALS FOR FRICTION COMPONENTS OF THE BRAKE MECHANISM	447
MVM2026-032	Zoran Papić Nenad Saulić Milja Simeunović	PREDICTION OF EES VALUES IN VEHICLE IMPACTS USING AI	461
MVM2026-035	Marijana Jeremić Lazar Krstić Miloš Ivanović Mihailo Lazarević Milan Matijević	DIGITAL TWIN DESIGN FOR TORSIONAL STIFFNESS ESTIMATION IN MOTOR-LOAD OSCILLATORY SYSTEMS USING PHYSICS- INFORMED NEURAL NETWORKS	471
MVM2026-040	Nebojša Jovičić Angelina Cvetanović Goran Bošković	EVALUATING THE EFFICIENCY OF OPTIMIZED WASTE COLLECTION ROUTES USING DATA ENVELOPMENT ANALYSIS	485
MVM2026-046	Aikaterini Zafeiri Clio Vossou Dimitrios Koulocheris	FLUID-STRUCTURE INTERACTION IN A TANK VEHICLE TRANSPORTING LIQUID FUEL	497
MVM2026-048	Ognjen Jovanović Milan Matijević	APPLICATION OF THE TIA PORTAL ENVIRONMENT FOR SOFTWARE-IN-THE-LOOP SIMULATION OF PLC CONTROL OF A FIRST- ORDER DYNAMIC SYSTEM	507
MVM2026-058	Nikola Gunić Hana Stefanović Milan Matijević	A NEW GENERATION OF WHEEL POSITION AND SPEED INTELLIGENT SENSORS FOR MOTOR VEHICLES	523
MVM2026-065	Danijela Miloradović Jasna Glišović Jovanka Lukić Nadica Stojanović	CONDITIONAL SPECTRAL ANALYSIS OF VEHICLE VIBRATION DATA	529
MVM2026-066	Matija Simanić Ilija Vidović Luka Milić Momir Drakulić Aleksandar Đurić	SIMULATION-BASED MOTION ANALYSIS OF A LIGHTWEIGHT TRACKED ROBOT USING WEBOTS	541
MVM2026-075	Branko Miličić Nikola Frlić Sekulić Miloš Mitrović Ivan Blagojević	IDENTIFICATION OF EFFECTIVE THERMO- PNEUMATIC TIRE PARAMETERS FROM REAL- WORLD ROAD TEST DATA	553

SECTION D

Driver/Vehicle Interface, Information and Assistance Systems

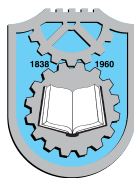
MVM2026-005	Slobodan Mišanović	THE INFLUENCE OF ENERGY DEMAND FOR PASSENGER COMPARTMENT CLIMATE CONTROL OF THE ENERGY EFFICIENCY OF ELECTRIC BUS	567
MVM2026-019	Dragan Ružić Miloš Vujković	DETERMINING THE FUEL CONSUMPTION REQUIRED FOR AIR-CONDITIONING OF A PASSENGER CAR UNDER REAL-WORLD CONDITIONS	579

MVM2026-020	Dragan Stojadinović Aleksandar Đurić Snežana Jovanović Miroslav Jovanović	THE INFLUENCE OF SEAT DESIGN AND SURFACE TYPE ON THE LEVEL OF VIBRATIONS EXPERIENCED BY A TRUCK DRIVER	589
MVM2026-063	Slavica Mačužić Saveljić Ognjen Matić Igor Saveljić	MACHINE LEARNING-BASED PREDICTION AND EXPLAINABILITY OF DRIVER DISCOMFORT AND FATIGUE: A DATA-DRIVEN EXTENSION OF A RAMSIS-BASED DIGITAL HUMAN MODEL STUDY	599
MVM2026-072	Jovanka Lukić Jasna Glišović Danijela Miloradović	COMPONENT COHERENCE-BASED ASSESSMENT OF MASKING EFFECTS IN TWO- DIRECTIONAL WHOLE-BODY VIBRATION	609
MVM2026-074	Milan Blagojević Saša Milojević Živče Šarkočević Ivica Čamagić Dragan Lazarević	FIAT 500L REAR IMPACT PERFORMANCE IN EURO NCAP AND IIHS ASSESSMENTS	623

SECTION E

Transport Challenges in Emerging Economies

MVM2026-033	Janez Kopač Franci Pušavec	HIGHWAY ROAD TRAPS AS HIDDEN SOURCES OF CRASH RISK	633
MVM2026-044	Nadica Stojanović Ali Belhocine Ivan Grujić Željko Đurić Suzana Petrović Savić Oday I. Abdullah	THE IMPACT OF “DRUNK BUSTERS” ON THE ADEQUATE PERFORMANCE OF TASKS	645
MVM2026-055	Vladimir Vukašinović Dušan Gordić Vanja Šuštersiћ Mladen Josijević	SUSTAINABLE BIOFUELS FOR THE DECARBONISATION OF THE TRANSPORT SECTOR IN CITIES	659
MVM2026-062	Goran Bošković Nebojša Jovičić Angelina Cvetanović Saša Milojević	ASSESSMENT OF THE NUMBER OF END-OF- LIFE VEHICLES IN THE REPUBLIC OF SERBIA	669
MVM2026-064	Bojana Bošković Nadica Stojanović Saša Babić Milena Petrović Anđela Egerić	PREDICTION AND TIME-SERIES ANALYSIS OF ROAD DEATHS PER MILLION INHABITANTS IN THE REPUBLIC OF SERBIA AND THE EUROPEAN UNION FOR THE PERIOD 2012 TO 2030	677
MVM2026-069	Saša Jovanović Zorica Đorđević Danijela Nikolić Lozica Ivanović Saša Milojević	A SAW-BASED DECISION SUPPORT MODEL FOR THE SELECTION OF NEW AND USED PASSENGER CARS	691



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EXPERIMENTAL INVESTIGATION OF THE COMBUSTION PROCESS AND EFFICIENCY OF A DIESEL ENGINE IN THE CASE OF BIODIESEL FUEL APPLICATION

ABSTRACT: In wine-producing regions, oil extracted from waste grape seeds can be used as a feedstock for biodiesel production. This paper presents the results of experimental research on combustion process parameters and engine efficiency when using conventional diesel fuel (D100) and blends of conventional diesel fuel with biodiesel produced from waste grape seed oil. Four biodiesel–diesel blends with biodiesel contents of 7%, 14%, 21%, and 28% by volume (B7, B14, B21, and B28) were used. The tests were conducted on a single-cylinder direct injection diesel engine at full load at engine speeds of 1635 rpm, 1937 rpm, and 2239 rpm. It was found that all blends exhibited a higher peak (maximum) heat release rate (HRR) and higher peak (maximum) cylinder pressure than D100. Blends with higher biodiesel contents (B21 and B28) had the heat release centroid located closer to top dead center (TDC), which is favorable for indicated thermal efficiency (ITE). The engine achieved a higher brake thermal efficiency (BTE) with the B14 blend (0.296 at 1635 rpm, 0.324 at 1937 rpm, and 0.277 at 2239 rpm) than with the B7, B21, and B28 blends. In terms of engine efficiency, the B14 blend exhibited performance comparable to that of D100.

KEYWORDS: biofuels, biodiesel, differential heat release law, cumulative heat release law

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EKSPERIMENTALNO ISTRAŽIVANJE PROCESA SAGOREVANJA I EFIKASNOSTI DIZEL MOTORA ZA SLUČAJ PRIMENE BIODIZEL GORIVA

REZIME: U područjima gde se proizvode veće količine vina, kao jedna od sirovina za proizvodnju biodizel goriva može se koristiti i ulje od otpadnih semenki grožđa. U radu su prikazani rezultati eksperimentalnih istraživanja parametara procesa sagorevanja i efikasnosti motora za slučaj primene konvencionalnog dizel goriva (D100) i mešavina konvencionalnog dizel goriva i biodizel goriva dobijenog od ulja otpadnih semenki grožđa. Korišćene su četiri mešavine sa zapreminskim udelima biodizel goriva od 7%, 14%, 21% i 28% (B7, B14, B21 i B28). Ispitivanje je rađeno na jednocilindričnom dizel motoru sa direktnim ubrizgavanjem na punom opterećenju, pri brojevima obrtaja 1635 min^{-1} , 1937 min^{-1} , 2239 min^{-1} . Ustanovljeno je da sve mešavine imaju veću maksimalnu brzinu oslobađanja toplote i veći maksimalan pritisak u cilindru nego D100. Mešavine sa većim udelima biodizel goriva (B21 i B28) imaju težište procesa oslobađanja toplote bliže spoljnoj mrtvoj tački (SMT), što je povoljno sa aspekta indikatorskog stepena korisnosti. Primenom mešavine B14 motor ima veći efektivni stepen korisnosti (0,296 na 1635 min^{-1} , 0,324 na 1937 min^{-1} i 0,277 na 2239 min^{-1}) nego primenom mešavina B7, B21 i B28. Mešavina B14 se, sa aspekta efikasnosti motora, može smatrati ravnopravnom sa D100.

KLJUČNE REČI: biogoriva, biodizel, diferencijalni zakon oslobađanja toplote, integralni zakon oslobađanja toplote

INTRODUCTION

Biodiesel has been commercially used for several decades and has traditionally been produced from edible vegetable oils through transesterification process. Over the last decade, biodiesel has increasingly been produced from waste-derived feedstocks, including waste oils and residues generated by the food and beverage industry. Nikolić, B. D. et al. (2025) reported that, in 2022, approximately 27% of global biodiesel production originated from waste-derived feedstocks.

In terms of physicochemical properties, biodiesel differs significantly from conventional diesel, while considerable variations can also be observed among different biodiesel types depending on the feedstock and production process employed. In addition, diesel engines are primarily designed to operate on conventional diesel, therefore, investigating the combustion characteristics of biodiesel is essential for its efficient utilization while maintaining engine performance and efficiency. Although alternative biodiesel production methods have been investigated and developed, transesterification remains the most widely used production process. All biodiesel fuels considered in this study were produced through transesterification and were used either as neat biodiesel or, more commonly, as blends with conventional diesel.

The effects of biodiesel on combustion characteristics, ITE, BTE, and engine performance parameters have been extensively investigated in numerous studies. Numerous studies have focused on first-generation biodiesel fuels, while recent research has increasingly focused on second-, third-, and fourth-generation biodiesel fuels.

Objective and Scope of This Research

This paper presents an investigation of the combustion process, with particular emphasis on heat release rate parameters and engine efficiency. The aim of the study is to evaluate the influence of different fuels (D100, B7, B14, B21, and B28) on combustion parameters and engine efficiency. The experimental investigation was carried out at full load at engine speeds of 1635 rpm, 1937 rpm, and 2239 rpm.

Review of Previous Research

First-generation biodiesel fuels are produced through the transesterification of edible vegetable oils derived from dedicated oil crops, such as rapeseed, soybean, palm, sunflower, and corn. The cylinder pressure evolution differs between conventional diesel fuel and biodiesel fuels derived from rapeseed, soybean, and palm oils. According to Knežević, D. (2014), variations in the pressure rise rate and maximum pressure are also observed among individual biodiesel fuels, depending on the feedstock used for biodiesel production. These differences are evident both for neat biodiesel fuels and for B50 biodiesel–diesel blends.

Ayhana, V. et al. (2020) reported that, despite the less favorable physicochemical properties of biodiesel fuels, including higher density, increased viscosity, and lower volatility compared with conventional diesel fuel, the use of an optimized biodiesel blending ratio can improve engine performance under specific operating conditions. Blends containing corn oil biodiesel demonstrated higher effective power output and lower specific fuel consumption compared with diesel fuel.

According to Mehra, K. S. & Goel (2025), the cost of feedstocks used for biodiesel production represents approximately 75–90% of the total production cost. The high cost of edible feedstocks has encouraged the increased utilization of alternative feedstocks, including waste cooking oils, by-products from the food and beverage industry, and non-edible oil crops cultivated on marginal or low-quality land. Biodiesel produced from these feedstocks is generally classified as second-generation biofuel. The combustion characteristics and heat release behavior of second-generation biodiesel fuels vary significantly depending on the feedstock type and biodiesel blending ratio, which consequently affects engine efficiency and fuel consumption.

Can, Ö. (2014) reported that B5 and B10 biodiesel blends produced from waste cooking oil and conventional diesel fuel exhibit lower heating values (LHV) compared with conventional diesel fuel. As a result, the application of these blends leads to an increase in brake-specific fuel consumption (BSFC) of up to 4% and a reduction in BTE of up to 2.8% compared with conventional diesel operation.

Erdogan, S. et al. (2019) investigated the combustion characteristics of biodiesel blends produced from beef bone marrow and conventional diesel fuel. Their results showed that, at low engine loads, the B20 blend exhibited a higher peak heat release rate compared with diesel fuel.

Biodiesel suitable for application in compression ignition (CI) engines can also be produced from various types of agricultural and industrial waste. Emma, A. F. et al. (2022) reported that low-percentage blends containing biodiesel derived from coffee husk oil can be used in diesel engines without significant modifications. Furthermore, these blends demonstrated improved combustion characteristics compared with conventional diesel fuel.

Waste grape seeds, generated as a by-product of wine production, represent a potential feedstock for biodiesel production. Chelladorai, P. et al. (2018) investigated the application of neat biodiesel produced from waste grape seed oil in a single-cylinder direct-injection diesel engine. Their results showed that, at full engine load and an engine speed of 1500 rpm, the BTE was 6.4% lower compared with conventional diesel fuel.

Contributions

The biodiesel fuel used to produce the blends differs significantly from D100 in terms of calorific value and kinematic viscosity (Table 3). The research determined:

- Whether the engine can operate stably with blends B7, B14, B21, and B28 at full load;
- Which blend exhibits the most favorable heat release profile from the perspective of ITE, and whether there is a clear trend in the heat release profile with increasing biodiesel content in the blend;
- With which blend the engine achieves the highest BTE;
- Whether there is a clear trend in ITE and BTE depending on the proportion of biodiesel in the blend.

EXPERIMENTAL SETUP

For the experimental investigation, a single-cylinder direct-injection (DI) diesel engine – DMB 3DA450 (Figure 1, Table 1) – was used. The engine is equipped with a mechanical fuel injection system. The fuel injection timing was fixed at 21 °CA before top dead center (BTDC) for all tested fuels, including the conventional fuel and its blends. The combustion process was analyzed based on the indicated cylinder pressure.

Table 1 Test engine characteristics

Name	Description
Model	DMB SDA 450
Power/engine speed, kW/rpm	7.3/2500
Torque/engine speed, Nm/rpm	28/1700
Engine combustion sys./cooling	Direct injection/Air cooled engine
Engine displacement, cm ³	454
Number of cylinders	1
Piston diameter/piston stroke, mm	85/80
Compression ratio, -	17.5:1
Injection timing	21 °CA BTDC fixed (factory setup)

Table 1 (continuation)

Parameters of engine valve mechanism	Intake valve opens 16 °CA BTDC
	Intake valve closes 40 °CA ABDC
	Exhaust valve opens 40 °CA BBDC
	Exhaust valve closes 16 °CA ATDC
	Valve overlap 32 °CA

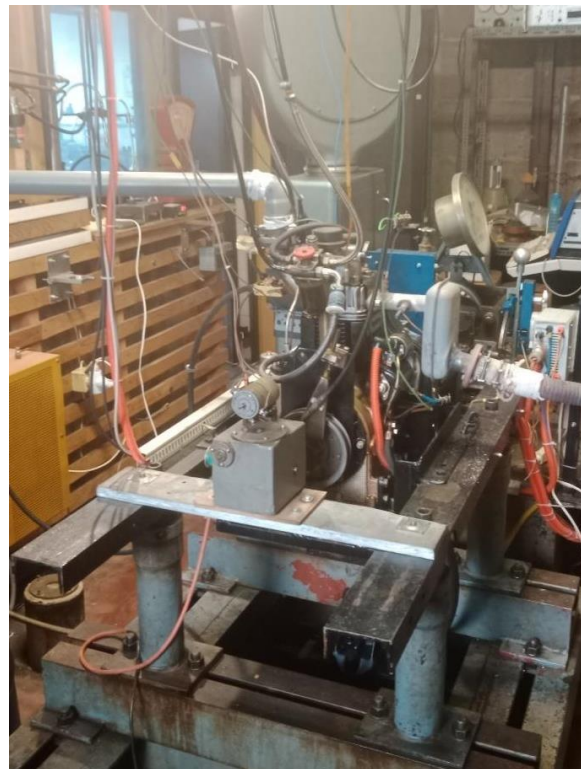


Figure 1 Test engine

The pressure inside the cylinder was measured using the measurement system shown in Figure 2. The measurement system consists of analog and digital components. The analog part includes a piezoelectric pressure sensor and an amplifier for signal conditioning. The digital part consists of a crankshaft angle optical marker and SMT position, an optical transmitter, as well as a signal multiplier.

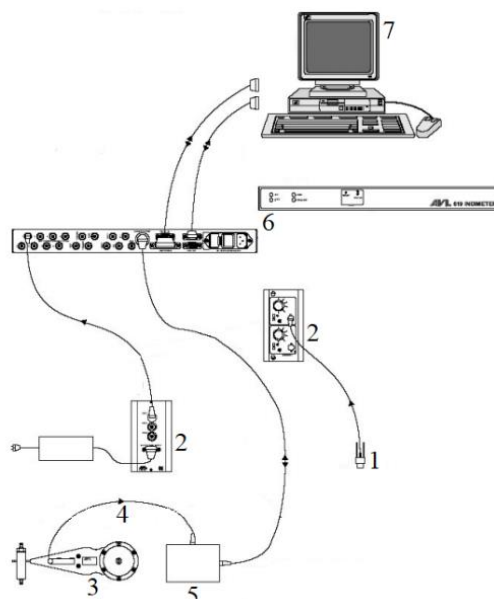


Figure 2 The measuring chain for the cylinder pressure: 1 – pressure sensor AVL QC32D, 2 – signal amplifier KISTLER 5007, 3 – angle encoder, 4 – optical transmitter, 5 – signal multiplier AVL 365CC, 6 – acquisition system AVL Indimeter 619, 7 – computer with acquisition software AVL IndiCom 1.2

EXPERIMENTAL INVESTIGATION

The engine operating speeds used in the experimental investigation were determined in accordance with the European Stationary Cycle (ESC) procedure (EUR-Lex.europa.eu. 1999). The standardized test procedure was applied to ensure better comparability of the obtained results with other authors in the future.

The engine tests were conducted using conventional diesel fuel (D100) and four biodiesel–diesel fuel blends. Biodiesel was produced through a batch transesterification process. Methanol was used as the alcohol reactant, with an oil-to-methanol molar ratio of 6:1. Potassium hydroxide (KOH) was used as the catalyst in an amount of 1 wt.% relative to the oil mass. The transesterification reaction was carried out at a temperature of 63 °C and atmospheric pressure for 60 min. The main properties of the produced biodiesel are presented in Table 2. The conventional diesel fuel (D100) complies with the requirements specified in the SRPS EN 590:2022 standard. The fuel blends were prepared to ensure that all four mixtures had approximately the same LHV as the reference diesel fuel. The biodiesel energy fractions of 5%, 10%, 15%, and 20% corresponded to volumetric fractions of 7%, 14%, 21%, and 28%, respectively; therefore, the blends were designated as B7, B14, B21, and B28. This approach enables a more accurate evaluation of the influence of biodiesel addition on engine thermal efficiency by minimizing the effect of differences in fuel energy content.

Table 2 Characteristics of the biodiesel fuel

Property	Unit	EN-14214 Limit	Measured Value	Meth. of testing
Density (at 15 °C)	kg/m ³	860–900	885	SRPS EN ISO 3675. (2007)
Kinematic viscosity (at 40 °C)	Mm ² /s	3.5–5	5.15	SRPS EN ISO 3104. (2024)
Flash point	°C	>101	>185	SRPS EN ISO 2719. (2021) SRPS EN ISO 3679. (2022)
Lower heating value	MJ/kg		33.965	ASTM 240 (Internet Archive. 2009)
Ester content	%(m/m)	>96,5	97.3	SRPS EN ISO 14103. (2020)

RESEARCH RESULTS AND DISCUSSION

The rate of heat release during the different phases of combustion is a key parameter governing the efficiency of converting the fuel's chemical energy into thermal energy. The HRR also influences the cylinder pressure variation, which in turn affects the mechanical loads on the engine and the level of noise emitted by the engine. The combustion process parameters can be most effectively analyzed using the cylinder pressure variation diagram (Figure 3) and the differential and cumulative heat release rate diagrams (Figure 4).

Table 3 presents the main combustion parameters, including the maximum cylinder pressure, its corresponding crank angle relative to top dead center (TDC), the maximum heat release rate, its corresponding crank angle relative to TDC, and the crank angles corresponding to 5%, 10%, 50%, and 90% of the total heat released during the cycle.

In all three operating regimes, the fuel blends exhibited higher peak heat release rates than D100. The highest peak heat release rate was observed at the lowest engine speed (1635 rpm) for the B21 blend, reaching 163.1 kJ·m⁻³·°C·s⁻¹. At engine speeds of 1937 rpm and 2239 rpm, the B28 blend exhibited the highest peak heat release rates, amounting to 133 kJ·m⁻³·°C·s⁻¹ and 156.16 kJ·m⁻³·°C·s⁻¹, respectively.

The blends reached their peak heat release rates at later crank angles, except for B7 at 1937 rpm, where B7 and D100 reached their peak heat release rates simultaneously at 2 °CA. This trend in the peak heat release rate and the crank angle corresponding to its maximum relative to TDC can be attributed to injection timing, ignition delay, and the oxygen content of the biodiesel fuel in the blends.

Blends with a higher biodiesel content generally exhibit a higher peak heat release rate; however, this trend is not consistent under all operating conditions, as the mixture formation and combustion processes are influenced by numerous parameters whose effects may vary across different operating regimes.

Due to their higher peak heat release rates, the blends also exhibit higher peak cylinder pressures (Figure 3), which ultimately result in greater mechanical loads and higher levels of engine noise.

In modern diesel engines, however, this issue is mitigated through the use of multiple injection strategies, which enable better control of the combustion process. The peak heat release rates of the blends occur at later crank angles

relative to TDC than that of D100, which partially mitigates the effects associated with their higher peak heat release rates, such as increased mechanical loads and engine noise.

Table 3 Combustion process parameters at 100% load (1635 rpm, 1937 rpm, and 2239 rpm)

Parameter	Value/Description				
	D100	B7	B14	B21	B28
Load			100%		
Engine speed, rpm			1635		
Maximum cylinder pressure, bar	70.45	74.05	74.84	76.13	75.06
Position of the maximum cylinder pressure relative to TDC, °CA	9	9	9	8	8
Maximum heat release rate, kJ·m ⁻³ ·°CA ⁻¹ ,	106.8	133.26	151.54	163.1	155.43
Position of the maximum heat release rate relative to TDC, °CA	0	1	1	1	1
Crank angle for 5% fuel burned, °CA	-1.38	-1.62	-1.19	-1.03	-1.32
Crank angle for 10% fuel burned, °CA	-0.59	-0.66	-0.34	-0.19	-0.39
Crank angle for 50% fuel burned, °CA	8.33	6.91	6.75	6.45	6.30
Crank angle for 90% fuel burned, °CA	25.52	22.97	23.29	22.95	22.06
Engine speed, rpm			1937		
Maximum cylinder pressure, bar	67.59	71.84	72.52	72.53	72.78
Position of the maximum cylinder pressure relative to TDC, °CA	9	10	10	10	10
Maximum heat release rate, kJ·m ⁻³ ·°CA ⁻¹ ,	98.32	127.32	131.6	132.7	133
Position of the maximum heat release rate relative to TDC, °CA	2	2	3	3	3
Crank angle for 5% fuel burned, °CA	0.08	-0.29	0.20	0.11	0.04
Crank angle for 10% fuel burned, °CA	0.92	0.73	1.17	1.08	1.07
Crank angle for 50% fuel burned, °CA	9.46	8.62	8.46	8.24	8.30
Crank angle for 90% fuel burned, °CA	26.51	25.08	24.93	24.79	23.90
Engine speed, rpm			2239		
Maximum cylinder pressure, bar	65.22	69.02	68.66	68.82	69.45
Position of the maximum cylinder pressure relative to TDC, °CA	10	9	9	9	9
Maximum heat release rate, kJ·m ⁻³ ·°CA ⁻¹ ,	115.65	148.01	152.99	145.9	156.16
Position of the maximum heat release rate relative to TDC, °CA	4	5	5	5	5
Crank angle for 5% fuel burned, °CA	2.02	2.07	2.39	2.35	2.16
Crank angle for 10% fuel burned, °CA	2.94	3.16	3.47	3.43	3.27
Crank angle for 50% fuel burned, °CA	10.34	9.75	9.75	9.62	9.61
Crank angle for 90% fuel burned, °CA	28.26	27.99	27.93	28.11	27.36

Based on the cumulative heat release curve, it is possible to determine how the fraction of fuel burned changes during the combustion process. From the perspective of ITE, the position of the combustion centroid, defined as the crank angle at which 50% of the total heat is released, is particularly important. The rate of heat release during the second half of the combustion process is largely determined by the flow within the combustion chamber, as the flow characteristics affect the supply of oxygen to the flame zone.

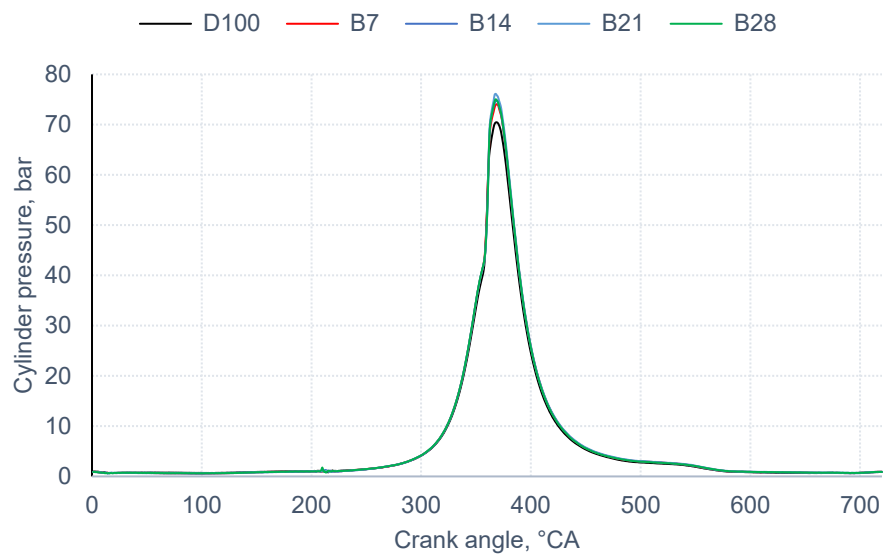
For all three operating regimes, 50% of the total heat is released earlier when the blends are used compared with D100. When blends are used, the combustion rate increases with increasing biodiesel content in the blend, except at 1937 rpm, where the earliest occurrence of 50% heat release is observed for B21.

For all three operating regimes, 90% of the total heat is released earlier with the blends than with D100, with the earliest occurrence observed for B28. This trend in the heat release process is likely influenced by the oxygen content of the biodiesel fuel.

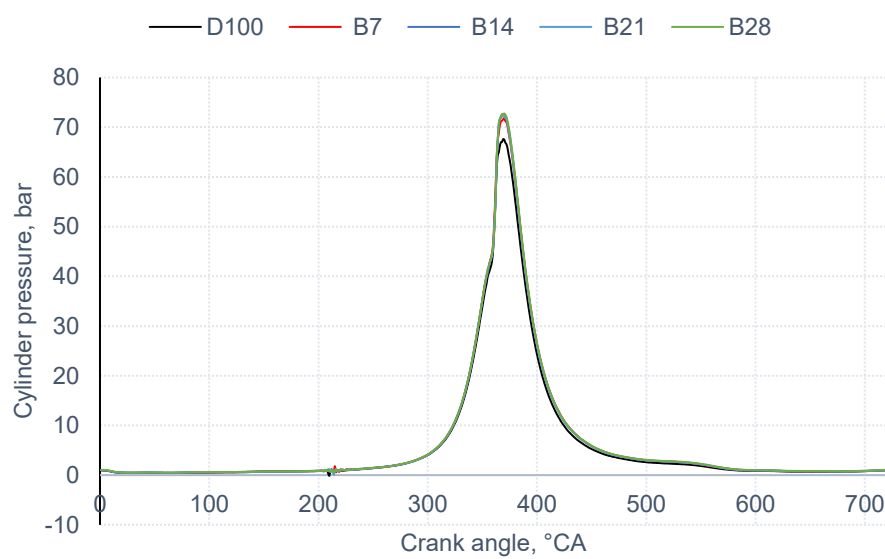
Therefore, considering the combustion process parameters and their impact on ITE, the use of biodiesel–diesel blends is more favorable than D100.

The values of the engine efficiency parameters are presented in Table 4. It can be observed that all blends exhibit favorable combustion characteristics. In almost all operating regimes, with only a few exceptions, the blends exhibit more complete combustion and higher ITE values than D100. This can be attributed to the oxygen content of the blends and the appropriate injection timing of 21 °CA BTDC.

a)



b)



c)

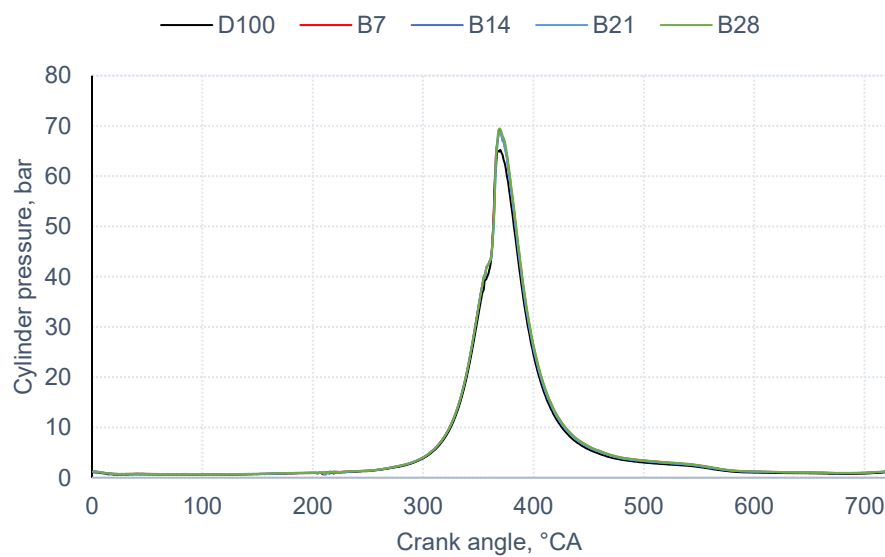


Figure 3 Cylinder pressure vs. crank angle at full load:

- a) 1635 rpm
- b) 1937 rpm
- c) 2239 rpm

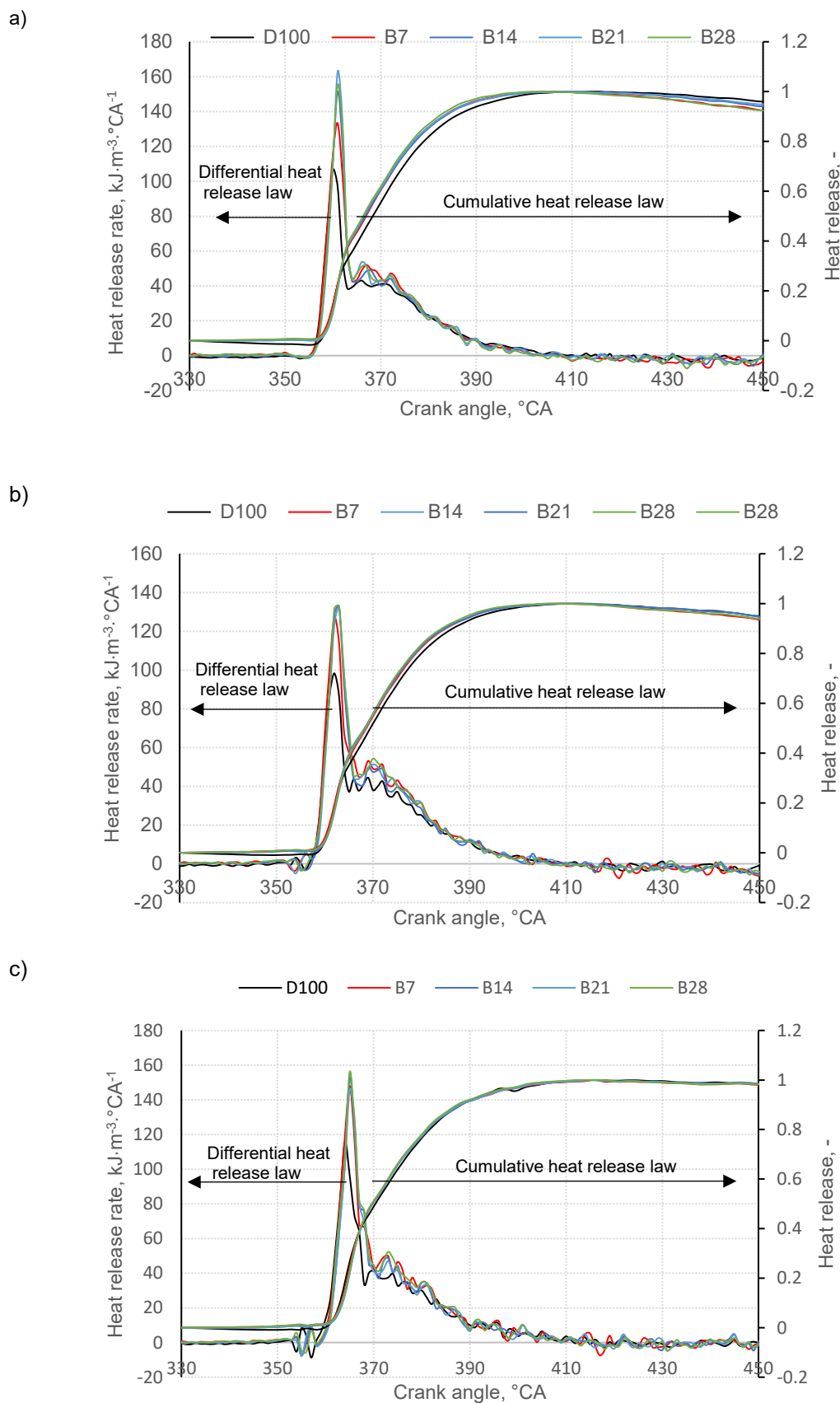


Figure 4 Differential and cumulative heat release laws at full load: a) 1635 rpm, b) 1937 rpm, and c) 2239 rpm

In terms of BTE, the blends exhibit values comparable to those of D100 and, under certain operating regimes, even higher values. Among all the blends, B14 stands out, exhibiting relatively high BTE values of 0.296 at 1635 rpm, 0.324 at 1937 rpm, and 0.277 at 2239 rpm.

It can also be observed that there is no clear trend in ITE and BTE with increasing biodiesel content in the blends that is consistent across all engine operating regimes at full load.

Djurić, Ž. et al. (2026) presented almost identical results from tests conducted on a single-cylinder, direct-injection engine fueled with D100 and blends of biodiesel produced from waste grape seed oil and conventional diesel fuel (B7 and B14) at 75% and 100% engine load.

A.K. Azad & M.G. Rasul (2019) tested a four-cylinder diesel engine fueled with D100 and blends of biodiesel derived from waste grape seed oil and conventional diesel fuel (B5 and B10). B10 and D100 exhibited identical peak heat release rate values, whereas B5 exhibited slightly lower values than B10 and D100. When using the blends, the engine exhibited lower BTE, leading the authors to conclude that increasing the biodiesel content in the blend reduces engine efficiency.

Table 4 Indicated, mechanical, and brake thermal efficiency of the engine at full load

Parameter	Value/Description				
	D100	B7	B14	B21	B28
Load					100%
Engine speed, rpm					1635
Indicated thermal efficiency, -	0,403	0,394	0,411	0,395	0,386
Mechanical efficiency, -	0.747	0.723	0.721	0.719	0.715
Brake thermal efficiency, -	0.301	0.285	0.296	0.284	0.276
Engine speed, rpm					1937
Indicated thermal efficiency, -	0.364	0.381	0.452	0.400	0.383
Mechanical efficiency, -	0.755	0.724	0.717	0.690	0.711
Brake thermal efficiency, -	0.275	0.276	0.324	0.276	0.272
Engine speed, rpm					2239
Indicated thermal efficiency, -	0.378	0.393	0.389	0.375	0.383
Mechanical efficiency, -	0.744	0.696	0.712	0.695	0.701
Brake thermal efficiency, -	0.281	0.273	0.277	0.261	0.268

CONCLUSIONS

The effects of biodiesel fuel application on combustion process parameters and engine efficiency depend on the feedstock used for fuel production, the production method, and the conditions under which the fuel is utilized. Based on the investigation of the combustion process parameters of biodiesel blends produced from waste grape seed oil and conventional diesel fuel at full engine load, the following conclusions can be drawn:

- Although biodiesel fuel has a lower heating value and higher kinematic viscosity, the use of B7, B14, B21, and B28 blends ensures stable engine operation at full load.
- The blends exhibit higher peak heat release rates than D100, resulting in a higher pressure rise rate and higher peak cylinder pressure, which are associated with greater mechanical loads and increased engine noise.
- At 1937 rpm, the peak heat release rate increases with increasing biodiesel content in the blend, whereas at the other engine speeds, no clear trend in the peak heat release rate with increasing biodiesel content is observed.
- The peak heat release rates of the blends occur at later crank angles than that of D100, which partially mitigates the effects associated with higher pressure rise rates, such as increased mechanical loads and engine noise.
- The peak heat release rates occur at the same crank angle for all blends, except for B7 at 1937 rpm.
- The heat release centroid is located closer to TDC for the blends than for D100, which has a positive effect on ITE when the blends are used.
- The heat release centroid is closest to TDC for B28, at 6.30 °CA ATDC at 1635 rpm and 9.61 °CA ATDC at 2239 rpm, and for B21, at 8.24 °CA ATDC at 1937 rpm.
- In all cases, the position of the peak cylinder pressure is shifted closer to TDC due to the relatively advanced injection timing, which was set for operation with the earlier diesel fuel formulation ($CN \geq 45$). Optimization of the injection timing could result in more favorable combustion characteristics.
- In terms of BTE, the blends exhibit values comparable to those of D100, with B14 showing the most favorable values: 0.296 at 1635 rpm, 0.324 at 1937 rpm, and 0.277 at 2239 rpm.
- No clear trend in ITE and BTE with increasing biodiesel content in the blends is observed that is consistent across all engine operating regimes at full load.

Abbreviations

The following Abbreviations are used in this manuscript:

D100	Conventional diesel fuel
B7	Fuel blend with 7% of biodiesel made from grape seeds
B14	Fuel blend with 14% of biodiesel made from grape seeds
B21	Fuel blend with 21% of biodiesel made from grape seeds
B28	Fuel blend with 28% of biodiesel made from grape seeds
HRR	Heat release rate
TDC	Top dead center
ITE	Indicated thermal efficiency
BTE	Brake thermal efficiency
BSFC	Brake-specific fuel consumption
LHV	Lower heating values
CI	Compression ignition
CA	Crankshaft angle
BTDC	Before top dead center
ATDC	After top dead center
BDC	Bottom Dead Center
ABDC	After Bottom Dead Center
BBDC	Before Bottom Dead Center
KOH	Potassium hydroxide

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