NAPREDNI PROCESI ZGOREVANJA

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Napredni procesi zgorevanja
Course title:	Advanced Combustion Processes
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Energetsko strojništvo (smer)	1. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566851
Koda učne enote na članici/UL Member course code:	6002-M

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	prof. dr. Tomaž Katrašnik, izr. prof. dr. Mitja Mori, Tine Seljak

Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Energetsko strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Energy engineering, which is an elective specialised course in other fields of study.

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisites:**
Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Vsebina: **Content (Syllabus outline):**

1. Predavanje: Uvod in fenomenološka razlaga procesa zgorevanja:
   - Umestitev zgorevanja v energijske procese in področja uporabe;
   - Predstavitev negativnih vplivov klasičnega zgorevanja na okolje;
   - Predstavitev realnih pristopov za minimiranje/izničenje negativnih vplivov zgorevanja na okolje z uporabo inovativnih goriv in naprednih procesov zgorevanja;
   - Fenomenološka razlaga procesa zgorevanja z vpeljavo osnovnih pojmov in pojavov.
2. Predavanje: Termodinamika procesa zgorevanja:
   - Stehiometrične enačbe;
   - Standardne tvorbene entalpije;
   - Ravnotežni kriteriji termodinamskih spremenljivk;
   - Ravnotežje mešanice plina – kemijski potencial;
   - Adiabatna temperatura plamena.
3. Predavanje: Kinetika zgorevanja in reakcijski mehanizmi:
   - Hitrost reakcij in red reakcij;
   - Elementarne reakcije;
   - Temperaturna in tlačna odvisnost hitrosti reakcij;
   - Značilnosti reakcijskih mehanizmov;
   - Analiza reakcijskih mehanizmov.
4. Predavanje: Transportni pojavi pri zgorevanju in vžig zmesi:
   - Interakcija reakcij zgorevanja in dinamike tekočin;
   - Diagrami različnih režimov turbulentnega zgorevanja homogene zmesi;
   - Stabilnost plamena;
   - Vžig zmesi.
5. Predavanje: Laminarno zgorevanje:
   - Laminarno zgorevanje homogene zmesi;
   - Laminarno difuzijsko zgorevanje.
6. Predavanje: Turbulentno zgorevanje:
   - Turbulentno zgorevanje homogene zmesi;
   - Turbulentno difuzijsko zgorevanje.
7. Predavanje: Tvorba plinskih onesnažil:
   - Klasifikacija plinskih onesnažil;
   - Kinetika nastanka plinskih onesnažil;
   - Vpliv lastnosti goriv na plinska onesnažila;
   - Pristopi za radikalno znižanje izpustov plinskih onesnažil.
8. Predavanje: Tvorba delcev:

1. Lecture: Introduction and phenomenological explanation of the combustion process:
   - Positioning of combustion in energy processes and applications;
   - Presentation of negative impacts of conventional combustion on the environment;
   - Presentation of realistic approaches to minimize/eliminate the negative impacts of combustion using innovative fuels and advanced combustion processes,
   - Phenomenological explanation of the combustion process with the introduction of basic concepts and phenomena.
2. Lecture: Thermodynamics of combustion process:
   - Stoichiometric equations;
   - Standard enthalpies of formation;
   - Equilibrium criteria of thermodynamic variables;
   - Gas mixture balance - chemical potential;
   - Adiabatic flame temperature.
3. Lecture: Combustion kinetics and reaction mechanisms:
   - Reaction rate and reaction order;
   - Elemental reactions;
   - Dependence of reaction rates – temperature, pressure
   - Characteristics of reaction mechanisms;
   - Analysis of reaction mechanisms.
4. Lecture: Transport phenomena in combustion and ignition process of the mixture:
   - Interaction of combustion reactions and fluid dynamics;
   - Modes of turbulent combustion in homogeneous mixture;
   - Flame stability;
   - Ignition of the mixture.
5. Lecture: Laminar combustion:
   - Laminar premixed combustion
   - Laminar nonpremixed combustion
6. Lecture: Turbulent combustion:
   - Turbulent combustion of a homogeneous mixture;
   - Turbulent diffusion combustion.
7. Lecture: Formation of gaseous pollutants:
   - Classification of gaseous pollutants;
   - Kinetics of gaseous pollutants;
   - Influence of fuel properties on formation of pollutants;
   - Approaches for radical reduction of gas pollutants emissions.

- Kinetika nastanka delcev;
- Vpliv lastnosti goriv na tvorbo delcev;
- Pristopi za radikalno znižanje izpustov delcev.

9. Predavanje: Znižanje koncentracije onesnažil z naknadno obdelavo produktov zgorevanja in diagnostiko procesa zgorevanja:
   - Ustrezna izbira metod za naknadno obdelavo produktov zgorevanja z ozirom na sestavo in temperaturo produktov zgorevanja;
   - Eksperimentalne metode za diagnostiko procesa zgorevanja.
10. Predavanje: Napredni nizkotemperaturni procesi zgorevanja:
    - Prednosti nizkotemperaturnih procesov zgorevanja;
    - Pogoji za nizkotemperaturno zgorevanje;
    - Brezplamensko zgorevanje;
    - Pogoji za doseganje ultra nizkih izpustov onesnažil.
11. Predavanje: Modeliranje naprednih procesov zgorevanja:
    - Reakcijski mehanizmi, občutljivost reakcij, število upoštevanih komponent;
    - Uporaba nadomestnih komponent;
    - Zgorevanje v laminarnem in turbulentnem toku;
    - Pristopi za zmanjševanje računske zahtevnosti modelov.
12. Predavanje: Zgorevanje kapljevitih in trdnih goriv ter alternativnih goriv:
    - Piroliza, devolatilizacija, termični razpad, površinske reakcije zgorevanja
    - Mehanizmi razpada curka, izparevanje, povezava s kemijsko-fizikalnimi lastnostmi goriv

Integracija pridobljenih znanj za snovanje in implementacijo naprednih procesov zgorevanja, ki bodo omogočili visoke izkoristke in nizke izpuste onesnažil v:

13. Predavanje: Stacionarnih kuriščih

14. Predavanje: Turbinskih motorjih

15. Predavanje: Napredni procesi zgorevanja v batnih motorjih

8. Lecture: Formation of particles:
   - Particle formation kinetics;
   - Effect of fuel properties on particle formation;
   - Approaches for radical reduction of particle emissions.
9. Lecture: Reduction of pollutant emissions by post-treatment of combustion products and diagnostics of the combustion process:
   - Selection of methods for subsequent treatment of combustion products with respect to the composition and temperature;
   - Experimental methods for diagnostics of combustion process.
10. Lecture: Advanced low temperature combustion processes:
    - Advantages of low temperature combustion processes;
    - Prerequisites for low temperature combustion;
    - Flameless combustion;
    - Prerequisites for achieving ultra-low pollutant emissions.
11. Lecture: Modelling of advanced combustion processes:
    - Reaction mechanisms, sensitivity of reactions, number of components considered;
    - Use of fuel surrogates;
    - Combustion in laminar and turbulent flow;
    - Approaches to reduce the computational complexity of models.
12. Lecture: Combustion of liquid, solid and alternative fuels:
    - Pyrolysis, devolatilization, thermal decomposition, surface combustion reactions
    - Mechanisms of spray formation, evaporation and correlation with chemical and physical properties of fuels

Transfer of acquired knowledge to design and to implement advanced combustion processes with the objective to achieve high efficiency and low emissions in:

13. Lecture: Stationary furnaces

14. Lecture: Turbine Engines

15. Lecture: Advanced Combustion Processes in Piston Engines

Temeljna literatura in viri/Readings:

1. J. Warnatz, U. Mass, R.W. Dibble, Combustion : physical and chemical fundamentals, modeling and simulation, experiments, pollutant formation, 3rd ed., Springer, 2001, ISBN - 3-540-67751-8, [COBISS.SI-ID 23305989]
2. D.A. Tillman, N.S. Harding, Fuels of opportunity : characteristics and uses in combustion systems,
3. R. Pavletič, Zgorevanje : teoretične osnove, goriva, inženirska uporaba, Fakulteta za strojništvo, 1996, ISBN - 86-7217-126-8, [COBISS.SI-ID 1426459]
4. K.M. Bryden, et.al. Combustion engineering, 3rd ed., CRC Press, 2022, ISBN - 978-1-138-06538-3; 978-1-032-24688-8; 978-1-315-15972-0, [COBISS.SI-ID 147336451]

Cilji in kompetence:

Cilji:

1. Razumeti teoretične osnove procesov zgorevanja.
2. Razumeti reakcijske mehanizme in kinetiko zgorevanja.
3. Razumeti mehanizme tvorbe onesnažil.
4. Razumeti delovanje sistemov za naknadno obdelavo produktov zgorevanja.
5. Razumeti pristope za modeliranje naprednih procesov zgorevanja in znati uprabljati ustrezna napredna simulacijska orodja.
6. Razumeti pristope za razvoj naprednih-okolju prijaznejših procesov zgorevanja.

Kompetence:

1. S2-MAG, P2-MAG: Obvladovanje temeljnih teoretičnih in aplikativnih znanj naprednih procesov zgorevanja
2. S8-MAG: Sposobnost kritične presoje ustreznih zasnov procesov zgorevanja z ozirom na omejitve izpustov onesnažil
3. P2-MAG: Sposobnost razmevanja interakcije relevantnih mehanizmov procesa zgorevanja in sistema, v katerem poteka proces
4. P4-MAG: Sposobnost fizikalnega, matematičnega in numeričnega modeliranja problemov na področju naprednih procesov zgorevanja

Objectives and competences:

Objectives:

1. Understand the theoretical foundations of combustion processes.
2. Understand reaction mechanisms and kinetics of combustion.
3. Understand the mechanisms of pollutant formation.
4. Understand the operation of after-treatment systems of flue gas.
5. Understand approaches to model advanced combustion processes and the use of advanced simulation tools.
6. Understand approaches to develop environmentally friendly combustion processes.

Competencies:

1. S2-MAG, P2-MAG: Mastering the basic theoretical and applied knowledge of advanced combustion processes
2. S8-MAG: Ability to critically evaluate appropriate combustion process designs with respect to pollutant emission limits
3. P2-MAG: Ability to comprehend the interaction of the relevant combustion process mechanisms and the combustion systems in which the combustion process takes place
4. P4-MAG: Ability to physically, mathematically and numerically model problems in advanced combustion processes

Predvideni študijski rezultati:

Znanja:

Z1: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za znanstveno in strokovno delo na področju razvoja, snovanja in diagnostike sistemov, ki temeljijo na zgorevanju.

Spretnosti:

Intended learning outcomes:

Knowledge:

Z1: In-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for scientific and professional work in the development, design and diagnostics of combustion-based systems.

Skills:

S1.1: Sposobnost vrednotenja procesov zgorevanje z ozirom na zvišanje izkoristka in znižanje izpustov onesnažil. S1.2: Samostojna uporaba pridobljenega znanja pri analizi, snovanju in diagnostiki inženirskih sistemov, ki temeljijo na zgorevanju. S1.3: Sposobnost snovanja okolju prijaznejših zgorevalnih sistemov, ki temeljijo na naprednih procesih zgorevanja, z minimalnimi negativnimi vplivi zgorevanja na okolje. S1.4: Sposobnost nadaljnjega, samostojnega študija.	S1.1: Ability to evaluate combustion processes in terms of maximizing the efficiency and reducing pollutant emissions. S1.2: Independent use of acquired knowledge in the analysis, design and diagnostics of combustion systems. S1.3: Ability to design environmentally friendly combustion systems based on advanced combustion processes with minimal negative environmental impacts. S1.4: Ability of independent self-driven education and research

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P2: Obravnava snovi po urejeni in vnaprej razloženi sistematiki. P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4: Laboratorijske vaje. P5: Uporaba študijskega gradiva v obliki (e-verzija predstavitve predavanj). P8: Izdelava in predstavitev aplikativnih seminarskih nalog P10: Uporaba anket v realnem času P14: Virtualni eksperimenti P15: Uporaba video vsebin kot priprava na predavanja in vaje	P1: Classroom lectures with inclusion of solving selected typical and practical examples. P2: Presenting of the learning content in an orderly and pre-interpreted systematics P3: Tutorials where theoretical knowledge of lectures is supported by computational examples. P4: Laboratory work. P5: Use of study materials in format (e-version of lecture presentation). P8: Design and presentation of applied seminar work P10: Use of real-time surveys P14: Virtual Experiments P15: Using video content to prepare for lectures and exercises

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
Teoretične vsebine (predavanja)	50,00 %	Theory (lectures)
Samostojno delo na vajah	50,00 %	Practical coursework

Ocenjevalna lestvica:	**Grading system:**
5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Tomaž Katrašnik:

1. **KATRAŠNIK, Tomaž**. An advanced real-time capable mixture controlled combustion model. *Energy*, ISSN 0360-5442. [Print ed.], Jan. 2016, vol. 95, str. 393-403. [COBISS.SI-ID 14407195].

2. VIHAR, Rok, ŽVAR BAŠKOVIČ, Urban, SELJAK, Tine, **KATRAŠNIK, Tomaž**. Combustion and emission formation phenomena of tire pyrolysis oil in a common rail Diesel engine. *Energy conversion and management*, ISSN 0196-8904. [Print ed.], Oct. 2017, vol. 149, str. 706-721. [COBISS.SI-ID 15296027].
3. SELJAK, Tine, **KATRAŠNIK, Tomaž**. Emission reduction through highly oxygenated viscous biofuels : use of glycerol in a micro gas turbine. *Energy*, ISSN 0360-5442. [Print ed.], Feb. 2019, vol. 169, str. 1000-1011. [COBISS.SI-ID 16434459].
4. JURIĆ, Filip, PETRANOVIĆ, Zvonimir, VUJANOVIĆ, Milan, **KATRAŠNIK, Tomaž,** VIHAR, Rok, WANG, Xuebin, DUIĆ, Neven. Experimental and numerical investigation of injection timing and rail pressure impact on combustion characteristics of a diesel engine. *Energy conversion and management*, ISSN 0196-8904. [Print ed.], Apr. 2019, vol. 185, str. 730-739. [COBISS.SI-ID 16595739].
5. AGWU, Ogbonnaya, VALERA-MEDINA, Augustin, **KATRAŠNIK, Tomaž**, SELJAK, Tine. Flame characteristics of glycerol/methanol blends in a swirl-stabilised gas turbine burner. Fuel. [Print ed.]. Apr. 2021, vol. 290, str. 1-12, ilustr. ISSN 0016-2361. [COBISS.SI-ID 45241091].

Mitja Mori:

1. **MORI, Mitja**, GRAMC, Jure, HOJKAR, Domen, LOTRIČ, Andrej, SMEACETTO, Federico, FIORILLI, Sonia, FIORE, Silvia, STROPNIK, Rok. New life cycle inventories for end-of-life solid oxide cells based on novel recycling processes for critical solid oxide cell materials. International journal of hydrogen energy. [Online ed.]. 2025, vol. 104, str. 635-650, ilustr. ISSN 1879-3487. https://www.sciencedirect.com/science/article/pii/S0360319924035882, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.ijhydene.2024.08.411. [COBISS.SI-ID 208306179].
2. **MORI, Mitja**, GUTIÉRREZ, Manuel, CASERO, Pedro. Micro-grid design and life-cycle assessment of a mountain hut's stand-alone energy system with hydrogen used for seasonal storage. International journal of hydrogen energy. [Print ed.]. Aug. 2021, vol. 46, iss. 57, str. 29706-29723, ilustr. ISSN 0360-3199. https://www.sciencedirect.com/science/article/pii/S0360319920344013, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.ijhydene.2020.11.155. [COBISS.SI-ID 41896707].
3. MLAKAR, Nejc, LOTRIČ, Andrej, SEKAVČNIK, Mihael, **MORI, Mitja**, ARAYA, Samuel Simon, ANDREASEN, Simon, VANG, Jakob Rabjerg. Evaluation of performance degradation of high temperature proton exchange membrane fuel cells using a simple start-stop testing protocol. V: IYCE'22 : 8th International Youth Conference on Energy, 6th – 9th July 2022, Eger, Hungary. [S. l.]: IEEE, 2022. Str. 1-7, ilustr. https://ieeexplore.ieee.org/document/9857525, DOI: 10.1109/IYCE54153.2022.9857525. [COBISS.SI-ID 125939203].
4. **MORI, Mitja**, ŽVAR BAŠKOVIČ, Urban, DROBNIČ, Boštjan, ŠIPEC, Robert, KATRAŠNIK, Tomaž. Green military site supporting public hydrogen mobility. V: Proceedings of WHEC-2022 : WHEC-2022. 23rd World Hydrogen Energy Conference, June 26-30, 2022, Istanbul, Turkey. Istanbul: [s. n.], 2022. Str. 978-980. ISBN 978-625-00-0843-0. https://tinyurl.com/yckvv7ma. [COBISS.SI-ID 113975043].
5. LACKO, Rok, STROPNIK, Rok, **MORI, Mitja**, DROBNIČ, Boštjan. Connecting individual residential hydrogen chp energy systems with renewables into different sized grids. V: KITANOVSKI, Andrej (ur.), POREDOŠ, Alojz (ur.). ECOS 2016 : proceedings of the 29th International Conference on Efficiency, Cost, Optimisation, Simulation and Environmental Impact of Energy Systems, June 19. - 23. 2016, Portorož, Slovenia. Ljubljana: Faculty of Mechanical Engineering, 2016. Datoteka p404_connecting individual residential hydrogen ... (11 f.), ilustr. ISBN 978-961-6980-15-9. [COBISS.SI-ID 14709275].

Tine Seljak:

1. BUFFI, Marco, **SELJAK, Tine**, CAPPELLETTI, Alessandro, BETTUCCI, Lorenzo, VALERA-MEDINA, Augustin, KATRAŠNIK, Tomaž, CHIARAMONTI, David. Performance and emissions of liquefied wood as fuel for a small scale gas turbine. Applied energy. Nov. 2018, vol. 230, str. 1193-1204, ilustr. ISSN 0306-2619. [COBISS.SI-ID 16230171]

2. **SELJAK, Tine**, KATRAŠNIK, Tomaž. Emission reduction through highly oxygenated viscous biofuels : use of glycerol in a micro gas turbine. Energy, ISSN 0360-5442, Feb. 2019, vol. 169, str. 1000-1011, ilustr. [COBISS.SI-ID 16434459].
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4. **SELJAK, Tine**, ŽVAR BAŠKOVIČ, Urban, ROSEC, Žiga, KATRAŠNIK, Tomaž. Spatially selective dilution : a novel approach for heat release control in continuous combustion. Journal of environmental management. Aug. 2022, vol. 316, str. 1-13, ilustr. ISSN 1095-8630. [COBISS.SI-ID 107258115]
5. ROSEC, Žiga, ŽVAR BAŠKOVIČ, Urban, KATRAŠNIK, Tomaž, **SELJAK, Tine**. Exhaust gas recirculation with highly oxygenated fuels in gas turbines. Fuel. [Print ed.]. Oct. 2020, vol. 278, str. 1-12, ilustr. ISSN 0016-2361. [COBISS.SI-ID 20033539]