

UČNI NAČRT PREDMETA / COURSE SYLLABUS

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|----------------------|----------------|
| Predmet: | Gorivne celice |
| Course title: | Fuel Cells |

| Študijski program in stopnja Study programme and level | Študijska smer Study field | Letnik Academic year | Semester Semester |
|--|-------------------------------|-------------------------|----------------------|
| Ekotehnologije, 3. stopnja Ecotechnologies, 3 rd cycle | / | 1 | 1 |

Vrsta predmeta / Course type

Izbirni / Elective

Univerzitetna koda predmeta / University course code:

EKO3-611

| Predavanja Lectures | Seminar Seminar | Sem. vaje Tutorial | Lab. vaje Laboratory work | Druge oblike Others | Samost. delo Individ. work | ECTS |
|------------------------|--------------------|-----------------------|------------------------------|------------------------|-------------------------------|------|
| 15 | 15 | | | 15 | 105 | 5 |

**Navedena porazdelitev ur velja, če je vpisanih vsaj 15 študentov. Drugače se obseg izvedbe kontaktnih ur sorazmerno zmanjša in prenese v samostojno delo. / This distribution of hours is valid if at least 15 students are enrolled. Otherwise the contact hours are linearly reduced and transferred to individual work.*

Nosilec predmeta / Lecturer:

Prof. dr. Ingrid Milošev

Jeziki /

Predavanja / Lectures: Slovensko, angleško

Languages:

Vaje / Tutorial: Slovensko, angleško

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:

Izpolnjeni morajo biti pogoji za vpis na doktorski študij.

Prerequisites:

Student must fulfill the formal requirements for enrolling to the doctoral study program.

Vsebina:

- Osnove elektrokemije
- Osnove elektrokatalize
- Temelji vodikove ekonomije
- Elektrokemični členi na gorivo (gorivne celice)
 - Princip delovanja
 - Tipi gorivnih celic
 - Tipi elektrolizerjev
- Podrobnejši opis delovanja PEMFC in DMFC gorivnih celic
 - Materiali v PEMFC
 - Prispevki k napetosti člena
 - Stabilnost in obstojnost katalizatorjev
 - Sinteza elektrokatalizatorjev
- Eksperimentalne tehnike za karakterizacijo samih materialov za pretvorbo in shranjevanje

Content (Syllabus outline):

- Basics of electrochemistry
- Basics of electrocatalysis
- Foundations of hydrogen economy
- Fuel cells
 - Principles of functioning
 - Types of fuel cells
 - Types of electrolyzers
- Detailed description of PEMFC and DMFC functioning
 - Materials in PEMFC
 - Cell voltage contributions
 - Catalyst stability and durability
 - Synthesis of electrocatalysts
- Experimental techniques for the characterization of the materials themselves for

energije in njihove učinkovitosti (potenciostat, elektronska mikroskopija, rentgenska praškovna difrakcija, ...)

- Konstrukcija in delovanje PEMFC
 - Elektrode
 - Elektrolit (membrana)
 - Membransko-elektrodni sklop
 - Bipolarne plošče
 - Sklad gorivnih celic
- Primerjava z drugimi tehnologijami
- Predstavitev najpomembnejših svetovnih raziskovalnih skupin in industrije
- Predstavitev pomembnih svetovnih dosežkov v zadnjem letu
- Ogljed laboratorijev na Kemijskem inštitutu in ostalih raziskovalnih ustanov v bližnji okolici

the conversion and storage of energy and their performance (potentiostat, electron microscopy, X-ray powder diffraction, ...)

- Construction and work of PEMFC
 - Electrode
 - Electrolyte (membrane)
 - Membrane-electrode assembly (MEA)
 - Bipolar plates
 - Fuel cell stack
- Comparison with other technologies
- Introduction of the most important global research groups and industry
- Presentation of important global achievements in the last year
- Tour of the laboratories at the National Institute of Chemistry and other research facilities in the area

Temeljni literatura in viri / Readings:

1. R. O'Hayre, *Fuel Cell Fundamentals*, Wiley, 2016
2. J. Larminie, A. Dicks, »*Fuel Cell Systems Explained*«, J. Wiley & Sons, Chichester, 2003
3. W. Vielstich, A. Lamm, H. A. Gasteiger, »*Handbook of Fuel Cells: Fundamentals, Technology, and Applications*«, 4 volumes, J. Wiley & Sons, Chichester, 2003
4. S. Hočevar, »*Hydrogen production and cleaning from renewable feedstock*«, Chapter in a book »*Renewable resources and renewable energy: a global challenge* M. Graziani, P. Fornasiero (Eds.), Boca Raton [USA]: CRC Press, cop. 2007, str. 157-196.
5. S. Hočevar and W. Summers, »*Production of Hydrogen*« Chapter in a book »*Hydrogen Technology*« A. Leon, H. Hahn (Eds.), Springer Verlag, 2007/2008 in preparation
6. Bard, »*Electrochemical Methods: Fundamentals and Applications*« Wiley
7. Bagotsky »*Fundamentals of Electrochemistry, 2nd Edition*« Wiley
8. Hodnik, Nejc, Dehm, Gerhard, Mayrhofer, Karl. Importance and challenges of electrochemical in situ liquid cell electron microscopy for energy conversion research. *Accounts of chemical research*, Sep. 2016, vol. 49, iss. 9, str. 2015-2022

Cilji in kompetence:

Študentje spoznajo:

- osnovne poti za pretvorbo energije iz primarnih neobnovljivih in obnovljivih primarnih virov,
- temelje elektrokemije in elektrokatalize gorivnih celic,
- temelje vodikove ekonomije,
- principe delovanja elektrokemičnih členov na gorivo in tipe teh členov,
- delovanje gorivne celice s protonsko izmenjalno membrano (PEMFC),
- s pridobljenim znanjem bodo študenti imeli vpogled v trajnostne tehnologije prihodnosti. Koristno je tako za bazične raziskave, inženirje

Objectives and competences:

Students acquire:

- introductory knowledge on energy pathways based on non-renewable and renewable primary energy sources,
- basic knowledge of fuel cell electrochemistry and electrocatalysis
- basic knowledge of hydrogen economy,
- knowledge of principles of fuel cell work and classification of fuel cell types,
- knowledge about construction and work of Proton Exchange Membrane Fuel Cells (PEMFC),
- with the acquired knowledge, students will have an insight into the sustainable technologies of the future. This is useful both for basic research,

kot tudi za splošno izobrazbo.

for engineers, and for general education.

Predvideni študijski rezultati:

Znanje in razumevanje:

- poznavanje in razumevanje osnov procesov direktne pretvorbe kemične energije v električni tok in toploto,
- poznavanje in razumevanje zgradbe in delovanja elektrokemičnih členov na gorivo (gorivnih celic).

Splošni rezultati:

- razumevanje tehnoloških podlag za vodikovo ekonomijo,
- poznavanje principov delovanja gorivnih celic,
- sposobnost vključevanja v raziskovalno-razvojne projekte na področju gorivnih celic in sistemov z gorivnimi celicami,
- sposobnost oceniti kakšne materiale se uporablja za te namene,
- sposobnost izbire ustrezne karakterizacijske tehnike za poglobljen študij teh materialov,
- kooperativnost, delo v skupini (tudi v mednarodnem okolju),
- sposobnost samostojne priprave projektne naloge.

Predmetno-specifični rezultati:

- diplomant se je sposoben vključevati v domače in mednarodne RR time v industriji in na akademskih ustanovah in uvajati ter uporabljati tehnologije na podlagi gorivnih celic.

Intended learning outcomes:

Knowledge and understanding

- Knowledge and understanding of process fundamentals for the direct chemical energy conversion to electricity and heat,
- Knowledge and understanding of the construction and function of fuel cells.

General Outcomes:

- Understanding of technological basis for hydrogen economy,
- Knowledge of fuel cells function principles,
- Capability of work in R&D project teams in the field of fuel cells and fuel cell systems,
- Capability of choosing the appropriate materials for electrochemical energy conversion application
- Ability to choose the appropriate characterization techniques for an in-depth study of these materials,
- Cooperativity, team work (including international environment),
- Capability to prepare individual project.

Course Specific Results:

- This course prepares students to work in R&D teams in industry and academic institutions at home and abroad and to implement and use fuel cell based technologies.

Metode poučevanja in učenja:

Predavanja in seminarji
Konzultacije
Individualno delo s študenti

Learning and teaching methods:

Lectures and seminars
Consultations
Individual work with students

Načini ocenjevanja:

- seminar
- ustni izpit

Delež (v %) /
Weight (in %)

Assessment:

- seminar
- oral exam

Reference nosilca / Lecturer's references:

- ŽERJAV, Gregor, LANZUTTI, Alex, ANDREATTA, Francesco, FEDRIZZI, Lorenzo, MILOŠEV, Ingrid. Characterization of self-assembled layers made with stearic acid, benzotriazole, or 2-mercaptobenzimidazole on surface of copper for corrosion protection in simulated urban rain. *Materials and corrosion*, ISSN 0947-5117, Jan. 2017, vol. 68, iss. 1, str. 30-41.

<http://onlinelibrary.wiley.com/doi/10.1002/maco.201608954/abstract>, doi: 10.1002/maco.201608954. [COBISS.SI-ID 5935642]

- MILOŠEV, Ingrid, KOVAČEVIĆ, Nataša, KOKALJ, Anton. Effect of mercapto and methyl groups on the efficiency of imidazole and benzimidazole-based inhibitors of iron corrosion. *Acta chimica slovenica*, ISSN 1318-0207. [Tiskana izd.], 2016, vol. 63, no. 3, str. 544-559, doi: 10.17344/acsi.2016.2326. [COBISS.SI-ID 29784871]
- MILOŠEV, Ingrid, RODIČ, Peter. Cerium chloride and acetate salts as corrosion inhibitors for aluminium alloy AA7075-T6 in sodium chloride solution. *Corrosion*, ISSN 0010-9312. [Print ed.], 2016, vol. 72, no. 8, str. 1021-1034, doi: 10.5006/1956. [COBISS.SI-ID 29450535]
- TREBŠE, Rihard, MIHELIČ, Anže, LEVAŠIČ, Vesna, CÖR, Andrej, MILOŠEV, Ingrid. Results of revision of total hip arthroplasty for alumina ceramic-on-ceramic bearing fracture. *Hip international*, ISSN 1120-7000, 2016, vol. 26, no. 3, str. 237-243. <http://www.hip-int.com/article/618332d2-aacb-4e10-8f5a-4a8dcc984046>, doi: 10.5301/hipint.5000340. [COBISS.SI-ID 29452071]
- COVACIU ROMONȚI, D., ISKRA, Jernej, BELE, Marjan, DEMETRESCU, Ioana, MILOŠEV, Ingrid. Elaboration and characterization of fluorohydroxyapatite and fluoroapatite sol-gel coatings on CoCrMo alloy. *Journal of alloys and compounds*, ISSN 0925-8388. [Print ed.], 2016, vol. 665, str. 355-364, doi: 10.1016/j.jallcom.2016.01.072. [COBISS.SI-ID 29240871]