



May 21-24, 2018, Tara Mountain, Serbia

Ovaj USB sadrži elektronsku Knjigu radova  
(u pdf formatu) prezenovanih u okviru  
Međunarodne konferencije **XX YuCorr**

This USB contains Proceedings  
(single pdf file) from  
International Conference **XX YuCorr**

U knjizi su **plavom bojom** obeleženi aktivni linkovi ka  
pojednim njenim delovima, iz Sadržaja do naznačenih stranica.

One can navigate easily through the book contents by a single  
click on the appropriate links in Contents (**showed in blue**)

U vrhu svake strane nalaze se prečice ka **Impresumu** i  
**Sadržaju** knjige, ka **Indexu** autora,  
kao i opcijama za štampanje (**Print**),  
zatvaranje dokumenta, odnosno izlaz iz knjige (**Exit**),  
i za povratak na ovu stranicu (**Intro**)

All contents of the Proceeding can be accessed through  
following shortcuts existing at the top of each page:  
**Impresum** (Impress of the Proceedings), **Contents**,  
**Index** (Author Index), **Print** (Print manager),  
**Exit** and **Intro** (which leads to this page).

**Autori snose punu odgovornost za sadržaj, originalnost, jezik i  
gramatičku korektnost sopstvenih radova.  
Authors bear full responsibility for the content, originality, language  
and grammatical correctness of their own works.**



---

MEĐUNARODNA KONFERENCIJA

*INTERNATIONAL CONFERENCE*

---

**STECIŠTE NAUKE I PRAKSE U OBLASTIMA KOROZIJE,  
ZAŠTITE MATERIJALA I ŽIVOTNE SREDINE**

---

***MEETING POINT OF THE SCIENCE AND PRACTICE IN THE FIELDS OF  
CORROSION, MATERIALS AND ENVIRONMENTAL PROTECTION***

---

***PROCEEDINGS***

---

**KNJIGA RADOVA**

**Pod pokroviteljstvom**

***Under the auspices of the***

**MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA**

**REPUBLIKE SRBIJE**

***MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL***

***DEVELOPMENT OF THE REPUBLIC OF SERBIA***

---

May 21-24, 2018 :: Tara Mountain, Serbia

CIP - Каталогизacija у публикацији - Народна библиотека Србије, Београд

620.193/.197(082)(0.034.2)

621.793/.795(082)(0.034.2)

667.6(082)(0.034.2)

502/504(082)(0.034.2)

66.017/.018(082)(0.034.2)

МЕЂУНАРОДНА конференција ЈУКОР (20 ; 2018 ; Тапа)

Stecište nauke i prakse u oblastima korozije, zaštite materijala i životne sredine [Elektronski izvor] : knjiga radova = Meeting Point of the Science and Practice in the Fields of Corrosion, Materials and Environmental Protection : proceedings / XX YuCorr [Jugoslovenska korozija] Međunarodna konferencija = XX YuCorr International Conference, May 21-24, 2018, Tara Mountain, Serbia ; [organizatori Udruženje inženjera Srbije za koroziju i zaštitu materijala ... [et al.] = [organized by] Serbian Society of Corrosion and Materials Protection ... [et al.] ; urednici, editors Miomir Pavlović, Miroslav Pavlović]. - Beograd : Udruženje inženjera Srbije za koroziju i zaštitu materijala UISKOZAM, 2018 (Beograd : Udruženje inženjera Srbije). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 200. - Bibliografija uz većinu radova. - Abstracts. - Registar.

ISBN 978-86-82343-26-4

1. Удружење инжењера Србије за корозију и заштиту материјала (Београд)

а) Премази, антикорозиони - Зборници б) Превлаке, антикорозионе - Зборници с)

Антикорозиона заштита - Зборници д) Животна средина - Заштита - Зборници е) Наука о материјалима - Зборници

COBISS.SR-ID 263766284

## **XX YUCORR – Međunarodna konferencija | International Conference**

### **IZDAVAČ | PUBLISHED BY**

UDRUŽENJE INŽENJERA SRBIJE ZA KORZIJU I ZAŠTITU MATERIJALA (UISKOZAM),

SERBIAN SOCIETY OF CORROSION AND MATERIALS PROTECTION (UISKOZAM)

Kneza Miloša 7a/II, 11000 Beograd, Srebija, tel/fax: +381 11 3230 028, [office@sitzam.org.rs](mailto:office@sitzam.org.rs); [www.sitzam.org.rs](http://www.sitzam.org.rs)

**ZA IZDAVAČA | FOR PUBLISHER:** Prof. dr MIOMIR PAVLOVIĆ, predsednik UISKOZAM

### **NAUČNI ODBOR | SCIENTIFIC COMMITTEE: Prof. dr M. Pavlović, Serbia – President**

Prof. dr Đ. Vaštag, Serbia; Prof. dr D. Vuksanović, Montenegro; Prof. dr D. Čamovska, Macedonia;

Prof. dr M. Antonijević, Serbia; Prof. dr S. Stopić, Germany; Prof. dr R. Zejnilović, Montenegro;

Prof. dr V. Alar, Croatia; Dr N. Nikolić, Serbia; Dr I. Krastev, Bulgaria; Prof. dr J. Bajat, Serbia;

Prof. dr M. Gvozdrenović, Serbia; Prof. dr S. Hadži Jordanov, Macedonia; Prof. dr R. Fuchs Godec, Slovenia;

Prof. dr J. Stevanović, Serbia; Dr R. Jeftić-Mučibabić, Serbia; Dr T. Vidaković-Koch, Germany;

Dr V. Panić, Serbia; Dr M. Pavlović, Serbia; Dr M. Mihailović, Serbia; Prof. dr M. Sak Bosnar, Croatia;

Prof. dr J. Jovičević, Serbia; Prof. dr D. Jevtić, Serbia; Dr F. Kokalj, Slovenia; Prof. dr A. Kowal, Poland;

Prof. dr Prof. dr M. Gligorić, Bosnia and Herzegovina; Prof. dr M. Tomić, Bosnia and Herzegovina

### **ORGANIZACIONI ODBOR | ORGANIZING COMMITTEE: Dr Miroslav Pavlović – president**

**Dr Nebojša Nikolić – vice president; Dr Marija Mihailović – vice president**

Prof. dr Miomir Pavlović; Dr Vladimir Panić; Jelena Slepčević, B.Sc.; Dr Vesna Cvetković;

Prof. dr Milica Gvozdrenović; Zagorka Bešić, B.Sc.; Gordana Miljević, B.Sc.; Miomirka Anđić, B.Sc.

Dr Aleksandar Dekanski; Marija Pavlović, M.Sc.; Marijana Pantović Pavlović, M.Sc.

Lela Mladenović – secretary

**UREDNICI | EDITORS:** Prof. dr Miomir Pavlović, Dr Miroslav Pavlović

**OBLAST | SCIENTIFIC AREA:** KORROZIJA I ZAŠTITA MATERIJALA / CORROSION AND MATERIALS PROTECTION

**KOMPJUTERSKA OBRADA I SLOG | PAGE LAYOUT:** Dr Miroslav Pavlović

**TIRAŽ | CIRCULATION:** 200 primeraka / copies

**ISBN 978-86-82343-26-4**

**ORGANIZATORI XX YUCORR-a  
XX YUCORR IS ORGANIZED BY**



**UDRUŽENJE INŽENJERA SRBIJE ZA KOROZIJU  
I ZAŠTITU MATERIJALA**

---

***Serbian Society of Corrosion and Materials Protection***



**INSTITUT ZA HEMIJU, TEHNOLOGIJU I METALURGIJU,  
UNIVERZITET U BEOGRADU**

---

***Institute of Chemistry, Technology and Metallurgy,  
University of Belgrade***



**SAVEZ INŽENJERA I TEHNIČARA SRBIJE**

---

***Union of Engineers and Technicians of Serbia, Belgrade***



**INŽENJERSKA AKADEMIJA SRBIJE**

---

***Engineering Academy of Serbia***

**XX YUCORR JE FINANSIJSKI POMOGLO**  
**XX YUCORR IS ORGANIZED UNDER THE AUSPICES OF THE**  
**MINISTARSTVO PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA**  
**REPUBLIKE SRBIJE**



**MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL**  
**DEVELOPMENT OF THE REPUBLIC OF SERBIA**

**GLAVNI SPONZOR | MAIN SPONSOR**

**FIRESTOP INTERNACIONAL d.o.o., Nova Pazova**

**SPONZORI | SPONSORS**

**INTERNATIONAL SOCIETY OF ELECTROCHEMISTRY, Switzerland**

**SAVEZ INŽENJERA I TEHNIČARA SRBIJE, Beograd**

**HELIOS SRBIJA a.d., Gornji Milanovac**

**UNIPROMET d.o.o., Čačak**

**HEMIPRODUKT, Novi Sad**

**JP EPS OGRANAK DRINSKO - LMSKE HE «BAJINA BAŠTA», Bajina Bašta**

**SURTEC ČAČAK d.o.o., Čačak**

**INSTITUT ZA PREVENTIVU d.o.o., Novi Sad**

**SZR "GALVA", Kragujevac**

**NOVOHEM d.o.o., Šabac**

# CONTENTS | SADRŽAJ

<b>PLENARNA PREDAVANJA   PLENARY LECTURES</b>	<b>1</b>
Novel nanostructured materials for energy conversion <b>Vuk V. Radmilović<sup>1</sup>, Peidong Yang<sup>2</sup>, Velimir R. Radmilović<sup>3</sup></b>	<b>2</b>
Environmental pollution with heavy metals in different media in the republic of Macedonia <b>Trajče Stafilov</b>	<b>4</b>
Underpotential deposition and one of the ways to use it <i>Elektrohemijsko taloženje metala pri potencijalima pozitivnijim od reverzibilnog i jedan od načina primene</i> <b>Jovan N. Jovičević</b>	<b>5</b>
Corrosion of steel with polyaniline based composite coatings: Between science and practice <b>Branimir N. Grgur</b>	<b>13</b>
Corrosion investigation of aluminium alloy protected by coatings containing zirconia and ceria nanoparticles <b>Sanja I. Stevanović<sup>1</sup>, Maria Lekka<sup>2</sup>, Alex Lanzutti<sup>2</sup>, Ljiljana S. Živković<sup>3</sup>, Lorenzo Fedrizzi<sup>2</sup>, Jelena B. Bajat<sup>4</sup></b>	<b>14</b>
Electrochemical treatment of leachate: a case study for sanitary landfill „Ramici“, Banja Luka <b>Borislav N. Malinović<sup>1</sup>, Miomir G. Pavlović<sup>2,3</sup>, Tijana Đuričić<sup>1</sup>, Draženko Bjelić<sup>4</sup>, Dragana Nešković Markić<sup>4</sup></b>	<b>16</b>
<b>PREDAVANJA PO POZIVU   INVITED LECTURES</b>	<b>27</b>
Celebrating YuCorr’s silver jubilee engineering – geniality that indepthed the mankind <i>Slaveći srebrejni jubilej YuCorr-a: Inženjerstvo – genijalnost koja ja zadužila čovečanstvo</i> <b>Svetomir Hadzi Jordanov<sup>1</sup>, Orce Popovski<sup>2</sup></b>	<b>28</b>
Influence of surface modified TiO <sub>2</sub> nanoparticles on thermal properties of poly(methyl methacrylate) <i>Uticaj površinski modifikovanih nanočestica TiO<sub>2</sub> na termička svojstva poli(metil metakrilata)</i> <b>Enis Džunuzović</b>	<b>29</b>
Eutectic freeze crystallization for resource recovery <b>Kerstin Forsberg</b>	<b>35</b>
Proton-intercalated TiO <sub>2</sub> nanotube arrays decorated with Pd nanoparticles: A novel approach to the hydrogen evolution reaction electrocatalysis <b>Uroš Lačnjevac<sup>1</sup>, Rastko Vasilić<sup>2</sup>, Tomasz Tokarski<sup>3</sup>, Grzegorz Cios<sup>3</sup>, Piotr Żabiński<sup>4</sup>, Nevenka Elezović<sup>1</sup>, Nedeljko Krstajić<sup>5</sup></b>	<b>36</b>
<b>USMENA SAOPŠTENJA   ORAL PRESENTATIONS</b>	<b>37</b>
Polar benzotriazoles in Slovenian environmental samples <b>Ida Kraševac, Helena Prosen</b>	<b>38</b>
Investigation of optical properties of the Cu-Mn oxide coatings <i>Ispitivanje optičkih svojstava prevlaka na bazi Cu-Mn oksida</i> <b>Bojan M. Jokić<sup>1</sup>, Biljana Babić<sup>2</sup>, Tanja Barudžija<sup>3</sup>, Miodrag Mitrić<sup>3</sup>, Milica Gvozdenović<sup>4</sup></b>	<b>43</b>

Hydrometallurgical treatment of acid mine drainage (AMD) solution <b>Srecko Stopic<sup>1</sup>, Yiqian Ma<sup>1</sup>, Brian Mwewa<sup>2</sup>, Sehliselo Ndlovu<sup>2</sup>, Geoffrey Simate<sup>2</sup>, Buhle Xakalashe<sup>1</sup>, Bernd Friedrich<sup>1</sup></b>	<b>44</b>
Aluminium electrodeposition onto glassy carbon from deep eutectic system made of AlCl <sub>3</sub> +urea <i>Elektrohemijsko taloženje aluminijuma na staklastom ugljeniku iz eutektičke smeše AlCl<sub>3</sub>+urea</i> <b>Vesna S. Cvetković, Nataša M. Vukićević, Jovan N. Jovićević</b>	<b>49</b>
Potential Radiobiological Effects on People's Health Due to the Presence of Radon ( <sup>222</sup> Rn) and Thoron ( <sup>220</sup> Rn) Descendants in Housing Facilities <i>Potencijalni radiobiološki efekti na zdravlje ljudi usled prisustva radonovih (<sup>222</sup>Rn) i toronovih (<sup>220</sup>Rn) potomaka u objektima za stanovanje</i> <b>Aco Janićijević</b>	<b>55</b>
Galvanostatic electrodeposition of aluminium onto aluminium from AlCl <sub>3</sub> +NaCl melt <i>Galvanostatsko elektrohemijsko taloženje aluminijuma na aluminijumu iz rastopa AlCl<sub>3</sub>+NaCl</i> <b>Nataša M. Vukićević, Vesna S. Cvetković, Jovan N. Jovićević</b>	<b>79</b>
Evaluation of urban contamination with Co, Ni and Pb in three urban parks in Serbia using pine ( <i>Pinus nigra</i> Arnold) needles and urban topsoil <b>Marija Pavlović*, Dragana Pavlović, Dragan Čakmak, Milica Marković, Zorana Mataruga, Miroslava Mitrović, Pavle Pavlović</b>	<b>84</b>
Electrical characteristics of polypyrrole based electrochemical secondary power sources <i>Električne karakteristike sekundarnih elektrohemijskih izvora električne energije na bazi polipirola</i> <b>Marija Janačković<sup>1</sup>, Milica Gvozdrenović<sup>2</sup>, Branimir Grgur<sup>2</sup></b>	<b>92</b>
Electrodeposition and corrosion evaluation of Zn-Co-CeO <sub>2</sub> nanocomposite <b>Marija Riđošić<sup>1,2*</sup>, Eva Garcia Lecina<sup>3</sup>, Asier Salicio Paz<sup>3</sup>, Ljiljana Živković<sup>4</sup>, Jelena Bajat<sup>2</sup>, Milorad Tomić<sup>1</sup></b>	<b>93</b>
Corrosion inhibitors encapsulated into micro or nano containers <i>Korozioni inhibitori inkapsulirani u mikro ili nano kontejnere</i> <b>Abdul Shaban<sup>1</sup>, Judit Telegdi<sup>1,2</sup>, Đendi Vaštag<sup>3*</sup></b>	<b>94</b>
Impact and importance of fire coating characteristics on formation of proper foam during coating expansion <i>Uticaj i važnost karakteristika protivpožarnog premaza za formiranje pravilne pene prilikom ekspanzije premaza</i> <b>Jana Vidaković*, Sandra Latinović</b>	<b>95</b>
Cathodic protection of the crude oil steel tank <i>Katodna zaštita pada čeličnih rezervoara za sirovu naftu</i> <b>Željko Krivačević, Dejan Grgić, Slaviša Gavrilović, Aleksandar Pešić</b>	<b>101</b>
<b>POSTERSKA SAOPŠTENJA   POSTER PRESENTATIONS</b>	<b>107</b>
Legislation on food contact packaging materials <b>Aleksandra Porjazoska Kujundziski<sup>1</sup>, Dragica Chamovska<sup>2</sup></b>	<b>108</b>
Determination of Methane Emission from Municipal Solid Waste Landfill in the Gilan Region <b>Afrim Berisha<sup>1</sup>, Biserka Dimishkovska<sup>1</sup>, Kiril Lisichkov<sup>2</sup>, Todor Anovski<sup>2</sup>, Blagoja Pavlovski<sup>2</sup></b>	<b>116</b>

Environmental tritium is still an efficient tool in determination the mechanism of recharge and aquifer characteristics of spring waters <b>Elena Anovska-Jovcheva<sup>1*</sup>, Kiril Lisichkov<sup>1</sup>, Dejan Dimitrovski<sup>1</sup>, Irena Mickova<sup>1</sup>, Kosta Anovski<sup>2</sup>, Stefan Kuvendziev<sup>1</sup>, Nauaf Baara<sup>3</sup>, Todor Anovski<sup>1</sup></b>	<b>121</b>
Optimal control of biological waste water treatment system <b>Erhan Mustafa<sup>1*</sup>, Kiril Lisichkov<sup>1</sup>, Stefan Kuvendziev<sup>1</sup>, Peyman Ghaffari<sup>2</sup>, Mirko Marinkovski<sup>1</sup>, Shaban Jakupi<sup>3</sup></b>	<b>127</b>
Application of the regime of reversing current (RC) in the second range on formation of the honeycomb-like electrodes of copper <i>Primena režima reversne struje (RC) u sekundskoj oblasti na formiranje elektroda bakra nalik pčelinjem saću</i> <b>Nebojša D. Nikolić<sup>1</sup>, Kata Berkesi<sup>2</sup>, Nevenka Elezović<sup>3</sup>, Uroš Lačnjevac<sup>3</sup>, Miomir G. Pavlović<sup>1</sup></b>	<b>133</b>
Electrochemical synthesis and initial corrosion behavior of <i>p</i> -toluensulfonic doped polyaniline on mild steel <i>Elektrohemijska sinteza i koroziono ponašanje polianilina dopovanog p- toluensulfonskom kiselinom</i> <b>Milica Gvozdrenović<sup>1</sup>, Miloš Uzelac<sup>1</sup>, Branimir Jugović<sup>2</sup>, Enis Džunuzović<sup>1</sup>, Bojan Jokić<sup>3</sup>, Jasmina Stevanović<sup>4</sup>, Branimir Grgur<sup>1</sup></b>	<b>134</b>
Sol-gel processing of ordered MnO <sub>2</sub> structures toward enhanced O <sub>2</sub> reduction catalysis for air batteries <b>Marija Mihailović<sup>1</sup>, Jasmina Stevanović<sup>1</sup>, Srećko Stopić<sup>2</sup>, Vladimir Panić<sup>1</sup>, Bernd Friedrich<sup>2</sup></b>	<b>135</b>
Improvement of the supercapacitor characteristics of perovskite oxides upon impregnation by RuO <sub>2</sub> <b>Sanja Eraković<sup>1</sup>, Miroslav M. Pavlović<sup>1</sup>, Srećko Stopić<sup>2</sup>, Jasmina Stevanović<sup>1</sup>, Vladimir Panić<sup>1</sup>, Bernd Friedrich<sup>2</sup></b>	<b>136</b>
Morphological characteristics of anaphoretically obtained hydroxyapatite/titanium dioxide coatings <b>Marijana Pantović Pavlović, Sanja Eraković, Miroslav M. Pavlović, Jasmina Stevanović, Vladimir Panić</b>	<b>142</b>
Influence of biodegradable matrix on electrical conductivity of copper filled composites <b>Zoran Janković<sup>1</sup>, Miroslav M. Pavlović<sup>2</sup>, Anto Gajić<sup>3</sup>, Marijana R. Pantović Pavlović<sup>2</sup>, Nebojša D. Nikolić<sup>2</sup>, Jasmina S. Stevanović<sup>2</sup>, Miomir G. Pavlović<sup>2</sup></b>	<b>143</b>
Impact of current density on the surface roughness of electrodeposited zinc coatings from sulphate baths <b>Marija G. Riđošić<sup>1*</sup>, Milorad V. Tomić<sup>1</sup>, Regina Fuchs-Godec<sup>2</sup>, Miroslav M. Pavlović<sup>3</sup>, Miomir G. Pavlović<sup>1</sup></b>	<b>151</b>
Determination of the content of heavy metals in herbal tea form the republic of srpska <b>Danijela Rajić, Dragan Tošković, Ljubica Vasiljević</b>	<b>153</b>
Adsorption of free fatty acids from sunflower oil after heating <i>Adsorpcija slobodnih masnih kiselina iz suncokretovog ulja nakon zagrijavanja</i> <b>Sanja Dobrnjac<sup>1</sup>, Ljubica Vasiljević<sup>2</sup>, Stevan Blagojević<sup>3</sup>, Zoran Obrenović<sup>4</sup>, Miladin Gligorić<sup>2</sup>, Dragan Tošković<sup>2</sup></b>	<b>159</b>
Analysis of the possibility for neutralization of waste water from tunel using NaCl <i>Analiza mogućnosti neutralizacije otpadnih voda iz tunela korišćenjem NaCl</i> <b>Dragan Radonjić, Darko Vuksanović, Refik Zejnilović, Jelena Šćepanović</b>	<b>167</b>



Selection of modern technology in the process of municipal waste disposal <i>Izbor savremene tehnologije u procesu odlaganja komunalnog otpada</i> <b>Jelena Šćepanović, Dragan Radonjić, Darko Vuksanović, Vanja Asanović</b> _____	173
Testing the possibility of incineration of sewage sludge of new plant for waste water treatment in Podgorica by selecting optimal technology <i>Ispitivanje mogućnosti spaljivanja kanalizacionog mulja iz novog postrojenja za prečišćavanje otpadnih voda u Podgorici izborom optimalne tehnologije</i> <b>Darko Vuksanović<sup>1</sup>, Petar Živković<sup>2</sup>, Vladan Vučelić<sup>3</sup></b> _____	179
The impact of pollutants due to work of crusher plant to quality of air in the industrial zone <i>Uticaj polutanata usljed rada drobilnog postrojenja na kvalitet vazduha u industrijskoj zoni</i> <b>Refik Zejnilović<sup>1</sup>, Darko Vuksanović<sup>1</sup>, Dragan Radonjić<sup>1</sup>, Jelena Šćepanović<sup>1</sup>, Nada Marstijepović<sup>2</sup></b> _____	190
Characterization of bolt shoulder AX.61972 and AX.61975 from the aspect of chemical composition, type of surface protection and determination of production technology <i>Karakterizacija bolt shoulder AX.61972 i AX.61975 sa aspekta hemijskog sastava, vrste površinske zaštite i određivanja tehnologije izrade</i> <b>Božidarka Arsenović, Zorana Živić, Ana Mičić, Borislav Pajkić</b> _____	198
Vitamin K –as a corrosion inhibitor for copper <b>Regina Fuchs–Godec<sup>1</sup>, Milorad. V. Tomić<sup>2</sup>, Miomir G. Pavlović<sup>2</sup></b> _____	205
Corrosion inhibition of sage extract on tinplate in 3% NaCl <b>Maja Dent<sup>1</sup>, Regina Fuchs–Godec<sup>2</sup></b> _____	211
Financial indicators of replacing heating oil by shallow geothermal energy using horizontal heat collectors on location in Serbia <b>Aleksandar Jokić, Nataša Lj. Lukić, Nevenka Nikolić</b> _____	217
Thermal stability and degradation of polyurethane elastomers based on polycarbonate diols <i>Toplotna stabilnost i ragradnja poliuretanskih elastomera na osnovu polikarbonatnih diola</i> <b>Dejan Kojić<sup>1</sup>, Jelena Pavličević<sup>1</sup>, Milena Špírková<sup>2</sup>, Katalin Mészáros Szécsényi<sup>3</sup>, Ayse Aroguz<sup>4</sup>, Mirjana Jovičić<sup>1</sup>, Jaroslava Budinski-Simendić<sup>1</sup></b> _____	222
Corrosion investigation of rapidly solidified Cu-Al-Ni alloy in NaCl solution <b>L. Vrsalović<sup>1</sup>, I. Garvanović<sup>1</sup>, S. Kožuh<sup>2</sup>, B. Kosec<sup>3</sup>, M. Bizjak<sup>3</sup>, I. Ivanić<sup>2</sup>, S. Gudić<sup>1</sup>, M. Gojić<sup>2</sup></b> ____	229
Purine as the inhibitor of copper corrosion in artificial blood plasma <b>Marija Petrović Mihajlović, Žaklina Tasić, Milan Radovanović, Ana Simonović, Milan Antonijević</b> _____	238
By-products of fermentation of extraction juice from sugar beet in bioethanol production <b>Rada Jevtić-Mučibabić, Bojana Filipčev, Olivera Šimurina, Nebojša Ilić</b> _____	244
Influences of construction of mini hydropower plants on environment <i>Uticaji izgradnje mini hidroelektrane na životnu sredinu</i> <b>Veljko Đukić</b> _____	249
The possibilities of the application of the "hydroclave" system in the disposal of medical waste <i>Mogućnosti primjene „Hydroclave“ sistema u zbrinjavanju medicinskog otpada</i> <b>Veljko Đukić</b> _____	257
Electrodeposition of Mn-Zn and Mn-Cu Alloys From Sulfate Solution Containing Complexing Additives	

---

<b>David G. Gogoli, Gigla S. Tsursumia</b> _____	<b>266</b>
Ecological and economic importance and influence of corrosion <i>Ekološki i ekonomski značaj i uticaj korozije</i>	
<b>Dragiša Obradović<sup>1</sup>, Dragan Obradović<sup>2</sup></b> _____	<b>268</b>
Electrochemical determination of the inhibition and kinetic properties of oxidoreductase immobilized with L-cysteine <i>Elektrohemijsko određivanje inhibicije i kinetičkih osobina oksidoreduktaze imobilizirane sa L-cisteinom</i>	
<b>Safija Herenda<sup>1*</sup>, Edhem Hasković<sup>2</sup></b> _____	<b>275</b>
<b>INDEKS AUTORA   AUTHOR INDEX</b> _____	<b>280</b>
<b>GLAVNI SPONZOR   MAIN SPONSOR</b> _____	<b>283</b>
<b>SPONZORI   SPONSORS</b> _____	<b>285</b>

---

## Aluminium electrodeposition onto glassy carbon from deep eutectic system made of $\text{AlCl}_3$ +urea

### *Elektrohemijsko taloženje aluminijuma na staklastom ugljeniku iz eutektičke smeše $\text{AlCl}_3$ +urea*

Vesna S. Cvetković, Nataša M. Vukićević, Jovan N. Jovićević

*Institute of chemistry, technology and metallurgy, University of Belgrade, Njegoševa 12,  
11001 Belgrade, Serbia*

Institut za hemiju, tehnologiju i metalurgiju, Univerzitet u Beogradu, Njegoševa 12,  
11001 Beograd, Srbija

#### **Abstract**

*Electrochemical deposition of aluminium onto glassy carbon from deep eutectic solvent (DES), made of the  $\text{AlCl}_3$ +urea, at 25-50°C have been investigated. The deposition was performed in potentiostatic mode. The morphology of the obtained deposits were characterized using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Critical overpotential of aluminium deposition decreased from around  $-0.150$  V at 25°C to around  $-0.100$  V at 50°C. All recorded currents were small but would substantially increase with increasing working temperature (from  $0.01$  mA  $\text{cm}^{-2}$  up to  $0.25$  mA  $\text{cm}^{-2}$ ). The deposits obtained showed variety of morphological shapes depending on the working temperature and potential applied. All the deposits were made of very small crystallites grouped randomly into more or less separate agglomerates. Density of the crystallites distribution over the substrate and complicity of the crystal forms increased with the potential applied.*

*Electrodeposition/dissolution of aluminium in used electrolyte onto used substrate obviously promises positive results if research aiming at reversible systems of such composition working at temperatures very close to room temperature.*

**Keywords:** *glassy carbon, aluminium deposition/dissolution, deep eutectic system, urea*

#### **Izvod**

*Ispitivano je elektrohemijsko taloženje aluminijuma na staklastom ugljeniku iz eutektičke smeše (DES),  $\text{AlCl}_3$ +urea, na temperaturama od 25-50°C. Elektrotaloženje je izvođeno potenciostatski. Morfologija dobijenih taloga je analizirana skenirajućom elektronskom mikroskopijom (SEM) i energetske disperzivnom spektroskopijom (EDS). Kritične prenapetosti elektrotaloženja aluminijuma kretale su se od oko  $-0.150$  V pri 25°C do oko  $-0.100$  V pri 50°C. Zabeležene gustine struje bile su male, ali su njihove vrednosti značajno rasle sa povećanjem radne temperature (od  $0.01$  mA  $\text{cm}^{-2}$  do  $0.25$  mA  $\text{cm}^{-2}$  uz povećanje temperature od 25°C do 50°C). Dobijeni talozi pokazali su raznovrsne morfološke oblike što je zavisilo od primenjene temperature i potencijala. Svi talozi sastojali su se od veoma malih kristala objedinjenih u aglomerate koji su bili nasumično raspoređeni po površini radne electrode. Gustina rasporeda kristalita po površini elektrode i njihova pojedinačna raznovrsnost po obliku rasle su sa povećanjem primenjenog potencijala.*

*Elektrohemijsko taloženje/rastvaranje aluminijuma u upotrebljenom elektrolitu i na upotrebljenoj podlozi obećava pozitivne rezultate u istraživanjima usmerenim na reverzibilne sisteme istog ili sličnog sastava koji bi trebalo da rade na temperaturama veoma bliskim sobnoj.*

**Ključne reči:** staklasti ugljenik, elektrohemijsko taloženje/rastvaranje aluminijuma, eutektička smeša, urea

## Introduction

The importance of aluminium and its alloys derives from their high level of corrosion resistance, electric conductivity, low density, high elastic modulus. These makes them promising materials for application in aerospace, military, automobile industry [1]. Different methods have been developed for Al coatings for corrodible materials, and besides hot dipping [2], vapour deposition, electroless plating, etc. [2], electrodeposition proved to be very promising way to obtain metal deposit at the micro or nano scale under controlled conditions. However, aluminium electrodeposition has to be done from non-aqueous electrolytes. In aqueous solutions aluminium deposition is preceded by hydrogen evolution due to very negative reduction potential of aluminium (-1.662 V vs. SHE). Numerous research efforts have been put into quest for non-aqueous electrolyte suitable for aluminium electrodeposition at low temperatures.

Some success was recorded in inorganic molten salts, like chloroaluminates, electrolytes with working temperatures between 200°C and 500°C producing aluminium deposits of good quality and adherence [3]. Some time ago these have been joined with relatively new class of solvents, known as room temperature molten salts or ionic liquids (IL), to be used for electrodeposition of pure aluminium or aluminium alloys. Most of the research regarding aluminium electrodeposition was carried out from AlCl<sub>3</sub>-1-ethyl-3methylimidazolium chloride [4]. Aluminium deposition from ionic liquids was observed only from acidic electrolyte, and aluminium deposited layer was reported to be relatively smooth with higher adhesive strength [4,5]. Recently, interest have been expanded to some aluminium chloride based electrolytes which in combination with some polarizable organic compounds produce nonaqueous solution near or close to room temperature. These systems are known as deep eutectic solvents (DESs) or solvate IL [4,6]. Due to their low cost and minimum environmental footprint these class of ionic liquids have been found to be of interest for electrodeposition of aluminium [7,8].

In this study, the synthesis of deep eutectic solvent based on AlCl<sub>3</sub>+urea, and their use for aluminium electrodeposition was reported. Cyclic voltammetry (CV), Chronoamperometry, and polarization curves were used to study aluminium electroreduction and deposition on glassy carbon working electrode in AlCl<sub>3</sub>+urea deep eutectic system.

## Experimental

In a small glass container urea (p.a. used as received, Carlo Erba, France) was added to AlCl<sub>3</sub> (>99%, Aldrich Chemical Company, Inc.), molar ratio was 1:1.6, and slowly mixed under argon atmosphere inside glove box. It took several seconds to form a homogeneous, yellow colored liquid (deep eutectic solvent – DES) which then was left to cool gradually at room temperature. Finally, DES from the beaker was transferred to a sealed three electrode electrochemical cell supplied with argon atmosphere. Electrochemical experiments in the cell were performed outside the glove box.

Two aluminium electrodes (99.99%, Alfa Products, Thiokol Ventron division, USA) were used: wire with 3mm diameter as a reference electrode and curved rectangular shovel with geometrical area = 15 cm<sup>2</sup> as a counter electrode. Cylindrical glassy carbon working electrode (GC) was placed in the centre of the cell, with surface area of 0.5 cm<sup>2</sup> exposed to ionic liquid electrolyte. Prior to every electrochemical measurement or electrodeposition process, aluminium electrodes were polished and etched as described elsewhere [9]. After being polished with 0.05 µm alumina powder (Merck) glassy

carbon working electrode was cleaned by sonification in Milli-Q water in several intervals for 5 min and finally rinsed with distilled water and absolute ethanol.

Cycling voltammetry (CV), Chronoamperometry and Chronopotentiometry were used to study aluminium deposition/dissolution from the DES under argon atmosphere, using EG&G PAR 273A Potentiostat/Galvanostat controlled by Power Suite software (Princeton Applied Research, USA).

## Results and discussion

Voltammograms were recorded for the linear potential changes from the starting potential,  $E_i$ , 100-150 mV negative to the working electrode open circuit potential (1.400 V vs.  $\text{Al}^{3+}/\text{Al}$ ) towards the negative end potential,  $E_f$ , and back using different scan rates. Typical examples of the voltammograms depicting Al deposition/dissolution on/from GC working electrode in the DES used are presented in Fig.1. Charges under deposition peaks are very close to the charges under dissolution peaks for all working temperatures used, which suggests good reversibility of the two processes. The reproducibility of the voltammograms recorded at the same conditions was very good. It was interesting to find that aluminium deposition and dissolution proceeds very well even at 25°C, although with rather small current densities. During experiments the electrolyte was not stirred.

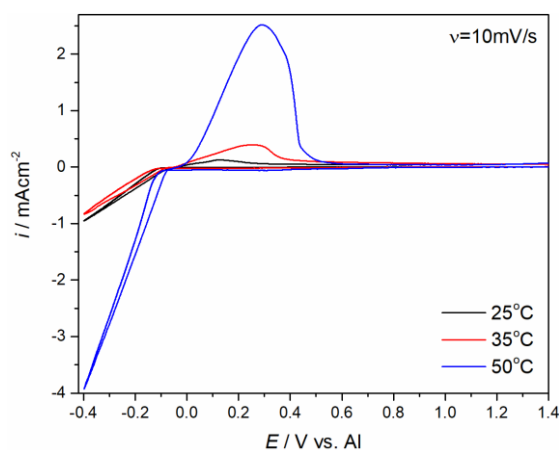


Figure 1. Voltammograms obtained on GC working electrode in DES used at three different temperatures.

Examples of the current-time transients obtained by aluminium electrodeposition conducted under constant potential ( $-0.120$  V vs.  $\text{Al}^{3+}/\text{Al}$ ) at three different temperatures: room temperature (25°C), 35°C and 50°C are presented in Fig.2. During aluminium deposition the electrolyte was not stirred.

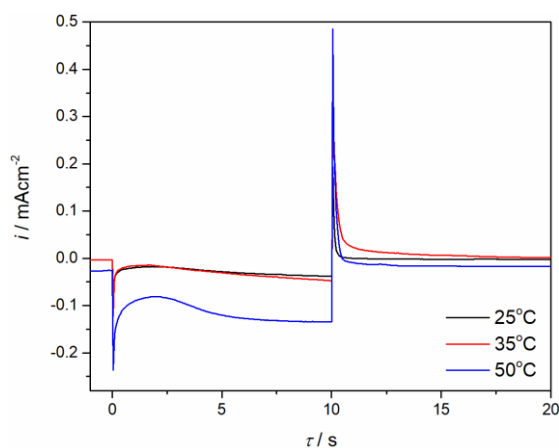


Figure 2. Current-time transients obtained with GS electrode in DES with cathodic overpotential of  $-0.120$  V (10 s duration) at three different temperatures.

It was found that overpotential of  $-0.120$  V was sufficient to initiate and sustain aluminium deposition even at room temperature. However, at  $25^{\circ}\text{C}$  recorded current densities were of the order of  $0.01$  mA cm $^{-2}$ . Initial portions of the transients at all applied temperatures indicated continuous nucleation and growth of the aluminium deposited.

After deposition completed, the obtained samples were thoroughly rinsed with absolute ethanol to remove any residues of the electrolyte and left to dry in air before characterisation. The microstructures of the deposits were visualised using scanning electron microscope (SEM, TESCAN Digital Microscope; model VEGA3, Brno, Czech Republic) and composition of the deposit was analysed by energy dispersive spectroscopy (EDS-TESCAN), see Fig.3.

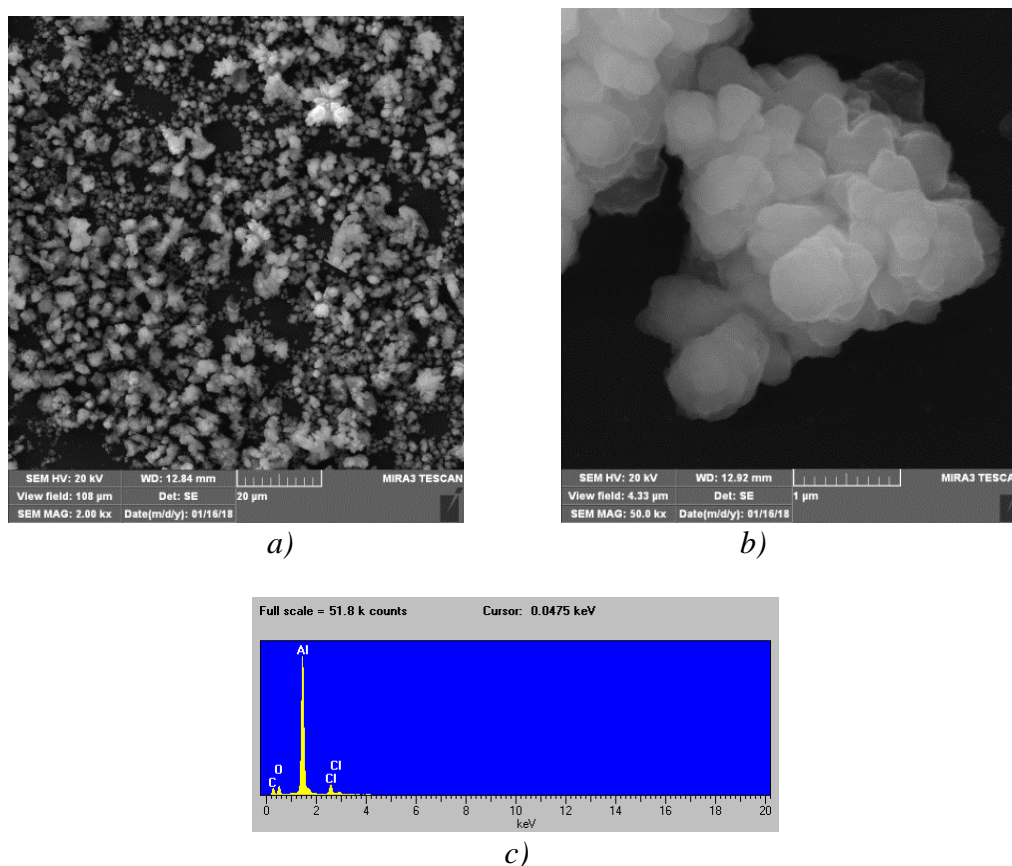


Figure 3. SEM and EDS analysis of GC working electrode after potentiostatically deposited aluminium at  $-0.250$  V for 30 min, temperature  $25^{\circ}\text{C}$ .

After 30 minutes of aluminium deposition at  $-0.250$  V at  $25^{\circ}\text{C}$ , GC working electrode becomes randomly covered with aluminium clusters,  $2\mu\text{m}$  of average size, Fig.3a. Most of the clusters were composed of hexagonal flakes, Fig.3b, and the smallest ones were pyramids and bipyramids of up to 200 nanometres in base. EDS analysis has shown that the deposit was aluminium.

The depositions made under all other conditions being the same but at elevated temperatures (namely  $35^{\circ}\text{C}$  and  $50^{\circ}\text{C}$ ) produced incoherent (loos) aluminium deposits made of clusters which were of bigger average size. However, no compact and adherent aluminium deposit was obtained. The deposits obtained were of very high surface area and reach morphology which points to diffusion controlled aluminium electrodeposition. It appears that after nucleation the grains develop as pyramids (or bipyramids) which after achieving a certain size (a few hundred nanometres up to a micrometre, depending on the applied temperature) either stop growing or continue to grow only on a few of the irregularities active on a crystallographic planes. When this might be the case the growth includes constructions made of hexagonal flakes bound together, Fig.3a.

This initial results are not sufficient for serious analysis on the mechanisms governing formation of so elaborate and complex deposit morphology. Deposition current densities are very small, particularly at 25°C (of the order of 0.01 mA cm<sup>-2</sup>), although they are not much greater at 35°C (around 0.05 mAcm<sup>-2</sup>) and 50°C (of the order of 0.1 mAcm<sup>-2</sup>). Such small currents could be attributed to very high electrolyte resistivity. No reliable value for diffusion limited deposition current density could have been determined. In several papers, published very recently [10,11], reporting on similar systems, no deeper discussion on the subject of similar deposit morphology had been opened. It is obvious that comprehensive specially designed experiments will be needed to unveil the roles of electrolyte resistance and aluminium ions diffusion control onto complex deposit morphologies observed.

## Conclusion

Aluminium has been successfully deposited onto glassy carbon from deep eutectic solvent (DES), made of the AlCl<sub>3</sub>+urea, at 25, 35 and 50°C.

Deposition and dissolution processes were reversible and reproducible, even at 25°C. Both, potentiostatic deposition and dissolution were performed with rather low current densities (bellow 0.1 mA cm<sup>-2</sup>).

Obtained deposits were made of individual randomly distributed aluminium clusters which were closer together and bigger as the deposition potential, deposition time and working temperature were increased. Although of high surface area, the deposits were not coherent and well adherent to the substrate.

The morphology of the obtained deposits was very complex and elaborate consisting of individual crystallites (pyramids, bipyramids), boulders with coral like additions and clusters made of hexagonal flakes.

How much the morphology was influenced by small current densities due to high electrolyte electric resistivity, and how much by possible diffusion controlled deposition at this initial stages of research was difficult to ascertain.

## References

1. Huang, W., Xia, X., Liu, B., Liu, Y., Wang, W., Ma, N., Electrodeposition of aluminum on aluminum surface from molten salt, *Acta Metall. Sin.* 2011, 24, 443-448.
2. Tang, J., Azumi, K., Optimization of pulsed electrodeposition of aluminum from AlCl<sub>3</sub>-1-ethyl-3-methylimidazolium chloride ionic liquid, *Electrochim. Acta*, 2011, 56, 1130-1137.
3. Stafford, G.R., Hussey, C.L. 2001. Electrodeposition of transition metal-aluminium alloys from chloroaluminate molten salts, In: Alkire RC, and Kolb DM, editors. *Advances in Electrochemical Science and Engineering*, Wiley-VCH Verlag GmbH, New York, Weinheim, 275–348.
4. Tsuda, T., Stafford R.G., Hussey, L.C., Review—Electrochemical Surface Finishing and Energy Storage Technology with Room-Temperature Haloaluminate Ionic Liquids and Mixtures, *J. Electrochem. Soc.* 2017, 164 (8) H5007-H5017.
5. Endres, F., Ionic Liquids: Solvents for the Electrodeposition of Metals and Semiconductors, *ChemPhysChem.* 2002, 3, 144 -154.
6. Smith, L.E., Abbott, P.A., Ryder, S.K., Deep Eutectic Solvents (DESs) and Their Applications, *Chem. Rev.* 2014, 114, 11060-11082.
7. Li, M., Gao, B., Chen, W., Liu, C., Wang, Z., Shi, Z., Hu, X., Electrodeposition behavior of aluminum from urea-acetamide-lithium Halide low-temperature molten salts, *Electrochim. Acta*, 2015, 185, 148-155.
8. Angell, M., Pan, C-J., Rong, Y., Yuan, C., Lin, M-C., Hwang, B-J., Dai, H., High Coulombic efficiency aluminum-ion battery using an AlCl<sub>3</sub>-urea ionic liquid analog electrolyte, *PNAS* 2017, 114, 5, 834-839.

9. Jovicević, N., Cvetković, S.V., Kamberović, Ž, Barudžija, S.T., Aluminium Underpotential Deposition from  $\text{AlCl}_3+\text{NaCl}$  Melts and Alloy Formation with Vanadium Substrate, *Int. J. Electrochem. Sci.*, 2015, 10, 8959-8972.
10. Abood, M.A.H., Dawood, L.N., Morphology of Electrodeposited Aluminium Metal from Aluminium Chloride-Urea Room Temperature Ionic Liquid (RTIL) at Variable Parameters, *International Journal of Science and Research*, 2015, 4, 753-760.
11. Jiao, H., Wang, C., Tu, J., Tian D., Jiao, S., A rechargeable Al-ion battery: Al/molten  $\text{AlCl}_3$ -urea/graphite, *Chem. Commun.*, 2017, 53, 2331-2334.