Procesing '24

37. Međunarodni kongres o procesnoj industriji

29–31. maj 2024, Beograd

ZBORNIK RADOVA
Proceedings

www.procesing.smeits.rs

ZBORNIK RADOVA

pisanih za 37. Međunarodni kongres o procesnoj industriji

PROCESING ′24

Privredna komora Srbije, Beograd

Izdavač
Savez mašinskih i elektrotehničkih
inženjera i tehničara Srbije (SMEITS)
Društvo za procesnu tehniku
Kneza Miloša 7a/II,
11000 Beograd

Predsednik Društva za procesnu tehniku

pri SMEITS-u
prof. dr Aleksandar Jovović, dipl. inž.

Urednici
Prof. dr Nikola Karličić, dipl. inž. maš.
Prof. dr Marko Obradović, dipl. inž. maš.
Prof. dr Miroslav Stanojević, dipl. inž. maš.
Prof. dr Aleksandar Jovović, dipl. inž. maš.

Tiraž
50 primeraka

CD umnožava
SMEITS, Beograd

ISBN
978-86-85535-18-5

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

621(082)(0.034.2)
66.01(082)(0.034.2)

МЕЂУНАРОДНИ конгрес о процесној индустрији ПРОЦЕСИНГ (37 ; 2024 ; Београд)

Zbornik radova [pisanih za] 37. Međunarodni kongres o procesnoj industriji, PROCESING ‘24, 29–31. maj 2024, Beograd [Elektronski izvor] = Proceedings / [urednici Nikola Karličić ... [et al.]]. - Beograd : Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS), Društvo za procesnu tehniku, 2024 (Beograd : SMEITS). – 1 elektronski optički disk (CD-ROM) ; 12 cm. Sistemski zahtevi: Nisu navedeni. - Radovi na srp. i engl. jeziku. - Nasl. sa naslovne strane dokumenta. - Tiraž 50. - Bibliografija uz svaki rad. – Abstracts.

ISBN 978-86-85535-18-5

a) Машинство – Зборници b) Процесна индустрија – Зборници

COBISS.SR-ID 148188937

Organizatori

Društvo za procesnu tehniku pri SMEITS-u

Katedra za procesnu tehniku Mašinskog fakulteta u Beograd

Privredna komora Srbije Beograd

Održavanje 37. Procesinga finansijski je pomoglo Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije

Programski pokrovitelji

- Mašinski fakultet Univerziteta u Beogradu, Beograd
- Tehnološko-metalurški fakultet Univerziteta u Beogradu, Beograd
- Fakultet organizacionih nauka Univerziteta u Beogradu, Beograd

Sponzori

Institut za nuklearne nauke „Vinča“ Beograd

Beograd

Inženjerska komora Srbije Beograd

Beograd

Subotica

Beograd

Beograd

Beograd

MEĐUNARODNI NAUČNI ODBOR

Dr Nikolina Banjanin	*Univerzitet u Beogradu, Medicinski fakultet, Beograd, Institut za higijenu sa medicinskom ekologijom, Srbija*
Dr Damir Đaković	*Fakultet tehničkih nauka Univerziteta u Novom Sadu, Srbija*
Dr Mirko Dobrnjac	*Mašinski fakultet, Banja Luka, BiH*
Dr Maja Đolić	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Srbija*
Dr Srbislav Genić	*Univerzitet u Beogradu, Mašinski fakultet, Srbija*
Dr Milan Gojak	*Univerzitet u Beogradu, Mašinski fakultet, Srbija*
Dr Dušan Golubović	*Univerzitet u Istočnom Sarajevu, Mašinski fakultet, BiH*
Dr Dijana Grgas	*Prehrambeno biotehnološki fakultet, Sveučilište u Zagrebu, Hrvatska*
Dr Zvonimir Guzović	*Fakultet strojarstva i brodogradnje Sveučilišta u Zagrebu, Hrvatska*
Dr Gorica Ivaniš	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Srbija*
Dr Jelena Janevski	*Univerzitet u Nišu, Mašinski fakultet, Srbija*
Dr Rade Karamarković	*Fakultet za mašinstvo i građevinarstvo u Kraljevu Univerziteta u Kragujevcu, Srbija*
Dr Milica Karanac	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Srbija*
Dr Mirjana Kijevčanin	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Srbija*
Dr Atanas Kočov	*Mašinski fakulteta Univerziteta Skopje, Severna Makedonija*
Dr Čedo Lalović	*Akademija strukovnih studija Šumadija - Odsek Aranđelovac, Srbija*
Dr Tibela Landeka Dragičević	*Prehrambeno biotehnološki fakultet, Sveučilište u Zagrebu, Hrvatska*
Dr Dorin Lelea	*University Politehnica Timisoara, Rumunija*
Dr Stefan Mandić-Rajčević	*University of Milan, Italija*
Dr Ljiljana Medić-Pejić	*Universidad Politécnica de Madrid Madrid, Španija*
Dr Sanda Midžić-Kurtagić	*Mašinski fakultet, Univerzitet u Sarajevu, Sarajevo, BiH*
Dr Nenad Mitrović	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Dr Sanja Milivojević	*Univerzitet u Beogradu, Mašinski fakultet, Srbija*
Dr Biljana Miljković	*Fakultet tehničkih nauka Univerziteta u Novom Sadu, Srbija*
Dr Dobrica Milovanović	*Fakultet inženjerskih nauka Univerziteta u Kragujevcu, Kragujevac, Srbija*
Dr Srđan Nešić	*Ohio University, Russ College of Engineering and Technology, Ohio, SAD*
Dr Nataša Nord	*Norwegian University of Science and Technology, Trondheim, Norveška*
Dr Marko Obradović	*Mašinski fakulteta Univerziteta u Beogradu, Srbija*
Dr Goran Orašanin	*Mašinski fakultet Univerziteta u Istočnom Sarajevu, BiH*
Dr Milan M. Petrović	*Univerzitet u Beogradu, Mašinski fakultet, Srbija*
Dr Darko Radenković	*Univerzitet u Beogradu, Mašinski fakultet, Srbija*
Dr Dejan Radić	*Mašinski fakultet Univerziteta u Beogradu, Srbija*
Dr Ivona Radović	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Srbija*
Dr Jelena Ruso	*Univerzitet u Beogradu, Fakultet organizacionih nauka, Srbija*
Dr Niko Samec	*Mašinski fakultet Univerziteta u Mariboru, Slovenija*
Dr Stojan Simić	*Univerzitet u Istočnom Sarajevu, Mašinski fakultet, BiH*
Dr Mirjana Stamenić	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Dr Olivera Stamenković	*Tehnološki Fakultet Univerziteta u Nišu, Leskovac, Srbija*
Dr Vladimir Stevanović	*Univerzitet u Beogradu, Mašinski fakultet, Srbija*
Dr Jasna Tolmač	*Univerzitet u Novom Sadu, Tehnički fakultet „Mihailo Pupin“ u Zrenjaninu*
Dr Radoje Vujadinović	*Mašinski fakultet Univerziteta Crne Gore, Crna Gora*
Dr Igor Vušanović	*Mašinski fakultet Univerziteta Crne Gore, Crna Gora*
Dr Nikola Živković	*Institut za nuklearne nauke „Vinča“, Srbija*

ORGANIZACIONI ODBOR

Aleksandar Branković	*SET, Trebinje*
Dr Mirjana Ćujić	*Univerzitet u Beogradu, Institut za nuklearne nauke „Vinča“, Laboratorija za hemijsku dinamiku i permanentno obrazovanje*
Dr Mladen Đurić	*Univerzitet u Beogradu, Fakultet organizacionih nauka, Beograd*
Dr Nikola Karličić	*Univerzitet u Beogradu, Mašinski fakultet, Beograd (predsednik)*
Ilija Kovačević	*Pro-Ing d.o.o., Beograd*
Dr Aleksandar Petrović	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Vera Ražnatović	*Privredna komora Srbije, Beograd*
Jelena Salević	*SMEITS, Beograd*
Alija Salkunić	*Elixir Group, Šabac*
Ljubinko Savić	*Privredna komora Srbije, Beograd*
Zoran Simić	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Antonela Solujić	*Privredna komora Srbije, Beograd*
Dr Miroslav Stanojević	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Dr Dušan Todorović	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Dr Branislav Todorović	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Dr Marta Trninić	*Akademija tehničkih strukovnih studija, Beograd*

RECENZENTI

Prof. dr Miroslav Stanojević	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Prof. dr Nikola Karličić	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Prof. dr Marko Obradović	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Prof. dr Dušan Todorović	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Prof dr Antonije Onjia	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Prof. dr Đorđe Veljović	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Prof. dr Vladimir Pavićević	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Prof. dr Dragana Živojinović	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Doc. dr Nevena Prlainović	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Doc. dr Maja Đolić	*Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd*
Prof. dr Mladen Đurić	*Univerzitet u Beogradu, Fakultet organizacionih nauka, Beograd*
Doc dr Ana Rakić	*Univerzitet u Beogradu, Fakultet organizacionih nauka, Beograd*
Doc dr Jelena Ruso	*Univerzitet u Beogradu, Fakultet organizacionih nauka, Beograd*
Zoran Simić	*Univerzitet u Beogradu, Inovacioni centar Tehnološko-metalurškog fakulteta u Beogradu*

POČASNI ODBOR

Prof. dr Bratislav Blagojević	*Predsednik SMEITS-a*
Prof. dr Vladimir Popović	*dekan Mašinskog fakulteta Univerziteta u Beogradu*
Marko Čadež	*Predsednik Privredne komore Srbije*
Prof. dr Petar Uskoković	*dekan Tehnološko-metalurškog fakulteta Univerziteta u Beogradu*
Prof. dr Milan Martić	*dekan Fakulteta organizacionih nauka Univerziteta u Beogradu*
Prof. dr Srđan Kolaković	*dekan Fakulteta tehničkih nauka Univerziteta u Novom Sadu*
Prof. dr Svetlana Karić	*Predsednik Akademije strukovnih studija Šabac*
Prof. dr Martin Bogner	*Univerzitet u Beogradu, Mašinski fakultet, Beograd*
Prof. dr Snežana Pajović	*Institut za nuklearne nauke "Vinča" – Institut od nacionalnog značaja za Republiku Srbiju – Univerzitet u Beogradu*
Mihajlo Mišić	*Inženjerska komora Srbije*
Veljko Todorović	*Grundfos Srbija, Beograd*
Dejan Dotlić	*Kazantrade Solution, Beograd*
Čaba Kern	*Cim gas, Subotica*
Nemanja Tubić	*Wilo Beograd, Beograd*
Dejan Margetić	*Vodavoda, Mionica*
Bojan Sretenović	*Ovex inženjering, Beograd*

Sadržaj

Uvodnik

Prof. dr Nikola Karličić

Energija u procesnoj industriji

1. SAGOREVANJE DRVETA I DRUGE VRSTE BIOMASE
Sonja Ketin, Boban Kostić, Rade Biočanin 15

2. PRIMENA SISTEMA AKTIVNE KONDENZACIJE ZA KORIŠĆENJE GORNJE TOPLOTNE MASE GORIVA
Milan S. Marjanović, Miloš V. Nikolić, Đorđe A. Novčić, Rade M. Karamarković, Dušan M. Todorović 17

Modelovanje i optimizacija procesnih i termoenergetskih postrojenja

3. NUMERIČKO MODELIRANJE INTERAKCIJE IZMEĐU VISKOPLASTIČNOG FLUIDA I VISKOELASTIČNOG ČVRSTOG TIJELA
Jaber Almutairi, Almin Halač, Amra Hasečić, Ejub Džaferović 19

4. ENERGETSKA EFIKASNOST TERMOKOMPRESORKIH SISTEMA PRIMENJENI U INDUSTRIJSKIM KONCENTRATORIMA
Aleksandar Gjerasimovski, Nataša Gjerasimovska, Vasko Šarevski 21

5. NUMERIČKA ANALIZA MOGUĆNOSTI FLEŠBEKA U SLUČAJU PRETHODNO MEŠANOG SAGOREVANJA VODONIK-VAZDUH
Filip Kokalj, Marc Jaeger, Matjaž Hriberšek, Niko Samec. 23

6. EKSERGIJSKA ANALIZA ZA OPTIMIZACIJU PROCESA U ELEKTROLUČNOJ PEĆI
Vaso Manojlović, Jelena Ivanović, Nataša Gajić 25

7. KORIŠĆENJE AKTIVNE KONDENZACIJE U SISTEMU DALJINSKOG GREJANJA NA BIOMASU
Milan Marjanović, Rade Karamarković, Dušan Todorović, Marko Obradović, Aleksandar Jovović, Dejan Radić 27

Hidraulički i pneumatski transport

8. ANALIZA STACIONARNIH I PRELAZNIH REŽIMA U NAFTNIM POSTROJENJIMA
Aleksandar Petković, Jovan Ilić 29

Inženjerski menadžment, kvalitet i standardizacija

9. INTEGRACIJA METODOLOGIJA ZA KONTINUIRANO UNAPREĐENJE I ZELENIH INOVACIJA: PUT KA ODRŽIVIM ORGANIZACIJAMA
Alija Salkunić, Lidija Gadže, Anđela Vila 37

10. OPTIMIZACIJA, VALIDACIJA I VERIFIKACIJA ICP-MS METODE ZA ODREĐIVANJE METALA IZ EMISIJE STACIONARNIH IZVORA
Filip Živković, Maja Đolić, Liljana Janković Mandić, Mirjana Ćujić 51

11. ZNAČAJ PRIMENE STANDARDA ZA SISTEM MENADŽMENTA ŽIVOTNE SREDINE
Sara Dimitrijević, Mladen Đurić, Jelena Ruso 53

12. PROCENA MERNE NESIGURNOSTI PRILIKOM ODREĐIVANJA SADRŽAJA TEŠKIH METALA U UZORCIMA LETEĆEG PEPELA
Dušan Trajković, Aleksandra Perić Grujić, Dragana Živojinović 55

13. ZNAČAJ MENADŽMENTA KVALITETA I RIZIKA ZA STARTAPOVE
Lena Bogdanović 63

14. MOGUĆNOSTI PRIMENE 8D METODOLOGIJE ZA POBOLJŠANJE KVALITETA U IT KOMPANIJAMA
Aleksandra Mitrović, Mladen Đurić 73

15. DOSTIGNUĆE INDUSTRIJE 5.0 U VISOKOŠKOLSKIM USTANOVAMA NA OSNOVU BALANCED SCORECARD (BSC) – FOKUS NA PERSPEKTIVU INTERNIH POSLOVNIH PROCESA
Nedeljka Živković, Maja Glogovac, Sanela Arsić, Isidora Milošević, Nedeljko Živković 87

Procesi i postrojenja u pripremi i prečišćavanju vode u procesnoj industriji

16. TRENDOVI KORIŠĆENJA CRVENOG MULJA KAO ADSORBENTA ZA UKLANJANJE RAZLIČITIH POLUTANATA IZ INDUSTRIJSKIH OTPADNIH VODA
Maja Rajković, Ivana Jelić, Marija Janković, Dragi Antonijević, Marija Šljivić-Ivanović 97

17. HIDRAULIKA PRANJA FILTERA SA AKTIVNIM UGLJEM U POSTROJENJIMA ZA PREČIŠĆAVANJE VODE
Miodrag Stanojević, Aleksandar Petković 99

18. UKLANJANJE METOMILA IZ VODENIH RASTVORA UPOTREBOM TERMIČKI REGENERISANIH UGLJENIČNIH MIKROSFERA
Branislav Stojković, Denis Dinić, Stevan Stupar, Anđelka Tomašević, Dušan Mijin, Peđa Stojisavljević, Negovan Ivanković 109

19. UPRAVLJANJE VODOM U KOMPLEKSIMA HLADNIH VALJAONICA – NAPREDNE I NOVE TEHNOLOGIJE
Jovana Gradinac 119

20. PREČIŠĆAVANJE VODE U PROCESNOJ INDUSTRJI
Stanko Stankov 121

21. OPORABA OTPADA U UKLANJANJU NUTRIJENATA IZ OTPADNIH VODA
Dijana Grgas, Nikola Karličić, Tea Štefanac, Tibela Landeka Dragičević, Marko Obradović, Dušan Todorović 141

22. ANALIZA UTICAJA PREČNIKA MEŠAČA NA STRUJANJE U BIOREAKTORU POSTROJENJA ZA PREČIŠĆAVANJE OTPADNIH VODA U APATINU
Sofija Petrović, Ivan Božić, Branislava Lekić, Bogdan Ristić 143

Inženjerstvo životne sredine i održivi razvoj u procesnoj industriji

23. KUĆA OD SLAME - TERMIČKI ASPEKTI
Biljana Miljković 155

24. MEDITERANSKA TRSKA U FITOSTABILIZACIJI TEHNOSOLA: PRELIMINARNI REZULTATI ISTRAŽIVANJA
Nikola Milanović, Snežana Brajević, Željko Dželetović, Gordana Andrejić, Aleksandar Simić, Uroš Aleksić 157

25. GUSTINE I VISKOZNOSTI BINARNIH SISTEMA SA DIMETILANILINOM I TETRA ETILEN GLIKOLOM DIMETIL ETROM ILI N-METIL-2-PIROLIDONOM, KAO POTENCIJALNI SOLVENTI U PROCESIMA ODSUMPORAVANJA DIMNIH GASOVA
Nikola Živković, Emila Živković, Mirjana Kijevčanin 167

26. TEHNIČKI ASPEKTI KORIŠĆENJA OKLASKA KUKURUZA ZA DOBIJANJE TOPLOTNE ENERGIJE
Stojan Simić, Davor Milić, Goran Orašanin 177

27. VEŠTAČKI ZASLAĐIVAČI ACESULFAM I SUKRALOZA: OD SASTOJAKA OTPADNE VODE DO ZAGAĐUJUĆIH MATERIJA PODZEMNIH VODA
Eleonora Gvozdić, Ivana Matić Bujagić, Tatjana Đurkić, Svetlana Grujić 185

28. UKLANJANJE BOJE ACID VIOLET 109 IZ OTPADNE VODE TEKSTILNE INDUSTRIJE UNAPEĐENIM PROCESOM OKSIDACIJE
Ana Dajić, Marina Mihajlović 191

29. INTEGRISAN PRISTUP UPRAVLJANJU OTPADOM U AUTOMOBILSKOJ INDUSTRIJI
Marija Štulović, Dragana Radovanović, Zoran Anđić, Sanja Jevtić, Nataša Gajić, Jovana Đokić, Željko Kamberović 197

30. ODRŽIVI TRETMAN KOMUNALNIH OTPADNIH VODA I MULJA: SIMULACIJA TEHNOLOŠKIH PROCESA
Jovana Đokić, Zoran Anđić, Dragana Radovanović, Marija Štulović, Nataša Gajić, Željko Kamberović 199

31. ANALIZA PROSTORNE I VREMENSKE DISTRIBUCIJE ZAGAĐUJUĆIH MATERIJA U BEOGRADU
Jelena Obradović, Milena Jovašević-Stojanović, Antonije Onjia 215

32. PREDLOG TEHNOLOŠKE ŠEME ZA VALORIZACIJU CINKA I BAKRA IZ HETEROGENIH SEKUNDARNIH SIROVINA
Nataša Gajić, Miloš Marković, Dragana Radovanović, Jovana Đokić, Marija Štulović, Nikola Jovanović, Željko Kamberović 217

33. POTENCIJALNO TOKSIČNI ELEMENTI U PODZEMNIM VODAMA RUDNIKA BAKRA: ZASTUPLJENOST, NIVOI ZAGAĐENJA I PROCENA RIZIKA PO ZDRAVLJE
Jelena Vesković, Antonije Onjia 219

34. GEOSTATISTIČKA DISTRIBUCIJA TEŠKIH METALA(LOIDA) U ZEMLJIŠTU NA PROSTORU NEKADAŠNJEG POSTROJENJA ZA RECIKLAŽU AKUMULATORA
Andrijana Miletić, Jelena Vesković, Milica Lučić, Antonije Onjia 221

35. EFEKTI FAKTORA OKRUŽENJA NA MENTALNO ZDRAVLJE LJUDI
Nikolina Banjanin, Martina Balać 223

36. TERMODINAMIČKA ANALIZA DVOKOMPONENTNOG SISTEMA γ-VALEROLAKTON+2-METILTETRAHIDROFURAN OD ZNAČAJA ZA PROIZVODNJU BIOGORIVA
Gorica R. Ivaniš, Ana Kostić, Ivona R. Radović, Mirjana Lj. Kijevčanin 225

37. UPOTREBA ZELENOG RASTVARAČA METIL LAURATA ZA EKSTRAKCIJU ACETONA IZ OTPADNIH VODENIH TOKOVA
Zoran Simić, Mirjana Kijevčanin, Ivona Radović 227

38. ANALIZA ALTERNATIVNIH REŠENJA GREJANJA GRADA POŽAREVCA U SLUČAJU GAŠENJA BLOKOVA TERMOELEKTRANE „KOSTOLAC“ A1 I A2
Milan M. Petrović, Jugoslav Pavlović, Srđan Čimburović, Sanja Milivojević, Vladimir Stevanović 229

39. REAKTIVACIJA ISTROŠENOG AKTIVNOG UGLJA I PONOVNA UPOTREBA U TRETMANU OTPADNIH VODA
Vanja B, Gujaničić, Miloš S. Nikolić, Negovan D. Ivanković, Marija P. Marković, Rajko M. Gujaničić, Stevan Lj. Stupar 231

40. EFEKTI USLOVA RADNE SREDINE NA ZDRAVLJE LJUDI
Nikolina Banjanin, Alexandr Ceasovschih 233

41. OD PLANIRANOG ZASTAREVANJA DO CIRKULARNIH INDUSTRIJSKIH PRAKSI
Vesna Alivojvodić 235

42. EFIKASNOST MERA ZA SMANJENJE EMISIJA PRAŠKASTIH MATERIJALA IZ PROCESA SAGOREVANJA BIOMASE
Dušan M. Todorović, Marko Obradović, Rade Karamarković, Miloš Nikolić, Aleksandar Jovović, Dejan Radić, Nikola Karličić 237

Sušenje i sušare

43. SIMULACIJA KONVEKTIVNOG PROCESA SUŠENJA BANANE
Danka Kostadinović 243

44. PRORAČUN KOMBINOVANE SOLARNE SUŠARE
SA UREĐAJEM ZA SAGOREVANJE BIOMASE
Danka Kostadinović 245

45. UTICAJ PREDTRETMANA I METODA SUŠENJA NA SADRŽAJ ELEMENATA
U CRVENOJ ZAČINSKOJ PAPRICI (CAPSICUM ANNUUM)
Milica Lučić, Ivana Sredović Ignjatović, Steva Lević, Ivan Zlatanović, Antonije Onjia 247

Procesne tehnologije

46. LETEĆI PEPEO – OD OTPADNOG MATERIJALA DO SIROVINE
ZA DOBIJANJE STRATEŠKI VAŽNIH ELEMENATA. OPTIMIZACIJA METODA EKSTRAKCIJE I
UTICAJ NA LUŽENJE TOKSIČNIH I RETKIH ELEMENATA ZEMLJE
IZ LETEĆEG PEPELA UGLJA – HEMOMETRIJSKI PRISTUP
Dragana Z. Živojinović 249

47. ODREĐIVANJE GUSTINE PVC POLIMERNIH MATERIJALA METODOM URANJANJA U
TEČNOST
Matilda Lazić, Dragan Halas, Aleksandar Dedić, Duško Salemović 263

48. HIDROGELOVI NA BAZI POLI(METAKRILNE KISELINE)
DOBIJENI EKOLOŠKI PRIHVATLJIVOM METODOM:
BUBRENJE I KONTROLISANO OTPUŠTANJE LIDOKAIN HIDROHLORIDA
Maja Marković, Nina N. Miladinović, Vesna V. Panić,
Pavle M. Spasojević, Sanja I. Savić, Olga J. Pantić, Rada V. Pjanović 269

49. KORELACIJA STRUKTURE I POTENCIJALNE FARMAKOLOŠKE AKTIVNOSTI
SPIROHIDANTOINA DOBIJENIH IZ A-TETRALONA
Anita Lazić, Ivana Đorđević, Kristina Gak Simić, Luka Matović,
Aleksandra Mašulović, Jelena Lađarević, Nemanja Trišović 279

50. UTICAJ PROCESNIH PARAMETARA NA SADRŽAJ (POLI)FENOLA
PRI RAZLIČITIM POSTUPCIMA EKSTRAKCIJE LISTA BOROVNICE
Milica Bučkić, Vladan Mićić, Nebojša Vasiljević 289

51. ODREĐIVANJE FARMAKOLOŠKE AKTIVNOSTI
SINTETSKIH BOJA NA BAZI PIRIDONA
Aleksandra Mašulović, Anita Lazić, Ivana Đorđević, Dušan Mijin,
Nemanja Trišović, Luka Matović, Jelena Lađarević 299

52. PROCEDURA IZRAČUNAVANJA VISKOZNOSTI NEZASIĆENIH ESTARA
PRIMENOM PROŠIRENOG MODELA ČVRSTE SFERE
Divna Majstorović, Emila M. Živković, Velisa Vesovic 305

53. PRIMENA NOVIH JEDINJENJA NA BAZI STILBAZOLIJUM-SOLI
U SOLARNIM ĆELIJAMA AKTIVIRANIM BOJOM
Luka Matović, Aleksandra Mašulović, Anita Lazić,
Kristina Gak Simić, Marija Milošević, Nemanja Trišović, Dušan Mijin 307

54. ISPLATIVA PROIZVODNJA LEGURE CuCrZr PRIMENOM METALURGIJE PRAHA
Marko Simić, Jelena Stašić, Dušan Božić,
Andrijana Žekić, Milica Milojević, Jovana Ružić 309

55. MODELOVANJE TERMODINAMIČKIH SVOJSTAVA DVOKOMPONENTNE SMEŠE CITRALA
I ETANOLA U INTERVALU TEMPERATURE (288,15–323,15) K
I NA ATMOSFERSKOM PRITISKU KORIŠĆENJEM HERIC-BREWER-JOUYBAN-ACREE
TROPARAMETARSKOG MODELA
Nikola Grozdanić, Zoran Simić, Mirjana Kijevčanin, Ivona Radović 315

56. MORFOLOŠKE I MAGNETNE OSOBINE NANOPRAHOVA CuO DOPIRANIH Ag
Maria Čebela, Uroš Čakar, Milena Rosić 317

57. UTICAJ TERMIČKE OBRADE NA SPEKTROSKOPSKE I MORFOLOŠKE OSOBINE NANOPRAHOVA $Co_{0.9}Ho_{0.1}MoO_4$
Milena Rosić, Maja Milošević, Uroš Čakar, Dragana Jordanov, Bojana Laban, Tijana Vlašković, Maria Čebela 319

58. UKLANJANJE METIL ORANŽA KORIŠĆENJEM DVOSLOJNOG SLOJEVITOG HIDROKSIDA POREKLOM OD ISTROŠENE KISELINE
Mladen Bugarčić, Aleksandar Jovanović, Milica Mišić, Milan Milivojević, Nataša Knežević, Jovana Bošnjaković, Miroslav Sokić 320

59. UTICAJ TEHNOLOGIJE UVOĐENJA PLASTIFIKATORA U SMEŠU LIVENOG KOMPOZITNOG EKSPLOZIVA NA PROCESNA SVOJSTVA
Danica Bajić, Mladen Timotijević, Mirjana Krstović, Aleksandar Milojković, Slavko Mijatov 327

Projektovanje, izgradnja, eksploatacija i održavanje procesnih postrojenja

60. RAZVOJ PROIZVODA I POSTROJENJA ZA PROIZVODNJU FILTER-ANTRACITA U RUDNIKU ANTRACITA VRŠKA ČUKA
Jovica Sokolović, Rade Đolović 335

61. AKTIVNI GASOVI KAO SREDSTVA ZA GAŠENJE POŽARA
Ivan Aranđelović, Nikola Tanasić, Radenko Rajić 343

62. NEELEKTRIČNA OPREMA U POTENCIJALNO EKSPLOZIVNIM ATMOSFERAMA
Miroslav Gojić, Srbislav Genić, Predrag Bogdanović, Ivan Aranđelović 345

63. OPTIMALNI PARAMETRI NAFTOVODA, INVESTICIONA ULAGANJA I TROŠKOVI
Jasna Tolmač, Saša Jovanović, Slavica Prvulović, Milan Marković, Uroš Šarenac 347

64. INERTNI GASOVI I AEROSOLI KAO ALTERNATIVNA SREDSTVA HALONIMA ZA GAŠENJE POŽARA
Milica Ivanović, Ivan Aranđelović, Srbislav Genić, Aleksandar Simonović 355

Oglasni deo

Procesing '24
37. Međunarodni kongres o procesnoj industriji
29–31. maj 2024, Beograd

Originalni naučni rad
https://doi.org/10.24094/ptk.024.321

UKLANJANJE METIL ORANŽA KORIŠĆENJEM DVOSLOJNOG SLOJEVITOG HIDROKSIDA POREKLOM OD ISTROŠENE KISELINE

REMOVAL OF METHYL ORANGE USING LAYERED DOUBLE HYDROXIDE ORIGINATED FROM SPENT ACID LIQUOR

Mladen Bugarčić*[1], Aleksandar Jovanović[1], Milica Mišić[1], Milan Milivojević[2], Nataša Knežević[3], Jovana Bošnjaković[4], Miroslav Sokić[1]

[1]Institut za tehnologiju nuklearnih i drugih mineralnih sirovina, Beograd
[2]Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd
[3] Univerzitet u Beogradu, Institut za nuklearne nauke „Vinča“, Beograd
[4]Univerzitet u Beogradu, Institut za hemiju, tehnologiju i metalurgiju, Beograd

Proizvodnja organskih boja je u stalnom porastu poslednjih decenija, pa njihova upotreba ostavlja negativan uticaj na životnu sredinu najčešće na živi svet u vodi. Otpadne vode koje nose rastvorene boje su toksične za sve organizme koji postoje u vodi, pa se takvi tokovi otpadnih voda moraju na odgovarajući način tretirati pre nego što se ispuste u životnu sredinu. Izrada efikasnih adsorbenata koji se mogu koristiti u prečišćavanju otpadnih voda postala je mandatorna. U toku pripreme adsorbenata često nastaju i sporedni proizvodi kao što su istrošene kiseline ili baze pošto se one obično koriste za aktivaciju površine adsorbenata. Istrošena kiselina nastala tokom aktivacije ekspandiranog vermikulita (EVer) korišćena je kao polazni materijal za pripremu dvoslojnog slojevitog hidroksida (DSH-EVer) metodom koprecipitacije pri niskoj prezasićenosti. Pripremljeni adsorbent je karakterisan metodom infracrvene spektroskopije sa Furijeovom transformacijom (FTIR) i skenirajuće elektronske mikroskopije sa energetski disperznom spektrometrijom (SEM-EDS). DSH-EVer korišćen je za uklanjanja metil oranža iz vodenog rastvora. Tokom eksperimenata, vreme kontakta je varirano i na taj način je određena brzina adsorpcije. Dobijeni rezultati pokazuju visok kapacitet adsorpcije od 63 mg g^{-1}.

Ključne reči: *DSH; metil oranž; boje; anjonska izmena*

Production of organic dyes has been constantly increasing in the last decades, hence their usage leaves a huge environmental impact usually on aquatic biota. Wastewaters carrying dissolved dyes are toxic to all organisms existing in water, therefore such wastewater streams have to be appropriately treated before they can be released into the environment. Development of effective adsorbents, which can be used in wastewater treatment, is mandatory. Another concern in the production of sorbing materials is the formation of spent acids or bases since they are commonly used for the activation of adsorbents. Spent acid liquor produced during the activation of expanded vermiculite (EVer) is utilized as the start material for the preparation of layered double hydroxide (LDH-EVer) by the method of co-precipitation process at low supersaturation. The prepared adsorbent was

* Corresponding author: m.bugarcic@itnms.ac.rs
https://orcid.org/0000-0002-6119-4414

Aleksandar Jovanović: https://orcid.org/0000-0001-9867-9282
Milica Mišić: https://orcid.org/0009-0001-8274-3136
Nataša Knežević: https://orcid.org/0000-0003-4572-4398
Miroslav Sokić: https://orcid.org/0000-0002-4468-9503

characterized by Fourier transform infrared spectroscopy (FTIR) and Scanning electron microscopy with X-ray energy dispersive spectroscopy (SEM-EDS). Fabricated material is utilized as an adsorbent of methyl orange dye from aqueous solutions. During the experiments, contact time were varied and thus the rate of adsorption is determined. The obtained results show a high adsorption capacity of 63 mg g^{-1}.

Key words: *LDH; methyl orange; dyes; anion exchange*

1. Theoretical introduction

The discharge of wastewater effluents containing azo dyes from different sources has become a significant contributor to water pollution. Azo dyes are widely used as coloring agents in the industries such as textile, leather, paper, paint, food and cosmetics [1-4]. Additionally, they serve as pH indicators and spectrophotometric reagents in many research and experimental laboratories [5, 6]. The textile industry is the largest producer of dye wastewater [7]. During the dyeing process, about 20% of synthetic dyes used fail to adhere to fibers, leading to the release of unbonded dye into wastewater streams [8]. This accounts for the discharge of approximately 28,000 t of unfixed dyes into the environment each year [3]. Azo dyes are known for their stability, chemical versatility, high fixation, and resistance to light and moisture. However, these characteristics directly affect their degradability, making them a significant environmental concern [8].

Methyl orange (MO), a common anionic azo dye, soluble in water, was selected as a model compound for this study due of its broad use across industries and its potential adverse effects on the environment and living organisms. Azo-ionic dyes like MO have the ability to attach to suspended organic matter through electrostatic interactions, leading to their accumulation in sediments or wastewater sludge, thus prolonging their persistence in water bodies and impacting aquatic life and human health through the food chain [8]. Discharge of untreated azo dyes into water bodies results in the formation of aromatic amines – through the cleavage of their central azo bonds – known for their recalcitrance, bioaccumulative nature, and toxicity, mutagenicity, and carcinogenicity [8]. Additionally, even at low concentrations, these dyes in water reduce sunlight penetration, lower dissolved oxygen content, reduce gas solubility, inhibit plant growth, and increase organic pollution levels [3, 8].

Many physicochemical methods have been developed for treatment of wastewater containing dyes, including adsorption, osmosis, coagulation, flocculation, membrane separation, oxidation, photochemical degradation, ion exchange, and ozonation [9]. Currently, adsorption is the most widely adopted technique for dye removal due to its low cost, high efficiency, eco-friendliness, and ease of use, making it favored by researchers and widely applied [2]. Adsorbents, the core of this technology, come from various sources and types [2].

During the activation process of the vermiculite sample, a significant amount of waste solution is obtained, motivating this research to repurpose it into a new product—an adsorbent for removing MO from aqueous solutions. This study also aimed to assess the feasibility of utilizing layered double hydroxides (LDH), derived from waste solutions, for MO removal from aqueous solutions. It is important to note that while physicochemical methods like adsorption effectively decolorize pollutants, they do not facilitate pollutant degradation [3]. Furthermore, post-adsorption, the dye remains bounded to the adsorbent, which is difficult to remove and this problem remains unsolved [10].

2. Materials and methods

The synthesis of LDH, following the procedure outlined by Tomanec et al. [11], utilizing a waste solution derived from the activation of vermiculite (Ver) with hydrochloric acid (*Zorka Šabac*, 36 wt.%)

for 3 h at 72°C, while maintaining a solid/liquid ratio of 0.1 g mL^{-1}, was used. In Table 1 is given the composition of the resulting waste solution post-activation with HCl solution. Using a *Hanna HI 2210* pH meter, the pH of the solution was measured at 0.10 and then the solution was evaporated. The residue obtained post-evaporation was utilized in the preparation of the LDH-EVer sample.

Table 1. Quantitative analysis of the solution resulting from EVer sample activation with HCl

K [g L^{-1}]	*Na [g L^{-1}]*	*Mg [g L^{-1}]*	*Ca [g L^{-1}]*	*Fe [g L^{-1}]*	*Al [g L^{-1}]*
2.51	0.302	10.39	0.22	3.60	1.70

In 10 ml of deionized water (18 MΩ cm), 16 g of salts obtained by evaporating the acid solution were added, along with 2.97 g of $AlCl_3$ x $6H_2O$ (*NPK Engineering Belgrade*, 99.9 wt.%). Following dissolution, precipitation was carried out at low supersaturation by gradually adding 1.0 M NaOH (*Centrochem Belgrade*, 98 wt.%) with stirring. The pH of the solution after precipitation was 9.80 and remained unchanged for 2 h following the final addition of NaOH solution. Following filtration, the solid LDH-EVer sample underwent washing with deionized water, drying (at 50 °C for 4 h) and annealing (at 500°C for 3 h). The resulting sample was then ground using a mortar and pestle and stored in plastic containers designated for solid samples until further analysis. For an in-depth preparation procedure, refer to the study by Vuksanović et al. [12], while the methodology for the adsorption experiments can be found in the study by Bugarčić et al. [13].

The adsorption of MO dye was conducted in a batch system, a detailed study of the kinetics and the equilibrium of adsorption that were used to determine the rates and thermodynamics of the process. The initial dye concentration for both studies was set at 15 mg L^{-1}. Monitoring of the adsorption kinetics involved measuring the solution's absorbance during the MO adsorption process in a beaker, at a temperature of 25 °C. The adsorbate volume was 75 mL, and the LDH-EVer adsorbent mass was set at 10 mg.

Equilibrium adsorption experiments were carried out at temperatures of 25, 35, and 45 °C, wherein the adsorbent mass was varied from 1 to 10 mg, while maintaining a constant adsorbate volume of 7.5 mL. The concentration of MO dye was determined by measuring the light absorbance using a UV/VIS spectrophotometer *Shimadzu 1800* within a range from 200 to 800 nm. Subsequently, the MO concentration was recalculated using the Lambert-Beer law (Eq. 1), and the adsorption capacity was determined using Eq. 2.

$$C = \frac{A}{\varepsilon l} \tag{1}$$

$$q = \frac{(c_p - c)V}{m_{ads}} \tag{2}$$

The adsorption rate was determined utilizing two adsorption models, pseudo second order (PSO) model and Weber–Morris (WM) model, with their nonlinear forms presented in Eqs. (3) and (4) respectively.

$$Q_t = \frac{t}{\frac{1}{k_2 Q_e^2} + \frac{t}{Q_e}} \tag{3}$$

$$Q_t = k_{id}\sqrt{t} + C \tag{4}$$

where t – time [min], k_2 – PSO rate constant [g (mg min)$^{-1}$], Q_e – sorption capacity at equilibrium [mg g^{-1}], k_{id} – interparticular rate constant [mg min^{-1} g/2], C – intercept [mg g^{-1}]

For structural and chemical characterization of the adsorbent, FTIR and SEM-EDS techniques were used.

3. Results and discussion

Figure 1 illustrates the progressive decrease in MO concentration over time. Within the same figure, UV spectra of MO containing adsorbates are presented throughout the adsorption duration. From the same Figure it can be seen that prepared adsorbent steadily removes MO dye from water.

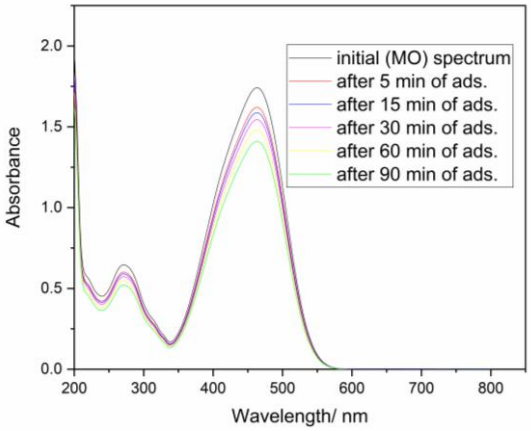

Figure 1. UV/Vis spectra of MO depending as a function of the contact time of adsorbate solution with LDH-EVer

After 90 min of observation, MO concentration was reduced for 23%, which is a good sign of efficiency of prepared materials. Table 2 shows the values of parameters obtained by the correlation of the PSO and WM models. The results of the adsorption kinetics experiment indicate a notable alignment with the PSO reaction model, while the WM model emerged as the most fitting among the diffusion models, showcasing the highest level of alignment.

Table 2. Correlation parameters values influencing the kinetics of MO adsorption experiment on the LDH-EVer sample (T=298 K; C_0=15 mg L^{-1}; m:V=8:60 g L^{-1})

Model	*PSO*		*WM*	
Parameter	k_2 [g (mg min)$^{-1}$]	Q_e [mg g^{-1}]	k_{id1} [mg/(min$^{1/2}$g]	k_{id2} [mg/(min$^{1/2}$g)]
Value	0.000698	69.4	5.89	2.96

In the provided Table 2, the expected equilibrium capacity, Q_e, is 69.4 mg g^{-1}, showcasing a very good adsorption outcome comparable to the results of other studies performed on similar samples. Also in this table it can be seen that the diffusion of MO dye takes place in two phases. The initial phase exhibits rapid diffusion and represents the diffusion of the dye to the adsorbent particle, while the subsequent phase represents the intraparticle diffusion, as the dye permeates through the pores of the adsorbent. The values of Gibbs energy change, along with the changes in standard enthalpy and entropy of the process, were determined through data correlation. In Table 3 is provided the thermodynamic parameters associated with the MO adsorption process on the LDH-EVer sample.

Table 3. Gibbs energy change and standard enthalpy and entropy changes for MO adsorption process on LDH-EVer sample

ΔG^{θ} [kJ mol^{-1}]	ΔH^{θ} [kJ mol^{-1}]	ΔS^{θ} [J (mol K)$^{-1}$]
-38.6	28.6	9.84

Table 3 shows that the adsorption process is spontaneous and moderately endothermic. The primary factor driving spontaneity of the process is the increase in entropy during adsorption. This observation aligns with expectations, considering MO dye's classification among anionic dyes, and the LDH-EVer adsorbent's characteristic of harboring exchangeable anions within its interlayer structure.

4. Conclusion

The dye constituents found in industrial wastewater must be efficiently removed prior to their discharge into water bodies to protect public health, the environment, and aquatic ecosystems. To reduce the environmental impact of human activities, it is necessary to establish and execute effective wastewater treatment systems and processes. Among various techniques, the adsorption process stands out as a widely employed method for dye removal due to its advantages, making it an optimal and sustainable solution. Numerous diverse adsorbents are available for this purpose.

In this study, we utilized the waste solution obtained from the chemical activation of the Ver sample with HCl for synthesizing LDH via the precipitation method at low supersaturation using NaOH solution. The obtained LDH-EVer sample was utilized for the adsorption of MO from the aqueous solution. The resulting LDH-EVer sample exhibited promising adsorption capabilities, removing up to 69.4 mg g^{-1} of MO from the aqueous solution.

The research findings indicate that the adsorption process occurs in two phases, with intraparticle diffusion being the limiting phase. Equilibrium adsorption experiments indicated an endothermic adsorption process with a significant increase in entropy, which can be attributed to the ion exchange of hydroxyl anions with the MO anion. These insights contribute to our understanding of the mechanisms involved in dye removal processes and underscore the potential of LDH-EVer as an effective adsorbent in wastewater treatment applications.

5. Acknowledgements

This work was funded by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-66/2024-03/200023; 451-03–66/2024-03/200017; 451-03-66/2024-03/200026; 451-03-65/2024-03/200135).

6. Nomenclature

Ver – vermiculite
EVer – expanded vermiculite
DSH – dvoslojno slojeviti hidroksid
LDH – layered double hydroxide
SEM – scanning electron microscope
EDS – X-ray energy dispersive spectroscopy
FTIR – Fourier-transform infrared spectroscopy
MO – methyl orange
PSO – pseudo second order
WM – Weber – Morris model

7. References

[1] **Ai, L. H.; Zhou, Y.; Jiang, J.** Removal of methylene blue from aqueous solution by montmorillonite/$CoFe_2O_4$ composite with magnetic separation performance, *Desalination, 266* (2011), 1-3, pp. 72–77.

[2] **Wu, L., Liu, X., Lv, G., Zhu, R., Tian, L., Liu, M., Tianming L., Liao, L.** (2021). Study on the adsorption properties of methyl orange by natural one-dimensional nano-mineral materials with different structures, *Scientific reports*, *11*(2021), 1, 10640

[3] **Kishor, R., Purchase, D., Saratale, G. D., Ferreira, L. F. R., Hussain, C. M., Mulla, S. I., Bharagava, R. N.** Degradation mechanism and toxicity reduction of methyl orange dye by a newly isolated bacterium Pseudomonas aeruginosa MZ520730, *Journal of Water Process Engineering*, *43* (2021), 102300.

[4] **Abdulsalam, K. A., Olagoke, H. B., Oladosu, I. A., Olawoye, B. M., Amodu, B. H., Fakorede, O. K., Tiamiyu A., Owolabi, S. O.** Methyl Orange, An Organic Dye: Its Health Impact And Sorptive Removal From Waste Water, *International Journal of Progressive Sciences and Technologies (IJPSAT), 33* (2022), 1, pp. 150–160.

[5] **Kishor, R., Purchase, D., Ferreira, L., Mulla, S., Bilal, M., Bharagava, R.** *Environmental and health hazards of textile industry wastewater pollutants and its treatment approaches*, Springer Nature, Cham, Switzerland, 2020.

[6] **Eltaboni, F., Bader, N., El-Kailany, R., Elsharif, N., Ahmida, A.** Chemistry and Applications of Azo Dyes: A Comprehensive Review, *Journal of Chemical Reviews*, *Volume 4* (2022), issue 4, pp. 313–330.

[7] **Hadibarata, T., Yusoff, A. R. M., Kristanti, R. A.** Decolorization and metabolism of anthraquionone-type dye by laccase of white-rot fungi Polyporus sp. S133, *Water, Air, & Soil Pollution*, *223* (2012), pp. 933–941.

[8] **Alzain, H., Kalimugogo, V., Hussein, K., Karkadan, M.** A Review of Environmental Impact of Azo Dyes, *International Journal of Engineering Research and General Science, 10* (2023), 6, pp. 64–689.

[9] **Dutta, S. K., Amin, M. K., Ahmed, J., Elias, M., Mahiuddin, M.** Removal of toxic methyl orange by a cost-free and eco-friendly adsorbent: mechanism, phytotoxicity, thermodynamics, and kinetics, *South African Journal of Chemical Engineering*, *40* (2022), pp. 195–208.

[10] **Vatandoostarani, S., Lotfabad, T. B., Heidarinasab, A., Yaghmaei, S.** Degradation of azo dye methyl red by Saccharomyces cerevisiae ATCC 9763, *International Biodeterioration & Biodegradation*, *125* (2017), pp. 62–72.

[11] **Tomanec, R., Popov, S., Vucinic, D., Lazic, P.** Vermiculite from Kopaonik (Yugoslavia). Characterization and processing, *Fizykochemiczne Problemy Mineralurgii*, *31* (1997), 1, pp. 247–254.

[12] **Vuksanović, M. M., Egelja, A., Barudžija, T., Tomić, N., Petrović, M., Marinković, A., Radojević V., Heinemann, R. J.** Inorganically modified particles FeAl-LDH@ SiO2 as reinforcement in poly (methyl) methacrylate matrix composite, *Royal Society Open Science*, *8* (2021), 9, 210835.

[13] **Bugarčić, M., Lopičić, Z., Šoštarić, T., Marinković, A., Rusmirovic, J. D., Milošević, D., Milivojević, M.** Vermiculite enriched by Fe (III) oxides as a novel adsorbent for toxic metals removal, *Journal of Environmental Chemical Engineering*, *9* (2021), 5, 106020.

Republika Srbija
Ministarstvo nauke, tehnološkog razvoja
i inovacija

Sponzori

GRUNDFOS · Kazantrade · OVEX INŽENJERING · CIM GAS · wilo · VODAVODA

Medijski partner

ČASOPIS grenef.
GRAĐEVINARSTVO & ENERGETSKA EFIKASNOST

Organizator

Savez mašinskih i elektrotehničkih inženjera i tehničara Srbije
Društvo za procesnu tehniku
www.smeits.rs