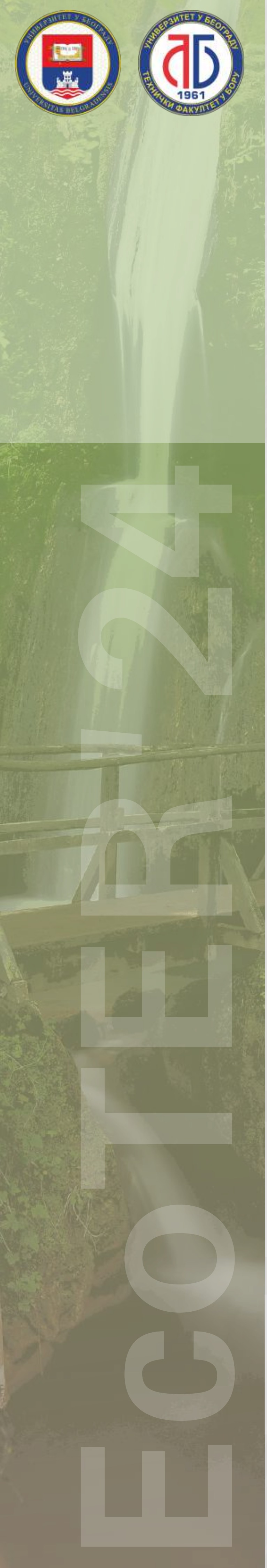

University of Belgrade
Technical Faculty in Bor

31st International conference

Ecological Truth & Environmental Research

Editor
Prof. Dr Snežana Šerbula

PROCEEDINGS

Hotel Sunce, Sokobanja, Serbia
18–21 June 2024

PROCEEDINGS

31st INTERNATIONAL CONFERENCE

ECOLOGICAL TRUTH & ENVIRONMENTAL RESEARCH – EcoTER'24

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Cover design:

Aleksandar Cvetković, BSc, University of Belgrade, Technical Faculty in Bor

Publisher: University of Belgrade, Technical Faculty in Bor

For the publisher: Prof. Dr Dejan Tanikić, Dean

Printed: University of Belgrade, Technical Faculty in Bor, 100 copies, electronic edition

Year of publication: 2024

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CIP - Каталогизација у публикацији
Народна библиотека Србије, Београд

502/504(082)(0.034.2)
574(082)(0.034.2)

INTERNATIONAL Conference Ecological Truth & Environmental Research (31 ; 2024 ; Sokobanja)
Proceedings [Elektronski izvor] / 31st International conference Ecological Truth & Environmental Research - EcoTER'24, Sokobanja, Serbia, 18-21 June 2024 ; [organized by] University of Belgrade, Technical faculty in Bor (Serbia) ; [co-organizers University of Banja Luka, Faculty of Technology – Banja Luka (B&H) ... [et al.]] ; [editor Snežana Šerbula]. - Bor : University of Belgrade, Technical faculty, 2024 (Bor : University of Belgrade, Technical faculty). - 1 elektronski optički disk (CD-ROM) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Preface / Snežana Šerbula. - Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-6305-152-2

а) Животна средина -- Зборници б) Екологија – Зборници

COBISS.SR-ID 147002889

The 31st International Conference
Ecological Truth & Environmental Research – EcoTER'24

is organized by:

UNIVERSITY OF BELGRADE
TECHNICAL FACULTY IN BOR (SERBIA)

Co-organizers of the conference:

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The EcoTER'24 conference is financially supported
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PREFACE

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 focuses on showing the latest research findings and innovations in the field of ecology, environmental protection and sustainable development. The conference will be held in Sokobanja (Serbia) in hotel Sunce in the period of 18–21 June 2024.

The aim of the conference is to connect the experts in various fields in order to transform attitudes and behaviors in everyday practices, as well as in the industry and economy sector which is essential for achieving the desired changes that our society must undergo.

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology; the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica; the University of Zagreb, Faculty of Metallurgy – Sisak; the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Society of Young Researchers – Bor.

These Proceedings encompass 119 papers from the authors coming from the universities, research institutes and industries in 15 countries: Brazil, Norway, USA, Spain, Austria, Libya, Italy, Israel, Slovenia, Croatia, Romania, Bulgaria, Montenegro, Bosnia and Herzegovina, North Macedonia, and Serbia. It is a great honor and pleasure to cordially wish a warm welcome to all the participants of the conference.

As a part of this year's conference, the 6th Student Section – EcoTERS'24 will be held. We appreciate the contribution of the students and their mentors who have also participated in the conference and hope that students will continue to explore and to be curious, since education is a never-ending process, and knowledge is continuously growing.

The organization of the EcoTER'24 conference has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The support of the Donors and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'24 conference. The organizing committee would like to extend their appreciation and gratitude to the Platinum donors of the conference – Serbia ZiJin Copper doo Bor and HBIS SERBIA, to the Gold donor of the conference – Elixir Group, as well as to the Silver donor of the conference – Serbian Chamber of Engineers.

We would like to express our sincere appreciation to all the authors who have contributed to the Proceedings. We would also like to express our gratitude to the members of the scientific, organizing and honorary committees, reviewers, speakers, chairpersons and all the conference participants for their support of the EcoTER'24. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'24.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

TABLE OF CONTENTS

Plenary Lectures

Branko Bugarski
ELECTROSTATIC DISPERSION OF POLYMER SOLUTIONS IN THE PRODUCTION OF MICROGEL BEADS CONTAINING BIOCATALYST 1

Anupama Ghosh, M. R. Del Grande, L. T. Teixeira, S. Letichevsky, C. A. Senna, M. D. Carbajal Ccoyllo, J. F. Chaves e Silva, V. C. Gois de Oliveira, R. N. Correia de Siqueira
HEAT TREATMENT OF IRON-ADSORBED FUNCTIONALIZED NANOCELLULOSE FIBERS IN ORDER TO SYNTHESIZE HYBRID INORGANIC-CARBON MATERIAL 8

Alena Bartonova
ENVIRONMENTAL PROTECTION: WHY IS EUROPE'S AIR (MOSTLY) SO CLEAN? 14

Invited Lectures

Nevenka Rajić, J. Pavlović
APPLICATION OF NATURAL ZEOLITE – CLINOPTILOLITE IN WATER TREATMENT BY ADSORPTION AND PHOTOCATALYSIS 17

Dušan Nikolić, A. Tasić
THE EUROPEAN PERCH (*Perca fluviatilis*) AS AN INDICATOR OF OCPs POLLUTION IN DIFFERENT TYPES OF RESERVOIRS IN SERBIA 24

Jelena Korać Jačić, M. R. Milenković, D. Bartolić
DEGRADATION OF TETRACYCLINE ANTIBIOTICS IN AQUATIC ENVIRONMENT BY UV IRRADIATION AND FERRIC ION PHOTOLYSIS 30

Conference Papers

Environmental monitoring and impact assessment

Aleksandra Papludis, S. Alagić, S. Milić, J. Nikolić, I. Zlatanović, S. Jevtović, V. Stankov Jovanović
NAPHTALENE SCREENING IN BOR'S MUNICIPALITY BASED ON ITS CONCENTRATIONS IN LEAVES AND STEMS OF *Hedera helix* L. 38

Darko Anđelković, M. Branković
APPLE PEEL AS A BARRIER TO PESTICIDES MIGRATION INTO DEEPER FRUIT PARTS 43

Darko Anđelković, M. Branković

PERFORMANCES OF QuEChERS BASED GC-MS AND LC-MS/MS METHODS FOR PESTICIDES ANALYSIS IN APPLES 49

Darko Anđelković, M. Branković

COMPARISON OF PESTICIDES STABILITY STORED IN TWO SOLVENTS OF DIFFERENT VISCOSITY 55

Milena Tadić, I. Nikolić, D. Đurović, N. Cupara, J. Vuković

TRIHALOMETHANES CONTENT IN HOTEL'S SWIMING POOLS WATER IN A SOUTH OF MONTENGRO 61

Jelena Vranković, K. Jovičić, V. Đikanović

FIRST LINE DEFENCE ANTIOXIDANT ENZYMES IN *Blicca bjoerkna* (LINNAEUS, 1758) FROM THE BELGRADE SECTION OF THE DANUBE RIVER 66

Miomir Mikić, R. Marković, V. Marjanović, R. Rajković, M. Jovanović

RECULTIVATION OF RTH FLOTATION TAILINGS IN BOR, SERBIA 71

Miomir Mikić, V. Marjanović, R. Marković, M. Jovanović, R. Rajković

MINING AND THE ENVIRONMENT, ENVIRONMENTAL IMPACT MONITORING PROGRAM FOR FLOTATION TAILING RTH-BOR, SERBIA 77

Vesna Obradović, M. Perović, T. Vučković

EVALUATING CORROSION AND BIOFOULING POTENTIAL BASED ON GROUNDWATER MICROBIOLOGICAL COMPOSITION 83

Vesna Obradović, M. Perović, J. Lekić

EVALUATION OF CORROSION POTENTIAL USING PHYSICOCHEMICAL WATER QUALITY ASSESSMENT 89

Jelena Čanak Atlagić, A. Marić, K. Jovičić, J. Stanković, V. Đikanović, T. Mitić, M. Raković

QUESTIONING THE RESILIENCE OF THE DANUBE FISH FAUNA UNDER THE PRESSURE OF BELGRADE WASTEWATERS 95

Vladan Marinković, M. Maksimović, M. Jovanović, S. Trujić

MONITORING OF THE STATE OF THE ENVIRONMENT IN THE BOR DISTRICT, GIVEN THROUGH THE EXAMPLE OF THE DISTRIBUTION OF Pb IN THE SOIL LOCATED IN THE IMMEDIATE VICINITY OF THE BOR RIVER 101

Mirjana Ocokoljić, Dj. Petrov, N. Galečić, D. Skočajić, D. Vujičić, J. Čukanović, I. Simović

EFFECTIVENESS OF *Photinia × Fraseri* 'RED ROBIN' IN THE URBAN LANDSCAPE: TOWORDS OF CLIMATE CHANGE 106

Mirjana Ocokoljić, Dj. Petrov, N. Galečić, D. Skočajić, D. Vujičić, J. Čukanović, I. Simović

Chaenomeles japonica (Thunb.) Lindl. ex Spach IN THE DESIGN OF URBAN PARKS: LEARNING FROM NATURE 113

Mirjana Ocokoljić, J. Čukanović, Dj. Petrov, N. Galečić, D. Skočajić, D. Vujičić, I. Simović

Parthenocissus quinqefolia L.: PHENOMONITORING IN BLUE-GREEN INFRASTRUCTURE OF BELGRADE AND NOVI SAD 119

Bojana Tubić, J. Đuknić, K. Zorić, N. Popović, N. Marinković, M. Paunović, M. Raković

EFFECTS OF THE IRON GATE DAMS ON THE BENTHIC MACROINVERTEBRATE COMMUNITY 126

Danica Bogdanović, T. Anđelković, I. Kostić Kokić, M. Milovanović

GC-MS QUANTITATIVE DETERMINATION OF PHTHALATES IN PVC ARTICLES INTENDED FOR CHILDREN'S USE 132

Danica Bogdanović, T. Anđelković, I. Kostić Kokić, M. Milovanović

OPTIMIZATION OF LIQUID-LIQUID PHTHALATES EXTRACTION FROM ARTFICIAL SALIVA 138

Danica Bogdanović, T. Anđelković, I. Kostić Kokić, M. Milovanović

MIGRATION OF DI-2-ETHYLHEXYL PHTHALATE AND DI-N-OCTYL PHTHALATE FROM PVC ARTICLES TO ARTIFICIAL SALIVA 144

Daliborka Stanković, D. Z. Rajković, M. Raković, S. Skorić

HAEMOSPORIDIAN PARASITES IN LONG–EARED OWLS WINTERING IN BANAT, SERBIA 150

Nenad Zarić, I. Hotea, A. Lato, M. Zarić, F. Crista

UNVEILING PESTICIDE CONTAMINATION IN TRANSBOUNDARY WATERS: A CASE STUDY OF SERBIA AND ROMANIA 156

Nenad Zarić, F. Crista, A. Berbecea, I. Hotea, L. Crista, M. Zarić

COMPARATIVE ANALYSIS OF PESTICIDE RESIDUES IN AGRICULTURAL SOILS OF SERBIA AND ROMANIA 160

Milica Veličković, D. Voza

THE RELATIONSHIP BETWEEN PM_{10} AND METEOROLOGICAL PARAMETERS CLOSE TO THE MINING AREA 164

Biljana Budzakoska Gjoreska, S. Trajanovski

MACROZOOBENTHOS COMMUNITY AND ECOLOGICAL STATUS IN PRESPA LAKE (OTESHEVO, STENJE AND EZERANI) IN SPRING 2022 169

Suzana Patcheva, J. Leshoski, E. Veljanoska Sarafiloska

PHYTOPLANKTON COMMUNITY AS BIOINDICATOR OF WATER TROPHIC STATE IN LAKE PRESPA 176

Boris Novaković, M. Raković

EARLY, LATE AND OUT-BREEDING SEASON BIRD SINGING – EFFECTS OF CLIMATE CHANGE? 183

Boris Novaković, M. Raković

THE USE OF HOA (HEMIPTERA-ORTHOPTERA-AVES) INDICATORS TO FORMULATE THE SERBIAN CLIMATE CHANGE INDEX (S_{CCI}) 189

Ana Marić, V. Nikolić, D. Škraba Jurlina, V. Sokolović, D. Miličić, T. Karan Žnidaršič, T. Kanjuh, P. Simonović
ASSESSMENT OF NON-NATIVE SPECIES IMPACT ON FISH DIVERSITY IN THE ĆELIJE RESERVOIR: IMPLICATIONS FOR CONSERVATION AND MANAGEMENT 194

Ivana Jelić, A. Savić, T. Miljojčić, M. Rajković, M. Janković, N. Sarap, S. Dimović, M. Ćurčić, V. Stanić, D. Antonijević, M. Šljivić-Ivanović
THE IMPACTS OF WASTE MATERIALS UTILIZATION IN LIQUID RADIOACTIVE WASTE SOLIDIFICATION BY MORTAR MATRIX 200

Stefan Đorđievski, M. Đukić, A. Petrović, D. Adamović, J. Petrović, Lj. Lekić
INSIGHTS FROM THE DAILY MONITORING OF WATER QUALITY PARAMETERS IN CEROVO RIVER NEAR BOR CITY IN OCTOBER 2023 206

Nataša Kojadinović, S. Đuretanović, A. Milošković, M. Radenković, M. Jakovljević, T. Veličković, M. Nikolić, V. Simić
FISH DIVERSITY ASSESSMENT OF THE IBAR RIVER: A 20-YEAR PERSPECTIVE 212

Milanka Negovanović, L. Kričak, S. Milanović, N. Simić, J. Majstorović
APPLICATION OF EXPANSIVE MORTARS FOR THE FORMATION OF ARTIFICIAL SCREENS DURING BLASTING IN URBAN AREAS 216

Snežana Šerbula, T. Kalinović, A. Radojević, J. Kalinović, J. Jordanović
AIR POLLUTION IN THE BOR REGION FROM 1994 TO 2023 225

Irena Blagajac, I. Samardžić
CAUSES OF FLOODING AND MEASURES TO MITIGATE THE CONSEQUENCES – CASE STUDY OF RAKOVICA MUNICIPALITY (BELGRADE, SERBIA) 231

Urban and industrial ecology

Žarko Radović, N. Tadić
SIMULATION OF THE EAF DUST RECYCLING 240

Mirko Gojić, S. Kožuh, I. Ivanić, D. Dumenčić
DEVELOPMENT OF METALLURGY AND ENVIRONMENTAL PROTECTION IN THE REPUBLIC OF CROATIA IN THE PERIOD FROM 1900 TO 2020 246

Air, water and soil pollution, prevention and control

Viša Tasić, T. Apostolovski-Trujić, V. Kamenović, B. Radović, I. Zlatković, N. Ristić, Z. Damnjanović
APPLICATION OF LOW-COST NETWORK FOR URBAN MICROCLIMATE AND AIR QUALITY MONITORING 251

Nebojša Tadić, Ž. Radović, A. Knežević

ANALYSIS OF THE INFLUENCE OF NATURAL GAS COMPOSITION AND EXCESS AIR COEFFICIENT ON COMBUSTION PRODUCTS 258

Aleksandar Jovanović, N. Knežević, M. Bugarčić, J. Petrović, M. Sokić, M. Stevanović, A. Marinković

INVESTIGATION OF MULTI-CYCLE USAGE OF NANOPHOTOCATALYSTS IN DEGRADATION OF THIOPHANATE-METHYL 265

Vesna Obradović, M. Perović, P. Pajić

PHYSICO-CHEMICAL AND MICROBIAL ANALYSIS IN SELECTED GROUNDWATER IN SERBIA 270

Silvia Dimova, K. Zaharieva, O. Dimitrov, P. D. Petrov, H. Penchev

METHATHESIS SYNTHESIZED OLIGOMERIC POLYPHENYLACETYLENE AS STERIC STABILIZER OF CARBON NANOTUBES/PLANT EXTRACT SYNTHESIZED ZINC OXIDE HYBRIDS 276

Miljan Marković, M. Gorgievski, N. Štrbac, V. Grekulović, M. Marković, K. Božinović, D. Jovanović

EQUILIBRIUM ANALYSIS OF COPPER IONS BIOSORPTION ONTO HAZELNUT SHELLS 282

Vesna M. Marjanović, R. Marković, D. Božić

CALCULATION OF CALCIUM OXIDE CONSUMPTION IN THE MINE WASTEWATER TREATMENT FROM INACTIVE OPEN PITS OF THE COPPER MINE 287

Marina Marković, M. Gorgievski, N. Štrbac, V. Grekulović, M. Marković, M. Zdravković, D. Jovanović

THERMODYNAMIC ANALYSIS AND INFLUENCE OF THE pH VALUE ON THE BIOSORPTION OF COPPER IONS ONTO HAZELNUT SHELLS 294

Jelena Korać Jačić, D. Bartolić, M.R. Milenković

THE IMPACT OF FERROUS AND FERRIC IONS ON DEGRADATION OF ANTIHYPERTENSIVE DRUG DIHYDRALAZINE IN IRON-BASED FLOCCULATION AND COAGULATION METHODS FOR WASTE WATER TREATMENT 299

Berina Sejdinović

OILY WASTEWATER 305

Vesela Radović, S. Krnjajić, S. Stanković, V. Tomić, G. Knežević

ENVIRONMENTAL RISKS CAUSED BY THE POLLUTION FROM AGRICULTURAL PLASTICS – A BRIEF STATE OF ART 311

Marija Koprivica, J. Dimitrijević, J. Petrović, M. Ercegović, M. Simić

COMPARISON BETWEEN HYDROCHAR AND ITS ALKALI MODIFIED FORM IN THE REMOVAL OF Cd(II) IONS FROM AQUEOUS SOLUTION 317

Milena Pijović Radovanović, M. Seović, I. Perović, N. Zdolšek, J. Georgijević, P. Laušević, S. Brković
EFFICIENT REMOVAL OF RHODAMINE B FROM AQUEOUS SOLUTIONS USING CARBONIZED WASTE CAR TIRES: CHARACTERIZATION AND ADSORPTION STUDIES 323

Svetlana Butulija, J. Maletaškić, B. Todorović, G. Branković, A. Krstić, R. Mihailović, B. Matović
SYNTHESIS, CHARACTERIZATION AND ADSORPTION POTENTIAL OF CORN COB-DERIVED ACTIVATED CARBON 329

Vladan Nedelkovski, S. Stanković, D. Medić, D. Buzdugan, I. Hulka, S. Milić, M. Radovanović
PHOTOCATALYTIC PROPERTIES OF C-ZnO NANOPARTICLES SYNTHESIZED *via* MECHANOCHEMICAL METHOD 335

Aleksandar Zdravković, M. Nikolić, D. Marković Nikolić, D. Stojadinović, G. Petković, T. Nikolić
EQUILIBRIUM AND THERMODYNAMICS OF NITRATE SORPTION BY MODIFIED ZEOLITE FROM AQUEOUS SOLUTION 341

Aleksandar Zdravković, M. Nikolić, D. Marković Nikolić, D. Stojadinović, I. Ristić, T. Nikolić
POTENTIAL USAGE OF OAT STRAW FOR ANIONS REMOVAL FROM WATER: A KINETIC STUDY 348

Aleksandar Zdravković, M. Nikolić, A. Pavlović, D. Marković Nikolić, G. Petković, T. Nikolić
ULTRASOUND-ASSISTED EXTRACTION OF ACETAMIPRID FROM POLLUTED SOIL 354

Katerina Zaharieva, B. Barbov
PLANT-MEDIATED SYNTHESIS AND PHOTOCATALYTIC INVESTIGATIONS OF CeO_2-ZnO COMPOSITES 358

Milena Milošević, M. Abdualatif Abduarahman, M. M. Vuksanović, Z. Veličković, N. Knežević, B. Najdanović, A. Marinković
CELLULOSE BASED MEMBRANE FOR CATIONIC POLLUTANTS REMOVAL FROM WATER 363

Milena Milošević, A. Marinković, M. M. Vuksanović, Z. Veličković, I. Đuričković, B. Najdanović, N. Knežević
HEMP MODIFIED WITH BETAINE AS A GREEN AND EFFICIENT ADSORBENT FOR REMOVAL OF ANIONIC DYES FROM WATER 369

Nevena Surudžić, M. Spasojević, M. Crnoglavac Popović, M. Stanišić, R. Prodanović, O. Prodanović
PHENOL REMOVAL FROM WASTEWATER WITH HORSERADISH PEROXIDASE IMMOBILIZED BY PERIODATE METHOD ONTO NOVEL MACROPOROUS POLY(GMA-CO-EGDMA) CARRIERS 375

Miljana Radović Vučić, N. Velinov, J. Mitrović, S. Najdanović, M. Petrović, M. Kostić, A. Bojić

MODIFIED ACTIVATED WOOD SAWDUST AS GREEN ENVIRONMENTAL-FRIENDLY CATALYST FOR TREATMENT OF PHARMACEUTICAL EFFLUENT 381

Jelena Mitrović, M. Radović Vučić, N. Velinov, S. Najdanović, M. Kostić, M. Petrović, A. Bojić

ADVANCE OXIDATION OF TEXTILE DYE BY ACTIVATED HYDROGEN PEROXIDE WITH UV-C LIGHT 387

Protection and preservation of natural resources

Gordana Šekularac, M. Aksić, T. Dimitrijević, M. Ratknić, N. Gudžić

QUANTIFYING SOIL EROSION OF THE TOM'S BROOK CATCHMENT (WESTERN SERBIA) 393

Gordana Šekularac, M. Aksić, T. Dimitrijević, S. Gudžić, N. Gudžić, D. Gračak, M. Grčak, M. Ratknić

EFFECT OF IRRIGATION RATE ON THE ONSET INTENSITY OF GREY MOULD AND LATE BLIGHT IN GREEN HOUSE TOMATOES 399

Tatjana Dimitrijević, M. Ratknić, G. Šekularac, M. Aksić

INFLUENCE OF SOIL TYPE ON MEAN TREE HEIGHTS OF FIR TREES IN A 40-YEAR PROVENANCE TRIAL 406

Dragana Božić, Lj. Avramović, V. Trifunović, R. Marković, Z. Stevanović, V. Marjanović, E. Požega

AGITATION LEACHING OF FLOTATION TAILINGS AT THE PILOT PLANT 412

Ivana Kerkez Janković, D. Violić, M. Nonić, J. Devetaković, M. Šijačić-Nikolić

FOREST FRUIT SPECIES OF URBAN FOREST "KOŠUTNJAK" (SERBIA) – GENEPOOL ASSESSMENT AND CONSERVATION 418

Boris Novaković, N. Paskaš, M. Raković

NEW DATA ON THE DISTRIBUTION OF AQUATIC BEETLES IN SERBIA 424

Matej Fike, M. Pezdevšek, A. Roger

COMPARING FROST PROTECTION STRATEGIES FOR SUSTAINABLE AGRICULTURE IN SLOVENIA 430

Filip Maksimović, M. Nonić, D. Vilotić, I. Kerkez Janković, M. Šijačić-Nikolić

GENE POOL OF FOREST FRUIT TREES IN THE PROTECTED AREA OF THE NATURAL MONUMENT "KOŠUTNJAK FOREST" – THEN AND NOW 435

Dragana Medić, S. Milić, N. Milošević, M. Nujkić, M. Pešić, V. Nedelkovski, S. Stanković

APPLICATION OF THE SHRINKING CORE MODEL IN THE LEACHING PROCESS OF $LiNiMnCoO_2$ 441

Ecotoxicology and environmental safety

Branko Matovic, J. Maletaskic, S. Butulija, S. Petrovic, B. Todorovic
IMMOBILIZATION OF LEAD USING CERIA CRYSTAL STRUCTURE 448

Dragana Medić, S. Milić, N. Milošević, M. Nujkić, S. Alagić, A. Cvetković, A. Papludis
CAUSES AND POSSIBLE CONSEQUENCES OF THERMAL RUNAWAY IN LITHIUM-ION BATTERIES 454

Nena Velinov, M. Radović Vučić, J. Mitrović, M. Petrović, S. Najdanović, D. Bojić, A. Bojić
KINETIC AND EQUILIBRIUM STUDIES OF CHROMIUM SORPTION USING ULTRASONICALLY MODIFIED WOOD SAWDUST BY ALUMINA 460

Hazardous materials and green technologies

Uroš Stamenković, I. Marković, V. Ćosović, B. Markoli
THE INFLUENCE OF AGEING PARAMETERS ON MICROHARDNESS, ELECTRICAL CONDUCTIVITY AND MICROSTRUCTURE OF SOME Al-Mg-Si ALLOYS 466

Marija Simić, D. Aćimović, B. Savić Rosić, M. Ječmenica Dučić, K. Stojanović, D. Maksin, T. Brdarić
KINETIC STUDY OF DEGRADATION BISPHENOL A BY FENTON PROCESS 472

Danka Aćimović, K. Stojanović, M. Simić, B. Savić Rosić, Z. Vranješ, M. Ječmenica Dučić, T. Brdarić
DETECTION OF BISPHENOL A INTERMEDIATES DURING FENTON PROCESS AND PREDICTION OF REACTION PATHWAYS 476

Tanja Brdarić, D. Aćimović, B. Savić Rosić, K. Stojanović, M. Simić, Z. Vranješ, M. Ječmenica Dučić
ADVANCED OXIDATION PROCESSES (AOPs) FOR WASTEWATER TREATMENT: BIBLIOMETRIC STUDY 480

Vanja Trifunović, S. Milić, Lj. Avramović
POSSIBILITY OF ZINC AND CADMIUM RECOVERY FROM HAZARDOUS INDUSTRIAL WASTE – EAF DUST 486

Sandra Bulatović, N. Nedić, T. Tadić, B. Marković, A. Nastasović
MAGNETIC BIOSORBENT BASED ON THE *Ambrosia arthemisiifolia* FOR ADSORPTION OF MALACHITE GREEN FROM WATER 491

Milan Nedeljković, S. Mladenović, J. Petrović, M. Mitrović
STUDIES OF THE INFLUENCE OF GRAPHENE NANOSHEETS ON THE WETTABILITY OF ECO-FRIENDLY SOLDER ALLOYS 497

Ana Simonović, M. Petrović Mihajlović, M. Radovanović, Ž. Tasić, M. Antonijević
ELECTROCHEMICAL SENSORS FOR DETERMINATION OF ANTIBIOTICS 502

Sonja Stanković, V. Nedelkovski, D. Buzdugan, I. Hulka, M. Gorgievski, S. Milić, M. Radovanović
INFLUENCE OF CALCINATION TEMPERATURE ON THE MORPHOLOGY, CHEMICAL COMPOSITION, AND STRUCTURE OF ZnO NANOPARTICLES 508

Human and ecological risk assessment

Milena Tadić, I. Nikolić, D. Đurović, J. Vuković, N. Cupara
CHILDREN HEALTH RISK ASSESSMENT OF TRIHALOMETHANES CONTENT IN HOTEL'S SWIMMING POOL WATER IN MONTENEGRO 515

Miljan Bigović, D. Đurović, Lj. Ivanović, M. Blagojević, A. Orahovac
HEALTH RISK ASSESSMENT OF ACRYLAMIDE IN POTATO CHIPS FROM MONTENEGRIN MARKET 520

Vesna Djikanović, K. Jovičić, J. S. Vranković, M. Dimitrijević, S. Kovačević, N. Pankov, B. Miljanović
ACCUMULATION OF HEAVY METALS AND HUMAN HEALTH RISK ASSESSMENT *via* THE CONSUMPTION OF FRESHWATER FISH *Esox lucius* 524

Agriculture: nutrition, organic food and health impacts

Vitaly Erukhimovitch, M. Huleihel
OPTIMIZATION OF PREPARATION PROCEDURES FOR FUNGAL INFECTED PLANTS BY FTIR ANALYSES 531

Mahmoud Huleihel, V. Erukhimovitch
POSSIBLE USE OF FOURIER–TRANSFORM INFRARED (FTIR) MICROSCOPY FOR IDENTIFICATION OF FUNGAL PHYTO–PATHOGENS 536

Ana Čučulović, J. Stanojković, R. Čučulović
RADIOACTIVITY IN SAMPLES OF IMPORTED MINERAL FERTILIZER ANALYZED IN THE PERIOD 2020–2022 541

Nenad Zarić, M. Zarić
METAL CONTENTS IN VEGETABLES ORIGINATING FROM COAL FIRED THERMAL POWER PLANTS REGION 547

Alternative energy: efficiency and environmental policy

Snežana Brković, N. Zdolšek, I. Perović, M. Seović, P. Laušević, J. Georgijević, M. Čebela
ENHANCING OXYGEN EVOLUTION: THE ELECTROCATALYTIC POWER OF Ag-DOPED BISMUTH FERRITE 552

Nebojša Potkonjak, Đ. Čokeša, M. Marković
NONLINERA PHENOMENA DURRING VOLTAMMETRIC MEASURMENT OF COPPER CORROSION 558

Mirjana Marković, Đ. Čokeša, N. Potkonjak
EVALUATION OF THE HYDROGEN DIFFUSION COEFFICIENT IN METAL HYDRIDE BATTERIES 562

Greenhouse effect and global climate change

Slobodan Milutinović, T. Rađenović, S. Živković
FORESTS UNDER THREAT: IMPLICATIONS OF CLIMATE CHANGE ON SERBIAN WOODLANDS 566

Danijela Nikolić, S. Jovanović, Z. Đorđević, D. Končalović, V. Vukašinović
GLOBAL WARMING – TREND ANALYSIS IN THE REPUBLIC OF SERBIA 574

Sustainable development and green economy

Dragana Ranđelović, A. Jovanović, B. Marković, M. Sokić
CONTRIBUTION OF THE INSTITUTE FOR TECHNOLOGY OF NUCLEAR AND OTHER MINERAL RAW MATERIALS TO THE SDGs – TOWARDS INTERNATIONAL DECADE OF SCIENCE FOR SUSTAINABLE DEVELOPMENT 580

Veljko V. Savić, J. D. Nikolić, V. Topalović, M. S. Djošić, M. Marković, S. Matijašević, S. Grujić
CHEMICAL DURABILITY EVALUATION OF SINTERED FLY ASH BASED GLASS 586

Stefan Mitrović, S. Brković, M. Seović, N. Zdolšek, P. Laušević, J. Georgijević, I. Perović
RECYCLING ELECTRONIC WASTE CPUs FOR ENHANCED HYDROGEN AND OXYGEN EVOLUTION: AN ECO-FRIENDLY LEACHING APPROACH 593

Adrijana Jevtić, D. Riznić, M. Vuković
BRAND MANAGEMENT AND SOCIO-ECONOMIC ASPECTS OF ADAPTATION TO CLIMATE CHANGES 598

Ana Radojević, J. Jordanović, T. Kalinović, J. Kalinović, S. Šerbula
PROSPECTS OF SUSTAINABLE UTILIZATION OF FOOD WASTE 606

Maja Bogdanović, I. Blagajac
DECENTRALIZATION OF THE URBAN TOURIST ZONE OF ZLATIBOR 613

Environmental biology

Slađana Popović, N. Nikolić, Ž. Savković, M. Stupar, D. Predojević, A. Anđelković, O. Jakovljević

ISOLATION AND CULTIVATION OF CHROOCOCCUS (CYANOBACTERIA) FROM AEROPHYTIC BIOFILM IN STOPIĆ CAVE 621

Tamara Mitić, J. Čanak Atlagić, J. Tomović, J. Stanković, D. Mrdak, D. Škraba Jurlina, A. Marić

MORPHOMETRIC STUDY OF EUROPEAN BULLHEAD *Cottus gobio* FROM DIFFERENT DRAINAGE POPULATIONS 626

Jelena Đuknić, N. Popović, B. Vasiljević, B. Tubić, S. Andjus, M. Ilić, M. Paunović

ECOLOGICAL POTENTIAL OF THE DANUBE RIVER THROUGH SERBIA BASED ON BIOLOGICAL QUALITY ELEMENTS 632

Slađana Popović, G. Subakov Simić, S. Stanković, D. Lazić

Chlorella vulgaris GROWTH IN SMALL OPEN CULTIVATION SYSTEMS 638

Olga Jakovljević, S. Popović, D. Predojević

EPIPHYTIC DIATOMS AS TOOL IN BIOINDICATION OF LAKE PALIĆ 643

Mihailo Jovanović, J. Paunković

IMPROVING PALEOENVIRONMENTAL RECONSTRUCTIONS BASED ON SMALL VERTEBRATES IN THE BALKANS 648

Jovana Damjanović, M. Milković, A. Miščević, M. Šćiban, V. Lakušić, M. Stanković

SUPPLEMENT TO THE LIST OF ENTOMOFAUNA FROM THE RESEARCH ACTIONS AND CAMPS OF SRSBE "JOSIF PANČIĆ" AT SRN ZASAVICA 654

Mihajlo Stanković

"LIVING FOSSILS" IN THE CRASH FAUNA OF THE ZASAVICA SPECIAL NATURE RESERVE 662

Environmental and material flow management

Nataša Knežević, A. Jovanović, M. Vuksanović, M. Savić, M. Milošević, A. Marinković

DEGRADATION OF DYE CRYSTAL VIOLET RELEASED FROM THE TEXTILE INDUSTRY 669

Milenko Jovanović, D. Kržanović, E. Požega, V. Marinković, M. Mikić

APPLICATION AND ENVIRONMENTAL SUITABILITY OF HYBRID GEOGRIDS 674

Miroslav Drljača

MODERN APPROACH TO SUPPLY CHAIN BASED ON CIRCULAR ECONOMY PRINCIPLES 681

Isidora Berežni, T. Marinković, N. Stanisavljevic, M. Muhadinović, B. Batinić
ASSESSMENT OF THE MUNICIPAL SOLID WASTE MANAGEMENT – CASE STUDY: NOVI SAD (SERBIA) 687

Ljubiša Balanović, D. Manasijević, I. Marković, U. Stamenković, K. Božinović
CALCULATION OF THERMODYNAMIC PROPERTIES Al-Ga-Sn TERNARY ALLOY USING GENERAL SOLUTION MODEL 693

Life-Cycle-Analysis (LCA)

Danijela Nikolić, S. Jovanović, D. Mikić, Z. Đorđević
LIFE CYCLE ASSESMENT OF THE HAIR DRYER WITH ECO-it SOFTWARE 701

Student Section – EcoTER*S*'24

Students: Sofija Kostić, Aleksa Marjanović (Serbia)
Mentor: Maja Nujkić (Serbia)
SOME ASPECTS OF THE APPLICATION OF METAL-ORGANIC FRAMEWORKS 709

Student: Jelena Janković (Serbia)
Mentor: Maja Nujkić (Serbia)
MECHANISMS OF CADMIUM UPTAKE INTO THE PLANT 711

Student: Jovana Kumbrijanović (Serbia)
Mentors: Maja Nujkić, Sonja Stanković (Serbia)
COAGULATION PROCESS AND APPLICATION OF NEW ECOLOGICAL COAGULANTS 713

Student: Lazar Cvetković (Serbia)
Mentors: Maja Nujkić, Tanja Kalinović, Jelena Kalinović (Serbia)
SOME APPLICATION ASPECTS OF THE MATERIALS BASED ON THE GREEN MAGNESIUM OXIDE ECOLOGICAL COAGULANTS 715

Students: Milena Radivojević, Kristina Konstadinović (Serbia)
Mentors: Maja Nujkić, Dragana Medić (Serbia)
RECYCLING OF USED LITHIUM-ION BATTERIES 717

Student: Milica Denić (Serbia)
Mentor: Ana Radojević (Serbia)
MEDICAL WASTE ISSUES RELATED TO COVID-19 PANDEMIC 719

Student: Sara M. Pantović (Serbia)
Mentor: Enisa S. Selimović (Serbia)
PRESENCE OF TOXIC AND POTENTIALLY TOXIC ELEMENTS IN SOME DOMESTIC FRUIT FROM THE PEŠTER PLATEAU, SJENICA, SERBIA 721

Student: Milena Stanković (Serbia)
Mentor: Ljiljana Stanojević (Serbia)

CHEMICAL COMPOSITION OF ESSENTIAL OIL ISOLATED FROM FRESH AND DRY LEAVES OF *Geranium robertianum* L. 723

Student: Nikola Petrović (Serbia)
Mentor: Ana Simonović (Serbia)

TOXIC EFFECTS OF PETROLEUM DERIVATIVES ON LIVING ORGANISMS FROM CONTAMINATED SOILS 725

Students: Anja Antanasković, Nevena Ilić (Serbia)
Mentors: Milan Milivojević, Suzana Dimitrijević-Branković, Zorica Lopičić, Nikola Vuković (Serbia)

ENZYME IMMOBILIZATION ON MODIFIED BIOMASS: OPTIMIZATION AND CHARACTERIZATION 727

Student: Milena Balabanović (Serbia)
Mentor: Ana Radojević (Serbia)

BIOLOGICAL TREATMENT OF THE BIODEGRADABLE WASTE 729

Student: Natalija Stojanović (Serbia)
Mentors: Maja Nujkić, Vladan Nedelkovski (Serbia)

ADSORPTION MATERIALS BASED ON NANOPARTICLES FOR THE REMOVAL OF ARSENIC FROM WASTEWATER 731

Student: Jelena Vesković (Serbia)
Mentor: Antonije Onjia (Serbia)

HEALTH RISK ASSESSMENT OF RARE EARTH ELEMENTS IN GROUNDWATER NEAR A THERMAL POWER PLANT 733

Students: Vladimir Topalović, Anja Antanasković, Veljko Savić (Serbia)
Mentors: Marija Djošić, Zorica Lopičić, Ana Vujošević, Jelena Nikolić (Serbia)

EFFECT OF PHOSPHATE GLASS AND BIOCHAR ON ROSE GROWTH 735

Student: Aleksandra Milenković (Serbia)
Mentor: Ljiljana Stanojević (Serbia)

THE REDUCING POWER OF BLACK PEPPER (*Piper nigrum* L.) ESSENTIAL OIL HYDRODISTILLATION FRACTIONS 737

Student: Marija Tasić (Serbia)
Mentor: Dragan Cvetković (Serbia)

ENVIRONMENTAL METHOD OF GOLD NANOPARTICLES SYNTHESIS AND THEIR CHARACTERIZATION 739

Student: Marija Stanković (Serbia)
Mentor: Jelena Kalinović (Serbia)

PURIFICATION METHODS FOR POLLUTED AIR 741

Student: Marija Stanković (Serbia)
Mentor: Jelena Kalinović (Serbia)

PURIFICATION OF INDUSTRIAL WASTEWATER 743

Students: Željka Nikolić, Nebojša Radović (Serbia)
Mentor: Olga Tešović (Serbia)

RISKS OF CHLORINE EXPOSURE IN HOUSEHOLD CLEANING: A CALL FOR AWARENESS AND PREVENTION 745

Students: Željka Nikolić, Nebojša Radović (Serbia)
Mentor: Olga Tešović (Serbia)

IS THERE A NEED TO INFORM CITIZENS MORE DIRECTLY ABOUT THE HANDLING OF HOUSEHOLD HAZARDOUS WASTE? 747

Students: Nataša Simonović, Tamara Milosavljević (Serbia)
Mentors: Jelena Stanojević, Ljiljana Stanojević, Jelena Zvezdanović, Dragan Cvetković (Serbia)

SOLID WASTE FROM HYDRODISTILLATION OF HERNIARIAE HERBA (*Herniaria glabra* L.) AS A POTENTIAL SOURCE OF ANTIOXIDANTS 749

Students: Aleksa Vizi, Nebojša Radović, Željka Nikolić, Stefan Lekić (Serbia)
Mentors: Goran Roglić, Ksenija Stojanović, Vele Tešević (Serbia)

SUSTAINABLE SOLUTIONS IN ANALYTICAL CHEMISTRY: COMBINING OF INSTRUMENTAL TECHNIQUES AND ENVIRONMENTAL-FRIENDLY NATURAL INDICATORS FOR CLASSICAL VOLUMETRY 751

Students: Aleksa Vizi, Nebojša Radović, Željka Nikolić (Serbia)
Mentors: Ivan Kojić, Ksenija Stojanović (Serbia)

EFFICIENT DETERMINATION OF UNDECYLENIC ACID CONTENT IN PHARMACEUTICAL PRODUCTS: A NOVEL SIMPLE APPROACH 753

Student: Andrijana Miletić (Serbia)
Mentor: Antonije Onjia (Serbia)

HEALTH RISK ASSESSMENT OF POTENTIALLY TOXIC ELEMENTS IN AGRICULTURAL SOIL OF BRANIČEVO DISTRICT 755

Student: Jelena Obradovic (Serbia)
Mentor: Antonije Onjia (Serbia)

DISTRIBUTION OF $PM_{2.5}$, CO_2, HCHO, AND TVOC IN AIR IN A HIGH SCHOOL CLASSROOM 757

Student: Gordan Mišić (Serbia)
Mentors: Ana Radojević, Jelena Jordanović (Serbia)

TOXICOLOGICAL EFFECTS OF MICRO- AND NANO-PLASTICS ON HUMAN HEALTH 759

Student: Anđela Bogdanović (Serbia)
Mentor: Marija Petrović Mihajlović (Serbia)

MAGNESIUM AND ITS ALLOYS 761

Author index **763**

STUDIES OF THE INFLUENCE OF GRAPHENE NANOSHEETS ON THE WETTABILITY OF ECO-FRIENDLY SOLDER ALLOYS

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Abstract
Lead-based solders are harmful to the environment and human health, so they must be replaced. Numerous studies have focused on the production of "eco-friendly" solder alloys. Recently, there has been an increasing number of researches dealing with lead-free composite solder alloys. This paper presents a review of research on the influence of graphene nanosheets (GNS) on the wettability of tin-based solder alloys. GNSs have been used to improve the physical and mechanical properties of solder. The variable mass content of GNS particles was successfully pressed into lead-free solder using a high-planetary ball mill. This method enabled better homogeneous mixing and consolidation of the mixed powder. After that, the powder that was obtained was sintered, and the effect of GNS on wettability was investigated. Increasing the mass content of GNS reduces the surface tension between the substrate and the composite solder, resulting in a lower contact angle and improved wettability.

Keywords: lead-free solders, graphene nanosheets, high-planetary ball mill, sintering.

INTRODUCTION

In the electrical industry, soldering is the most crucial connection method. The solders were heated to the melting point before soldering. The molten solder wet the substrate, creating connections between the liquid (solder) and the solid (substrate). The solder then solidifies as the joins cool, creating solder joints. Solders are often made of low melting point alloys since melting is a need for the soldering procedures. The most common solders are Pb-Sn alloys, and research into their characteristics is significant [1–4]. Lead is toxic and poses a danger to the environment and human health, therefore its elimination is necessary. Recognizing these facts, several nations have begun to take necessary safety measures, such as establishing rules limiting or prohibiting the use of lead in electronics. In this regard, the European Union (EU) adopted two directives: WEEE (Waste Electrical and Electronic Equipment) and RoHS (Restriction of the Use of Certain Hazardous Substances) [5,6].

There is no lead-free solder that can entirely outperform lead solder characteristics. It has been challenging to substitute lead-based solder, and research is ongoing. The new solder alloys must meet specific requirements in terms of melting temperature, wettability, mechanical, and electrical properties. Additionally, it must exhibit the right corrosion resistance in various conditions and at various temperatures. The lead-free solders that are used most frequently today are Sn-Cu, Sn-Ag, and Sn-Ag-Cu [7].

Reinforcements can be added to standard alloys to create a composite lead-free solder. There are many methods for reinforcing these solders, including powder metallurgy (PM), melting and casting (MC), physical vapor deposition, precipitation, and others. PM includes mixing powders, compressing them at a certain pressure, and then sintering. The PM process is the most often used way of producing composite solder. Many researchers have chosen nano-sized particles for the reinforcements. As reinforcement, the following particles can be used: Si_3N_4, Al_2O_3, SiC, TiB_2, TiO_2, ZrO_2, SnO_2, and ZnO. Due to its remarkable properties, graphene has recently captured considerable attention from researchers. With superior mechanical properties, and electrical and thermal conductivity, graphene nanosheets (GNS) are expected to outperform carbon nanotubes (CNTs) and hold significant promise in the field of electronics [8]. To achieve better wettability and mechanical properties than the pure solder, Nai *et al*. [9] investigated the wettability of Sn-3.5Ag-0.5Cu solder reinforced with multi-wall carbon nanotubes (MWCNTs), produced by the PM method. The research results showed that with 0.07 mass.% MWCNTs in the matrix, the contact angle decreased from 29° to 24°, indicating an improvement in the wettability of the composite solder. The results corresponded with previous studies.

Solder wettability is a critical factor in determining the quality of the solder to substrate bond. Strong bonds between the solder and the substrate were promoted by good wetting. Wettability is the ability of a liquid to diffuse onto a solid surface in a specific environment, such as the atmosphere, temperature, and so on [10]. Wettability is defined by the contact angle (θ). Figure 1 illustrates the relationship between surface tension and contact angle, which can be described using the Young-Laplace equation (1):

$$\cos\theta = \frac{\gamma_{sa} - \gamma_{sl}}{\gamma_{la}} \qquad (1)$$

The contact angle is the angle between the tangent drawn from point A to the circular line representing the contour of the solder drop and the surface of the substrate.

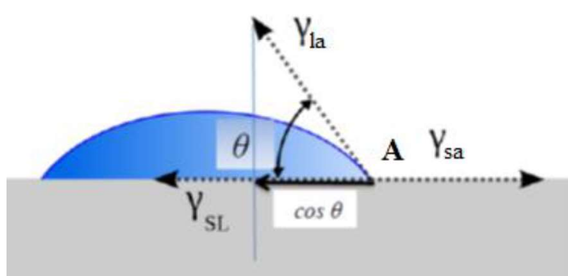

Figure 1 *Schematic of contact angle (θ) of liquid metal on a solid surface [11,12]*

When the contact angle (θ) is between 0° and 90°, the solder is considered to wet the substrate well. Better wettability is achieved with less contact angle, greater surface area, and spreading speed. Generally, a solder alloy with a smaller contact angle to the substrate provides a much more reliable interconnection during the soldering process [11,12].

This paper presents an overview of the research on the influence of GNS particles on the wettability of different tin-based composite solder alloys. The variable mass content of GNS has been successfully integrated into lead-free solder using a high-planetary ball mill. This technique provided significantly greater homogenous mixing and consolidation of the mixed powder. Following that, the powder was sintered and the wettability was determined. The contact angle was measured using the sessile drop technique. The droplet was photographed and analyzed, and the contact angle between the solid surface, air, and the droplet was determined.

OVERVIEW OF RECENT RESEARCH

Yin *et al*. [13] used the contact angle method to measure the wettability of the Sn-0.3Ag-0.7Cu composite solder depending on the mass content of GNS. The result of the test shows that adding GNS increased solder wettability significantly. Figure 2 shows the influence of different mass content of GNS on the contact angle of the composite solder. The figure presents that the contact angle of the Sn-0.3Ag-0.7Cu solder decreased by approximately 29% with the addition of 0.01% GNS. With a further increase in the mass content of the reinforcement, the contact angle continued to decrease.

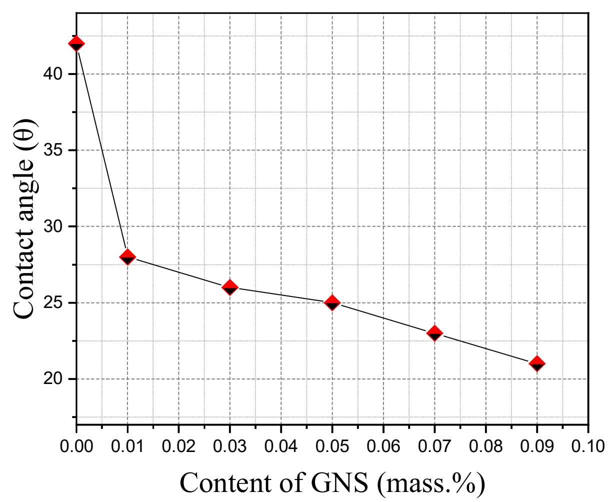

Figure 2 *Contact angle of Sn-0.3Ag-0.7Cu–x GNS solder on the copper substrate [13]*

After analyzing the results and reviewing previous research, they come to the following explanation. GNS are non-polar molecules with a hexagonal honeycomb lattice composed of carbon-carbon covalent bonds. When the GNS in the molten composite solder comes into contact with the non-polar organic acids in the rosin (solder paste) during soldering, the dispersion between the non-polar molecules of these substances can occur. The interphase tension between the composite solder and the rosin was reduced. When the interphase tension was reduced, the contact angle decreased, and the solder wettability was improved.

Liu *et al*. [14] studied the influence of GNS particles on the Sn-3Ag-0.5Cu composite solder and arrived at the following conclusions. As shown in Figure 3, the contact angle decreased as GNS content increased.

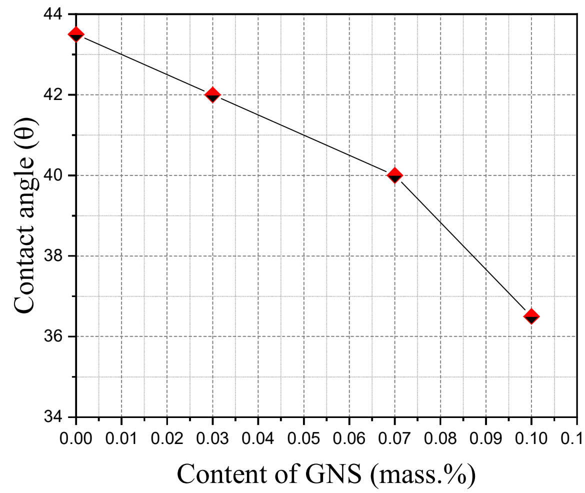

Figure 3 *Contact angle of Sn-3Ag-0.5Cu–x GNS solder on copper substrate [14]*

The composite solder with a mass content of GNS of 0.1% shows the smallest contact angle, which is 15.5% smaller than the starting solder. Analyzing the obtained results they came to the following conclusion. This improved wettability can be explained based on the effect of GNS particles on the interfacial tension between the composite solder and rosin during the soldering process. Through the soldering process, GNS should be dispersed at the solder/rosin interface. The presence of GNS can reduce the surface tension of the interface. Reduced interphase tension between the solder and the rosin causes a decrease in the contact angle. That improved the wettability of the composite solder.

Yin *et al*. [15] also studied the effect of different mass content of GNS on Sn-0.3Ag-0.7Cu composite solder and reached the following conclusions. In Figure 4, it can be seen that the contact angle decreases with the increasing mass content of GNS. The contact angle of Sn-0.3Ag-0.7Cu solder decreased by 31% by adding only 0.01% GNS particles. A further increase in the mass content of GNS up to 0.09% leads to a decrease in the contact angle. It follows that the wettability of the composite solder increases.

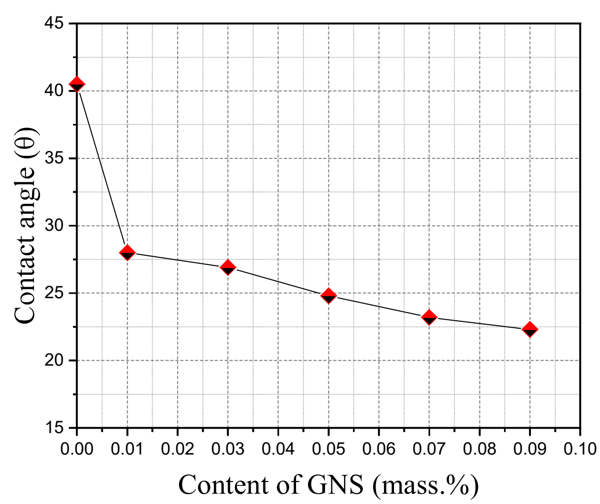

Figure 4 *Contact angle of Sn-0.3Ag-0.7Cu – x GNS solder on the copper substrate [15]*

According to the results, they reached the same conclusions as previous researchers. When the GNS particles present in the solder come into contact with the rosin, dispersion occurs between these compounds. The interfacial tension was reduced. Based on equation 1, reducing the interfacial tension between the composite solder and the rosin reduces the contact angle, which increases the wettability of the composite solder.

CONCLUSION

Solderability is the ability of solder alloys to wet and bond with a surface, forming a reliable and durable joint. Wettability tests were performed on several tin alloys reinforced with GNS particles, and the results were practically similar. The presence of GNS reduces the interfacial tension between the solder and the surface. As a result of the decreased contact angle, the wettability of the composite solder improved. By reviewing the literature and analyzing previous studies, it can be determined that the wettability of tin-based solder alloys reinforced with GNS increases.

ACKNOWLEDGMENT

The research presented in this paper was done with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, within the funding of the scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with registration number 451-03-65/2024-03/200131.

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