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**CONFERENCE PROCEEDINGS CONTENTS**
**SECTION ECOLOGY AND ENVIRONMENTAL PROTECTION**


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- 1. 3D FIRE SCALE MODELLING OF COMBINED WOOD AND PLASTIC INTERIOR**, Prof. Jana Mullerova, University of Zlina, Slovaki .....3
- 2. A RECLAMATION PROCEDURE SCHEME OF ABANDONED MINE SITES: A CONCEPTUAL MODEL**, Prof. Paulo Favas, Fund GeneralUAM NIF G80065279 Universidad Autonoma de Madrid, Spain .....9
- 3. ASSESSMENT OF THE MAN-MADE HAZARDS AT REGIONAL SCALE. THE CASE OF BUHAREST-ILFOV DEVELOPMENT REGION**, Dr. Ines Grigorescu, Dr. Mihaela Sima, Dr. Bianca Mitrica, Dr. Gheorghe Kucsicsa, Dr. Monica Dumitrascu, Institute of Geography - Romanian Academy, Romania.....15
- 4. A pH-, SALT- AND SOLVENT-RESPONSIVE POLY (SODIUM ACRYLATE) CO-ACRYLAMIDE/PECTIN SUPERABSORBENT COMPOSITE**, Master student M.A. Dovbeta, Dr. V.E.Sitnikova, Dr. A.I. Ivanova, Assoc. Prof. Roman O. Olekhovich, Prof. Dr. M.V. Uspenskaya, Prof. Dr. M.V. Uspenskaya, ITMO University, Russia.....23
- 5. ACID GENERATION AND METAL LEACHING POTENTIAL OF SULFIDE-BEARING ROCKS IN THE VERHNE-KRICHALSKAYA AREA (WESTERN CHUKOTKA, RUSSIA)**, PhD Tatyana Lubkova, Stud. Ludmila Dogadina, PhD Daria Yablonskaya, Stud. Olga Orlova, PhD Irina Nikolaeva, Lomonosov Moscow State University, Russia.....31
- 6. ADIPUR WASTEWATER TREATMENT OPTIMIZATION**, Lect. PhD. Eng. Dragos DRACEA, Assoc. Prof. PhD. Eng. Augustina TRONAC, Assoc. Prof. PhD. Eng. Sebastian MUSTATA, University of Agronomic Sciences and Veterinary Medicine of Bucharest, Romania .....39
- 7. ADVANTAGES AND THE PERSPECTIVE OF TO THE SMALL-SCALE FIRE MODELLING**, Janka Mullerova, University of Zlina, Slovakia .....47
- 8. AM-241 IN THE DON RIVER SEDIMENT CORE**, Prof. Yury Fedorov, Assoc. prof. Andrey Kuznetsov, PhD Vladislav Yaroslavtsev, Southern Federal University, Russia .....53
- 9. AN OVERVIEW ON THE MEMBRANES USED FOR CARBON DIOXIDE REMOVAL**, Marius Miricioiu, Felicia Bucura, Marius Constantinescu, Ramona Zgavarogea, Violeta Niculescu, National Institute for Research and Development for Cryogenics and Isotopes Technologies - ICSI Rm.Valcea, Romania .....61

- 10. ANALYSIS OF CONSTRUCTION ACCIDENT IN SAINT PETERSBURG BASED ON CONSIDERATION OF UNDERGROUND SPACE AS A CONTAMINATED MULTICOMPONENT SYSTEM**, Dashko R.E., Kotiukov P.V., Mining University of Saint Petersburg, Russia .....67
- 11. ANALYSIS OF THE FACTORS AFFECTING DEVELOPMENT OF THE MARITIME TERRITORIES OF LATVIA**, Dr.oec. Prof. Veronika Bikse, Dr.sc.admin. Una Libkovska, Mg. Inta Ozola, Ventspils City Council, Latvia.....75
- 12. ANALYSIS OF THE RELATIONSHIP BETWEEN THE EXTENT OF AMMONIA RELEASE THREATENED TERRITORY AND THE ATMOSPHERIC CONDITIONS CHANGE – CASE STUDY BASED ON ALOHA APPLICATION**, Assoc. Prof. Majlingova Andrea, Galla Stefan PhD, Zachar Martin, PhD., Fire Research Institute of the Ministry of Interior of the Slovak Republic, Slovakia .....85
- 13. ANTIOXIDANT CAPACITY AND MINERAL CONTENT OF SOME TOMATOES CULTIVARS GROWN IN OLTENIA (ROMANIA)**, Maria DINU, Gheorghita HOZA, Alexandra BECHERESCU, University Of Craiova, Romania .....93
- 14. ARD TREATMENT - BATCH VS. CONTINUOUS FLOW REACTION SYSTEMS FOR SULPHATE PRECIPITATION, A TECHNICAL NOTE**, L.R. Dinu, I. Balaiu, I. Cristea, Dr. V.R. Badescu, V. Dediu, National Research and Development Institute for Industrial Ecology - ECOIND, Romania ..... 101
- 15. ASSESSING LAND USE/COVER CHANGES IN THE PUTNA-VRANCEA NATURAL PARK. ROMANIA**, Dr. Roxana Cuculici, Dr. Ines Grigorescu, Dr. Monica Dumitrascu, MS Candidate Student Eliza Marin, Prof.. Costin Dumitrascu, Institute of Geography - Romanian Academy, Romania ..... 109
- 16. ASSESSMENT AND GIS ANALYSIS OF THE HUMAN HEALTH RISK FROM NEGATIVE EMISSIONS INTO THE AIR**, Assoc. Prof. Iraida Kirilchuk, Assoc. Prof. Alexey Barkov, Prof. Leonid Shulga, Southwest State University, Russia..... 117
- 17. ASSESSMENT OF SUPPLY SUFFICIENCY OF AGRICULTURAL LANDS BY WATER RESOURCES**, Akhmetkal Medeu, Irina Skorintseva, Tatyana Bassova, Viktoriya Krylova, Institute of geography, Kazakhstan..... 125
- 18. ASSESSMENT OF THE ACCUMULATION OF CHEMICAL ELEMENTS IN MOSSES FROM THE AREAS OF WASTE DISPOSAL FROM GOLD MINING (THE CASE OF KEMEROVO REGION, RUSSIA)**, Mezhibor A.M., Rikhvanov L.P., Baranovskaya N.V., Tomsk Polytechnic University, Russia..... 133
- 19. ASSESSMENT OF THE IMPACT OF RECREATION ON THE COMPONENTS OF FOREST PHYTOCENOSES FOR THE TERRITORY OF THE NORTH-EASTERN PART OF THE REPUBLIC OF MARI EL**, Vladimir Zakamskii, Volga State University of Technology, Russia ..... 141

- 20. ASSESSMENT OF VRANCEA EARTHQUAKES IMPACT RECORDED ON BULGARIAN TERRITORY**, Prof. Svetoslav Simeonov, Assoc. Prof. Kiril Hadjiyski, National Institute of Geophysics Geodesy and Geography, Bulgaria ..... 149
- 21. ASSESSMENT OF WATER POLLUTION IN THE CANALS OF HIGHWAYS IN THE EUROPEAN NORTH OF RUSSIA**, Assoc. Prof., Ph.D., Dr. Sergey Aksenov, Northern Arctic Federal University named after M.V. Lomonosov Faculty of Civil Engineering and Architecture, Russia ..... 157
- 22. BIOGEOCHEMICAL FEATURES OF EPIPHYTIC LICHENS FROM THE AREA OF THE TAILINGS OF A GOLD-POLYMETALLIC DEPOSIT (KEMEROVO REGION, RUSSIA) COMPARATIVE TO A REFERENCE AREA**, Engineer Dr. Tatiana Bolshunova, Prof. Dr. Leonid Rikhvanov, Assoc. Prof. Dr. Antonina Mezhibor, Prof. Dr. Natalia Baranovskaya, Tomsk Polytechnic University, Russia ..... 165
- 23. CAPTURING OF ACID DRAINAGE MINE WATER FROM THE BUNARDZIK WASTE DUMP IN FUNCTION TO INSTALLATION FOR LEACHING OF COPPER AND PROTECTION OF THE ENVIRONMENT IN THE BUCHIM COPPER MINE, REPUBLIC OF MACEDONIA**, Todor Serafimovski, Gerasim Konzulov, Goran Tasev, Sare Sarafiloski,, University Goce Delcev, FYR of Macedonia ..... 173
- 24. CERATOPHYLLUM DEMERSUM – RISKS OF INVASIVENESS IN CONNECTION WITH CHANGES IN THE CLIMATE AND IN THE QUALITY OF THE ENVIRONMENT**, Barbara Stalmachova, Emilie Pecharova, Alena Kasparkova, VSB-Technical University of Ostrava, Czech Republic ..... 183
- 25. CESIUM-137 AS AN INSTRUMENT FOR DETERMINING THE SEDIMENTATION RATES IN THE LAKES OF THE BLACK SEA DRAINAGE BASIN**, Prof. Yury Fedorov, Assoc. Prof. Andrey Kuznetsov, PhD st. Vladislav Yaroslavtsev, Assoc. Prof. Irina Dotsenko, Southern Federal University, Russia ..... 189
- 26. CHANCES OF GEOTOURISM DEVELOPMENT IN THE COLCA AND THE VOLCANOES OF ANDAGUA GEOPARK (PERU)**, Andrzej Galas, Slavka Galas, Bilberto Zavala, Denitza Churata, AGH University of Science and Technology, Poland ..... 197
- 27. CHARACTERIZATION OF ACID MINE DRAINAGE AT THE REGOUFE MINE, AROUCA GEOPARK, NORTHERN PORTUGAL**, Prof. Paulo Favas, Prof. Joao Pratas, Fund GeneralUAM NIF G80065279 Universidad Autonoma de Madrid, Spain ..... 205
- 28. CLADOCERA REMAINS FROM SEDIMENTS OF THERMOKARST LAKES OF NORTH-CENTRAL SIBERIA (RUSSIA)**, Assoc. Prof. Dr. Larisa Frolova, Dr. Larisa Nazarova, Student Elvira Zinnatova, Student Anastasia Frolova, Prof. Ulrike Herzsuh, Kazan (Volga Region) Federal University, Russia ..... 211

- 29. COMPARATIVE CHARACTERISTIC REMOVAL OF HYDROXOCOMPLEXES HOLMIUM BY ION FLOTATION AND EXTRACTION**, Lobacheva O.L., Dzhevaga N.V., Saint-Petersburg Mining University, Russia.....219
- 30. COMPARATIVE ENVIRONMENTAL ANALYSIS OF WASTE PROCESSING METHODS IN PAPER RECYCLING**, Dr Vitalii Ishchenko, Prof. Dr Volodymyr Pohrebennyk, Dr Anna Kochanek, Dr Grzegorz Przydatek, State Higher Vocational School Nowy Sacz, Poland .....227
- 31. COMPARISON OF TRIHALOMETHANES CONCENTRATION FOR VARIETY SYSTEMS OF SWIMMING POOL WATER PREPARATION**, Iwona Klosok-Bazan, Anita Sowa-Watrak, Opole Technical University, Poland.....235
- 32. COMPLEX SYSTEM DEDICATED TO MONITORING AND CONTROL OF HYDROPONIC GREENHOUSE ENVIRONMENT**, Stefan Mocanu, Alexandru Dumitrascu, Cosmin Popa, Politehnica University of Bucharest, Romania .....243
- 33. CONTRIBUTIONS REGARDING ENVIRONMENTAL IMPACT OF THE TECHNOLOGICAL PROCESS IN TEMPORARY CASTING FORMS**, Prof. Dr. Amza Gheorghe, Prof. Dr. Petrescu Valentin Dan, Assoc.Prof. Nitoi Dan Florin, Prof.Dr. Semenescu Agustin, Assoc.Prof. Chivu Oana Roxana, University POLITEHNICA of BUCHAREST, Romania .....257
- 34. CREATION OF THE END PRODUCT OF OCEANOGRAPHIC DATA OF THE GEORGIAN BLACK SEA AREA**, Kakhaber Bilashvili, Vakhtang Gvakharia, Nino Machitadze, Zurab Savaneli, Vazha Trapaidze, Ivane Javakhishvili Tbilisi State University, Georgia .....263
- 35. CULTIVATION OF THE PHRAGMITES AUSTRALIS (CAV.) TRIN. AS A PERSPECTIVE METHOD FOR POLLUTED SOIL REVITALIZATION**, Assoc. Prof. Peter Adamisin, Prof. Ondrej Hronec, Juraj Fazekas, Bogdan Mieszczak, Agnieszka Scieszka, University of Presov in Presov, Slovakia .....271
- 36. DESIGNING A PILOT SEWERAGE TREATMENT PLANT FOR SMALL LOCALITIES**, Ioan Sarbu, Alexandru Filip, Politehnica University of Timisoara, Romania.....277
- 37. DEVELOPMENT OF THE INVESTIGATION APPROACH TO WINTER MULTI-HAZARDS FOR CLOSED RESERVOIRS ON THE EXAMPLE OF THE CASPIAN SEA**, PhD Natalia Yaitskaya, Irina Tretyakova, George Makarovskiy, PhD Lev Shagarov, Institute of Natural and Technical Systems, Russia.....285
- 38. DYNAMIC QUALITY OF GROUNDWATER IN RADOVAN VILLAGE, DOLJ COUNTY-ROMANIA**, Ana Maria Dodocioiu, Diana Gilda Buzatu, University Of Craiova, Romania.....291

- 39. ECO-FRIENDLY METHODS FOR HEAVY METAL REMOVING FROM TARNITA MINING AREA**, Gabi Drochioiu, Andriana Surleva, Carmen Iacoban, El Mahdi Halim, Robert Vasile Gradinaru, Alexandru Ioan Cuza University, Romania.....297
- 40. ECO-SYSTEM SERVICES AND SOCIAL INNOVATIONS IN RURAL AREAS**, Assoc. Prof. Dr. Ligita Melece, Dr. Peteris Lakovskis, Institute of Agricultural Resources and Economics, Latvia .....305
- 41. ALTERNATIVES TO ENERGY RECOVERY OF FATS FROM NATURAL LEATHER**, Dr. Gheorghe COARA, Dr. Luminita ALBU, Prof. Dr. Margareta Stela FLORESCU, Lecturer Dr. Raluca MOCANU, Prof. Dr. Gheorghe LAZAROIU, INCDTP-Div. Leather and Footwear Research Institute ICPI, Romania.....313
- 42. ECOLOGICAL OR MINIMUM PERMISSIBLE FLOW IN RIVERS AS A TOOL CONCERNING RIVER ECOSYSTEMS HEALTHY FUNCTION**, Assoc. Prof. Dr. Mila Chilikova-Lubomirova, Institute of Mechanics - BAS, Bulgaria .....321
- 43. ECOLOGICAL POLICY MEASURES AND THE ENVIRONMENTAL IMPACT**, Lecturer Prof. Ph.D. Dana Constantinescu, Assoc. Prof. Ph.D. Marian Nicolae, Prof. Ph.D. Floarea Nicolae, Lecturer Prof. Ph.D. Violeta Grigore, Ph.D Student Simona Laura Turcu, Bioterra University of Bucharest, Romania .....329
- 44. EFFECT OF PAINTING LINE MODERNIZATION ON HEALTH OF LOCAL INHABITANTS**, Stanislav Bartusek, Alexander Skacel, VSB-Technical University of Ostrava, Czech Republic .....335
- 45. EFFECT OF RADIOACTIVE METAL IONS IN WHEAT: IN SEARCH FOR A BIOCHEMICAL MARKER**, Manuela Murariu, Karin Popa, Petru Poni Institute of Macromolecular Chemistry - Iasi, Romania.....345
- 46. EFFECTIVE METHODS OF PURIFICATION OF EXHAUST GASES OF TPP FROM SULFUR-CONTAINING COMPOUNDS**, Ponomarenko Oksana, Matveyeva Iona, Beisembayeva Luisa, Romanova Sofiya, al-Faraby Kazakh National University, Kazakhstan.....353
- 47. ELECTROCHEMICAL DETERMINATION OF LEAD IN WATER SAMPLES USING MODIFIED ELECTRODE BASED ON POLYAZULENE DERIVATES**, Mihaela-Eleonora Ungureanu, Gabriela-Geanina Vasile, Georgiana Luiza Arnold, Liviu Birzan, George-Octavian Buica, INCD ECOIND, Romania .....359
- 48. ELEMENTS-INDICATORS OF GEOCHEMICAL SITUATIONS IN THE SOUTH OF SIBERIA (RUSSIA) IN THE COMPOSITION OF MEADOWSWEET (FILIPENDULA ULMARIA (L.) MAXIM)**, Baranovskaya N.V., Mezhibor A.M., Chernenkaya E.V. , Kolesnikova E.A., Sobolev I.S., Tomsk Polytechnic University, Russia.....365

|   |     |
|---|-----|
| <b>49. ENVIROMENTAL FOOTPRINT ENTERPRISE AS INDICATOR OF BALANCE IT'S ACTIVITY</b> , Prof. Dr. Olena Mitryasova, Prof. Dr. Volodymyr Pohrebennyk, Dr. Anna Kochanek, Mas. Oksana Stepanova, State Higher Vocational School Nowy Sacz, Poland.....                                       | 371 |
| <b>50. ENVIROMENTAL TECHNOLOGY VERIFICATION: THE EUROPEAN SCHEME AS A NEW QUALITY IN VALIDATING THE PERFORMANCE OF ECOINNOVATION</b> , PhD. Eng. Michal Molenda, MSc. Izabela Ratman-Klosinska, PhD. Erika Sujova, Silesian University of Technology, Poland .....                      | 379 |
| <b>51. ENVIRONMENTAL PROTECTION THROUGH AUTOMATED MONITORING OF STEAM TEMPERATURE IN THE WORK INSTALLATIONS OF COMPOUND FEED FACTORIES</b> , Cristian VASILE, Mihnea GLODEANU, Tudor ALEXANDRU, University Of Craiova, Romania.....   | 387 |
| <b>52. ENVIRONMENTAL RISK ASSESSMENT BY RISK MATRIX METHOD</b> , Tamara Radu, Licia Balint, Gina.G. Istrate, Beatrice Tudor, Dunarea de Jos University of Galati, Romania.....  | 395 |
| <b>53. ECOLOGIC AND SAFE TISSUE PAPER PROCESSING</b> , Janka Mullerova, Iveta Coneva, University of Zlina, Slovakia .....   | 403 |
| <b>54. ER (III) SOLVENT SUBLATION FROM DILUTE AQUEOUS SOLUTIONS</b> , Assoc. Prof. Dr. Olga Lobacheva, Assoc. Prof. Dr. Igor Berlinskij, NATIONAL MINERAL RESOURCES UNIVERSITY, Russia .....  | 409 |
| <b>55. EVALUATION OF POTENTIAL GROWTH OF GULLY LENGTH ON HILLSIDE CATCHMENTS IN THE SOUTH OF WESTERN SIBERIA (BIYACHUMYSH ELEVATION AS A CASE STUDY)</b> , PhD Vadim Skripko, Altai State University Faculty of Geography, Russia.....  | 417 |
| <b>56. EVALUATION OF SURFACE WATER QUALITY IN MINING AND CHEMICAL INDUSTRY</b> , Prof. Dr. Volodymyr Pohrebennyk, Prof. Dr. Olena Mitryasova, Ms. Elvira Dzhumelia, Dr. Anna Kochane, State Higher Vocational School Nowy Sacz, Poland.....   | 425 |
| <b>57. EVOLUTION OF ADMINISTRATIVE TERRITORIAL UNITS AND THEIR INFLUENCE ON SUSTAINABLE DEVELOPMENT</b> , Pisleaga Mihaela, Eles Gabriel, Popescu Daniela, Stefanescu Camelia, Politehnica University of Timisoara, Romania.....  | 433 |
| <b>58. EXPERIMENTAL COMPARISON OF THE FIRE EXTINGUISHING PROPERTIES OF THE FIRESORB GEL AND WATER</b> , Galla Stefan, PhD.,Stefanicky Branislav, PhD., Assoc. prof. Majlingova, Andrea, PhD, Fire Research Institute of the Ministry of Interior of the Slovak Republic, Slovakia ..... | 439 |

|   |     |
|---|-----|
| <b>59. EXPERIMENTAL INVESTIGATION OF SORPTION OF MICROELEMENTS FROM MINE DRAINAGE ON ZEOLITE AND CLAY,</b> Makarova M.A., Abrosimova N.A., Rybkina E.O., Fayzullina R.V., Nikolaeva I.Yu., Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch RAS, Russia .....                  | 447 |
| <b>60. EXPERIMENTAL MEASUREMENTS AND TRNSYS SIMULATIONS OF ENERGY CONSUMPTION AND ENERGY EFFICIENCY OF HVAC SYSTEMS IN COOLING MODE IN OFFICE BUILDINGS,</b> Assoc. Prof. Dr. Mihai Ioan Cinca, Lect. Dr. Marius Adam, Assoc. Prof. Dr. Olga Bancea, Politehnica University of Timisoara, Romania ..... | 455 |
| <b>61. EXPERIMENTAL RESULTS REGARDING THE GROUNDWATER QUALITY IN RURAL ZONE IN ROMANIA,</b> Irimia Oana, Tomozei Claudia, Nedeff Valentin, Mirela Panainte Lehadus, Vasile Alecsandri University of Bacau, Romania.....   | 465 |
| <b>62. FEATURES OF DISTRIBUTION OF NICKEL IN SOILS OF THE ROSTOV REGION,</b> Kohanistaya N.V., Southern Federal University, Russia .....  | 471 |
| <b>63. FEATURES OF THE ORGANIC CARBON DISTRIBUTION AND ITS RELATIONSHIP WITH CONTENTS OF HEAVY METALS IN BOTTOM SEDIMENTS OF THE NORTHERN DVINA RIVER MOUTH AREA,</b> Zimovets A.A., Ovsepyan A.E., Fedorov Yu.A., Savitsky V.A., Southern Federal University, Russia .....                             | 479 |
| <b>64. FLOOD PROTECTION IN ZBOROV, SLOVAKIA - ENVIRONMENTAL IMPACT ASSESSMENT,</b> Vlasta Ondrejka Harbulakova, Martina Zelenakova, Daniel Constantin Diaconu, Cristian Constantin Draghici, Technical University of Kosice, Slovakia .....   | 487 |
| <b>65. FORMERLY USED SITES AND BARRIERS FOR FUTURE DEVELOPMENT,</b> Assoc. Prof. Ing. Ph.D. Barbara Vojvodikova, Ing. Natalie Szeligova, Ing. Marek Teichmann, VSB-Technical University of Ostrava, Czech Republic.....   | 495 |
| <b>66. FUNCTIONALIST ARCHITECTURE OF BATA COMPANY IN THE CITY ZLIN,</b> Martin Klempa, Petr Bujok, Eva Hrabinova, Jakub Ryba Martin Blaha, VSB-Technical University of Ostrava, Czech Republic .....  | 503 |
| <b>67. GAS COMPOSITION OF SULPHIDE MUD OF ANAPA DISTRICT,</b> SRA, PhD. Dmitry Garkusha, Prof. Dr. Yury Fedorov, St. Roman G. Trubnik, Southern Federal University, Russia.....   | 513 |
| <b>68. GENERALIZED IDEAS ABOUT THE STRUCTURE OF OIL DISPERSED SYSTEMS,</b> Kuzhaeva A.A., Dzhevaga N.V., Saint-Petersburg Mining University, Russia .....   | 521 |

- 69. GEOCHEMISTRY OF LAKE KULTUBAN (SOUTH URALS): THE IMPACT OF NATURAL AND ANTHROPOGENIC FACTORS ON THE CHEMICAL COMPOSITION OF THE SOILS, PLANTS, WATER, BOTTOM SEDIMENTS AND HYDROBIONTS**, A.Ju. Opekunov, M.G. Opekunova, V.V. Somov, Saint Petersburg State University, Russia.....529
- 70. GEOECOLOGICAL STUDY OF THE SYSTEM OF THE HUMAN-MADE LAKES GOLUBYE OZYORA**, Assoc. Prof. Elena Demenchuk, Immanuel Kant Baltic federal university Geography and Geoecology Faculty, Russia.....537
- 71. GEOGRAPHIC PARTICULARITIES OF THE TOURISM IN VULCANA-BAI COMMUNE, SENCOVICI MIHAELA**, Valahia University of Targoviste, Romania.....545
- 72. GEOSPATIAL ANALYSIS OF ENVIRONMENTAL RISKS OF UNAUTHORIZED DUMPS**, Assoc. Prof. Iraida Kirilchuk, Assoc. Prof. Vasily Yushin, Assoc. Prof. Vladislav Protasov, Southwest State University, Russia .....553
- 73. GREEN PATH AS A BUSINESS STRATEGY FOR RUSSIAN MANUFACTURING COMPANIES: CHALLENGES AND OPPORTUNITIES**, Nadezhda Shmeleva, National University of Science and Technology `M I Si S`, Russia .....559
- 74. HEAVY METALS AND PHYSICO-CHEMICAL CONDITIONS IN THE WATER OF THE SEA OF AZOV**, Assoc. Prof. Irina Dotsenko, Prof. Yury Fedorov, Sen.Lect. Anna Mikhailenko, Southern Federal University, Russia.....567
- 75. HYDROCARBON MARKERS OF THE GEOCHEMICAL BARRIERS**, Aleksandr Khaustov, Margarita Redina, Peoples Friendship University of Russia (RUDN University), Russia.....575
- 76. IDENTIFYING THE SOURCES OF POLLUTION IN THE BRAD AREAS CLOSED MINING**, Emilia-Cornelia Dunca, Tiberiu Rusu, Daniela-Ionela Ciolea, Iustin Olariu, University of Petrosani, Romania .....583
- 77. INCIDENCE OF INVASIVE NATIVE AND NON-NATIVE SPECIES IN PERMANENT GRASSLANDS FROM WESTERN ROMANIAN CARPATHIANS**, Sarateanu Veronica, Durau Carmen Claudia, Cotuna Otilia, Rechitean Dorin, Banat s University of Agricultural Sciences and Veterinary Medicine from Timisoara, Romania.....591
- 78. IRON: DISTRIBUTION, MODES OF OCCURRENCE AND MIGRATION INTO SURFACE WATERS OF THE EASTERN DONBASS**, Prof. Yuri Fedorov, PhD Lyudmila Predeina, PhD st. Leonid Dmitrik, PhD Irina Dotsenko, Southern Federal University, Russia.....597

- 79. LEGAL POSSIBILITIES OF THE RESCUE FORCES DURING THE EMERGENCY EVENT**, Janka Mullerova, Mojmir Mamojka, University of Zlina, Slovakia .....605
- 80. MAJOR TRENDS OF SCIENTIFIC AND EDUCATIONAL TOURISM DEVELOPMENT IN WESTERN MONGOLIA (KHOVD AIMAG AS A CASE STUDY)**, Sofya Platonova, Institute for Water and environmental Problems Siberial Branch of the RAS, Russia .....613
- 81. MANAGEMENT OF COMMUNAL SEWAGE SLUDGE IN POLAND**, M.Sc. Eng. Tymoteusz Turlej, AGH University of Science and Technology, Poland .....619
- 82. MANAGEMENT OF COMMUNAL WASTE IN POLAND**, M.Sc. Eng. Tymoteusz Turlej, AGH University of Science and Technology, Poland .....627
- 83. MEASUREMENT OF THE NOISE LEVEL OF THE TAILORS**, Tomozei Claudia, Irimia Oana, Nedeff Valentin, Mirela Panainte Lehadus, Vasile Alecsandri University of Bacau, Romania .....635
- 84. METAL ACCUMULATION IN SALVIA OFFICINALIS GROWN IN CONTAMINATED SOIL FROM A WASTE MINING DUMP**, Cristina Dinu, Gabriela-Geanina Vasile, Mihaela-Eleonora Ungureanu, Lidia Kim, Liliana Valeria Cruceru, INCD ECOIND, Romania .....643
- 85. METHANE AND HYDROGEN SULFIDE PELOIDS ARE IN BIG LAKE TAMBUKAN**, Prof. Dr. Yury Fedorov, SRA, PhD. Dmitry Garkusha, Southern Federal University, Russia .....651
- 86. METHANE AND HYDROGEN SULFIDE: FORMATION AND DISTRIBUTION IN BOTTOM SEDIMENTS OF THE EASTERN DONBASS SMALL RIVERS**, Prof. Yury Fedorov, PhD Dmitry Garkusha, PhD st. Roman Trubnik, Southern Federal University, Russia .....659
- 87. METHODS TO REDUCE NITROGEN POLLUTION IN SWINE FARMS BY USING SYNTETIC AMINO ACIDS AND VOLCANIC TUFF**, Monica Marin, Carmen Georgeta Nicolae, Dumitru Dragotoiu, Georgeta Dinita, Elena Pogurschi, University of Agronomic Science and Veterinary Medicine - Bucharest, Romania .....667
- 88. MODERN METHODS OF ENVIRONMENTAL MONITORING FOR INDUSTRIAL GAS EMISSION**, Suad Zuher El Salim, Cheremisina O.V., Sergeev V.V., Fedorov A.T., Ilina A.P, CEO, Limited Liability Company "Omega", Russia ...673
- 89. MONITORING HEAVY METALS IN BOTTOM SEDIMENTS ON EAST OF SLOVAKIA AND THEIR COMPARISON WITH CURRENT LEGISLATION**, Dr. Eva Singovszka, Petra Pavlikova, Prof. Dr. Magdalena Balintova, Technical University of Kosice - Faculty of Civil Engineering, Slovakia .....681

- 90. MULTISPECTRAL TELEVISION MEASUREMENTS OF PARAMETERS OF NATURAL BIOLOGICAL MEDIA**, Dr Sergey Kvaternyuk, Prof., Dr Volodymyr Pohrebennyk, Dr Roman Petruk, Dr Anna Kochanek, Olena Kvaternyuk, State Higher Vocational School Nowy Sacz, Poland .....689
- 91. NATURAL RESERVES OF ROMANIA. A STUDY CASE OF MEADOWS WITH DAFFODILS**, Vasca Zamfir Diana and Slave Camelia, University of Agronomic Science and Veterinary Medicine - Bucharest, Romania.....697
- 92. OBSERVATIONS REGARDING THE AGRONOMIC AND USE VALUE OF POTATO VARIETIES IN SOUTHERN MUNTENIA’S ECOSYSTEMS**, Loredana Beatrice Neagu Frasin, Razvan Ionut Teodorescu, Valahia University of Targoviste, Romania.....705
- 93. ON THE DYNAMICS OF MERCURY IN THE MOUTH AREA WATERS OF THE NORTHERN DVINA RIVER FOR A 10-YEAR OBSERVATION PERIOD**, Assoc. Prof. Asya Ovsepyan, Senior Lect. Alina Zimovets, Prof. Yury Fedorov, Southern Federal University, Russia .....713
- 94. OPTIMIZATION OF SCREENING METHOD FOR DETERMINATION OF ALKYLPHENOLS IN WATER SAMPLES BY SOLID-PHASE MICROEXTRACTION**, M. Alimzhanova, Y. Adilbekov, A. Zharylgap, D. Onglassynkyzy, A. Alipuly, Center of Physical Chemical Methods of Research and Analysis, al-Farabi KazNU, Kazakhstan .....721
- 95. OPTIMIZATION OF THE SAMPLE PREPARATION PARAMETERS IN CRUDE OIL ANALYSIS**, M. Alimzhanova, M. Sergazina, Y. Adilbekov, S. Azmagambetova, Center of Physical Chemical Methods of Research and Analysis, al-Farabi KazNU, Kazakhstan .....729
- 96. PGPR-BACTERIA AND THEIR CAPACITIES TO ELIMINATE LEAD USING PHYTOREMEDIATION**, Ing. Veronika Molinkova, Ing. Aneta Babicova, Ing. Marek Dlabaja, VSB-Technical University of Ostrava, Czech Republic .....737
- 97. PHYSICAL AND CHEMICAL AND HYDROLOGICAL CONDITIONS AS A FACTOR INFLUENCING THE DISTRIBUTION AND BEHAVIOR OF MERCURY IN THE SMALL RIVERS OF THE SUBARCTIC AREA OF THE EUROPEAN TERRITORY OF RUSSIA.**, Fedorov Yu.A., Savitsky V.A., Zimovets A.A., Ovsepyan A.E., Southern Federal University, Russia .....747
- 98. POST-CLOSURE MONITORING THROUGH THE WIRELESS SENSORS AND MICROCONTROLLERS TO BRAD MINING AREA**, Emilia-Cornelia Dunca, Tiberiu Rusu, University of Petrosani, Romania .....751
- 99. POTENTIAL AND POSSIBILITIES REMEDIATION THE TERRITORY AFTER MINING (CASE STUDY OF RUDNANY, MIDDLE SPIS, SLOVAKIA)**, Juliana Krokusova, Eva Michaeli, Vladimir Solar, Monika Ivanova, University of Presov in Presov, Slovakia .....757

|   |     |
|---|-----|
| <b>100. PRELIMINARY STUDIES OF ZOOPLANKTON COMMUNITIES AND ASSESMENT OF THE ECOLOGICAL STATUS OF LAKE SUTURUOHA (NE SIBERIA, RUSSIA),</b> L. Frolova, G. Nigamatzyanova, D. Subetto, L. Pestryakova, Kazan (Volga Region) Federal University, Russia .....  | 765 |
| <b>101. RATIONAL USE OF SCIENCE OF CHEMISTRY AS A FACTOR FOR ENVIRONMENTAL SAFETY AND ENSURING ECOSYSTEM PURITY,</b> Prof. Dr of Chemical Sciences Vadim E. Kogan, Associate professor, PhD in Chemistry Tamara S. Shakhparonova, Saint-Petersburg Mining University, Russia.....   | 773 |
| <b>102. REGIONAL RISK RANKING FOR INTEGRATED LAND-SEA RESOURCE MANAGEMENT,</b> Rodney L. Stevens and Environmental Geology Course Participants, University of Gothenburg, Sweden .....  | 781 |
| <b>103. RELATIONSHIP BETWEEN VEGETATION BIODIVERSITY AND SOIL FUNCTIONAL DIVERSITY OF ALKALIZED SOIL IN THE EMISSION AREA OF MAGNESIUM FACTORY JELSAVA – LUBENHK (SLOVAKIA),</b> Ing. Juraj Fazekas, prof. Ing. Danica Fazekasova, PhD., Mgr. Zuzana Boguska, PhD., Mgr. Petra Hulicova, PhD., doc. Ing. Peter Adamisin, PhD., University of Presov in Presov, Slovakia ..... | 789 |
| <b>104. REMOTE MONITORING APPLICATION WITH DATA PREDICTION ALGORITHM,</b> Dumitrascu Alexandru, Politehnica University of Bucharest, Romania.....   | 797 |
| <b>105. RESEARCH AND PROPOSALS TO USE SLUDGE ON WASTE DUMPS LUPENI, ROMANIA,</b> Daniela Ionela Ciolea, Emilia Cornelia Dunca, University of Petrosani, Romania.....  | 805 |
| <b>106. RESEARCH ON GENERAL DATA TO LOOK AT DEFORESTATION IN ROMANIA: PROBLEMS AND POSSIBLE CONSEQUENCES,</b> Assoc. Prof. Ph.D. Marian Nicolae, Prof. Ph.D. Ion Nicolae, Biologist Ph.D Student Simona Laura Turcu, Lecturer Prof. Ph.D. Dana Constantinescu, Student Repanovici Francisc, Bioterra University of Bucharest, Romania.....                                    | 813 |
| <b>107. RESEARCH ON OREOCHROMIS NILOTICUS INCREASING IN ROMANIAN AQUACULTURE,</b> Lect. Ph.D. Daniela Cristiana Alexandrescu, Ph.D. Eng. Mioara Costache, Valahia University of Targoviste, Romania .....   | 821 |
| <b>108. RESEARCHES AND PROPOSALS ON THE ECO-RECOVERY BY COMBINED METHODS OF THE SLUDGE RESULTED IN URBAN WASTEWATER TREATMENT,</b> Daniela Ionela Ciolea, University of Petrosani, Romania.....   | 827 |
| <b>109. RISK ANALYSIS WITHIN ENVIRONMENTAL IMPACT ASSESSMENT – A REVIEW,</b> Martina ZELENKOVA, Lenka ZVIJAKOVA Daniel PEPTENATU, Radu-Daniel PINTILII, Technical University of Kosice, Slovakia .....  | 835 |

- 110. RISK ASSESMENT REVIEW OF HEVY METAL ACCUMULATIONS (Cu, Cr, Ni, Pb AND Zn) IN S. BREVIS-BUSHEHR AREA**, Afsoon Moatari-Kazerouni, Rhodes University, South Africa.....843
- 111. SECONDARY POLLUTION IN WATER SUPPLY SYSTEM ON THE EXAMPLE THE OPOLE CITY**, Iwona Klosok-Bazan, Paulina Kotas, Opole Technical University, Poland .....853
- 112. SINGLE STEP METAL AND SULPHATE PRECIPITATION, A PARTICULAR SUITABLE MINE WATER CASE**, L.R. Dinu, I. Cristea, V. Dediu, M. Stefanescu, M.A. Constantin, National Research and Development Institute for Industrial Ecology - ECOIND, Romania.....861
- 113. SMALL-SCALE SIMULATION OF ROOM FIRE INCLUDING WOOD AND PLASTIC MATERIAL**, Jana Mullerova, Maros Krajcir, University of Zlina, Slovakia .....869
- 114. SPATIAL DISTRIBUTION MODELING OF THANATOPHILUS SINUATUS (COLEOPTERA: SILPHINAE) IN THE CZECH REPUBLIC**, Pavel Jakubec, Jan Ruzicka, Czech University of Life Sciences Prague, Czech Republic .....875
- 115. SPECIFIC GEOGRAPHIC RISKS AFFECTING THE TOURISM RESORT OF PRAID, ROMANIA**, Attila Peteley, Adrian Nita, Vasile Mara, Mihaly Seer, George-Bogdan Tofan, Babes-Bolyai University, Romania.....883
- 116. SPECIFIC STRUCTURAL FEATURES OF ZOOPLANKTON OF POLYGONAL POND (LENA RIVER DELTA, RUSSIA, ARCTIC)**, G. Nigamatzyanova, L. Frolova, Kazan (Volga Region) Federal University, Russia .....891
- 117. STRUCTURE THE LANDSCAPE IN THE INDUSTRIAL TOWN KROMPACHY IN TIME HORIZON 1958 – 2009 THE SLOVAK REPUBLIC**, Eva Michaeli, Monika Ivanova, Vladimir Solar, Matej Hruska, University of Presov in Presov, Slovakia .....899
- 118. STUDIES FOR DEVELOPING AN AUTOMATION SYSTEM FOR RECYCLING THE FLOAT RESULTED FROM THE PICKLING PROCESS OF BOVINE HIDES**, Ass. Prof. Dr. Bogdan HANCHEVICI, Dr. Gheorghe COARA, Dr. Luminita ALBU, Dr. Gheorghe BOSTACA, Eng. Eugen ALBU, INCDTP-Div. Leather and Footwear Research Institute ICPI, Romania.....907
- 119. STUDY OF ION - EXCHANGE PROCESS FOR SULPHATE REMOVAL UNDER DYNAMIC CONDITIONS**, Petra Pavlikova, Prof. Dr. Magdalena Balintova, Stefan Demcak, Technical University of Kosice - Faculty of Civil Engineering, Slovakia .....913
- 120. STUDY ON PARAMETERS OF USED WATER IN A CHEESE-PROCESSING FACTORY**, Gabriela Constantinescu, Amelia Buculei, Monica Dinu, Delia Cerlinca, Stefan cel Mare University of Suceava, Romania.....921

- 121. INDUSTRIAL ACTIVITY ON THE PRECIOUS AREA OF NATURAL SUCCESSION OF A CLOSED FLOTATION TAILINGS DISPOSAL FACILITY**, Izabela Kotarska , Barbara Mizera, Foundation for Lower Silesian Mineral Cluster, Poland .....929
- 122. TECHNOLOGY OF PROCESSING OF APATITES IN THE PRODUCTION OF FUSED PHOSPHATES AS MODERN HIGHLY EFFECTIVE FERTILIZERS**, Karapetian K.G., Dzhevaga N.V., Saint-Petersburg Mining University, Russia.....939
- 123. THE ACTIVITY OF SOIL PHOSPHATASE ON THE METALLIC AND ALKALINE CONTAMINATED SOILS**, Mgr. Petra Hulicova, PhD., Prof. Ing. Danica Fazekasova, PhD., Ing. Juraj Fazekas, University of Presov in Presov, Slovakia .....947
- 124. THE ENVIRONMENTAL BENEFITS OF THE USE OF ALTERNATIVE FUELS FOR SINTERING PROCESS**,  
doc. Ing. Pavlina Pustejovska, Ph.D., Bc.Michal Sikora, Ph.D., doc.Ing. Silvie Brozova.  
Ing. Simona Jursova,, VSB-Technical University of Ostrava, Czech Republic .....955
- 125. THE INFLUENCE OF THE BENTONITE PARTICLES ON OPERATING PROPERTIES OF GELATIN/STARCH/GLYCEROL/BENTONIT BIOCOMPOSITE FILMS**, PhD student Maria Zakharova, Prof. Mayya V. Uspenskaya, Aleksandr Podshivalov A., ITMO University, Russia .....961
- 126. THE INTERACTIVE VIDEOTOUR AND ITS USE FOR GEOTOURISM DEVELOPMENT OF FORGOTTEN ARTIFICIAL WATER RESERVOIRS IN SELECTED MINING AREA**, Tometzova Dana, Hlavnova Barbara, Technical University of Kosice, Slovakia.....967
- 127. THE OPTIMIZATION OF THE NANOFILTRATION (NF) CONCENTRATE RECIRCULATION FOR PHOSPHORUS RECOVERY IN MBR WASTEWATER TREATMENT**, R. Zgavarogea, V. Niculescu, N. Paun, A. Iordache, M. Miricioiu, National Institute for Research and Development for Cryogenics and Isotopes Technologies - ICSI Rm.Valcea, Romania .....973
- 128. THE PRINCIPLES OF ECOTOURISM - INDICATOR FOR THE DEVELOPMENT OF ECOTOURISM DESTINATIONS**, Iuliana Ioana Merce, Elena Pet, I. Petroman, T. Iancu, Ioana Anda Milin, University of Agricultural Science and Veterinary Medicine of Banat Timisoara, Romania .....979
- 129. THE RELATIONS BETWEEN THE LIVING ORGANISMS AND THE EDAPHIC FACTOR**, SENCOVICI MIHAELA, Valahia University of Targoviste, Romania.....985

- 130. THE RISK OF SPREAD OF INVASIVE PLANTS IN THE FLOODPLANE OF THE OSTRAVICE RIVER (CZECH REPUBLIC)**, Barbara Stalmachova, Emilie Pecharova, Alena Kasparkova, VSB-Technical University of Ostrava, Czech Republic.....993
- 131. THE STUDY OF MECHANISM OF THE OXIDATIVE DESULPURISATION**, Berlinskii I.V., Kuzhaeva A.A., NATIONAL MINERAL RESOURCES UNIVERSITY, Russia .....1001
- 132. THE TOXIC EFFECTS OF AIR POLLUTION CAUSED BY THERMAL POWER SE PAROSENI ACTIVITY ON THE SPECIES OF ACACIA**, Emilia-Cornelia Dunca, Tiberiu Rusu, Daniela-Ionela Ciolea, Iustin Olariu, Andras Iosif, University of Petrosani, Romania.....1009
- 133. THE USE OF ENVIRONMENTALLY-FRIENDLY MATERIALS IN HARMONY WITH THE EUROPEAN LEGISLATION TO THE CONSTRUCTION OF ENERGY PASSIVE DWELLINGS**, Bogdan-Gabriel Carp, Daniela Laura Buruiana, Stefan Dragomir, Elena Lacramioara Lisa, University "Dunarea de Jos", Romania .....1017
- 134. THE USE OF VERTICAL ELECTRICAL SOUNDING BY THE METHOD OF TWO COMPONENTS FOR ALLOCATION OF AN INITIAL PHASE OF A LANDSLIDE**, O.R. Kuzichkin, N.V. Dorofeev, A.V. Grecheneva, A.A. Bykov, R.V. Romanov, Vladimir State University named after Alexander Grigoryevich and Nickolay Grigoryevich Stoletovs - Faculty of Information Technology, Russia .....1025
- 135. TREATMENT OF NEUTRAL MINE WATERS FROM METALS AND METALLOIDS**, Natalya Abrosimova, Olga Saeva, Natalya Yurkevich, Svetlana Bortnikova, Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch RAS, Russia .....1033
- 136. TREATMENT OF PULP AND PAPER PLANT WASTEWATERS USING AN ANAEROBIC MEMBRANE BIOREACTOR**, Prof. Dr. Leonid Gubanov, Assoc. Prof. Dr. Inna Katraeva, Assoc. Prof. Elena Moralova, Researcher Dr. Elza Mikheeva, Prof. Dr. Elena Petrova, Nizhny Novgorod State University of Architecture and Civil Engineering, Russia .....1041
- 137. TURISM DEVELOPMENT VERSUS SUSTAINABLE MANAGEMENT IN NATURA 2000 SITES. STUDY CASE: ROMANIAN SECTOR OF THE BLACK SEA COAST**, Mioara Clius, Madalina Ristea, Mihai Mustatea, University of Bucharest, Romania.....1047
- 138. URBAN ECOLOGICAL ANALYSIS OF LOCAL GEOSYSTEMS ON THE EXAMPLE OF THE CITY OF KAZAN**, Ulengov R.A., Urazmetov I.A.,, Kubyshkina E.N., Kazan (Volga Region) Federal University, Russia.....1055

- 139. URBAN ECOSYSTEMS FUNCTION AND SERVICES. CHALLENGES WITH REGARD TO THE ENVIRONMENTAL CONDITIONS**, Assoc. Prof. Dr. Mila Chilikova-Lubomirova, Institute of Mechanics - BAS, Bulgaria .....1063
- 140. USING HYDRODYNAMIC CAVITATORS FOR WASTEWATER POST-TREATMENT AND DESINFECTION**, Assoc. Prof. Dr. Dmitry Mizgiriyov, Prof. Dr. Aleksandr Kurnikov, Assoc. Prof. Dr. Inna Katraeva, Assoc. Prof. Elena Moralova, Researcher Dr. Elza Mikheeva, Nizhny Novgorod State University of Architecture and Civil Engineering, Russia .....1071
- 141. WATER QUALITY IN THE RIVER BASIN DESNATUI, DOLJ COUNTY, ROMANIA**, Ana Maria Dodocioiu, Diana Gilda Buzatu, Gheorghe Matei, University Of Craiova, Romania .....1077
- 142. WEED FLORA IN VINEYARDS OF RAHOVEC MUNICIPALITY**, Rozafa Fetahaj, Prof.Arben Mehmeti, Prof.Adem Demaj, Prof.Enver Sherifi, Prof.Rainer Waldhardt, University of Prishtina "Hasan Prishtina", Kosovo .....1085

## COMPARATIVE ENVIRONMENTAL ANALYSIS OF WASTE PROCESSING METHODS IN PAPER RECYCLING

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### ABSTRACT

The paper deals with processing the waste generated in paper recycling: initial waste of paper mill and sludge after wastewater treatment. The authors have analyzed characteristics of the waste of paper recycling generated in paper recycling plant near Kyiv (Ukraine): calorific value, moisture and ash content. The heating value of waste of paper recycling range from 6.5 to 24 kJ/kg and significantly depends on moisture content. Potential environmental impact depends largely on the physical and chemical characteristics of the waste, first of all on humidity and composition. For comparative analysis, investigated waste (a mixture of initial waste of paper mill and sludge, equal weights) has been thermally processed by several existing methods (used in thermal processing of other waste types): incineration in rotary kiln, incineration in grate incinerator and plasma melting. Each equipment had the same minimal gas cleaning system configuration. The environmental performance of waste processing was experimentally identified. The concentrations of the most common pollutants emitted into the air were measured: fine particles (dust), nitrogen oxides, carbon monoxide, sulfur dioxide and hydrogen chloride. Incineration in rotary kiln had over-limit emissions for dust and carbon monoxide, hydrogen chloride concentration was close to the limit. For nitrogen oxides and sulfur dioxide limit excess was not observed. Grate incinerator provided over-limit concentrations for all measured substances except nitrogen oxides. The greatest excess was observed for dust and carbon monoxide (7-8 times). When using plasma melting the authors have measured over-limit concentration only for nitrogen oxides. The data received indicate that regarding to environmental performance the best incineration method for recycling paper waste among those analyzed is plasma melting. Besides, one can assume that minimal gas cleaning system for such incinerators is not enough to capture pollutants effectively.

**Keywords:** waste paper, paper recycling waste, thermal processing, waste processing, environment

### INTRODUCTION

It is known, that waste paper is characterized by one of the highest recycling level among all waste types and it is widely used to produce a large number of new products. Also, paper recycling plants are among Europe's largest producers of alternative energy

[1]. Volume of recycling paper is constantly growing. According to research [2], this is not only due to the improvement of technology, but also due to awareness by natural resources depletion.

However, during the recycling of waste paper containing impurities, new waste is generated. Waste composition and both physical and chemical properties depend on the quality and type of paper as is shown by the authors [3]. Initial waste is generated just after paper mill. This waste contains paper fibers (cellulose and its derivatives) and many other substances: polyethylene, polypropylene, polystyrene, polyethylene terephthalate (PET), fluorocarbon-based polymers, polyvinyl chloride, polyamide, fillers and binders, surfactants, adhesives, bleaches, traces of heavy metals and other [4, 5, 6, 7]. Also, this waste contains textiles and metal inclusions. Besides, after further operations of waste paper recycling, other waste is generated. This is wastewater sludge containing the remains of paper fibers, fillers and fine particles [6].

The specific form of such waste causes problems with its disposal. This is especially true for biosludge formed during biological treatment. Thus, the need of new waste processing arises. One of the most common ways of such waste handling is incineration for energy production. The incineration process can be not very efficient due to the high moisture and ash content of waste. Besides, the authors [10, 11] indicate that incineration for energy production in some cases can be even more efficient comparing to recycling, depending on the input and assessment criteria. Landfilling is also used, but it is much worse option due to environmental consequences (for example, the authors [8, 9] have proved negative effect of substances, contained also in waste of paper recycling, on living organisms).

From an environmental point of view, the main shortcomings of paper recycling waste incineration are potentially high levels of air pollution, including chlorine-containing compounds, and heavy metals concentrated in the ash. Thus, depending on the composition, physical and chemical characteristics of the waste and incineration method, an expensive gas cleaning system may be required. In order to reduce the incineration costs and provide compliance with emissions standards, it is worth to analyze the environmental performance of different methods that can be used for paper recycling waste incineration.

## **MATERIALS AND METHODS**

To make valid conclusions regarding to various incineration technologies, the authors have analyzed the waste of paper recycling generated in paper recycling plant near Kyiv (Ukraine). These include: initial waste generated in paper mill and wastewater sludge (final waste of paper production – dewatered sludge of wastewater treatment system, consists mainly of cellulose fibres). The following parameters were measured: calorific value (calorimeter B-08-MA), moisture content (drying cabinet SNOL-3,5.3,5.3,5/3,5-II), ash content (electric oven SNOL 8,2/1100).

For comparative analysis, investigated waste (a mixture of initial waste of paper mill and sludge, equal weights) has been thermally processed by several existing methods (used in thermal processing of other waste types): incineration in rotary kiln, incineration in grate incinerator and plasma melting. Each equipment had the same minimal gas cleaning system configuration: neutralization of acid gases by lime,

capturing filter for fine particles, soda injection solution for nitrogen oxides capturing. The environmental performance of waste processing was experimentally identified. The concentrations of the most common pollutants emitted into the air were measured: fine particles (dust), nitrogen oxides, carbon monoxide, sulfur dioxide (gas analyzer TESTO-335) and hydrogen chloride (gas analyzer UG-2). Measurements were carried out just after the gas cleaning system.

## RESULTS AND DISCUSSIONS

### *Characteristics of the paper recycling waste*

The initial waste of paper recycling mostly includes packaging tape (65%), mainly consisting of polyethylene or PVC film. Besides, there are also other polymers and textiles. Therefore, it is possible to use such waste for energy production as the initial waste mainly consists of polymers with high calorific value (see Table 1).

Table 1.

The calorific value of polymers in the initial waste of waste paper recycling

| Type of polymer                  | Calorific value, kJ/kg |
|----------------------------------|------------------------|
| Polyethylene                     | 47767                  |
| Polystyrene                      | 37800                  |
| Polypropylene                    | 45670                  |
| Polyethylene terephthalate (PET) | 21270                  |
| Fluorocarbon-based polymers      | 8130                   |
| Polyamide                        | 31000                  |
| Polyvinyl chloride (PVC)         | 21000                  |
| Textile                          | 27470                  |
| Mean value                       | 30013                  |

The results of waste characteristics measurement (Table 2) indicate a significantly greater energy potential of initial waste (waste of paper mill).

Table 2.

Characteristics of the paper recycling waste

| Parameter                  | Waste                       |        |
|----------------------------|-----------------------------|--------|
|                            | Initial waste of paper mill | Sludge |
| Net calorific value, kJ/kg | 14150                       | 4400   |
| Moisture content, %        | 43.7                        | 59.5   |
| Ash content, %             | 10.1                        | 44.4   |

In case of priority of waste processing over energy production, the initial waste of paper mill and sludge can be mixed. If this is done in equal weights, the total calorific value of the mixture is about 24000 kJ/kg for absolutely dry mixture. Moisture content significantly reduces calorific value (see Table 3).

Table 3.

Estimated calorific value of initial waste of paper mill and sludge mixture (equal weights)

| Moisture content, % | Calorific value, kJ/kg |
|---------------------|------------------------|
| 0                   | 24229                  |
| 10                  | 19952                  |
| 20                  | 17103                  |
| 30                  | 12826                  |
| 40                  | 9262                   |
| 50                  | 6486                   |

For measured moisture content, the calorific value of waste investigated is reduced more than twice. Therefore, it is essential to dry the waste before incineration. High moisture content, as well as high content of volatile substances in the paper recycling waste, strongly influences the incineration process, as also indicated in the research [12].

*The environmental performance of thermal processing of paper recycling waste*

Grate incinerator is the simplest and most common thermal method of waste treatment. It is characterized by low power consumption. However, during the incineration, there are about 25-30% of unburned waste remained on the grates, refractory slag and ash containing toxic substances (e.g. heavy metals) are also generated. These require special handling and disposal on special landfills creating new environmental problem. Another disadvantage is the need for significant excess air to ensure the completeness of waste incineration, which causes air emissions increasing.

Plasma melting method is more advantageous regarding to the environment. There are no hydrocarbons (including dioxins) in the emissions due to the high temperature (up to 3000°C). However, for the same reason, there is increased nitrogen oxides content. However, the undeniable disadvantage is huge energy consumption in order to provide high temperature. This results in large operational costs strongly limiting this method use.

The incineration in a rotary kiln has limited application due to technical features and is mainly used for hazardous waste combustion. The relatively low incineration efficiency for the waste similar to those under investigation causes the need for complex and expensive gas cleaning system.

Waste incinerators are designed so that the temperature of the gas generated during the waste incineration rise to at least 850°C for at least two seconds by the most unfavorable conditions. Besides, since waste of paper recycling usually contains a significant amount of polymers including those chlorinated, then according to [13] the required incineration temperature must be at least 1100°C. This is due to the need for dioxins and furans decomposition. When using grate incinerator this temperature is quite difficult to achieve, additional burner using fossil fuel is required. Considering this, plasma melting method is more environmentally friendly (incineration temperature is up to 3000°C). Although, nitrogen oxides emissions are increased as mentioned above.

Considering the measured concentrations of pollutants generated during the incineration of paper recycling waste, one may say that none of the methods investigated (with minimal gas cleaning system) ensure 100% compliance with European environmental standards (see Table 4).

Table 4.

Results of pollutant concentrations measuring, mg/m<sup>3</sup>

| Substance         | Waste incineration method |                   |                | EU limit [13] |
|-------------------|---------------------------|-------------------|----------------|---------------|
|                   | Rotary kiln               | Grate incinerator | Plasma melting |               |
| Dust              | 11                        | 85                | 5              | 10            |
| Nitrogen oxides   | 50                        | 137               | 211            | 200           |
| Carbon monoxide   | 190                       | 337               | 8              | 50            |
| Sulfur dioxide    | 43                        | 68                | 12             | 50            |
| Hydrogen chloride | 9                         | 17                | 2,5            | 10            |

#### *Dust*

Only use of plasma melting complied with air emissions standard. A significant limit excess was observed for grate incinerator.

#### *Nitrogen oxides*

Limit excess was measured only for plasma melting (explanation is given above). Much less nitrogen oxides emissions were found in rotary kiln.

#### *Carbon monoxide*

The same situation as for dust emissions: complying with standards for plasma melting, and strong excess for grate incinerator.

#### *Sulfur dioxide*

The use of rotary kiln and plasma melting complied with air emissions standard.

#### *Hydrogen chloride*

The concentrations below the limit were observed in plasma melting and rotary kiln with value close to the limit in latter incinerator.

Regarding to waste incineration methods, the results are as follows. Incineration in rotary kiln had over-limit emissions for dust and carbon monoxide, hydrogen chloride concentration was close to the limit. For nitrogen oxides and sulfur dioxide limit excess was not observed. Grate incinerator provided over-limit concentrations for all measured substances except nitrogen oxides. The greatest excess was observed for dust and carbon monoxide (7-8 times). When using plasma melting the authors have measured over-limit concentration only for nitrogen oxides.

The data received indicate that regarding to environmental performance the best incineration method for recycling paper waste among those analyzed is plasma melting. Besides, one can assume that minimal gas cleaning system for such incinerators is not enough to capture pollutants effectively.

It should be noted that incineration of paper recycling waste in the fluidized bed incinerators is also used. Such incinerators, according to the authors [14, 15], produce a large amount of carbon monoxide and dust, which is associated with high ash content in the waste of paper recycling. Also, the authors [12] studied the incineration of paper recycling waste with wood waste. However, these technologies were not studied in this paper due to technical reasons.

## CONCLUSION

Comparative analysis of thermal methods of paper recycling waste processing has shown that the potential environmental impact depends largely on the physical and chemical characteristics of the waste, first of all – on humidity and composition. Existing thermal methods and equipment for other waste types processing with minimal cleaning systems allow efficient processing of paper recycling waste, but do not provide the necessary level of environmental protection.

According to the results of laboratory measurements of pollutants concentrations, we can conclude that none of the methods under investigation with minimal gas cleaning system provides the appropriate treatment in accordance with regulations. Some advantage in environmental performance has plasma melting method, although it produces more nitrogen oxide emissions and is the most expensive at the same time.

The worst environmental performance has grate incinerator. The highest over-limit pollutants concentrations were observed for dust and carbon monoxide. Also, the results obtained show that minimal gas cleaning system for incineration of paper recycling waste is not enough to capture pollutants effectively.

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