BACKGROUND

The roots of Serbian technical civilization date as early as the time of the Nemanjics. Beginnings of engineering activities were associated with mining and metallurgical undertakings (Novo Brdo) and to building of magnificent medieval sacral structures of the Serbian state.

After the First (1804) and second Serbian Uprising (1815) the technical tradition was renewed and Serbian joined the then current European trends. First educated engineers came in Serbia from Austro-Hungarian Empire in 1830s. At that time, the main preoccupations of engineers were railway construction, town planning, construction of sewage disposal and water supply systems, as well as creating of national defense system. At that time 1834/35 from Austrian Empire arrived first schooled engineers France Janke and Franz Baron Kordon who served as so called “drzavni inzilirin” or state engineers.

In Serbia in the 19th century there were a total number of about 6000 engineers engaged in various activities. In an eighty–year period from 1834-1914 the State Construction Administration (which from 1880 also included railways) employed one third of these engineers. However other ministries were also competent for some engineering affairs like, for example the Ministry of Finance was responsible for mining, or the Ministry of Education and Church Affairs was responsible for education of technical stuff. From 1838 this primarily referred to the Licej: according to “Establishment of public institutions of learning” of 1844, the Department for Philosophy included also subjects such as Pure and Practical Geometry and Higher Mathematics, and Architecture, while in 1853 a separate Natural Sciences and Technical Department was introduced in the Licej and in 1863 the Great School with Technical Faculty started operating. The first classes held at the Technical Faculty of the Great School in 1863 marked turning point in schooling of Serbian engineers.

Out of some 600 engineers, approximately one third were schooled in Serbia and one fifth of them studied abroad as “state grants students”, while about one fourth were foreigners and Serbs from “across the Danube”.

In 1868 one of preconditions which might have contributed to professional associating of engineers was the numerosity of professionals and models from abroad established half a century earlier (engineering associations in Great Britain, Germany and America) had influence on establishing professional associations in Serbia.

The Founding Assembly of the Technicians’ Society was held on the 3rd February 1868 in the premises of Great School. Engineer Emilijan Josimovic was elected for the first President of the Society. It is important to mention that this happened only a year after Turkish commander in Belgrade Ali -Riza pasha gave the town and the fortress keys to duke Mihailo Obrenovic. Shortly afterward in 1869 was established Society for Agrarian Economy that is the Serbian Agricultural Society. Association of Serbian Engineers was established in 1890 while in 1896 was established the Association of Serbian Engineers and Architects.

The first scientific magazine published by this Association in 1890 was “Srpski tehnicki list” The
“Srpski tehnicki list” besides professional articles also published detailed information related to the work of the Association. The members at that time, who numbered around one hundred of them, initiated a whole series of issues and demand the same to be solved by the competent bodies. During the First World War, two volumes of “Srpski tehnicki list” were published in Thessaloniki. The magazine was initiated by the engineers and architects who were in Thessaloniki as members of the Serbian Army. In Thessaloniki was held the General Assembly of the Association in 1918 attended by 463 engineers.

During his short stay in Belgrade, in 1892, famous scientist Nikola Tesla was elected for the first honorary member of the Association of Serbian Engineers.

Providing assets from its own incomes, bank loans, gifts and donations of its organizations-members and its individual members Association built the House of Engineers in Belgrade, Kneza Milosa 7 str in 1932/35. The House of Engineers “Nikola Tesla” in Belgrade Kneza Milosa 9-11 str was built between 1962 and 1969. In the premises of these two Houses of Engineers besides the Union of Engineers and Technicians of Serbia today perform their activities 26 republic’s professional and multidisciplinary engineering-technicians’ associations out of 41 collective members of UETS.

Besides Emilijan Josimovic who was first President of the Technicians’ Society, prominent figure of that time, Rector of Licej and Great School and honorary member of the Serbian Royal Academy, to work of our Union contributed as well: Kosta Alkovic, professor at the Great School, Minister of Construction and member of Serbian Learned Society and Serbian Royal Academy, Dimitrije Stojanovic professor at the Technical Faculty, first Director of Serbian State Railways, and member of Serbian Learned Society and Serbian Royal Academy, Milos Savcic, Minister of Construction and President of Belgrade Municipality, famous businessman who gave the greatest donation for the construction of House of Engineers in 1932, as well as presidents of the Serbian Academy of Sciences and Arts Josif Pancic, Jovan Zujovic, Simo Lozanic, Kirilo Savic, Aleksandar Despic, Nikola Hajdin and other famous scientists.

ACTIVITIES

The Union of Engineers and Technicians of Serbia - Savez inženjera i tehnicara Srbije is a voluntary, non-governmental, non-profit, scientific, interest, professional, non-party organization of engineers and technicians, and their organizations in the Republic of Serbia, open for cooperation with other scientific, commercial and other organizations, on the basis of mutual recognition, mutual respect and independence in work.

Union of Engineers and Technicians of Serbia and its collective member finance their own activities from their own assets.

Purposes and tasks of UETS are:

- Assembling and organizing of engineers and technicians of Serbia for the purpose of increase of their expert knowledge, providing appropriate status in the community, on the basis of their contribution to the, scientific-technological and economic and development in general of Republic of Serbia;
- Joining, strengthening and massification of basic engineering-technicians’ organizations of Serbia, development of mutual cooperation as well as the cooperation with appropriate international organizations of engineers and technicians;
- Improvement of order-interest, reputation and protection of members of the engineering-technicians’ organization of Serbia;
- Providing help to engineers and technicians in scientific, expert improvement and organization of appropriate forms of permanent education;
- Monitoring contemporary development of engineering and technology and pointing out the currents of events and changes in this area and providing opinions on optimality of engineering and technological solutions in investment and other enterprises;
- Caring for and development of ethics of engineering-technician profession, human rights and liberties;
- Stimulating, organization and publishing of scientific and expert papers, magazines and other publications of interest for engineering-technician organization and technical intelligence;
- Work on technical regulations (laws, regulations and standards), providing its modernity, adequacy, actuality and functionality;
- Consideration and providing expert opinions on plans, programs, analysis and other acts, which are important for the development of engineering, technology and production in the Republic of Serbia;
- Stimulating and helping the activities and initiatives, aiming to preserve the human environment and area organization, saving and rationalization of spending of all sorts of energy;
- Preparation and maintenance of the meetings with purpose of permanent education of engineers and technicians;
Providing help in development of technology and economy whose purposes are similar to the purposes of engineering-technicians’ organization;

- Organization of multidisciplinary meetings and meetings of wider social importance;
- Cooperation with appropriate expert, commercial organizations and other organizations and organs at the realization of tasks of mutual interest;
- Management of Houses of Engineers and other property of Union of Engineers and Technicians of Serbia.

Union of Engineers and Technicians of Serbia has developed cooperation with organs of local government, state ministries, Serbian Academy of Sciences and Arts, Serbian Chamber of Engineers, Engineering Academy of Serbia, Chamber of Commerce and Industry of Serbia, with numerous companies, professional associations, faculties and universities and other institutions. UETS also has developer international cooperation.

In accordance with the Law and Contract with republic ministries in the framework of UETS are organized and performed specialist’ exams for several engineering branches.

Union of Engineers and Technicians of Serbia has several thousand individual members and 41 collective members in the Republic of Serbia: 19 republic’s professional associations (associations of architects, town planners, mechanical engineers, electrical engineers, mining and geological engineers, surveyors, agricultural engineers, chemical engineers etc) 7 republic’s multidisciplinary engineering-technicians’ associations (ecology, standardization and quality, material protection and corrosion, informatics etc) 1 provincial engineering-technicians’ association, 14 municipal and regional engineering-technicians’ associations.

Union of Engineers and Technicians of Serbia is founder of the Engineering Academy of Serbia, and collective member of the Chamber of Commerce and Industry of Serbia.

Union of Engineers and Technicians of Serbia, in a cooperation with faculties, universities, enterprises, economic and professional associations organizes various scientific meetings, professional reunions, congresses, seminars, conferences. UETS members publish their expert magazines; “KGH”; “Procesna tehnika”, “Ecologica”, “Tekstilna industrija”, “Forum”, “Sumarska industrija”, “Zastita materijala” and maintain professional reunions, seminars, conferences and congresses in branches of architecture, mechanical engineering, chemistry, electrical engineering, agriculture, forestry etc.

All activities of the Union are performed in accordance with the procedures and standards of QMS - Quality Management System.

Union of Engineers and Technicians of Serbia is National member of FEANI – European Federation of National Engineering Associations from Serbia. FEANI is a federation of professional engineers that unites national engineering associations from 32 European countries. Thus, FEANI represents the interests of over 3,5 million professional engineers in Europe. FEANI is striving for a single voice for the engineering profession in Europe and wants to affirm and develop the professional identity of engineers. Through its activities and services, especially with the attribution of the EUR ING professional title, FEANI aims to facilitate the mutual recognition of engineering qualifications in Europe and to strengthen the position, role and responsibility of engineers in society.

Union of Engineers and Technicians of Serbia is member of COPISSE – Permanent Conference of the Engineers of Southeast Europe. Collective members of UETS are members of international professional associations and have developed international cooperation.

With all that has been done and with accomplished results, objectively solid conditions have been provided for further and more successful work, business operation and development of the Union of Engineers and Technicians of Serbia.
NEW MATERIALS

Original scientific papers
Kristina Stevanović, Jelena Maksimović, Branislav Stanković, Maja Pagnacco, Determination of Experimental Conditions for Examination of Analytes in Bray-Liebhafsky Oscillatory Reaction in Open Reactor Conditions ....................................................... 9

OUR CIVIL ENGINEERING

Review paper
Nikola Tošić, Snežana Marinković, Aleksandar Stojanović, Sustainability of the Concrete Industry – Current Trends and Future Outlook ................................................................. 17

Professional paper
Ivan Milićević, Nenad Pecić, Creep and Shrinkage of Concrete According to Eurocode 2 .............. 25

MINING, GEOLOGY AND METALLURGY

Original scientific paper
Nikola Lilić, Aleksandar Cvjetić, Vladimir Milisavljević, Uroš Pantelić, Ljiljana Kolonja, Environmental Noise Management in the Area of Opencast Mines ........................................... 37

Original scientific paper
Dragana Petrović, Vesna Cvetković, Vladica Cvetković, Spatial Distribution of the Demir Kapija (FYR Macedonia) Ophiolite Based on Geomagnetic Data ................................................................. 43

Original scientific paper
Uroš Stamenković, Svetlana Ivanov, Ivana Marković, Nada Štrbac, Aleksandra Mitovski, The Influence of the Temperature of Solution Heat Treatment on the Properties of 6000 Series Aluminum Alloys ......................................................................... 49

MECHANICAL ENGINEERING

Original scientific paper
Rađivoj Topić, Milan Božović, Goran Topić, Drying and Dryers from the Aspects of Renewable Energy Sources and Sustainable Development .................................................. 57

Review paper
Merim Aličić, Models of Heat Exchange in Thermal Power Stations With Ultra-supercritical Steam Parameters .............................................................................................................. 64
ELECTRICAL ENGINEERING

Original scientific paper
Đoko Bandur, Branimir Jakšić, Miloš Bandur, Statistical Analysis of the First Order of $\alpha$-q Model of Fading. .......................................................... 73

Review paper
Aleksandar Lebl, Dragan Mitić, Žarko Markov, Tomislav Šuh, Mladen Mileusnić, Predrag Jovanović, Vladimir Matić, Branimir Trenkić, Miroslav Popović, Željka Tomić, Petar Daković, Ivan Vidaković, Borivoje Mitrović, Development of Methods for Traffic Simulation of Telecommunication Processes in IRITEL over last 45 years ................. 78

TRAFFIC

Review papers
Dušan Radosavljević, Aleksandar Manojlović, Olivera Medar, Nebojša Bojović, Assessment of the Transport Process’ Overall Effectiveness .............................................................. 89
Dragana Petrović, Jadranka Jović, Vladimir Dorić, The Research on Weather Impact on Trip Generation in European Cities ................................................................. 97

MANAGEMENT

Original scientific papers
Vladimir Todić, Ilija Ćosić, Zdravko Tešić, Bojan Lalić, Nemanja Tasić, Assessing the Recycling Costs in the Product Development Phase .......................................................... 105
Biljana Panić, Dragana Makajić-Nikolić, Maja Hadžiahmetović, Mirko Vujošević, Bullwhip Dependency of Participants’ Risk Preferences in the Supply Chain ........................................ 113

QUALITY IMS, STANDARDIZATION AND METROLOGY

Original scientific paper
Branislava Matić, Uroš Rakčić, Snežana Dejanović, Verica Jovanović, Marija Jevtić, Nela Donović, Industrially Contaminated Areas in Serbia as a Potential Public Health Threat to the Exposed Population ...................................................... 121

Review paper
Dragomir Marković, Radojica Graovac, Physical Security of Water/Wastewater Infrastructure – Planning and Equipment Selection .................................................. 128
Determination of Experimental Conditions for Examination of Analytes in Bray-Liebhafsky Oscillatory Reaction in Open Reactor Conditions

KRISTINA Z. STEVANOVIĆ, University of Belgrade, Faculty of Physical Chemistry, Belgrade
JELENA P. MAKSIMOVIĆ, University of Belgrade, Faculty of Physical Chemistry, Belgrade
BRANISLAV S. STANKOVIĆ, University of Belgrade, Faculty of Physical Chemistry, Belgrade
MAJA C. PAGNACCO, University of Belgrade, Faculty of Physical Chemistry, Belgrade

The Bray–Liebhafsky oscillatory reaction, as an extremely sensitive matrix, can be used for examination of properties of different active substances. Here, bifurcation analysis in continuously feed well stirred tank reactor and construction of bifurcation diagram were done in order to find the best conditions for testing properties of different analytes and their influences on reaction dynamics. Andronov-Hopf supercritical bifurcation point was obtained at temperature, $T=45.9\degree C$, flow rate, $jo = 0.007\text{ min}^{-1}$, and initial experimental concentrations, $\left[H_{2}O_{2}\right]_{0} = 6.0\times10^{-2}\text{ M}$, $\left[KIO_{3}\right]_{0} = 5.9\times10^{-2}\text{ M}$, and $\left[H_{2}SO_{4}\right]_{0}=5.5\times10^{-2}\text{ M}$. The regions in vicinity of bifurcation points are identified as optimal conditions for analytes test, since the system is the most sensitive to any perturbations in this dynamical state.

**Key words:** Bray–Liebhafsky reaction, oscillatory reaction, bifurcation diagram, Andronov-Hopf bifurcation, analyte

1. INTRODUCTION

The Bray–Liebhafsky (BL) reaction is the decomposition of hydrogen peroxide into water and oxygen in the presence of hydrogen and iodate ions [1, 2]:

$$H_{2}O_{2} \xrightarrow{[H^{+}, I^{\cdot}O_{3}^{\cdot}]} H_{2}O + O_{2} \quad (1)$$

The BL reaction is an oscillatory reaction, meaning that it represents complex dynamic system in which the concentrations of reactants and products change with time in cascades, while the concentrations of intermediate species oscillate (from where the term “oscillatory reaction” ordinates) [1-3].

The mechanism of this reaction consists of two complex processes, which are reduction of iodate to iodine (2) and oxidation of iodine to iodate (3):

$$2IO_{3}^{-}+2H^{+}+5H_{2}O_{2} \rightarrow I_{2}+6H_{2}O+5O_{2} \quad (2)$$

$$I_{2} + 5H_{2}O_{2} \rightarrow 2IO_{3}^{-} + 2H^{+} + 4H_{2}O \quad (3)$$

Although the BL reaction seems to be very simple, it has been the subject of intense investigations for many years, since it has vast of the dynamics states, reaction paths and chemical species at the first place, as well as due to the still unknown oscillatory mechanism [4-7].

Far from the thermodynamic equilibrium, and depending on the initial experimental conditions, the BL reaction may be in different dynamics states (stable non-equilibrium steady state, oscillatory state, chaos, etc.) [5, 8-10]. If this reaction is performed in the batch reactor then, due to the of the reactants consumption, the transient or pseudo-steady states can be obtained.

The steady states can be obtained in the open reactor (continuously fed well-stirred tank reactor – CSTR) conditions also, where the open reactor refers to constant mass flow (usually with peristaltic pumps),
e.g. inflow of reactants and outflow of reaction mixture (intermediates, products, and reactants). Different dynamic states in the open reactor can be maintained infinitely long, i.e. until the experimental conditions or control parameters (temperature, reactants concentrations, specific flow rate, etc.) do not change. In particular, this advantage of the open reactor allows detailed investigations of the certain dynamic states. Still, the number of papers on the topics of the BL reaction in the CSTR conditions is significantly lower compared to the those on the BL reaction in a batch reactor. This is primarily due to complexity of experimental procedure, but also due to the duration of the experiments in CSTR. Bifurcation analysis is the examining control parameter influence on the system dynamics. Bifurcation point is the value of control parameter at which dynamics of the system changes under the used experimental conditions and can be obtained by the analysis of the states diagram. In the vicinity of the bifurcation point system is extremely sensitive to external influences (perturbations) [11]. Because of that, the BL reaction can be used as a matrix for the examination of different analytes. By the definition, analyte is a substance or chemical constituent which is an object of the interest in the analytical procedure [11]. It is clear that analyte can be any biologically or pharmaceutically important sample or the catalyst, as well as the new material. What does the examination of analyte mean? At the first place, it refers to determination of some property or concentration of the analyte which is obtained by the perturbation with analyte in the vicinity of the bifurcation point in order to get the answer from the BL system. If the signal from the system is linear for different analyte concentrations, then we can construct the calibration curve and BL matrix can be used for efficient and economical determination of the unknown analyte concentration.

Taking into account complexity of the oscillatory reaction, analyte can have the different physicochemical influences on the BL matrix. The most common one is the kinetic influence, whereby reacting with certain reaction species of the BL system analyte can influenced existing reaction pathways and produces the new ones. It is important to outline that analyte examination through the analyte-BL matrix interaction includes the indirect investigation of BL reaction. Due to the fact that the BL oscillatory reaction is a still unknown, matrix behavior during the perturbations with the analyte can contribute to the expanding knowledge about this oscillatory system.

Until now BL reaction under the CSTR conditions was successfully used for the determination of the following analytes: quercetin [12, 13], rutin [14], hesperidin [15], polymer carrier [16], paracetamol [17], morphine [18], 6-O-acetyl morphine [19], ascorbic acid [20], B vitamins (B1, B2, B3 and B6) [21], uric acid [22] and piroxicam [23]. Also, the influence of several ions (Cl\(^-\), Br\(^-\), I\(^-\), Mn\(^{2+}\)) on the BL dynamics was analyzed [12] and it was found that glucose, fructose, heroin, Cr\(_2\)O\(_7^{2-}\), MoO\(_3^{2-}\), Ni\(^{2+}\), Ca\(^{2+}\) and Mg\(^{2+}\) don’t affect (i.e. they are inactive in the BL system).

Aim of this work is to find experimental conditions in the open reactor under which examination of wide range of analytes in the BL reaction can be implemented. Finding of the mentioned reaction conditions is performed by the bifurcation analysis and is the first step in the analysis of the analyte, its physicochemical properties, concentration, as well as the mechanism of the BL reaction.

2. EXPERIMENTAL

Figure 1 shows schematic view of experimental setup which was used for investigation of BL reaction dynamics in CSTR. A schematic diagram of the experimental setup which was used for investigation of BL reaction dynamics in CSTR is shown in Figure 1.

![Figure 1 – Schematic view of experimental setup. P1 and P2 are peristaltic pumps, while R1, R2 and R3 are tags for the reactants (KIO₃, H₂SO₄ and H₂O₂)](image)

Reactants were delivered separately in a closed glass reaction vessel in the form of three solutions: R1-water solution of KIO₃, R2-water solution of H₂SO₄ and R3-water solution of H₂O₂. The reactants, aqueous solutions of KIO₃ (R1), H₂SO₄ (R2) and H₂O₂ (R3), were introduced into a closed glass reaction vessel separately. Inflow of the reactants was carried by peristaltic pump (Manuel/RS 232 Controlled Peristaltic Pump, Type 110). Reaction vessel was protected from external light with opaque foil.

Total volume of the reaction mixture was 53.0 ± 0.2 ml. Reaction mixture volume was kept constant by glass pipe connected with silicon channel with the second peristaltic pump, which was used for outflow of surplus volume. The volume of the reaction mixture was kept constant by removing the surplus volume of the reaction mixture through the U-shaped glass
tube, which is connected with the second peristaltic pump by a silicon tube. Time evolution of the BL system was followed potentiometrically potentiometrically with special data acquision voltmeter (PC-Multilab EH4 16-bit ADC). Voltmeter was connected directly with personal computer which was used for recording of the difference in the potentials of the working and reference electrode in the fuction of the time. Working electrode was Pt (Metrohm Model 6.0301.100), while the reference electrode was Ag/AgCl (Metrohm Model 6.0726.100).

All used chemicals, KIO$_3$, H$_2$SO$_4$ i H$_2$O$_2$ (Merck, Darmstadt, Germany), were of analitical grade purity and were used without any additional purification. All used chemicals, KIO$_3$, H$_2$SO$_4$ i H$_2$O$_2$ (Merck, Darmstadt, Germany), were of analitical grade purity and were used without further purification for preparing the solutions. Due to the fact that BL reaction is very sensitive to small amounts of impurities, deionized water was used for all of solutions. Deionized water was obtained with MILLIPORE system (Mili-Q, Bedford, SAD) and it had the specific resistance of $\rho = 18$ M$\Omega$ cm.

Dynamic behavior behavior of the BL matrix was investigated by variation of the temerature, like the controlal parameter, in the range from 45,0 to 58,0 $^\circ$C, while the others parameters were kept constant: $[\text{KIO}_3]_0=5,9\times10^{-2}$ M, $[\text{H}_2\text{SO}_4]_0=5,5\times10^{-2}$ M, $[\text{H}_2\text{O}_2]_0=6,0\times10^{-2}$ M, specific flow rate $j_0=0,007$ min$^{-1}$ and stirring speed $\sigma=900$ rpm.

3. RESULTS AND DISCUSSION

The BL reaction, because of its sensitivity to external influences (perturbations), is usually used for determination of the analyte concentrations, as well as for the examination of the mechanism of analyte action [25-28]. The sensitivity of the reaction can be noticed from the changes in oscillatory parameters (amplitude and period of oscillations), but also from the changes of the dynamic state (for example from the oscillatory to the stable steady state) depending on the perturbar "strength". Consequently, the construction and understanding of the state diagram (bifurcation diagram) are necessary.

The bifurcation diagram can be constructed by the continuous change of the control parameter (temperature in our case). Under given experimental conditions and temperature changes from 45,0 $^\circ$C to 58,0 $^\circ$C, different dynamic states of the system were found (Figure 2). With temperature increasing system passes from stable steady state (Figure 2, State (1)) to oscillatory state (Figure 2, States 2-6).

During the oscillatory state, increase in temperature causes increasing of the oscillations period and amplitude (Figure 2, States 2-6). Besides, increase in temperature affects the oscillation’s shape. In Figure 2 it can be noticed that bifurcation point (in which system passes from stationary to oscillatory state) is in the temperature range from 45,9 $^\circ$C to 47,0 $^\circ$C. For the precise determination of the bifurcation point value, it is necessary to examine reaction dynamic states in this range so detailed as possible. Detailed analyze implies changing the control parameter (temperature) for minimal, experimental acceptable step.

![Figure 2 – Stable dynamic structures obtained under following experimental conditions: $[\text{KIO}_3]_0=5,9\times10^{-2}$ M, $[\text{H}_2\text{SO}_4]_0=5,5\times10^{-2}$ M, $[\text{H}_2\text{O}_2]_0=6,0\times10^{-2}$ M, specific flow rate $j_0=0,007$ min$^{-1}$, stirring speed $\sigma=900$ rpm and temperature: 1) 45,9$^\circ$C, 2) 47,0$^\circ$C, 3) 47,4$^\circ$C, 4) 49,6$^\circ$C, 5) 52,5$^\circ$C, 6) 57,3$^\circ$C. All states obtained for the investigation of BL reaction at different operating temperatures are presented on bifurcation diagram (Figure 3). The potentials characterized stable steady states are labeled by triangles, while the extreme potential (minimal and maximal) values during the oscillations are labeled by circles on bifurcation diagram. It can be also noticed the bifurcation point at which stationary state passes to oscillatory ones. One can expect that system is the most sensitive to perturbations in the vicinity of the bifurcation point [11].

Due to the fact, that oscillations presented in the vicinity of bifurcation point may be characterized with small amplitudes (sinusoidal), it can be assumed that it is supercritical Adronov-Hopf bifurcation. In order to
confirm this, it was examined whether there is a hysteresis with a decrease in temperature.

**Figure 3** – Bifurcation diagram which represents the transition from the stable steady state (triangles) to the oscillatory state (circles), obtained by temperature variation, under following experimental conditions: 
\[ [\text{KIO}_3]_0 = 5.9 \times 10^{-2} \text{ M}, \ [\text{H}_2\text{SO}_4]_0 = 5.5 \times 10^{-2} \text{ M}, \ [\text{H}_2\text{O}_2]_0 = 6.0 \times 10^{-2} \text{ M}, \] specific flow rate \( j_0 = 0.007 \text{ min}^{-1}, \) stirring speed \( \sigma = 900 \text{ rpm}. \]

By control parameter changing in the opposite direction, the described scenario is repeated. In other words, the system passes through the same oscillatory states in the temperature range from 58.0°C to 46.0°C and the same stable steady states below 45.0°C, meaning that hysteresis doesn’t exist. Furthermore, the square of the amplitude of the temperature dependence was drawn as one more justification for Adronov-Hopf bifurcation (Figure 4).

**Figure 4** – Amplitude – temperature dependence (\( T_{BT} \) is the temperature of bifurcation point)

From Figure 4, it is obvious that in the vicinity of the bifurcation point the square of the oscillation’s amplitude (the difference between extreme values of the potential) linearly depends with control parameter (temperature). The oscillation period -temperature dependence is also linear in the vicinity of the bifurcation point. Linear change in the square of the amplitude and period with control parameter, absence of the hysteresis, as well as the fact that oscillations which are obtained (or lost, depending on experimental direction) in the bifurcation point, unequivocally indicates that here found bifurcation point is supercritical Andronov-Hopf (i.e. system passes from the one state to another “smoothly”).

The change of the control parameter, the construction of bifurcation diagram and the determination of bifurcation point value and type, are the first steps in the examination of different analytes. What is the advantage of the given experimental conditions? Obtained bifurcation diagram points that system enters the oscillatory state through oscillations of small amplitudes (Adronov-Hopf bifurcation point), meaning it has not gone through the chaos [8]. This provides an incomparably easier quantification of the potential oscillograms obtained in the presence of various analytes. Further investigations will be separated into two different parts. In the first case analyte will be added in the stationary state in the vicinity of the bifurcation point, while the second one the addition will be also the vicinity of the bifurcation point but in the oscillatory state. In both cases, the answer of the BL system, as a consequence of the analyte addition, will be followed. If the analyte is active (gives the answer), appropriate calibration curves will be constructed, the existing interferences of the given analyte with other analytes will be analyzed, and the responses of different analytes of a similar chemical structure will be compared. Results obtained can help to acquire the knowledge about the properties, feature, characteristics and concentration of the investigated analyte, as well as about the mechanism of analyte action in the Bray-Liebhafsky system.

4. CONCLUSION

In this paper, experimental conditions for the testing of a wide range of analytes (biological, medical, pharmacological samples, various materials, catalysts, etc.) in the Bray-Liebhafsky oscillatory reaction were found. By varying the temperature, as a control parameter, a bifurcation diagram is constructed. For the used experimental conditions, the bifurcation point, in which the system with the increase in passes from the stable stationary to the oscillatory state, is at \( T = 45.9 ^\circ \text{C}. \) The found bifurcation point corresponds to the supercritical Andronov-Hopf bifurcation. The resulting bifurcation point is the first step in the testing of the different analytes. The system is the most sensitive to perturbation in the vicinity of the bifurcation point, and thus an examination of the analyte should be done there. The advantage of the given experimental
conditions is the absence of chaos, which allows incomparably easier quantification of the results obtained in the presence of the analyte.

5. ACKNOWLEDGEMENT

This research was supported by the Ministry of Education, Science and Technological Development of Republic of Serbia, through the Project No. 172015-OI. The authors also wish to thank the organizers of the 15YRC 2016 conference which enabled the presentation of research results.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, № 4.

REFERENCES


REZIME

ODREĐIVANJE EKSPERIMENTALNIH USLOVA ZA ISPITIVANJE ANALITA U BRAY-LIEBHAFSKY OSCILATORNOJ REAKCIJI U OTVORENOM REAKTORU

Bray-Liebhafsky oscilatorna reakcija, kao izuzetno osetljiv sistem, ima veliku primenu kao matrica za ispitivanje osobina različitih aktivnih supstanci. U ovom radu je, sa ciljem da se pronađu povoljni uslovi za ispitivanje svojstva različitih analita i njihovog uticaja na dinamiku reakcije, urađena bifurkaciona analiza u kontinualnom dobro mešajućem reaktoru i konstruisan bifurkacioni dijagram. Andronov-Hopf superkritična bifurkaciona tačka dobijena je na temperaturi T=45.9 °C, pri: protoku, \( j_o = 0.007 \text{ min}^{-1} \), i početnim koncentracijama, \( [\text{H}_2\text{O}_2]_0 = 6,0\times10^{-2} \text{ M}, [\text{KIO}_3]_0 = 5,9\times10^{-2} \text{ M}, \text{ i } [\text{H}_2\text{SO}_4]_0 = 5,5\times10^{-2} \text{ M}. \) Uslovi u okolini bifurkacione tačke su optimalni za ispitivanje različitih analita, s obzirom da je sistem u ovim dinamičkim stanjima najosetljiviji na perturbacije.

Ključne reči: Bray-Liebhafsky reakcija, oscilatorna reakcija, bifurkacioni dijagram, Andronov-Hopfova bifurkacija, analit
OUR CIVIL ENGINEERING

Our Civil Engineering - Notre génie civil
- Unser Bauwesen – Наше строительство


EDITOR-IN-CHEF
Prof. Branko Božić, D.Sc University of Belgrade,
Faculty of Civil Engineering, Belgrade

DEPUTY EDITOR-IN-CHIEF
Doc. Ivan Ignjatović, D.Sc University of Belgrade,
Faculty of Civil Engineering, Belgrade

EDITORIAL COUNCIL
Prof. Radomir Folić, D.Sc University of Novi Sad,
Faculty of Technical Sciences, Novi Sad

Prof. Nenad Ivanšević, D.Sc, University of Belgrade,
Faculty of Civil Engineering, Belgrade

Prof. Radomir Kapor, D.Sc, University of Belgrade,
Faculty of Civil Engineering, Belgrade

Prof. Miloš Kněžević, D.Sc, University of Montenegro,
Faculty of Civil Engineering, Podgorica

Docent Goran Mladenović, D.Sc, University of Belgrade,
Faculty of Civil Engineering, Belgrade

Docent Ivan Ignjatović, D.Sc, University of Belgrade,
Faculty of Civil Engineering, Belgrade

Docent Budimir Sudimac, M.Sc, University of Belgrade,
Faculty of Architecture, Belgrade

Docent Stevan Radojičić, D.Sc, Military Geographical
Institute, Belgrade

Marijan Čeh, D.Sc University of Ljubljana, Faculty of
Civil and Geodetic Engineering, Ljubljana

Assistant Professor Tomas Hanák, Brno University of
Technology, Faculty of Civil Engineering, Institute
of Structural Economics and Management, Brno

EDITORIAL OFFICE: Union of Engineers and
Technicians of Serbia, 11000 Belgrade, Kneza Miloša 7a/I,
Tel. +381/11/ 32 35 891, Fax +381/11/ 32 30 067
Sustainability of the Concrete Industry – Current Trends and Future Outlook

NIKOLA D. TOŠIĆ, University of Belgrade,
Faculty of Civil Engineering, Belgrad
Review paper

SNEŽANA B. MARINKOVIĆ, University of Belgrade,
Faculty of Civil Engineering, Belgrade

ALEKSANDAR S. STOJANOVIĆ, International University
College of Turin, Torino, Italy

Achieving sustainability of all human actions has been recognized as an urgent and top priority since the warnings of anthropogenic climate change are overwhelming. However, the precise goal, aim and method of shifting the global paradigm towards sustainability are still contested.

Among all human activities, the concrete industry has one of the largest environmental footprints, not only because concrete is the second most used material in the world, but also because the production of cement for concrete is highly energy-intensive and inevitably releases large amounts of CO₂.

In this paper, a historic and theoretical background to the environmental problems, arising from the production and use of concrete, is presented. The specific problems it poses are recognized as natural resource consumption, CO₂ emissions, and waste generation. A technical discussion based on Life Cycle Assessment analyses is presented alongside a societal interpretation within the framework of common resource and externality management.

Possible technical solutions in the form of recycling waste concrete and replacing cement with industrial by-products are presented and finally, a necessity for a shift towards a holistic and environmental paradigm is highlighted.

Key words: sustainability, concrete, CO₂, cement, waste, recycled concrete aggregate, fly ash

1. INTRODUCTION

Sustainability, as a keyword in many areas, has become ever present in our society today. However, the precise meaning of the term is often misunderstood or unclear. The Rio Declaration from 1992 states as its first principle that “Human beings are at the centre of concerns for sustainable development” [1]. Sustainability can then be seen as an endeavour to maintain the species Homo sapiens.

Humankind has actually come so far that it has emerged as a geological force shaping the environment. The International Commission on Stratigraphy has started deliberating a proposal to proclaim a new geological epoch—the Anthropocene—which would be considered to have started between the Industrial revolution and the end of World War II [2]. Mankind is making an impact on the planet that will be felt for millennia, and in the process endangering its own existence and the existence of other species.

A significant way in which our impact is realized is through the built environment—through the structures we build and use.

The construction industry itself is responsible for one of the largest impacts of all human activities: 40% of raw stone, gravel and sand consumption, 25% of virgin wood, 40% of total energy and 16% of annual water consumption [3].

2. BACKGROUND

Concrete is the material of the modern build environment. It is, in fact, the most widely used man-made material in the world with a global annual production of up to 20 billion tons [4]. It reached its current status in less than 200 years. Even though early finding suggest types of concrete were used in many ancient civilizations—from Egypt to Rome—the modern story of concrete begins in the 18th century and the patent for
Portland cement obtained by Johnson Aspden in 1824 [5]. Shortly afterwards came the invention of reinforced and prestressed concrete (1850-1920) [5]. The development was finalized in the second half of the 20th century with the invention of superplasticizers, fibre reinforcement and ultra-high strength concretes.

The large annual production of concrete consequently leads to an equally large consumption of component materials - annually around 15 billion tons of aggregates and 4.2 billion tons of cement [6], [7].

One of the greatest environmental problems arising from the concrete industry are the large CO₂ emissions from cement production. On average, per each kg of cement, approximately 700-900 g of CO₂ is released [8], [9].

In total, this amounts to 5–7% of all anthropogenic CO₂ emissions. Although the cement industry is moving toward using renewable energy sources in their production process, the chemical reaction of calcination requires an inevitable release of CO₂.

\[
\text{CaCO}_3 + \text{heat} \rightarrow \text{CaO} + \text{CO}_2 \quad (1)
\]

Hence, there is a natural limit to how much these emissions can be decreased.

Beside this problem related to the production of concrete, there is another one related to the end-of-life phase of concrete structures. After their service life expires - due to whatever reason - concrete structures are demolished. In this way, large quantities of construction and demolition waste (CDW) are generated.

In the EU alone, 850 million tons of CDW are generated annually, accounting for around 30% of total waste [10]. A large part of this waste is demolished concrete and the main method of dealing with it is still landfilling.

3. TECHNICAL CONTEXT

The quantitative aspect of concrete’s (un)sustainability is well documented. This is mostly done through Life Cycle Assessment (LCA) studies. LCA is a methodology for evaluating the environmental load of processes and products during their life cycle [11].

When studying concrete, LCA is used to quantify and compare the emissions to air, ground and water arising during the life cycle of different concretes. Varying approaches can be taken in LCA, taking into account different parts of concrete’s life cycle in so-called cradle-to-grave, cradle-to-gate or gate-to-gate scenarios, Figure 1.

After choosing a scenario, data must be gathered about the studied processes, preferably for the location which is being examined. Collected data should include energy consumption and emissions of gases. This is done for all the life cycle stages; in the case of Figure 1, for cement, aggregate and concrete production and transport.

**Figure 1 – A cradle-to-gate scenario in LCA**

In the end, emissions are compiled into several impact categories. One of the most important ones in LCA is the global warming potential, expressed in grams of CO₂-equivalent (a compound metric of CO₂ and other greenhouse gases). Other impact categories include the potential for acidification, eutrophication, ozone depletion, abiotic resource depletion, etc. They can also be related to damages to human health, such as Disability Adjusted Life Years, a World Health Organization measure of how many years of healthy life have been lost [8], [12].

When looking at all LCA studies regarding concrete, one conclusion stands out - cement production is responsible for a lion’s share of the environmental impact caused during all life cycle phases. In almost all impact categories, cement production is responsible for 60–90% of the environmental load; transport comes at a distant second place [8], [13], [14].

The unavoidable CO₂ emissions from cement production, combined with its large annual production are a recipe for environmental problems. The cement industry is a highly agglomerated and corporatized industry. Table 1 presents the data for top five cement producing countries. The main conclusion drawn from the data is that cement production in China is almost five times larger than the other countries combined.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>2014 cement production (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>2500</td>
</tr>
<tr>
<td>2</td>
<td>India</td>
<td>280</td>
</tr>
<tr>
<td>3</td>
<td>USA</td>
<td>83.3</td>
</tr>
<tr>
<td>4</td>
<td>Iran</td>
<td>75.0</td>
</tr>
<tr>
<td>5</td>
<td>Turkey</td>
<td>75.0</td>
</tr>
</tbody>
</table>

In large part, this has to do with China’s fast economic development in which it is catching up with developed countries. However, cement demand is also high because of the urbanization concept adopted by
the Chinese government - whole cities are built “from scratch” and then populated. This type of state-planned urbanization leads to a high cement demand because it relies on high-rise apartment buildings (usually cement-intensive), rather than relying on a more organic development of the city, e.g. building low-rise houses in suburbs (which can be built from masonry or wood).

What are the outlooks that cement demand will stabilize or decrease in the future? In 2002, Mahasenan et al. looked at the correlations between cement demand, gross domestic product (GDP) and population of developed and developing countries [16]. They found that per capita cement demand was proportional to per capita GDP up to approximately US$8,000 (expressed in 1990 dollars; ca. US$13,000 in 2016 dollars), after which it became proportional to the total population [16].

By analysing demand data for several countries they obtained the following equation

$$\text{Demand} = \frac{AX^{-\gamma} + BX^\gamma}{X^{-\gamma} + X^\gamma} \quad (2)$$

Where $A = \alpha \cdot \text{GDP}$ (demand proportional to GDP at low incomes), $B = \beta \cdot \text{population}$ (demand proportional to population at high incomes), $X = \text{per capita GDP}$ (scaled to US$8,000), and $\gamma$ = shape parameter.

According to World Bank data, the per capita GDP of China (in 2016 dollars) is just over US$8,000 [17]. Hence, if the model is accurate, cement demand will further increase to even larger levels and then stabilize at those high levels because of China’s large population. This problem is slowly being realized and addressed by researchers [18].

The other large and often overlooked problem that LCA studies point to is the end-of-life of concrete structures. The large amounts of CDW being generated are still mainly being landfilled, with the exception of several developed countries that have a shortage of natural aggregates (NA), e.g. the Netherlands, or very limited landfilling capacities, e.g. Japan. Although CDW waste is generally inert and not toxic, the shear amounts of it are causing environmental concerns, especially because it tends to be generated and concentrated near urban centres.

Since a large portion of the built environment in the developed countries is approaching the end of its service life (e.g. most of Europe’s infrastructure was built after World War II), the problem is only expected to get more serious.

Having in mind these issues, the scientific community has worked for several decades to identify areas in which improvements can be made. One approach which deals with two problems simultaneously is recycling of CDW. Waste concrete cannot be recycled back into its original constituent materials nor original form. Concrete can be crushed into aggregates called recycled concrete aggregates (RCA) which can be used in new applications. On the one hand, using RCA lowers demand for natural aggregates and on the other, reduces the amount of CDW.

Another approach is concentrated on reducing concrete’s environmental impact through the reduction of cement use. This is mainly achieved by using so-called supplementary cementitious materials, of which the most widespread are blast furnace slag (a by-product of steel production) and fly ash (a by-product of coal combustion).

They can be used to replace a certain percentage of cement or they can be used in concretes produced completely without cement in which these materials are “activated” with alkali solutions to produce alkali-activated concretes.

The production of RCA is carried out in mobile or stationary facilities and usually involves a two-stage crushing and sieving process and a removal of any impurities such as steel, wood, gypsum, masonry, glass, etc. Since concrete consists of NA bound by hardened cement paste, after recycling a certain amount of this “residual cement paste” is left bound to the aggregates.

This means that RCA is actually a two-phase material containing natural aggregates and cement paste. The presence of this residual cement paste causes a certain deterioration of RCA properties such as higher porosity and water absorption between 3.5 and 10% (compared with only around 1% in the case of NA) [19], [20].

Because of this, RCA is still mainly considered to be inferior compared to NA and is relegated to use in applications such as road sub-base and nonstructural elements. However, the positive effects of concrete waste recycling can be fully utilized only if recycled concrete aggregates find their use in all types of concrete. Concrete made with RCA is called recycled aggregate concrete (RAC).

The replacement of NA can be total (100%) or partial (<100%). The applicability of RCA and the properties of RAC have been studied for several decades [21]. More and more, RAC is being investigated on both macroscopic and microscopic levels. Mechanical and durability-related properties are being tested as well as the structural behaviour of full-scale elements such as beams, columns or slabs [22], [23].

Using LCA, various authors have compared recycled aggregate concrete to natural aggregate concrete (NAC). In [8], the authors reported that the same environmental impacts for both concretes can be obtained only if the transport distances of RCA are smaller than the transport distances of NA.
The authors of [24] found that if the additional amount of cement used in RAC (justified by weaker properties of RCA compared to NA) is below 10%, the impacts from NAC and RAC will be comparable. In [25], a multi-criteria optimization method was employed to find the best choice of concrete type (between NAC, RAC with 50% and 100% of coarse aggregate replacement) taking into account economic and environmental criteria and found RAC with 50% replacement to be the optimal choice in all criteria ranking scenarios.

All of these results point to potential environmental benefits of using RCA in concrete. However, the production of RCA in recycling facilities is far from a developed industry. The economic viability of RAC use was broadly studied and discussed. The case of Ireland was analyzed in [26]. Under the assumptions of perfect competitiveness of the recycling centres and no possibilities of illegal C&D waste disposal, the authors found that economic viability will occur when the cost of landfilling exceeds the cost of transporting waste to the recycling centre and the cost of using NA exceeds the cost of using RCA.

Recycling centres were shown to benefit from economies of scale. Both studies [26] and [25] advocate the enforcement of the „polluter pays“ principle and find market based instruments such as increases in landfill taxes, subsidies on recycled aggregates and taxes on the use of natural aggregates to be the best option for policy makers in incentivizing the recycling industry. As for the operation of the recycling facility itself, in the case of Portugal it was found that they can be profitable with a return on investment period under 8 years in all cases of a sensitivity analysis [27], [28].

As for reducing cement use in concrete, the World Bank data show that in 2013 41.3% of total electricity produced came from coal sources i.e. coal burning thermal power plants [17]. As a result large amounts of fly ash, a by-product of coal combustion, are being generated worldwide. The U.S. produces roughly 131 million tons of fly ash each year, China and India 300 million tons [29].

Fly ash, as well as a number of other industrial by-products, consists mainly of silicon and aluminium oxides and has pozzolanic properties which means it reacts with cement hydration products and strengthens the paste matrix, contributing to the properties of the final material. Hence, it is reasonable to assume that a replacement of a certain amount of cement by fly-ash will not have adverse effects on concrete.

Such concretes in which more than 30% of cement is replaced by fly ash are called high-volume fly ash concretes (HVFAC). Because the pozzolanic reaction is slower than cement hydration HVFAC exhibits slower strength development than ordinary cement concrete which has to be taken into account [30]. The benefits of using fly ash include better workability due to a finer packing density of particles and improvement of certain durability-related and long-term properties such as shrinkage.

However, since fly ash is a by-product of coal combustion and effectively of electricity production it is no longer considered to be a waste material [31]. Therefore, in LCA analyses a certain amount of emissions from electricity production has to be allocated to FA. Whether this is done according to “mass“ or “economic“ allocation, it worsens the environmental performance of HVFAC relative to NAC [32].

4. SOCIO-ECONOMIC CONTEXT

It seems that today the world is faced with a particular challenge (CO₂ emissions from cement production and disposal of demolished concrete structures) but also that technical means to overcome it have been developed (“green” alternatives). At the same time, it can be seen that these technical solutions are rare and limited in their effect. The question is then, “Why are policy makers not reacting to the conclusions reached by the scientific community?”

In his 1968 article “The Tragedy of the Commons”, Garrett Hardin famously pointed out that there is a class of human problems that could be classified as so-called “no technical solution problems”. These are problems which cannot be overcome by mere tweaks and adjustments in technical sciences and without any changes in human values or ideas [33].

This is obvious when looking at the debate surrounding sustainability and sustainable development (the kind of development that should be pursued in order to achieve sustainability) [34]. From the point of view of biophysical concerns, sustainable development is a purely anthropocentric problem. Hence, one’s interpretation of this topic will be highly influenced by his value system—ranging from a utilitarian to a more spiritual worldview [35].

A distinction exists between “strong” and “weak” sustainability. For proponents of weak sustainability all forms of “natural capital” (i.e. products of nature) are commensurable with and can be substituted by human-made capital (i.e. products of human labour), while the supporters of strong sustainability argue that some natural capital stocks are incommensurable and not substitutable by human-made capital [35].

In the case of the concrete industry, the standpoint of weak sustainability implies free, unregulated cement production under the assumption that the harm due to CO₂ emissions is reversible. This assumption is clearly unrealistic, since the concrete industry is so
specific that even the green alternatives cannot radically diminish the ecological footprint.

This proves that following the logic of weak sustainability, questions are raised whether the Western model of development may run up against social and political limits before reaching environmental planetary constraints [36]. This means that thinking about the way that the challenge of sustainability has to be approached necessitates considering a more general context.

It is established that “sustainable” is more than just ecological (i.e. based on the measurement of climate change). It pertains to a set of important normative issues and particularly equality. In the case of sustainable concrete it is necessary to put the previous analysis in a broader context of social values that sustainability implies.

The relevant broader context of sustainability also implies that the pervasive emphasis on “development” and “growth” as the world’s panacea, all too often takes on the form of knowledge, capital and technology transfer and export from developed countries, i.e. the further accumulation of capital by the core developed countries with no regard to the specifics of each country and to what sustainable practices already exist within them [37].

In underdeveloped economies, utilized technologies are usually a generation old, bought from the developers in the developed countries. At the same time, the existing research capacities are not used for development of technology at home. For example, in many of these economies the practice of using municipal waste as a source of energy instead of coal in cement plants is only now beginning to be implemented.

Of course, Hardin’s question of what has to be changed for the appropriate technology to be utilized stays unanswered. The potential of regulation is not implemented as it is something that would make the countries less attractive to investment, which leads to difficulties for countries that already find themselves in economic turmoil.

Looking at actual policy attempts of considering the construction and concrete industries in this broader context, the findings are hardly satisfying. The fact is that policy response to the structural problems of pollution and particularly the solution to problems related to concrete have not been adequate [31], [38].

The existing interstate framework is founded on the idea of the protection of rights in the context of multiple sovereign states [39]. Because of this it has been limited to problems that do not put this sovereignty into question. In reality this limitation has excluded the possibility of any regulatory attempts that would be imposed with an eye on the global character of the problem.

All of them would intervene in the domain of private law issues of sovereign states [40]. This implies that the problem of pollution and construction also leads to an inquiry about which actor would be able to tackle the structural problems on a global scale.

5. FUTURE OUTLOOK

This paper tried to briefly present a technical and socio-economic context for the concrete industry within the broader global sustainability debate. The true potential of sustainability can only be realized if it acts as an integrating concept [35]. This was the aim of this study, to present all sides of the story and enable an integrating discussion to be started and conclusions to be drawn.

It is becoming clearer that the interrelatedness of these dimensions implies that even though the solution of the problems will be a result of a precise and close focus on each of them, they cannot be separated fully and that they will have to be approached in their interconnectedness. A “paradigm shift” is needed from a mechanistic to a holistic and ecological worldview [41].

From this realization slowly arises a new R&D agenda that is attempting to encompass all the enablers and actions necessary for carrying out the paradigm shift [34].

Technology enablers are the physical infrastructure, systems, models and know-how; institutional enablers are national and local governments, planning and implementing agencies, academic and research institutions and professional associations; value enablers are the personal codes of conduct and community behaviours. Together, they have tasks and actions to perform in search of this common goal of achieving sustainability [34].

Hopefully, the contribution of this study will be to present concisely ideas and data about the concrete industry necessary for participating in the debate about its future and ultimately, our planet’s future.

6. ACKNOWLEDGMENT

The work reported in this study is a part of the investigation within the Research Project TR36017: “Utilization of by-products and recycled waste materials in concrete composites in the scope of sustainable construction development in Serbia: investigation and environmental assessment of possible applications”, supported by the Ministry for Education, Science and Technology, Republic of Serbia. This support is gratefully acknowledged.
REMARK

This paper was published in the Magazine „Tehnika“, LXXII, 2017, Nº 1.

REFERENCES


REZIME

ODRŽIVOST INDUSTRIJE BETONA – SAVREMENI TRENDovi I IZGLEdI ZA BUDuĆNOST

Postizanje održivosti svih ljudskih aktivnosti je prepoznato kao hitan i prioritetan zadatak s obzirom da su upozorenja o ljudskim uzrocima klimatskih promena brojna. Međutim, tačan cilj i način promene globalne paradigme ka održivosti su i dalje nejasni i neusaglašeni.

Od svih ljudskih aktivnosti, industrija betona ima jedan od najvećih uticaja na životnu sredinu, ne samo usled toga što je beton drugi najkorišćeniji materijal na svetu, već i usled toga što je proizvodnja cementa energetski veoma zahtevna i neizbežno dovodi do emisije velikih količina CO₂.

U ovom radu su predstavljeni istorijski podaci i teorijske osnove ekoloških problema koji nastaju usled proizvodnje betona. Konkretni problemi do kojih dolazi su potrošnja prirodnih resursa, emisije CO₂ i proizvodnja otpada. Tema rada je predstavljena sa tehničkog aspekta na osnovu analiza životnog ciklusa, a društveno-ekonomska interpretacija je data u teorijskom okviru upravljanja zajedničkim dobrima i eksternalijama.

Predstavljena su moguća tehnička rešenja u vidu recikliranja otpadnog betona i zamene cementa industrijskim nusproizvodima. Na kraju je ukazano na potrebu za zaokretom globalne paradigme ka holističkom i ekološkom pogledu na svet.

Ključne reči: održivost, beton, CO₂, cement, otpad, reciklirani agregat, leteći pepeo
1. INTRODUCTION

Design should provide satisfactory performance of engineering structures during service life. A common procedure involves the ultimate limit state design and checking of the serviceability requirements. Behaviour of concrete structure under a sustained load is significantly affected by the time-dependant properties of concrete – creep and shrinkage. Prediction of concrete properties, including time-dependant ones, is essential for serviceability design, stability analyses or design of prestressed concrete structures. Therefore, the models for concrete properties should provide a reliable prediction for both the final values of creep and shrinkage strains, as well as their evolution in course of time, based on parameters that mostly affect these complex phenomena.

For design purposes, suitable models are those that rely only on parameters which can be reasonably anticipated by designer: compressive strength of concrete, size of the element, type of cement, relative humidity, curing time, duration of loading and concrete age at time of loading. Time-dependant properties of concrete do not actually depend on compressive strength or age at loading, but rather on the composition of concrete (cement content, water-cement ratio, aggregate stiffness, etc.) and degree of hydration at time of loading. However, the effect of each parameter highlighted above on the values of time-dependent properties of concrete has been investigated thoroughly over the past few decades. As a result, there are several proposals for prediction models with different level of complexity.

Code for design of concrete structures BAB 87 [1], which was in use in the republics of former Yugoslavia, provides tabulated values of creep coefficient and shrinkage strains. The values were derived from creep compliance and shrinkage of concrete according to CEB Model Code 78 [2], with regard to conducted experiments and measured data in Yugoslavia [3].

Creep and shrinkage in Eurocode 2 [4] are based on CEB-FIP Model Code 1990-99 [5] which defines creep coefficient as a product function and total shrinkage strain as a sum of two components – autogenous and drying shrinkage strain. The next generation of structural Eurocodes will be based on FIB Model Code 2010 [6] and the creep coefficient will be also decomposed into two basic components.

This paper discusses Eurocode 2 [4] models for creep and shrinkage. A parametric study has been conducted to evaluate the impact of single parameter variations on the final values of creep coefficient and shrinkage strain. As a result, values of the creep coefficient and shrinkage strain are tabulated in compact form, suitable for design purposes. Furthermore, the comparison between Eurocode 2 [4] and Yugoslavian code BAB 87 [1], regarding the final values of creep coefficient and shrinkage strain, is also presented.
2. CREEP AND SHRINKAGE ACCORDING TO EUROCODE 2

Eurocode 2 [4] provides the mean values of creep coefficient (with coefficient of variation of 20%) and shrinkage strain (with coefficient of variation of 30%), for both normal strength and high strength concrete.

1.1. Creep of concrete

Eurocode 2 [4] applies the creep coefficient $\varphi(t,t_0)$ for evaluation of the creep strains. The creep coefficient is related to the tangent modulus of concrete $E_c = 1.05E_{cm}$, where $E_{cm}$ is the value of the secant modulus of elasticity determined at an age of 28 days.

The creep coefficient $\varphi(t,t_0)$ is obtained from:

$$\varphi(t,t_0) = \beta_c(t,t_0) \times \beta(t_0) \times \varphi_{RH} \quad (1)$$

where

$\beta_c(t,t_0)$ is a coefficient expressing the evolution of creep with time after loading,

$\beta(t_0)$ accounts for the effects of concrete age at loading $t_0$ and type of cement (class $S$, $N$ and $R$ according to [4]),

$\varphi_{RH}$ accounts for the effects of relative humidity $RH(\%)$, notional size $h_0$ (mm) of the cross-section and the mean cylinder compressive strength $f_{cm} (= f_{ck}^0 + 8$ MPa) at the age of 28 days,

$h_0$ is the notional size (mm) of the element, $h_0 = 2A/u$, where $A$ is the area of the cross-section and $u$ is the perimeter of the element in contact with the atmosphere.

Coefficient $\beta_c(t,t_0)$ depends mostly on the duration of loading $(t-t_0)$ and, to some extent, on the relative humidity $RH$, the notional size $h_0$ and the concrete strength $f_{cm}$. For a selected time interval $(t-t_0)$, the range of $\beta_c(t,t_0)$ is narrow and mostly affected by combination of the values of $RH$ and $h_0$. The range of values of coefficient $\beta_c(t,t_0)$ for $RH = 50-90 \%$, $h_0 = 200-500$ mm and $f_{cm} = 25-50$ MPa is shown in Figure 1. The “final” value of $\beta_c(t,t_0)$ (value that corresponds to the final creep coefficient, $t \to \infty$) is always equal to 1.0, regardless of $RH$, $h_0$ and $f_{cm}$. Effective value of the final creep coefficient $\varphi(\infty,t_0)$ in Eurocode 2 [4] is related to load duration of 70 years. Corresponding values of $\beta_c(t,t_0)$ are close to 1.0, as shown in Figure 1. Values of the creep coefficient presented in further text are calculated with the value $\beta_c(t,t_0) = \beta_c(\infty,t_0) = 1.0$.

**Figure 1 – Evolution of creep in course of time**

Coefficient $\beta(t_0)$ describes the effect of concrete age $t_0$ at loading. Actual age of the concrete is modified to account for different hardening rates depending on the type of cement ($S$, $N$ or $R$). Values of $\beta(t_0)$ are shown in Figure 2.

Impact of the type of cement is moderate, but slightly emphasized in case of early loading (for cement classes $S$ and $R$ difference is about ±10 % in comparison to class $N$ for $t_0 = 7$ days, and ±7 %, for $t_0 = 14$ days; after that, differences are negligible). Corresponding values of the creep coefficient are shown in Figure 4d.

**Figure 2 – Dependence of $\beta(t_0)$ on age at loading $t_0$ and type of cement**
Coefficient $\varphi_RH$ introduces the effect of relative humidity. It is a linear function of the $RH$ and decreases with an increase of the humidity. It also depends on the notional size of the element $h_0$ and the strength $f_{cm}$. Values of $\varphi_RH$ are in the range from 1.0 to 2.1, for common ambient conditions and concrete grades, Fig. 3. Influence of the relative humidity $RH$ and the notional size $h_0$ on creep coefficient is illustrated in Figs. 4c and 4b.

Effects of single parameter variations on the final value of creep coefficient $\varphi(\infty,t_0)$ are considered in Figs. 4a-d. It can be noticed that the age of concrete at loading $t_0$ has major influence on the creep coefficient. The relative humidity (Fig. 4c) and the concrete strength (Fig. 4a) also have significant influence. Unlike Eurocode 2 [4], Yugoslavian code BAB 87 [1] derives values of the creep coefficient only from $t_0$ and $RH$.

Parametric study of the Exp. (1), regarding the effect of the values of single parameter on the final creep coefficient $\varphi(\infty,t_0)$, led to the following conclusion: It is suitable to tabulate values of the final creep coefficient for a single concrete class (and selected values of other parameters) and to establish the corresponding multiplier for all other classes. This approach is implemented for calculation of the creep coefficients tabulated in Annex 2. The reference concrete class is C30/37 and $\beta_s(t,t_0) = \beta_s(\infty,t_0) = 1.0$ (Table 5). Multipliers for classes C20/25 - C50/60 are given in Table 6 in Annex 2.

**Figure 3 – Dependence of $\varphi_RH$ on parameters $RH$, $h_0$ and $f_{cm}$**

Basic value of the creep coefficient is given in Table 5. It also represents the final value of $\varphi(\infty,t_0)$ for concrete class C30/37. Value of the final creep coefficient for another class is obtained by multiplying the basic value with corresponding coefficient from Table 6. The obtained value differs no more than few percent from the “exact” value from Exp. (1).

Values of the creep coefficient $\varphi(t,t_0)$ from Exp. (1) are valid in the temperature range from -40 to +40 °C [4]. The effect of elevated or reduced temperatures to the hardening process of concrete may be taken into account by adjusting the concrete age $t_0$. The procedure is presented in Annex B of Eurocode 2 [4, Exp. B10].

**Figure 4 – Effect of single parameter variations on the final creep coefficient $\varphi(\infty,t_0)$**

a) effect of concrete strength

b) effect of notional size
c) effect of relative humidity
d) effect of cement class
For concrete stress not greater than 0.45$f_{ck}(t_0)$, where $f_{ck}(t_0)$ is the characteristic concrete strength at the age of loading $t_0$, the stress-strain relation is considered to be linear and $\varphi(t,t_0)$ from Exp. (1) applies. Non-linear creep of concrete should be taken into account when concrete stress exceeds that limit. Creep coefficient from Exp. (1) should be enlarged ([4], Exp. (3.7)).

2.2 Shrinkage of concrete

The total shrinkage strain $\varepsilon_{ct}$, according to Eurocode 2 [4], is equal to (Fig. 5):

$$\varepsilon_{ct} = \varepsilon_{ca} + \varepsilon_{cd}$$

(2)

where $\varepsilon_{ca}$ is the autogenous shrinkage strain, $\varepsilon_{cd}$ is the drying shrinkage strain.

The total shrinkage strain is resolved into components in order to describe the shrinkage behaviour of both normal strength and high strength concrete by a single model.

Contribution of the autogenous shrinkage strain $\varepsilon_{ca}$ to the total shrinkage strain is relatively small for normal strength concrete and noticeably larger for high strength concrete, Fig. 5. On the other hand, the total shrinkage strain fairly depends on concrete strength.

The autogenous shrinkage strain is given as:

$$\varepsilon_{ca} = \beta_{ds}(t)\varepsilon_{ca}(\infty)$$

(3)

where

\begin{itemize}
  \item a) concrete class C30/37
  \item b) concrete class C80/95
\end{itemize}

$\varepsilon_{ca}(\infty)$ is the final value of autogenous shrinkage strain, which is a linear function of concrete strength $f_{ck}$.

$\beta_{ds}(t)$ describes the evolution of the autogenous shrinkage strain in course of time $t$.

The drying shrinkage strain is given as:

$$\varepsilon_{cd} = \beta_{ds}(t, t_s)k_h\varepsilon_{cd,0}$$

(4)

where $\varepsilon_{cd,0}$ is the basic drying shrinkage strain, which accounts for the effects of relative humidity, concrete strength $f_{cm}$ and cement type,

$k_h$ is the coefficient which accounts for the effects of notional size of the element $h_0$,

$\beta_{ds}(t, t_s)$ describes the evolution of the drying shrinkage strain, which is a function of duration of moist curing $t_c$ and notional size of the element $h_0$.

Both the drying shrinkage strain $\varepsilon_{cd}$ and the total shrinkage strain $\varepsilon_{ct}$ decrease with increasing of the concrete strength and the relative humidity, Fig. 5.

The autogenous shrinkage occurs during hydration process and concrete hardening, as a result of self-drying within the material itself, without interaction with the ambient. Most of the autogenous shrinkage strain occurs within first few days after concreting (function $\beta_{ds}(t)$ in Fig. 6).

The drying shrinkage is a result of the migration of water through the hardened concrete and the evaporation. Diagram of the function $\beta_{ds}(t, t_s)$ in Fig. 6 shows that the drying shrinkage strain develops slowly.
Different evolution rates of shrinkage components $e_{\text{sh}}$ and $e_{\text{cr}}$ after concreting (Fig. 6a), as well as their contribution to the total shrinkage strain (Fig. 5), are relevant in case that new concrete is cast against hardened concrete (sequential or staged construction).

The final value of total shrinkage strain $e_{\text{sh}}(\infty)$ is usually relevant for deflection check and control of cracking. Fig. 6b shows that values of evolution functions are close to 1.0 after few years. Values of the creep coefficient presented in the further text are calculated with the value $\beta_{\text{cd}}(\infty) = \beta_{\text{cd}}(\infty, t_s) = 1.0$.

Effects of parameters $RH$, $f_{ck}$, $h_0$ and cement type on the final value of total shrinkage strain $e_{\text{sh}}(\infty)$ are considered in Figs. 7a-c. It can be noticed that the relative humidity $RH$ and cement type are of major influence on the total shrinkage strain. The notional size $h_0$ is also relevant, while concrete strength is of moderate influence. Concrete strength and cement type are not considered for calculation of the total shrinkage strain according to Yugoslavian code BAB 87 [1].

Parametric study of the Exp. (2), regarding the effects of the value of single parameters on the final value of total shrinkage strain $e_{\text{sh}}(\infty)$, lead to the similar conclusion as for creep coefficient: It is suitable to tabulate values of $e_{\text{sh}}(\infty)$ for a single concrete class (and selected values of other parameters) and to establish the corresponding multiplier for all other classes. The obtained value is again close to the “exact” value calculated from Exp. (2).

This approach is implemented for calculation of the total shrinkage strains tabulated in Annex 1. The reference concrete class is C30/37 and $\beta_{\text{cd}}(\infty) = \beta_{\text{cd}}(\infty, t_s) = 1.0$ (Table 3). Multipliers for classes C20/25 - C50/60 are given in Table 4 in Annex 1. Basic value of the total shrinkage strain is given in Table 3. It also represents the final value of $e_{\text{sh}}(\infty)$ for concrete class C30/37. Value of the total shrinkage strain for another class is obtained by multiplying the basic value with corresponding coefficient from Table 4.

3. COMPARISONS EUROCODE 2 – YUGOSLAVIAN CODE BAB 87

Creep coefficients and shrinkage strains provided in Yugoslavian code BAB 87 [1] follow the approach from Model Code 78 [2]. Experimental results on locally produced concrete, especially concerning shrinkage of concrete, were also taken into account [3].

Yugoslavian code [1] provides no expressions for calculation of creep coefficients and shrinkage strains. Only the final values are tabulated. The evolution in course of time is also given by tabulated coefficients in clauses 58 and 60 [1]. These values of creep coefficients and shrinkage strains are derived for concrete grade 30 (MB30), [7], made with Portland cement and no additives [1].

Properties of such concrete correspond to the properties of concrete class C25/30 made with cement class N in Eurocode 2 [4]. Therefore, concrete class C25/30 is applied for comparison of creep coefficients and shrinkage strains provided in [1] and [4], which is presented below.

Figure 7 – Effect of single parameter variations on the total shrinkage strain $e_{\text{sh}}(\infty)$

Figure 8 – Comparison of creep coefficients provided by BAB 87 and EC 2 (C 25/30)
3.1. Creep of concrete

Creep coefficient provided in BAB 87 [1] is a function of concrete age at loading, relative humidity and notional size of the element. In addition to these parameters, Eurocode 2 [4] accounts for concrete strength and type of cement. As an illustration, the values of creep coefficient, for relative humidity RH = 40, 70 and 90 % and h0 = 200 mm, are presented in Fig. 8. It can be noticed that corresponding values are similar. The values differ more for lower humidity and early loading. Differences are smaller if the age at loading is higher. Significant differences in Table 1 are for relatively slender elements (h0 = 100 mm) or for delayed loading (after 3 years), which is rare design situation.

However, the differences are larger when the effect of concrete strength according to Eurocode 2 [4] is considered. As an illustration, the values of the creep coefficients for concrete classes C20/25, C25/30 (= MB30) and C35/45 are shown in Fig. 9.

Presented values in Table 1 and in Figs. 8 and 9 indicate that, in most cases, Yugoslavian code BAB 87 [1] provides slightly higher values of the creep coefficient in comparison to Eurocode 2 [4].

3 godine

<table>
<thead>
<tr>
<th>Concrete age at loading t0 (days/years)</th>
<th>Notional size of the element h0 (mm)</th>
<th>Final values of creep coefficient φ(∞,t0)</th>
<th>Relative humidity - RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BAB 87</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>4.30</td>
<td>3.10</td>
</tr>
<tr>
<td>7</td>
<td>200</td>
<td>4.10</td>
<td>3.32</td>
</tr>
<tr>
<td>7</td>
<td>400</td>
<td>3.80</td>
<td>2.98</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>4.00</td>
<td>3.45</td>
</tr>
<tr>
<td>14</td>
<td>200</td>
<td>3.80</td>
<td>3.05</td>
</tr>
<tr>
<td>14</td>
<td>400</td>
<td>3.60</td>
<td>2.73</td>
</tr>
<tr>
<td>14</td>
<td>100</td>
<td>3.70</td>
<td>3.12</td>
</tr>
<tr>
<td>28</td>
<td>200</td>
<td>3.60</td>
<td>2.76</td>
</tr>
<tr>
<td>28</td>
<td>400</td>
<td>3.40</td>
<td>2.47</td>
</tr>
<tr>
<td>28</td>
<td>100</td>
<td>2.70</td>
<td>2.58</td>
</tr>
<tr>
<td>90</td>
<td>200</td>
<td>2.80</td>
<td>2.28</td>
</tr>
<tr>
<td>90</td>
<td>400</td>
<td>2.90</td>
<td>2.04</td>
</tr>
<tr>
<td>90</td>
<td>100</td>
<td>1.70</td>
<td>2.01</td>
</tr>
<tr>
<td>365</td>
<td>200</td>
<td>1.80</td>
<td>1.78</td>
</tr>
<tr>
<td>365</td>
<td>400</td>
<td>2.00</td>
<td>1.59</td>
</tr>
<tr>
<td>365</td>
<td>100</td>
<td>0.90</td>
<td>1.64</td>
</tr>
<tr>
<td>365</td>
<td>3 godine</td>
<td>200</td>
<td>1.10</td>
</tr>
</tbody>
</table>
3.2. Shrinkage of concrete

Shrinkage strain provided in BAB 87 [1] is a function relative humidity and notional size of the element. In addition to these parameters, Eurocode 2 [4] accounts for concrete strength and type of cement.

Corresponding values of the final shrinkage strain from [1] and [4] are presented in Table 2. Eurocode 2 [4] values are calculated for concrete class C25/30 and cement class N.

The values from both codes, presented in Table 2, are similar. Impact of the concrete strength is relatively small (Fig. 7a).

However, one should have in mind that the use of cement classes S and R leads to larger differences than those presented in Table 2.

Table 2. Comparison of shrinkage strains provided by BAB 87 and EC 2 (cement class N)

<table>
<thead>
<tr>
<th>Notional size of the element $h_0$ (mm)</th>
<th>Final values of total shrinkage strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative humidity - RH (%)</td>
</tr>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>100</td>
<td>BAB 87</td>
</tr>
<tr>
<td>0.56</td>
<td>0.40</td>
</tr>
<tr>
<td>0.59</td>
<td>0.34</td>
</tr>
<tr>
<td>0.40</td>
<td>0.30</td>
</tr>
<tr>
<td>0.48</td>
<td>0.20</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

For common load histories and ambient conditions, presented analysis shows that there are no major differences in prediction of time-dependant properties of concrete according to Eurocode 2 and Yugoslavian code BAB 87.

Eurocode 2 uses more parameters to define values of the creep coefficient and the shrinkage strain in comparison to Yugoslavian code BAB 87. Additional parameters are concrete strength and cement class. For design purposes, the final values of creep coefficient and shrinkage strain according to Eurocode 2 can be tabulated using age at loading, relative humidity and notional size as basic parameters, similarly as in BAB 87. Provided multipliers can be used to account for the effects of additional parameters.

ACKNOWLEDGMENT

The authors express the gratitude to the Ministry of Education, Science and Technological Development of the Republic of Serbia for the financial support under the project TR-36048 „Research on condition assessment and improvement methods of civil engineering structures in view of their serviceability, load-bearing capacity, cost effectiveness and maintenance”.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 5.

REFERENCES

ANNEX 1 – Final values of the total shrinkage strain according to EN 1992-1-1:2004

Table 3. Final values of the total shrinkage strain ε_{cs}(∞) (%) for concrete class C30/37

<table>
<thead>
<tr>
<th>ho (mm)</th>
<th>Cement class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>100</td>
<td>0.44</td>
</tr>
<tr>
<td>200</td>
<td>0.38</td>
</tr>
<tr>
<td>300</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 4. The ratio of total shrinkage strains ε_{cs}(∞) for particular class and for class C30/37

<table>
<thead>
<tr>
<th>Concrete class</th>
<th>RH (%) = 50</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>C20/25</td>
<td>1.06</td>
<td>1.04</td>
<td>1.02</td>
<td>0.95</td>
</tr>
<tr>
<td>C25/30</td>
<td>1.03</td>
<td>1.02</td>
<td>1.01</td>
<td>0.97</td>
</tr>
<tr>
<td>C35/45</td>
<td>0.98</td>
<td>0.98</td>
<td>1.00</td>
<td>1.03</td>
</tr>
<tr>
<td>C40/50</td>
<td>0.95</td>
<td>0.97</td>
<td>1.00</td>
<td>1.06</td>
</tr>
<tr>
<td>C45/55</td>
<td>0.93</td>
<td>0.96</td>
<td>1.00</td>
<td>1.09</td>
</tr>
<tr>
<td>C50/60</td>
<td>0.92</td>
<td>0.96</td>
<td>1.00</td>
<td>1.13</td>
</tr>
</tbody>
</table>

ANNEX 2 – Final values of the creep coefficient according to EN 1992-1-1:2004

Table 5. Final values of the creep coefficient φ(∞, to) for concrete class C30/37

<table>
<thead>
<tr>
<th>to (days/years)</th>
<th>ho (mm)</th>
<th>Cement class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>N</td>
</tr>
<tr>
<td>7</td>
<td>3.80</td>
<td>3.43</td>
</tr>
<tr>
<td>200</td>
<td>3.41</td>
<td>3.07</td>
</tr>
<tr>
<td>300</td>
<td>3.21</td>
<td>2.90</td>
</tr>
<tr>
<td>14</td>
<td>3.19</td>
<td>3.01</td>
</tr>
<tr>
<td>200</td>
<td>2.86</td>
<td>2.70</td>
</tr>
<tr>
<td>300</td>
<td>2.69</td>
<td>2.55</td>
</tr>
<tr>
<td>21</td>
<td>2.90</td>
<td>2.79</td>
</tr>
<tr>
<td>200</td>
<td>2.60</td>
<td>2.50</td>
</tr>
<tr>
<td>300</td>
<td>2.45</td>
<td>2.36</td>
</tr>
<tr>
<td>28</td>
<td>2.72</td>
<td>2.64</td>
</tr>
<tr>
<td>200</td>
<td>2.43</td>
<td>2.37</td>
</tr>
<tr>
<td>300</td>
<td>2.30</td>
<td>2.23</td>
</tr>
<tr>
<td>45</td>
<td>2.45</td>
<td>2.41</td>
</tr>
<tr>
<td>200</td>
<td>2.20</td>
<td>2.16</td>
</tr>
<tr>
<td>300</td>
<td>2.07</td>
<td>2.04</td>
</tr>
<tr>
<td>60</td>
<td>2.31</td>
<td>2.28</td>
</tr>
<tr>
<td>200</td>
<td>2.07</td>
<td>2.05</td>
</tr>
<tr>
<td>300</td>
<td>1.95</td>
<td>1.93</td>
</tr>
</tbody>
</table>
I. MILIČEVIĆ et at.

CREEP AND SHRINKAGE OF CONCRETE ACCORDING TO EUROCODE 2

Table 6. The ratio of creep coefficients $\phi(\infty, t_0)$ for particular class and for class C30/37

<table>
<thead>
<tr>
<th>C20/25</th>
<th>RH (%) = 50</th>
<th>70</th>
<th>80</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>C25/30</td>
<td>1.22</td>
<td>1.21</td>
<td>1.20</td>
<td>1.19</td>
</tr>
<tr>
<td>C35/45</td>
<td>0.88</td>
<td>0.89</td>
<td>0.90</td>
<td>0.91</td>
</tr>
<tr>
<td>C40/50</td>
<td>0.79</td>
<td>0.81</td>
<td>0.82</td>
<td>0.83</td>
</tr>
<tr>
<td>C45/55</td>
<td>0.72</td>
<td>0.74</td>
<td>0.75</td>
<td>0.77</td>
</tr>
<tr>
<td>C50/60</td>
<td>0.66</td>
<td>0.68</td>
<td>0.70</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Table 6. The ratio of creep coefficients $\phi(\infty, t_0)$ for particular class and for class C30/37

<table>
<thead>
<tr>
<th>Cement class</th>
<th>$h_0$ (mm)</th>
<th>Final value of creep coefficient $\phi(\infty, t_0)$ for concrete class C30/37</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>N</td>
<td>R</td>
</tr>
<tr>
<td>90</td>
<td>100</td>
<td>2.13</td>
</tr>
<tr>
<td>200</td>
<td>1.91</td>
<td>1.89</td>
</tr>
<tr>
<td>300</td>
<td>1.80</td>
<td>1.79</td>
</tr>
<tr>
<td>365</td>
<td>100</td>
<td>1.61</td>
</tr>
<tr>
<td>200</td>
<td>1.45</td>
<td>1.44</td>
</tr>
<tr>
<td>300</td>
<td>1.36</td>
<td>1.36</td>
</tr>
<tr>
<td>3 days</td>
<td>100</td>
<td>1.30</td>
</tr>
<tr>
<td>200</td>
<td>1.17</td>
<td>1.17</td>
</tr>
<tr>
<td>300</td>
<td>1.10</td>
<td>1.10</td>
</tr>
</tbody>
</table>

REZIME

DEFORMACIJE TEČENJA I SKUPLJANJA BETONA PREMA EVROKODU 2


Ključne reči: beton, tečenje, skupljanje, Evrokod 2, BAB 87
TEHNIKA

INVITATION TO COOPERATION AND SUBSCRIPTION

TEHNIKA is the leading Serbian scientific and technical magazine covering areas from science and professional topics. It has been published for 72 years in a row by the Union of Engineers and Technicians of Serbia thus creating a unique scientific and technical basis for transfer of scientific, technologic, commercial and business information originating both locally and internationally. According to the Ministry of Education, Science and Technological Development of Republic of Serbia this magazine has been thought of as a first class magazine in its category.

All published contributions and papers are subjected to professional review in order to guarantee highest scientific and professional level. Published papers are being referred to in internationally renown magazines, such as: Geotechnical Abstracts, Metals Abstracts, Chemical Abstracts, Electrical and Electronics Abstracts, Science Abstracts, Ergonomics Abstracts and reference journals VINITI. They also serve as background source of information for international data base requirements: INSPEC (IEEE, London), METADEX (M. I., England), CASEARCH (CA, USA).

The magazine is being disseminated both throughout the country and abroad (in about 30 countries) through subscriptions and scientific magazine exchange.

Readership in Serbia includes businesses and companies, professional libraries, military readership, faculties, institutes, college level and high schools, social and political entities and organizations, embassies, representation offices, trade and public relations agencies, chambers of commerce, individuals and other.

The magazine offers its space to papers classified under areas, such as: New Materials, Our Civil Engineering, Mining, Geology and Metallurgy, Mechanical Engineering, Electrical Engineering, Transport and Traffic Engineering, Management, and Standardization, Quality and Metrology.

In addition, there are columns permanently covering a variety of topics, such as overviews of books and magazines, review of scientific and professional gatherings both local and international, technical news information.

This 180 page magazine is being published bi-monthly in A-4 format.

Cooperation with the magazine offers you the possibility to present not only the results of your efforts and expertise but also the knowledge and developments in the company you work for in a way that makes it known and available to relevant scientific and professional circles.

UNION OF ENGINEERS AND TECHNICIANS OF SERBIA

Kneza Milosa 7a/I, 11000 Belgrade, Serbia
Tel.: Editorship: (011) 32-35-891, 3237 363
e-mail: tehnika@sits.rs;  office@sits.rs
TECHNICS

MINING

GEOLGY AND

METALLURGY

Rudarstvo, geologija i metalurgija - Exploitation des mines, géologie et métallurgie - Bergbau, Geologie und Metallurgie - Горная промышленность геология и металлургия

YEAR 68 – 2017

EDITOR-IN-CHEF
Prof. Božo Kološna, D.Sc, University of Belgrade, Faculty of Mining and Geology, Belgrade

Editor for Mining
Prof. Dinko Knžević, D.Sc, University of Belgrade, Faculty of Mining and Geology, Belgrade

Editor for Geology
Prof. Aleksandar Kostić, D.Sc, University of Belgrade, Faculty of Mining and Geology, Belgrade

Editor for Metallurgy
Miroslav Sokić, D.Sc, Institute for Technology of Nuclear and other Mineral Raw Materials, Belgrade

EDITORIAL COUNCIL
Prof. Radule Tosović, D.Sc, University of Belgrade, Faculty of Mining and Geology, Belgrade

Prof. Todor Serumovski, D.Sc, Faculty of Mining and Geology, Štip, Macedonia

Mirko Maksimović, B.Sc, Association of Mining and Geological Engineers of Serbia, Belgrade

Prof. Nada Štrbac, D.Sc, University of Belgrade, Technical Faculty in Bor, Bor

Branislav Marković, D.Sc Institute for Technology of Nuclear and other Mineral Raw Materials, Belgrade

EDITORIAL OFFICE: Union of Engineers and Technicians of Serbia, 11000 Belgrade, Kneza Miloša 7a/I, Tel. +381/11/32 35 891, Fax +381/11/32 30 067
Environmental Noise Management in the Area of Opencast Mines

NIKOLA M. LILIĆ, University of Belgrade,
Faculty of Mining and Geology, Belgrade
ALEKSANDAR S. CVJETIĆ, University of Belgrade,
Faculty of Mining and Geology, Belgrade
VLADIMIR M. MILISAVLJEVIĆ, University of Belgrade,
Faculty of Mining and Geology, Belgrade
UROŠ R. PANTELIĆ, University of Belgrade,
Faculty of Mining and Geology, Belgrade
LIJILJANA R. KOLONJA, University of Belgrade,
Faculty of Mining and Geology, Belgrade

Environmental noise constitutes a threat regarding disturbance and deterioration of quality of living. There are numerous sources of environmental noise, among others mine objects, traffic roads etc. In Serbian practice open cast mines are commonly in vicinity of residential areas, which is the case of the Field C open cast coal mine and the Barosevac settlement. More complexity is added to noise management in such conditions through additional noise sources, not directly linked to mine objects and activities, such as local or regional roads. This paper describes an approach to noise management for the purpose of environmental noise impact reduction, from both traffic and industrial sources, related to the project Environmental Improvement Project in Kolubara Mine Basin in Barosevac settlement, as a part of acquisition of new Excavator-belt Conveyor-Stacker (ECS) system.

Key words: environmental noise, noise mapping, opencast coal mine

1. INTRODUCTION

Higher noise emissions into the environment (both working and natural natural) are inevitable during technological processes in coal production and processing. Also, noise constitutes a threat regarding damage to and in worst case loss of hearing capability. One of the means and most basic approach for overcoming this problem is noise mapping, or determination of noise zones in accordance with Directive 2002/49/EC [1] and the Law on Protection from Noise in Environment (“Official Gazette of RS”, no. 36/2009 and 88/2010) [2].

This topic was subject of research of many authors. An empirical model for calculation of noise distribution from different sources was developed by Sensogut and Cinar [3, 4]. They used it in Tuncbilek open cast mine, in Turkey. The model is based on large amount of data, obtained from 312 measuring stations for monitoring noise on mentioned open cast mine.

Research of Degan et al. [5] was directed to identification of simplified but efficient technique for measurement and analysis of noise impact in vicinity of mine (open cast).

Pathak et al. [6] developed technique for noise forecasting originated from operation of specific groups of mining machines. This technique can be used for assessment of comprehensive sound field in vicinity of open cast mine. Research of Lilić et al. related to open cast mine, resulted in developed noise mapping model for the purpose of definition of measures for reduction of negative noise impact in immediate vicinity of open cast mine [8, 11].

2. BASELINE CHARACTERISATION

In this paper the authors presented an approach to environmental noise management related to project Environmental Improvement Project in Kolubara Mine Basin - Part A – Procurement and Erection of ECS system for Field “C”.
At the start of the mentioned Kolubara Mine Basin project implementation, the Faculty of Mining and Geology, University of Belgrade, was engaged to perform baseline noise measurement in the Baroševac settlement. Measurements were performed on two locations in period from 15.06.2013 to 19.06.2013. Locations of measuring points are shown in Figure 1. First one was at the family house owned by Radosav Pantelic, with coordinates N44°23.926' and E20°22.236' and the second one was at the family house owned by Goran Nikolic with coordinates N44°24.006' and E20°21.852'. The terrain around the measurement points is of urban characteristics with open space, covered with low vegetation, and without barriers for sound propagation, as it could be seen on Figure 1. Background noise at this point originates from the traffic at the main road Stepojevac-Arandjelovac and from different activities usual for this type of settlement.

![Figure 1 - Locations of measuring points (Google map)](image)

The results of continuous 24-hour noise measurements on the locations for the purpose of baseline characterisation are given in the table 1. It is obvious that some recorded noise levels listed in table 1 exceed prescribed limit values for environmental noise according to the Act [2].

All noise measurements, presented in the table 1, was conducted by using handheld analyzer, type 2250 (Bruel&Kjaer) which technical characteristics fulfill the requirements from standards defining environmental noise measurements.

<table>
<thead>
<tr>
<th>Measurement period</th>
<th>Measuring Point 1, (dB(A))</th>
<th>Measuring Point 2, (dB(A))</th>
<th>Limited value of noise, (dB(A))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>60</td>
<td>61</td>
<td>63</td>
</tr>
<tr>
<td>Evening</td>
<td>64</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Night</td>
<td>55</td>
<td>54</td>
<td>64</td>
</tr>
</tbody>
</table>

Table 1. Applicable noise levels at measuring points and limited value of noise

4. DEVELOPMENT OF NOISE MAPPING MODEL

First step in creating a noise mapping model is identification of noise sources. In this case these are:

- excavator and stacker,
- drive stations of belt conveyors,
- belt conveyors.

Data on noise levels from above mentioned sources, in form of $L_{Aeq}$, are obtained by noise measurement and they are used as base for development of noise map presented in this paper.

Additional noise source at this location is regional road Lazarevac-Arandjelovac (Figure 2). Noise originated by the traffic along this road was also taken into consideration during development of the model [9].
Mapping software SoundPlan was used for development of noise model. Methodology of noise mapping stipulates validation of sources, which was performed with existing measurements in vicinity of the sources. Model validation was done with noise measurements at points presented in table 1. Results of noise measurements at same points are indicating levels in span from 57 dB(A) to 63 dB(A) at MP1, and 60-64 dB(A) at MP2. Such conditions are corresponding to the results of modelling. Model validation results are shown on Figure 3, together with data acquired by measurement at individual noise sources and at sensitive receptors (residential objects, MP1 and MP2).

Based on performed measurements and input data for modeling, it is concluded that most dominant individual source of noise on new ECS system on Field C open cast mine are drive stations of belt conveyors. Accepted level of equivalent noise, for the purpose of modelling, at drive stations is 86 dB(A). Noise at the stacker is significantly lower, and it is accepted at level of 74 dB(A). Somewhat lower noise was on the belt conveyor, which is accepted at level of 72 dB(A) for the modelling.

![Figure 2 - Disposition of Field “C”, road Arandje-lovac-Lazarevac and Barosevac willage](image)

![Figure 3 - Noise levels in vicinity of new ECS system at open cast mine "Field C" – initial condition (base condition)](image)

Results from the model validation process and from field measurements showed that marginal parts of Baroševac settlement (parts closest to the mine) will be in zone with equivalent noise in range 59-62 dB(A) (during day, evening and night). According to the Act [2] noise level in zone 4 (which is suitable for exposed objects) must not exceed 60 d(A) for day and evening and 50 dB(A) for night. Model suggests that daily operation of the mine with existing traffic along the regional road Lazarevac – Arandelovac, will generate exposure of mentioned parts of settlement to noise levels higher than allowed during the day and night.

5. SUGGESTED MEASURES FOR NOISE SUPPRESSION AND ABATEMENT

Measures for noise reduction was implemented on all drive stations of belt conveyors, resulting in reduction by 10 dB(A) in relation to initial value, in order to examine possibilities for improvement of environmental quality. It is possible to lower noise level by 11 dB(A) applying covering-enclosing of drive station [10]. Modelling results, after reduction of noise from drive stations by 10 dB(A), are shown on Figure 4.

![Figure 4 - Noise levels in vicinity of new ECS system at open cast mine "Field C" – modelled condition](image)

It is obvious that applying the measure will result in sufficient noise reduction and ensures compliance with requirements from the Act [2] for day and evening, but not during the night. In the night period noise is still above the limit of 50 dB(A).

Having in mind proximity of regional road and traffic intensity along the road as well as its contribution to the overall noise additional modeling is performed in order to establish the impact of individual components of ECS system in relation to intensity of night traffic along the section of regional road Lazarevac – Arandelovac.
Figure 4 - Noise levels in vicinity of new ECS system at open cast mine "Field C" after reduction of noise on drive stations along the new ECS system

Modeling of operation of new ECS system, with implemented measures for noise reduction along the Baroševac settlement, excluding traffic noise is shown on Figure 5.

As it can be seen on Figure 5, operation of new ECS system with implemented measures along the route through Baroševac, is in accordance to the requirements of Act for night operation - below 50 dB(A).

Based on that we can concluded about significant impact of the road on overall noise level affecting the settlement during night (Figure 6).

Figure 5 - Modelling results of new ECS system operation without the traffic noise from regional road Lazarevac – Arandelovac

Figure 6 - Noise modelling results of combined operation of new ECS system and night traffic along the regional road Lazarevac – Arandelovac
In favor of improving the noise environment it is a fact that part of regional road Lazarevac – Arandedlovac will be relocated as development of "Field C" open cast mine takes place, therefore it importance will be reduced.

Hence, it is confident to conclude that operation of new ECS system, with suggested measures for noise reduction at drive stations of belt conveyors, will be in accordance to the Act.

6. CONCLUSION

Environmental noise constitutes a threat regarding disturbance and deterioration of quality of living. There are numerous sources of environmental noise.

Case study presented in the paper describe issues in Barosevac settlement which is exposed to noise emitted from Field C open cast mine and a regional road. In Serbian practice open cast mines are commonly in vicinity of residential areas, which is the case of the Field C and the Barosevac settlement.

Higher noise emissions are inevitable during technological processes in coal production and processing. Since coal production process can't be stopped, as well as traffic along the mentioned road, it is difficult to make a conclusion which source has higher impact on neighboring housing and to what extent.

However, it is necessary to establish prominent source in order to plan measures for noise reductions in the environment within the noise management action plan.

Noise mapping is a tool which give us such potential and it is efficient way for assessment and management of noise, both in design and operational stage.

Modelling results for above-mentioned conditions are indicating that covering of drive stations along the route of belt conveyors, parallel to the Barosevac, noise level to neighboring parts of settlement can be successfully reduced to value bellow 60 dB(A), even bellow 50 dB(A), thus meeting requirements of Act [2] during the day, evening and night period. It should be mentioned that noise from the section of regional road Lazarevac – Arandedlovac has significant role to exposure of parts of the settlement along the route of the new ECS system.

7. ACKNOWLEDGMENT

Research described in this paper was performed during development of the project "Improvement of lignite opencast mining technology in order to increase energy efficiency and occupational safety" (TR33039). Development of this project is financed by Ministry of Education and Science of Republic of Serbia, for period 2011-2016.

REMARK

This paper was published in the Magazine „Tehnika“, LXXII, 2017, No 1.

REFERENCES


REZIME

UPRAVLJANJE BUKOM U ŽIVOTNOJ SREDINI NA PODRUČJU POVRŠINSKIH KOPOVA

Buka u životnoj sredini predstavlja realnu opasnost sa stanovišta uzemiravanja i pogoršanja kvaliteta života. Brojni su izvori buke u životnoj sredini, da napomenemo samo neke: rudarski objekti, saobraćajnice i sl. U Srbiji su površinski kopovi često u neposrednoj blizini stambenih objekata, što je slučaj i sa površinskim kopom uglja „Polje C”, koje je u neposrednoj blizini naselja Baroševac. Problem upravljanja bukom u takvim situacijama se usložnjava postojanjem dodatnih izvora buke, koji nisu u direktnoj vezi sa rudarskim objektima i aktivnostima, kako na primer lokalnih ili regionalnih saobraćajnica. U radu je opisana mogućnost upravljanja bukom, koja potiče od industrijskih izvora i okolnog saobraćaja, u cilju smanjenja njenog uticaja na životnu sredinu.

Ključne reči: buka u životnoj sredini, mapiranje buke, površinski kopovi uglja
Spatial Distribution of the Demir Kapija (FYR Macedonia) Ophiolite Based on Geomagnetic Data

DRAGANA D. ĐURIĆ, University of Belgrade, Faculty of Mining and Geology, Belgrade
VESNA V. CVETKOV, University of Belgrade, Faculty of Mining and Geology, Belgrade
VLADICA D. CVETKOVIĆ, University of Belgrade, Faculty of Mining and Geology, Belgrade

The Demir Kapija ophiolite is the largest outcrop of the East Vardar Zone in FYR Macedonia. The aim of this study was to determine the spatial position of this ophiolite by applying mathematical transformations of geomagnetic data. Analysis of anomaly values of geomagnetic data includes processing data that comprise Z component of the magnetic field. Based on these results, it is concluded that the Demir Kapija ophiolite dips to the east/southeast and that the shape of this body is a plate-like. The spatial position of the Demir Kapija ophiolite suggests that its contact with the adjacent Serbo-Macedonian massif is sub vertical close to the surface, and that it becomes less steep with increasing depth. The obtained data suggest that part of the East Vardar Zone is present below the Serbo-Macedonian unit.

Key words: geomagnetic data, mathematical transformation, spatial distribution, East Vardar Zone, Demir Kapija ophiolite

1. INTRODUCTION

The Vardar zone, in a wider sense, represents a suture zone, placed between the Drina-Ivanjica unit in the west and the Serbo-Macedonian massif (SMM) in the east, and consists of ophiolite and various rocks of the so-called accretion mélange. It is divided into the western, central and eastern zones [1]. The tectonic position of the East Vardar Zone (EVZ) is still a matter of debate between scientists. The East Vardar Zone includes the easternmost (Figure 1) narrow ophiolitic belt, which extends, from north to south, from the Apuseni Mts. in Romania [2], [3], [4], [5], through the central part of Serbia, including Ždraljica and Kuršumlija ophiolites, continuing further to the south in the Peonias zone in FYR Macedonia and Greece. In the territory of FYR Macedonia, the ophiolite complex can be traced within the Vardar valley, from Skopje to Gevgelija and the Macedonian-Greek border. The biggest outcrop of the EVZ in FYR Macedonia is represented by Demir Kapija ophiolite complex (Figure 1 and Figure 2).

Figure 1 - Simplified tectonic sketch of Macedonia, modified from [9]
Within the EVZ (Peonias zone), the Demir Kapija ophiolite was mapped in two different ways, as they were thrust onto SMM [6, 7] or as they were tectonically overlaid by SMM [8]. There are suggestions that this ophiolite complex was formed by opening a back arc basin behind Paikon arc [9, 10], and that is later thrust on it [11].

The ophiolite complex of Demir Kapija (OCDK) comprises a sequence composed of pillow basalt, dolerite, dolerite dyke and gabbros (Figure 2). Small, isolated bodies of serpentiniised peridotite are represented by the dunite and lerzolite [7]. Granitoids and granites are present from Štip, through Mt Konečka and further to Plaused-Furka (Fanos). These granites were formed during the post-collision tectonics, shortly after the Jurassic collision processes responsible for the emplacement of ophiolite [13].

On the east of OCDK a Serbo-Macedonian massive (SMM) is present. SMM is represented by Precambrian and Paleozoic metamorphosed sedimentary and magmatic rocks (gneiss, mica schist, amphibolite, greenschist and marbles). In this paper a very complex lithology of SMM is simplified and reduced to the zone of direct contact with the EVZ.

![Figure 2 - Simplified geological map of the Ophiolite Complex of Demir Kapija, modified from [14]](image)

The aim of this research was to determine the spatial position of the Demir Kapija ophiolite, based on geomagnetic data in the area of FYR Macedonia. By defining the position of this ophiolite complex, it was concluded that the Demir Kapija ophiolite dips to the east-southeast, i.e. that the EVZ in the territory of FYR Macedonia lies below the SMM.

2. METHODOLOGY

Mathematical transformations were applied to the anomaly field of the vertical component of the geomagnetic field in order to define the spatial position of the OCDK, and to allocate the "desired" response from the total signal. The allocation of response from the total signal, allows the analysis of the causes of anomalies. The appearance i.e. the shape of the anomaly in the section and in the plan indicates the depth and horizontal spread of the body that causes the anomaly (hereafter: the cause of anomaly).

The shallower causes induce anomalies with minor horizontal distribution, but with strong gradients, while the causes at greater depths have anomalies with wide horizontal distribution and small gradients. All transformations actually represent a unique filtering of the anomaly values of raw data in the frequency-domain.

The data of the vertical (Z) component of the geomagnetic field, obtained on the basis of the 1st order measurement in SFRY during the period from 1967 to 1979 were used. Values were reduced to the epoch 1970.0. The daily variation correction was entered according to the registrations obtained from Grocka Geomagnetic Observatory [15]. The density of data in the investigated area is 1 point to 4 km².

For the magnetic properties determination, the different lithological rocks were sampled. Oriented samples of tectonically undisturbed rock material were collected. From every rock sample cylindrical samples with size 2.5 cm x 2.5 cm were subsequently drilled. Measurements of natural remanent magnetization (NRM) and magnetic susceptibility were performed. Magnetic susceptibility was measured at the multi-frequency Kappabridge MFK1-A (AGICO), whereas the natural remanent magnetization was measured on the Spinner JR-5 magnetometer (AGICO).

A geophysical software package Geosoft Oasis Montaj was used for the analysis of the geomagnetic data and for the application of data transformations (in spatial domain) in order to define the position of the cause of anomaly, in the horizontal plane at different depths.

In order to simplify the shape of the magnetic anomaly, the reduction to pole (RTP) was applied, whereby the magnetic anomaly was transformed into an anomaly that would be measured in case that the body's magnetization and the ambient field were vertical, which is correct in case of small value of Kenigs-
berger ratio \(Q\). The influence of remanent \(J_r\) and induced \(J_i\) magnetization can be expressed by Kenigsberger ratio:

\[
Q = \frac{J_r}{J_i}
\]

Based on the data obtained by measuring, it was calculated that \(Q\) has the highest value of two for dolerite samples, which makes it possible to apply the reduction to pole procedure.

The method of upward continuation is based on the fact that the potentials of field at a certain level can be determined as well as at the other level. The upward continuation includes calculation of the successive derivative of the vertical field component \[16\], \[17\] and highlights the regional impact.

In the horizontal plane, the intensity of the field at a new point is calculated at a certain distance from the measuring surfaces, and the surface distribution is taken as an infinite layer of a certain thickness. In this paper, an upward continuation was applied up to the levels of 1000 m, 2000 m, 3000 m and 5000 m.

The procedure of tilt derivative angle (TDR) allows defining the edges of the cause of anomalies and obtaining information on their horizontal position \[18\] \[19\] \[20\] \[21\]. TDR procedure uses the value of the total horizontal output (THDR) and it is defined as:

\[
TDR = \tan^{-1}\left(\frac{VDR}{THDR}\right)
\]

where VDR and THDR are the first vertical and total horizontal derivatives \[17\] \[18\].

Due to the nature of the \(\arctan\) function, all the amplitudes are related to the range between \(-\pi/2\) and \(\pi/2\) (or \(+90\) and \(-90\)), irrespectively of the amplitude of the TDR and VDR. This fact allows the function to equalize the amplitude response of the vertical component of the geomagnetic field.

TDR has positive values above the cause of anomaly (positive anomaly), a negative value outside the cause, and a value of zero above or near the boundary of the cause of anomaly. In this case the vertical derivative is equal to zero, and the horizontal derivative is maximal \[18\].

In addition to the described procedures, a combination of TDR and upward continuation was applied in order to define the boundaries of the cause of the anomaly for different levels.

3. RESULTS

Map of the magnetic anomaly of the vertical component for the study area \(\Delta Z\) is shown in Figure 3. Anomalies, shown on the map, have a range from -240 to 480 nT. On the geomagnetic map six narrow areas are distinguished (Figure 4), extending in the direction of SZ-JI with high positive values \(\Delta Z\).

These low values of \(\Delta Z\) for gabbro are not common and could be caused due to a large difference in magnetic properties in relation to neighboring Paleozoic and Triassic/Jurassic units as well as to eastwardly present dolerite (C). It is noteworthy that the gabbro is tectonically disturbed. The C area, which is represented by dolerite, is characterized by extremely high values of \(\Delta Z\), ranging from 210 to 450 nT. The area D is represented by SMM metamorphic rocks and, considering the entire area, it is characterized by moderate values of \(\Delta Z\). The area E, with a range of \(\Delta Z\) values from 100 to 350 nT, corresponds to the position of granitoid rocks. The easternmost area F is also represented by SMM and has the same range of \(\Delta Z\) as the area D. It can be noted that the boundaries between the geotectonic units are distinctive, as well as the distribution of granitoid intrusions (Figure 4).
After the analytical upward continuation, for the levels: 1000 m, 3000 m, 5000 m (Figure 5), it can be determined that the most dominant geotectonic unit below the surface is the EVZ, i.e. that EVZ ophiolite cause highest values of $\delta Z$, compared to all other present units. Their western boundary is clearly expressed, while the eastern boundary is diffuse. It is noticeable that the EVZ dips toward the east and merges with the SMM at higher depths.

On the TDR map (Figure 6a), boundaries of the cause of anomalies in this area are determined. Those boundaries correspond to the boundaries of gabbros and dolerites shown on the Basic geological map (Figure 2). This complex represents part below the surface that has the greatest impact on the response of geomagnetic anomalies in the investigated area. After analyzing the maps obtained using the upward continuation, and then the tilt derivation angle (Fig. 6 b, c and d), for the levels 1000, 3000 and 5000 m, it is noticeable that the boundaries of the cause of anomalies under the surface are clearly expressed throughout the whole area. It can be concluded that the ophiolites in the southern part of the terrain, at greater depths, extend in the direction of N-S, unlike their surface occurrences that extend towards the NNW-SSE. Also, with increasing the depth, the boundary with the SMM is moved eastward.

The appearance of the anomalies in Figure 6 indicates that in the northern part of FYR Macedonia there is a break in the continuity, unlike the anomalies in the southern and central parts, which indicate a single body / belt.
On the basis of the data obtained by combining the method of upward continuation and the tilt derivative angle, it can be concluded that with increasing the depth the eastern boundary of the ophiolite complex dips to the east, and that the OCDK has at least twice in spreading with increasing depth (Figure 6c).

4. CONCLUSIONS

The results of applying mathematical transformations to geomagnetic data show that the OCDK has clear and sharp tectonic boundaries with the geological units in direct contact. It is also concluded that the ophiolite complex of Demir Kapija is most likely a platy shaped body that dips to the east, or southeast. The obtained results are in accordance with previous studies [22], according to which the entire EVZ dips towards the east / southeast and that part of it is located below the SMM. The determined position of the OCDK, i.e. the EVZ, is in agreement with the view that the EVZ ophiolites were placed by accretion mechanism during the in the closure of the Mesozoic Tethys [22], as well as with numerous geological-petrological and geochemical research [1][9][10].

5. ACKNOWLEDGEMENT

This study was supported by the Serbian Ministry of Education, Science and Technological Development, project No. 176016. D. D. thanks to Society of Geophysical Exploration.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXI, 2016, No. 2.

REFERENCES


REZUME

PROSTORNI POLOŽAJ OFIOLITSKOG KOMPLEKSA DEMIR KAPIJE (MAKEDONIJA)
UTVRĐEN NA OSNOVU GEOMAGNETSKIH PODATAKA


Ključne reči: geomagnetski podaci, matematičke transformacije, Istočna vardarska zona, ofiolitski kompleks Demir Kapije
The Influence of the Temperature of Solution Heat Treatment on the Properties of 6000 Series Aluminum Alloys

UROŠ S. STAMENKOVIĆ, University of Belgrade, Technical Faculty in Bor, Bor

SVETLANA LJ. IVANOV, University of Belgrade, Technical Faculty in Bor, Bor

IVANA I. MARKOVIĆ, University of Belgrade, Technical Faculty in Bor, Bor

NADA D. ŠTRBAC, University of Belgrade, Technical Faculty in Bor, Bor

ALEKSANDRA M. MITOVSKI, University of Belgrade, Technical Faculty in Bor, Bor

The 6000 series alloys belong to the group of aluminium alloys that contain magnesium and silicon as their two main alloying elements. In addition to these two alloying elements, the alloys contain manganese and other elements, in accordance to the type of alloy. Alloys from this series belong to the group of aluminium alloys which are susceptible to thermo-mechanical treatment. These alloys exhibit the best mechanical and physical properties when they are artificially aged, with the occurrence of the strengthening β′′ phase. The process of ageing includes solution heat treatment, quenching and ageing at predefined temperatures for a specified amount of time. All the aforementioned processes have a direct impact on the physical and mechanical properties of the alloy following the performed thermal treatment. In this paper the influence of the temperature of solution heat treatment on the properties of two aluminium alloys belonging to the 6000 series was examined, EN AW-6060 and EN AW-6082. The samples were examined at five different temperatures varying from 510-590° C. In order to examine the influence of the temperature of solution heat treatment, measurements of the hardness and electrical conductivity of the samples were performed, following adequate thermal treatment. After the testing, analysis of the results showed that with the increase of the temperature of soluble annealing, there occurred an increase in hardness, and a decrease in electrical conductivity in the aged samples, due to a better homogenization which caused a better distribution of metastable phases.

Key words: aluminium alloys, heat treatment, hardness, electrical conductivity

1. INTRODUCTION

Presently, Al-Mg-Si alloys (6000 series alloys) are widely used in automotive and construction industries. A special emphasis is placed on the strengthening of these alloys due to their application in the aforementioned industries [1]. What is of particular importance when discussing these alloys is their possibility of strengthening by precipitation hardening - aging [2-4].

Aging heat treatment includes solution heat treatment, quenching and aging at a defined temperature during a certain period of time. All of these processes have a direct impact on the mechanical and physical properties of the alloy after the applied heat treatment.

Precipitation hardening is a process that enhances the strength and hardness of metal alloys by the formation of extremely small uniformly dispersed particles of the secondary phase (finely dispersed precipitate) within the original phase (solid solution) matrix [5-7]. Finely dispersed precipitates slow down the movement of dislocations, forcing them to either intersect or bypass precipitated particles. The limiting of the movement of dislocations leads to alloy strengthening. The precipitation sequence for 6xxx Al alloys which is
generally accepted in the scientific literature is: SSSS (α) – GP zones – β'' – β' – β (stable), where SSSS (α) represents the super-saturated solid solution [2, 8, 9]. Each of these phases has a different ratio of magnesium and silicon. The most effective hardening precipitate for this type of materials is β'', β' is a metastable hardening precipitate, whereas β is stable phase [9]. During the homogenization of the structure of a solid solution which is inevitable at the dissolution temperature, there occur several different transformations which affect the final state of the alloy after the heat treatment. The dissolution of the equilibrium β-Mg2Si phase is very important because it directly affects the appearance of the metastable phases that are responsible for the hardening of the alloy during aging [3]. Therefore, it is very important to examine the effect of solution heat treatment in which the subject of this paper is reflected.

2. EXPERIMENTAL PART

The research was conducted on commercial aluminum alloys, concretely on EN AW-6060 and EN AW-6082. The chemical composition of the alloys was determined using a portable optical emission spectrometer „Belec Compact Port“ manufactured by the Belec Spektrometrie Opto-Elektronik GmbH, and can be seen in table 1. Both alloys were delivered in peak aged condition (T6 temper) by the company „AlCu metali d.o.o., Niš, Serbia“. The samples for analysis (figure 1) were cut into dimensions of 15x20x10 mm for the first one and 15x20x12 mm for the second one, respectively. These dimensions were carefully chosen so that the performed measurements would be as accurate as possible.

The heat treatment temperature of both alloys was determined based on data present in literature. In the first phase of the experiment, the samples were heated in a resistance furnace in order to remove the factory condition by keeping them at 550 °C for 6 h, after which the samples were air-cooled. The temperature of the solution heat treatment was in the range of 510-590 °C. The properties of the alloys were investigated immediately after quenching in ice water and after partial and complete aging. The experiment was defined in this manner as to determine the influence of the temperature of solution heat treatment at different stages of the alloy hardening.

The determining of the mechanical properties was performed by hardness measurement using the Vickers method with the force load of 98N (10 kP) for 10 seconds, while the measuring of the electrical conductivity was performed directly on “Sigma test 2.063” electrical conductivity tester, respectively. Several measurements were made and the average value was used.

To better investigate the effect of the temperature of the solution heat treatment, two temperatures ranging from 510-590 °C were selected and metallographic tests were performed using the optical microscope Carl Zeiss Epytip 2.

Table 1. Chemical composition of investigated alloys

<table>
<thead>
<tr>
<th>Elements in mass %</th>
<th>EN AW-6060</th>
<th>EN AW-6082</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>0.49</td>
<td>0.807</td>
</tr>
<tr>
<td>Fe</td>
<td>0.182</td>
<td>0.354</td>
</tr>
<tr>
<td>Cu</td>
<td>0.012</td>
<td>0.042</td>
</tr>
<tr>
<td>Mn</td>
<td>0.006</td>
<td>0.453</td>
</tr>
<tr>
<td>Mg</td>
<td>0.594</td>
<td>0.696</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;0.003</td>
<td>&lt;0.012</td>
</tr>
<tr>
<td>Ni</td>
<td>0.028</td>
<td>0.012</td>
</tr>
<tr>
<td>Zn</td>
<td>0.011</td>
<td>0.115</td>
</tr>
<tr>
<td>Ti</td>
<td>0.005</td>
<td>0.025</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.003</td>
<td>0.01</td>
</tr>
<tr>
<td>V</td>
<td>0.014</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Co</td>
<td>&lt;0.003</td>
<td>0.006</td>
</tr>
<tr>
<td>Sn</td>
<td>&lt;0.003</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Zr</td>
<td>&lt;0.003</td>
<td>&lt;0.003</td>
</tr>
<tr>
<td>Al</td>
<td>98.62</td>
<td>97.45</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

Figures 2 and 3 show the influence of the temperature of the solution heat treatment on hardness in three different states: immediately after the solution heat treatment and quenching (A1), after the partial aging for 1 hour at 180 °C (A2) and after the full aging treatment for 5 hours for EN AW-6060 and 6 hours for EN AW-6082 (A3), respectively.
Figure 2 - The influence of the temperature of the solution heat treatment on the hardness of EN AW-6060 alloy

Figure 3 - The influence of the temperature of the solution heat treatment on the hardness of EN AW-6082 alloy

Figure 4 - The influence of the temperature of the solution heat treatment on electrical conductivity of the EN AW-6060 alloy

Figure 5 - The influence of the temperature of the solution heat treatment on electrical conductivity of the EN AW-6082 alloy

Analysis of the presented results shows that the temperature of the solution heat treatment has an influence on the mechanical properties of the investigated samples. A slightly higher impact is observed in the EN AW-6082 alloy due to the higher amount of alloying elements that are responsible for the formation of metastable phases which increase the hardness values [3]. Also, the tendency of the hardness values increment due to the higher temperature of the solution heat treatment is more clearly observed on the fully aged samples, since the necessary phase transformations are carried out according to the precipitation sequence, and hence the degree of homogenization is more pronounced.

Figures 4 and 5 show the influence of the temperature of the solution heat treatment on the electrical conductivity of the investigated alloys.

An analysis of the presented results shows that the temperature of the solution heat treatment has an influence on electrical conductivity. Said influence is far less pronounced for EN AW-6060 alloy than in the EN AW-6082 alloy. The influence is far clearer with the EN AW-6082 alloy due to the difference in the chemical composition and the amount of alloyed elements.

When the temperature of the solution heat treatment is increased the dissolution of the stable and metastable phases in the investigated alloys intensified. The dissolution of these phases directly affects the appearance of metastable phases during aging. Additionally, the presence of metastable phases is directly defined by the amount of alloying elements [3]. Electrical conductivity is defined by the transfer of electrons through a crystal lattice. The metastable phases precipitated from the solid solution may be more or less coherent with the lattice of the solid solution, in this case the face-centered cubic lattice of aluminum. Each occurrence of incoherence leads to the scattering of the electrons in the crystal lattice, which in turn leads to a decrease in electrical conductivity. Based on the obtained results, it can be assumed that due to the
intensified heating of the samples, the increased dissolution of the phases occurred, which resulted in the appearance of a larger quantity of less coherent phases during the aging of the alloys. The partial coherence of the present phases has led to a decrease in the electrical conductivity in the material [4].

The microstructures of the investigated alloys at two chosen temperatures can be seen on Figures 6-9. These temperatures were selected so that the difference in the microstructures due to the change in temperature of the solution heat treatment could be seen. Samples are fully aged (state A3).

Figure 6 - Microstructure of the EN AW-6060 alloy solution heat treated at 510 °C, magnification x500

The influence of the temperature of the solution heat treatment can be seen on the presented microphotographs. The samples of the EN AW-6082 that are solution heat treated at higher temperatures have a more homogeneous structure, which is consistent with the results of hardness and electrical conductivity results.

Figure 8 - Microstructure of the EN AW-6082 alloy solution heat treated at 510 °C, magnification x500

Figure 9 - Microstructure of the EN AW-6082 alloy solution heat treated at 590 °C, magnification x500

The influence of the temperature of the solution heat treatment is somewhat weaker for the EN AW-6060 alloy, which is also in agreement with the obtained hardness and electrical conductivity results.

4. CONCLUSIONS

From the presented results, the following conclusions can be drawn:

- The temperature of the solution heat treatment as one of the parameters in aging heat treatment has an influence on the structure and properties of aluminum alloys in the 6000 series.
- The influence of the temperature of the solution heat treatment is stronger when the alloy is more alloyed due to the more intense dissolution of the alloying elements that are responsible for the formation of metastable phases. With the EN AW-6082 alloy this effect is more pronounced than in the EN AW-6060 alloy.

Figure 7 - Microstructure of the EN AW-6060 alloy solution heat treated at 570 °C, magnification x500
• With the increment of the temperature of the solution heat treatment, the hardness increases for both investigated alloys due to the dispersion of the metastable phases and better homogeneity. In the EN AW-6060 alloy, the maximum hardness value was obtained at temperature of the solution heat treatment of 570 °C, while for EN AW-6082 maximum hardness was achieved at 590 °C.

• An increment of the temperature of the solution heat treatment leads to a decrease in electrical conductivity due to more intense phase dissolution and the subsequent appearance of partially coherent phases which lead to the scattering of the electrons.

• The obtained results can be used during the thermo-mechanical treatment of the investigated alloys as a guideline for defining the output temperature of the semi-products after the hot working, which usually precedes the hardening process in industrial conditions.

• Continuation of the research could be reflected in the testing of the cooling rate (quenching) as one of the parameters in the aging heat treatment and the possibility of constructing the TTT diagrams for the given alloys.

5. ACKNOWLEDGEMENT

The research results were developed with the assistance of the Ministry of Education, Science and Technological Development of the Republic of Serbia under the project (OI 172037).

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 4.

REFERENCES


REZIME

UTICAJ TEMPERATURE RASTVORNOG ŽARENJA NA SVOJSTVA ALUMINIJUMSKIH LEGURA IZ SERIJE 6000


Ključne reči: aluminijumske legure, termička obrada, tvrdoća, elektroprovodljivost
Drying and Dryers from the Aspects of Renewable Energy Sources and Sustainable Development

RADIVOJ M. TOPIĆ, University of Belgrade, Faculty of Mechanical Engineering, Belgrade

MILAN R. BOŽOVIĆ, University of Pristina, Faculty of Science, Kosovska Mitrovica

GORAN R. TOPIĆ, Srbijagas, Novi Beograd

Sustainable development, energy efficiency, the use of renewable energy sources and environmental protection are the most current questions at the beginning of the new, 21st century. The most important role of renewable energy sources is in the reduction of the greenhouse effect, in the increase of energy security and the opening of new jobs through small and medium enterprises. This paper gives a brief overview of renewable energy sources in terms of sustainable development, energy efficiency and environmental protection and the role of the drying process technology in sustainable development (presenting existing solutions with additional energy sources and original solutions for drying using renewable sources) through: reducing energy "consumption", drying as source of biofuel, solar drying, using wind energy and biogas for drying, drying for reducing the “loss” of resources, drying for environmental protection, etc. Before application and global usage, every energy process and renewable energy source should be analyzed and valorized through the 4E principle: ecological, energy, economical and educational.

Key words: Renewable energy sources, sustainable development, drying, dryer, ecology, radiation

1. INTRODUCTION

The signing of the Kyoto Protocol from 1997. by 160 signatories has forced governments and intergovernmental organizations to allocate funds for sustainable development studies and projects. Legislation follows this trend. The European Union allocates funds for direct research in this field, as well as for researches into energy-related drying. Investing into researching drying processes would lead to acquiring technologies which contribute to sustainable development.

Estimating the available quantities of renewable energy sources is not simple as their name implies: if something is inexhaustible, or rather if its quantity keeps renewing, how much of it is actually there? Because of this when it comes to renewable resources instead of the terms reserves and resources most often terms of potential are used, which can be: theoretical, technical, and economical. The theoretical potential of renewable sources signifies their physical presence, for example the solar radiation which reaches the Earth’s surface, or the kinetic energy of wind.

2. WHY RENEWABLE ENERGY SOURCES?

The harmful effects on the environment from natural sources (volcanoes, forest fires, animal metabolism, etc.) have been going on since prehistoric times, but huge anthropogenic (human caused) air, water and soil pollution begins with the industrial revolution. One of the biggest energy crises occurred in Prussia in the 18th century caused by wood shortage due to uncontrolled deforestation and cold winters. Friedrich the Great, Prussian ruler at the time, began an action to improve energy efficiency which resulted in the invention of the first heating furnace with increased efficiency, known as the Berlin furnace (in 1763.).

Ecological regulations are not new either: back in 1280. in England a law was passed according to which burning coal, and city pollution caused by it, invoked the death penalty! In the seventies in the last century,
during the energy crises, most of the developed countries started extensive programs for increasing energy efficiency, for example improving energy facilities (power plants, heating plants, boilers, etc).

At the same time ideas started to emerge about once again using energy sources used since ancient times, and somewhat forgotten since the beginning of industrialization. It is known that biomass (wood, peat, dried plant residue, animal manure, etc.) has been a heating fuel through all of history. As early as 1280, in China the energy of sea waves was used in iron ore crushing plants, in 1580, in London a pump powered by tidal changes started working, in 1872, in South America solar energy powered a desalination plant, while in 1878, in India the first solar oven for cooking appeared.

On April 22nd, 1970, in the USA the first big international ecological gathering was held, and that day is celebrated every year as Earth Day. Also, in 1971, in Canada the international environmental organization Greenpeace was founded, and in 1973, in New Zealand the world’s first ecological “green” party. At the same time the United Nations begin holding international environmental protection conferences (the first was held in 1972, in Stockholm). In the last thirty odd years many environmental protection gatherings were held all over the world (Rio de Janeiro, Kyoto, Rotterdam, The Hague, Bonn, etc).

Renewable energy sources and environmental protection are becoming more and more popular among the public, so it is not a surprise that in 1979, the Catholic church announced a patron saint of environmental protection – St Francis of Assisi. It is also interesting to note that the plot of one of the popular secret agent James Bond movies was based around the control of a “device for efficient solar energy exploitation” (“The Man with the Golden Gun” by Guy Hamilton from 1974).

3. SUSTAINABLE DEVELOPMENT

Ecology has been obviously destined to become the most popular science of the 21st century. In recent years a new ecological ethics can be observed, which should be based on the active relationship of man who builds and renews his environment.

The United Nations World Commission on Environment and Development defines sustainable development the following way: “meeting the needs of current generations in a way that does not endanger the ability of future generations to meet their own needs.” The process of drying also has a significant role in the building of a new approach to the environment and the process of substituting fossil fuels with renewable energy sources.

4. THE DRYING PROCESS’ FIELDS OF INFLUENCE ON SUSTAINABLE DEVELOPMENT

4.1. Reducing energy “consumption”

In 1990, humanity has used up 309 EJ, of which 136 EJ was used up by the industry. Almost all of this energy was obtained by fossil fuel combustion, which resulted in an increase of CO$_2$ in the atmosphere, which causes the greenhouse effect. It is estimated that of the total energy used by the industrial sector, 12% is spent on drying processes. Reducing this share contributes also to the reducing of CO$_2$ emissions, which is possible by improving old existing drying technologies and acquiring and introducing new ones. Processes of mechanical moisture separation, turbulent drying, impulse drying, the use of heat pumps, and drying with overheated steam as the drying agent, can significantly contribute to the reduction of the drying processes’ energy consumption. Using overheated steam as a drying agent is a general purpose instrument for reducing energy consumption. Vapor recompression in the drying process enables the device’s energy consumption reduction by 1kg of separated moisture below the value of 2500 kJ (heat of the phase change at t=0ºC), while in other drying methods this value can be significantly higher. Another possibility is the use of high-temperature drying processes and the integration of drying processes into wider technological processes. Existing drying process solutions have observable technological and constructive possibilities which would lead to reducing the value of specific heat consumption. Greater application of the First principle of moisture separation (mechanical, sorption, osmotic, electroosmotic, etc.) would also be of significant importance.

4.2. Biomass drying, getting biofuel

One of the most important features of the twentieth century is the absolute dominance of oil, i.e. its derivatives as an energy source. The most developed countries, which are also the biggest consumers, have long started work on the possibilities of reducing its consumption, i.e. final substitutions with other energy sources. So far, two paths towards this goal have been formed. The first leads through improving the economy of oil using devices and reducing the use of oil to meet the demands for thermal energy. The second path leads through the affirmation of using alternative and if possible renewable energy sources. Both approaches require extensive and expensive research, as well as large investments into production technologies and exploitative structures. Biomass refers to those energy sources which are obtained through biological processes in relatively short time intervals. The major part of biomass occurs from carbon dioxide and water.
under the influence of solar energy in the process of photosynthesis. The surface thermal flux value of 150 W/m², which Earth’s surface absorbs, gives around 30 times more energy than the amount needed by the entire population. Part of this energy (around 0.1%) is used by plants to form the basis of biomass which can be used as biofuel. In the process of biofuel combustion only recycled CO₂ is released the release of which does not increase its total concentration, thus does not contribute to the greenhouse effect. By contrast the combustion of fossil fuels releases CO₂ which has been accumulating in them for millions of years. Biofuels are peat, wood bark, cuttings residues from orchards and vineyards, agricultural byproducts (straw, cobs, corn husks, sunflower seed shells, etc.), shredded sugarcane from which sugar has been extracted, shells, fruit peel, etc. This is a very important energy source if the quantity of side products of various cultures is taken into account. Some of them cannot be combusted without preliminary preparation which includes the drying process as well. And when their direct combustion is possible, energy utilization is more efficient when they are previously dried in special dryers. Dried fuels can be gasified or after briquetting or pelleting sold as a final product. Herein lie great possibilities of applying the drying process, because a dryer’s capacity is measured in tens of thousands of kilograms of water evaporated per hour. The wood biomass market in Serbia is not developed despite the fact that biomass is the most important renewable energy source. In Serbia, except in rare cases, wood processing companies do not use their own wood waste for heat production, instead it is burned or thrown into rivers thus polluting the environment. The fact is, a large number of companies lack funds for serious reconstructions or for purchasing new systems which produce energy from the wood waste the companies produce. This is a significant limiting factor regardless of the fact that wood as a biomass is a very cost-effective energy source.

As a contribution to sustainable development through the provision of energy savings (reduction of specific heat „consumption”), environmental protection, waste reduction and quality fuel provision, a technical technological system for high-temperature drying of sawdust has been developed, shown in Figure 1. The plant for high-temperature drying of sawdust is intended for drying sawdust of relative humidity in the range of 50 to 80%, using as fuel dried shavings with 15% relative humidity, and in order to provide raw materials for obtaining wood flour making briquettes and pellets as fuel for heating purposes and other thermal processes.

The basic elements of the high-temperature drying plant are: a heat source (dry shavings burning device – vertical cyclonic furnace); a high-temperature pneumatic drum dryer with three-way drum, as the drying chamber; a system for introducing wet materials into the drying chamber (the desire is to introduce the same moisture mass during the process); a system for transporting materials through the drying chamber and a system for separating the dried material from the produced drying agent (cyclone and main fan).

Figure 1 - The solution concept of the technical technological system for high-temperature drying of shavings and obtaining briquettes [6]. 1. pouring basket for wet materials, 2. transporter of wet materials (mechanical), 3. shredder of wood waste, 4. ventilator of the system for pneumatic transport of wet materials, shavings, 5. channel for pneumatic transport of wet materials, 6. cyclone for wet materials, 7. silo for wet materials, 8. transporter (mechanical) for introducing wet materials into the drying chamber with exporter from the silo, 9. fan with a system for introducing fuel and primary air into the furnace of the combustion device, 10. device for combusting dried shavings, 11. fan for introducing secondary air into the furnace of the combustion device, 12. gas burner for initial ignition, 13. channel for introducing drying agents (mixture of combustion products and ambient air) into the drying chamber, 14. high-temperature dryer with three-pass drying chamber, 15. channel of the system for pneumatic transport of dried materials, 16. cyclone of the system for pneumatic transport, 17. main fan of the system for pneumatic transport of dried materials, 18. transporter of dried materials (mechanical) to the mill, 19. mill for dried materials, 20. fan for transporting ground dried...
materials to the cyclone of the silo for dried materials, 21. channel for introducing ground dried materials into the cyclone of the dried materials silo, 22. dried materials cyclone, 23. silo for dried materials, 24. Transporter for bringing dried materials to the fan for introducing ground dried materials into the furnace of the combustion device, 25. transporter with extractor (mechanical), for taking the ground dried materials to the tampon silo, 26. tampon silo, 27. wound extractor, 28. briquetting press (eccentric press), 29. line for cooling briquettes, 30. packer, 31. scale, 32. briquette palette warehouse, 33. command hall

4.3. Solar drying, energy saving and better quality products

Solar drying directly uses the Sun’s energy. Today, outdoor solar drying is being replaced by indirect technologies.

People have re-discovered that products dried using the Sun’s energy are better quality than industrially dried products. Today’s technologies based on solar power provide heating of liquid and gaseous working fluids to relatively high temperatures.

Facts which have lead to the idea and the need to conquer solar dryer solutions are:

- that the intensity of solar radiation in our region is greatest in late spring, summer and early autumn days, which falls precisely at the time of cultivating agricultural crops,
- to dry fruits and vegetables, medicinal, aromatic and spice herbs,
- that the habitats of these cultures are farther away from urban areas, where the supply of liquid or solid relatively expensive fuel is difficult,
- that the interest for dried biological materials has increased greatly,
- that energy savings and an indirect way of drying are demanded,
- that most of the materials must be dried almost immediately after harvesting,
- that there is a growing demand for clean technologies,
- that almost the only and largest item, with using solar dryers, is the value of investment costs of the production of the dryer,
- that from an economical and ecological point of view, the dried product is significantly more competitive than the product obtained by conventional drying.

4.3.1. Solar mobile dryers

Mobile dryers are characterized by the existence of their own movable drive unit and for the relocation of which a propulsion unit, tractor, etc. is required.

Solar dryer solutions can be:

- solar dryers with Sun tracking, these are solutions which can automatically or with an operator follow the path of the Sun by turning the solution around on its vertical axis;
- solar dryers tracking the path and angle of the position of the Sun, in these solutions besides turning the solution around on its vertical axis, the moving of the solar energy receiver by height is also ensured in order to take the best position in relation to solar radiation.

Figure 2.a., shows a solution for a universal, mobile, chambered, convective, ecological, active – passive solar dryer. Also on Figures 2.b. and c. are solutions for a wind solar dryer and a direct indirect passive dryer. Figure 2.d. shows a solar dryer with a heat hump and a biomass powered furnace.

Figure 2.a. shows a solution for a mobile chamber of a solar dryer [1]. Drying is with the indirect use of solar energy and the forced flow of drying agents and with the ability to track the apparent path of movement and the angle of the position of the Sun. All the elements of the dryer and associated equipment are mounted on a special one-axle trailer, so the whole dryer can be easily transported to the working position and very quickly be transferred from the transporting position to the working position. The preparation of the drying agent is carried out in a solar flat receiver, and the forced flow of the drying agent is accomplished by a fan whose electric motors are driven by the electric current gained from the PV module, which sorts this dryer into the group of purely solar dryers as well. The structural solution of the dryer allows the following of the apparent path of movement and the angle of the position of the Sun.

4.3.2. Combined solar dryers

Combined solar dryers are solutions which, besides solar energy, use another additional energy source, which provides them with the ability to work regardless of weather conditions and they can be:

- solar dryers with a heat pump, with these solutions the additional energy source is a plant with a heat pump;
- drying with solar energy and biomass as the additional energy source, as an example of contributing to sustainable development of the use of biomass in the drying process as shown on Figure 3, solution for a dryer using biomass as an additional energy source. As the additional source
some types of heat exchangers, geothermal energy, etc. can also be used;

- drying with solar energy and biogas as the additional energy source, Figure 4 shows the solution for an indirect, active, chambered, solar dryer with a biogas combustion device as the additional energy source;
- drying with solar energy and wind energy as the additional energy source, the contribution of wind energy to the demands of sustainable development, among others, is achieved by developing drying solutions which use wind energy for the transport of drying agents.

**Figure 2 - Mobile universal, ecological, chambered, convective, indirect, active – passive solar dryer, a) [1], [5] and mobile, wind, chambered, ecological, passive, direct solar dryer b) [2], [5]; indirect, direct, passive solar dryer, c) [8]; solar dryer with heat pump and biomass furnace, d) [8] b) windmill, 2. axial fan, 3. valve regulator, 4. reflective surfaces, 5. transparent, 6. chassis, 7. wheels, 8. dishes for storage of drying materials; d) I – dryer works as direct, II – dryer works as indirect, drying chamber, 2. reflector, 3. input channel and absorber, 4. frame, 5. output channel (“chimney”), 6. chamber with transparent cover, 7. transparent, 8. dish with drying material, 9. rotary roof of the drying chamber – reflector, 10. door of the drying chamber, 11. solar radiation**

Original solution for a chambered, active, ecological, solar-wind dryer [2], is shown in Figure 2.b. The dryer is mobile, koor type whose constructive solution enables the drying of materials by direct and indirect use of solar energy. The basic elements and the corresponding dryer parts are mounted on a special single axle trailer, so that the complete drying plant can be easily transported to the place of work and very quickly be converted from the transport position into the working position.

**Figure 3 - Solar dryer with a biomass combustion device as an additional heat source, 1. Channel for the output of drying agents, 2. Ventilation opening, 3. layer of materials to dry, 4. concrete absorber, 5. pebbles, 6. stairs, 7. dryer’s foundation, 8. biomass combustion device, 9. air inlet, 10. wall, brick, 11. Translucent, glass.**

The system for providing a draft, removing humid air (generated vapor) from the drying chamber consists of a windmill with an axial fan, the drying agent dispenser with valve flaps and airbags (side antechambers) with built-in reflective surfaces.

**Figure 4 - Solar dryer with a biogas combustion device as the additional energy source, 1. gas tank, 2. cyclone, 3. and 4. filters, 5. gas combustion chamber, 6. heat exchanger, 7. Chimmer, 8. solar energy receiver, 9. Chambered dryer**

The drying of wet materials is done by heat from the solar radiation directly through the slanted transparent glass on both sides of the upper space above the dishes with the materials and reflected radiation from flat side mirrors whose position should follow the Sun, so that the material on the dishes is constantly covered with reflected radiation.

**4.4. Drying as a process that contributes to the preservation of resources**

One of the main requirements of the drying process is to provide materials of the highest quality,
which reduces the amount of waste. It is believed that around 20% of harvested crops go bad globally due to not using adequate drying processes. A quality drying process can prevent this waste of invested energy and resources used for sowing and harvesting. A good example is also the drying of timber. By properly carrying out the drying process it is possible to increase the use of wood as a building material. Provided the trees come from plantations and not old-growth forests, proper drying contributes to less CO₂ in the atmosphere. Wood processing can also be considered as a significant source of biofuels (solution of the technical technological system in Figure 1.), given that from the raw material, raw wood, 48% of timber material, 12% of crust, 10% of sawdust and 30% splinters are gained. So far, humidity as a product of drying processes has not been considered a resource and has been let go into the atmosphere. Soon it will be necessary to recycle moisture, especially in large drying plants. Ending the cycle with water as an end product could become a standard procedure in most industries. Nowadays there are plants where the entire industrial water arrives with raw materials and where no fresh water is used for working operations. A good example are sugar refineries, where the source of industrial water is in the sugar beets.

4.5. Drying as a process that contributes to the protection of the environment

It is clear that the drying process may have a negative impact on the environment. Negative consequences are: pollution of the atmosphere, drying of different materials and poor operation of the system for separating the dried materials from the drying agents, high energy consumption and associated CO₂ emissions as a consequence of energy production needed for drying. On the other hand, it is also clear that the drying process can be beneficial for the environment. The drying process enables and eases the use of biomass as a renewable energy source. It can provide the conversion of industrial waste (the solution of the technical technological system in Figure 1.) into usefully usable products and can reduce spoilage, and in some cases improve certain properties of agricultural products. Thereby improving the overall energy balance. It is also possible to anticipate the drying process as a way of converting secondary raw materials, waste, into products of various purposes. Previously drying, briquetting and pelleting wood waste was mentioned. The drying of green soybean plants, tops and leaves of sugar beets, entire corn plants, beer husks and grape husks is interesting. In sugar production, beet pulp dried in high-temperature pneumatic drum dryers and drum dryers is used as quality animal feed. Also lime mud dried in high-temperature dryers can be used as calcium fertilizer. Drying orange peels after the juice and essential oils have been extracted can produce biofuel or animal feed. All these possibilities suggest that the drying process prevents large quantities of various secondary raw materials from ending up on trash heaps.

5. CONCLUSION

The beginning of the 21st century has promoted a new ethics that is based on ecology and deals with sustainable development, energy efficiency, using renewable energy sources and environmental protection. The use of renewable forms of energy and the reduction of emissions of matter that are the cause of global warming of the Earth's atmosphere are inevitably the basic topics that contemporary society, and science as its driving part, are dealing with. There is a real basis for including domestic economy in the development of technologies and the production of equipment, as well as for participation in the competition for the placement of these products on the market. Bearing in mind that renewable energy sources are mostly located in rural areas, the development of these technologies would also ensure higher employment rates of rural populations, whose survival is also threatened by previous migrations towards the cities.

The program of the selective use of renewable energy sources (biomass, geothermal, solar and wind energy) aims to increase energy security and reduce the consumption of fossil imported energy sources. Significant savings can be achieved in the production of electricity, which is based on the use of coal in thermal power plants, which meets about 70% of the demand for this energy.

A significant part of the biomass cannot be used without prior preparation which implies the drying process as well. And in cases where direct combustion is possible, the use of biomass energy is more efficient when previously processed in dryers, and then it can be gasified, briquetted or pelleted.

The drying process is an inevitable and extremely important phase, because the economic effects of the use of biomass as fuel are directly dependent on its quality and efficiency.

In addition, a quality drying process prevents the waste of energy and resources used for sowing, cultivation and harvesting because it is estimated that globally around one-fifth of the harvested crops go bad due to not using adequate drying processes.

By condensing the separated moisture, as the accompanying product of the drying process, water is obtained, which is an additional resource and the amounts of which in large drying plants are not negligible.
Shown original solutions for plans for the high-temperature drying of shavings, as well as original solutions for solar dryers, solar and wind dryers, combined solutions for dryers and solutions with additional energy sources, which are shown in this paper can greatly contribute to environmental protection, energy security, reduction of necessary energy, development of local communities and issues related to sustainable development.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 1.

REFERENCES


REZIME

SUŠENJE I SUŠARE SA ASPEKTA OBNOVLJIVIH IZVORA ENERGIJE I ODRŽIVOG RAZVOJA

Održivi razvoj, energetska efikasnost, korišćenje obnovljivih izvora energije i zaštita okoline su najaktuelnija pitanja na početku novog, 21. veka. Najvažnija uloga obnovljivih izvora energije je u smanjenju efekta staklene baštine, u povećanju energetske sigurnosti i otvaranju novih radnih mesta kroz mala i srednja preduzeća. U radu je dat kratak pregled obnovljivih izvora energije sa aspekta održivog razvoja, energetske efikasnosti i zaštite okoline i uloga tehnologije procesa sušenja u održivom razvoju (prikaz postojećih rešenja sa dopunskim izvorom energije i originalnih rešenja za sušenje koja koriste obnovljive izvore) kroz: smanjenje “potrošnje” energije, sušenje izvornog biogoriva, solarno sušenje, korišćenje energije vetra i bogasa za sušenje, sušenje radi smanjenja “gubitaka” resursa, sušenje radi zaštitе životne sredine itd. Pre primene i globalnog korišćenja svaki energetski proces i obnovljivi izvor energije, treba analizirati i valorizovati kroz 4E princip: ekološki, energetski, ekonomski i edukacijski.

Ključne reči: obnovljivi izvori energije, održivi razvoj, sušenje, sušara, ekologija, zračenje
Models of Heat Exchange in Thermal Power Stations With Ultra-supercritical Steam Parameters

MERIM M. ALIČIĆ, PU Elektroprivreda BiH, ZD Mines „Kreka”, Tuzla, Bosnia and Herzegovina

Currently, thermal power plants with supercritical initial working steam parameters are being increasingly developed and built in the world. The operation of plants with these parameters is characterized by a higher degree of utility which is one of the main reasons for their application. The evaporation process is carried out in the pseudocritical region i.e. while reaching the pseudocritical temperature, when starting a continuous transition of water from liquid to gas state. This change is characterized by a sudden change of thermophysical properties such as specific heat, density, dynamic viscosity, thermal conductivity and other. The problem of impaired heat exchange is studied by the field of convective heat exchange and from the conditions of similarity of temperature field for the flow with no internal source of heat between which there is an established functional dependence called the Nusselt criterion of similarity.

Key words: supercritical fluid, pseudocritical region, heat transfer, Nusselt similarity criterion

1. INTRODUCTION

The process of heat exchange in thermal power plants with ultra-supercritical steam parameters takes place at the edge above the critical water point in the region of the supercritical fluid, as shown in the phase diagram for water (Figure 1).

A supercritical fluid is a fluid that possesses the density of fluid and viscosity of gas at temperature and pressure above its critical point. A critical temperature is a temperature above which there is no difference between liquid and gas phase and a temperature at which supercritical fluid is produced.

A critical pressure is a pressure at the critical temperature. Critical pressure and temperature are marked as a critical point on the phase diagram. Above the critical temperature, the liquid phase cannot be obtained by increasing pressure [1]. For all pressure values in the supercritical region, starting from the values close to critical points, the specific water heat reaches its maximum at a certain value of temperature.

The temperature value at which the maximum specific heat is reached is called the pseudocritical temperature [2]. The critical parameters of a steam cycle imply the parameters at which water directly converts into steam without changing the specific volume and have the following values: $t=374.15^\circ$C and $p=221.2$ bar [3].

The vapor parameters for the subcritical, supercritical and ultra-supercritical thermal energy plants are presented in table 1.
Table 1. Parameters for subcritical, supercritical and ultra-supercritical plants [3]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Subcritical parameters</th>
<th>Supercritical SC</th>
<th>Ultra-supercritical parameters USC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>bar</td>
<td>from 100-220</td>
<td>from 220-255</td>
<td>from 255-350</td>
</tr>
<tr>
<td>Temperature</td>
<td>°C</td>
<td>to 540</td>
<td>to 580</td>
<td>from 590 to 720</td>
</tr>
</tbody>
</table>

2. PSEUDOCRITICAL REGION

In the process of heat exchange in the region of subcritical parameters, the specific heat of water and steam is limited by its values on the saturation line, while in the region of supercritical parameters, the region in which evaporation occurs is not evident, thus the change of the specific heat values takes place according to other laws [2].

![Figure 2 – Pseudocritical region in p-T, p-\(c_p\) and p-\(T\)-\(c_p\) diagram [2]](image)

![Figure 3 – Thermophysical properties of water in the pseudocritical region for \(p=25\) MPa [6]](image)

For pressure values at a critical point of 221.2 bar, the critical temperature of 374.150 °C is also evident. At this temperature, specific heat has the maximum value. As the pressure increases, the value of the corresponding pseudocritical temperature also increases, but the maximum specific heat decreases in relation to the heat at the critical point. In addition to the specific heat in the pseudocritical area, other thermophysical water sizes also have leapfrog changes.

Due to the described changes in thermophysical sizes in the pseudocritical region, the heat exchange is impaired. The impaired heat exchange is typical for the process that takes place under conditions when the specific heat exceeds the values of \(c_p > 8 \text{ kJ/kgK}\), which represents the region of high specific heat [2].

3. THE PROCESS OF HEAT EXCHANGE IN PSEUDOCRITICAL REGION

The processes that take place in the region with the influence of critical and pseudocritical parameters can represent hazardous processes from the point of view of heat exchange. Specific heat suddenly increases, while at the same time specific density, dynamic viscosity and thermal conductivity decrease. By increasing the working
pressure, the change of thermophysical sizes becomes less severe, indicating greater stability in heat exchange at higher working pressures [4]. The problem of impaired heat exchange is studied by the field of convective heat exchange and from the conditions of similarity of temperature field, for the flow without an internal heat source, between which there is an established functional dependence called the Nusselt criterion of similarity [5]:

\[ Nu = f(R_e, P_t) \]  

(1)

The Nusselt number contains a heat transfer coefficient, so the previous relation can be written as:

\[ \alpha = \frac{1}{D} f(R_e, P_t) \]  

(2)

Based on the equation (2) we can see that the heat transfer coefficient from the tube wall to the fluid is dependent on the flow character, the reciprocal relationship between the temperature and velocity boundary layer, and the heat conductivity of the fluid and the equivalent diameter.

Based on the Nusselt criterion of similarity, heat exchange models were developed in the supercritical region by using experimental methods.

3.1. Heat exchange models in the supercritical area

There are several models of heat exchange process in the supercritical region, where coefficients correspond to the equation [6]:

\[ Nu = C \cdot Re_x^n \cdot Pr_x^m \cdot F \]  

(3)

\[ F = f \left( \frac{c_p}{c_p} \cdot \frac{\rho_w}{\rho_b} \cdot \frac{D}{L} \right) \]  

(4)

Model Dittus – Boelter (1930)

\[ Nu = 0.023 \cdot Re_b^{0.8} \cdot Pr_b^{0.43} \left( \frac{\rho_w}{\rho_b} \right)^{0.3} \]  

(5)

\[ Pr_{min} \] is the minimum value of \( Pr_{min} \) or \( Pr_b \).

Model Bichop (1964)

\[ Nu = 0.023 \cdot Re_b^{0.90} \cdot Pr_b^{0.66} \left( \frac{\rho_w}{\rho_b} \right)^{0.43} \cdot \left[ 1 + 2.4 \cdot \frac{D}{L} \right] \]  

(6)

Figure 4 – Changes of thermophysical sizes of water in the supercritical region [6]
MODEL SWENSON (1965)

\[ \text{Model Karnoshchekov (1967)} \]

\[ \text{Model Yamagata (1972)} \]

\[ \text{Model Karnoshchekov (1960)} \]

\[ \text{Model Jackson and Hall (1975)} \]

\[ \text{TECHNICS – MECHANICAL ENGINEERING (2017)} \]
Models Heat Exchange in the Thermal Power Station with Ultra...

Model Pioro and Duffy (2007)

Pioro and Duffy summed up several models of heat exchange in the supercritical region and provided one comprehensive correlation for calculating heat transfer in the supercritical region in 2007 [7]. Characteristic parameters (Nu, Re and Pr) in numbers from m₁ to m₇ are shown in table 2.

\[
Nu = C_1 \cdot Re^n \cdot Pr^m \cdot \left( \frac{\rho_u}{\rho_b} \right)^{n_3} \cdot \left( \frac{\mu_u}{\mu_b} \right)^{n_4} \cdot \left( \frac{k_u}{k_b} \right)^{n_5}.
\]

(23)

Table 2. Model Pioro and Duffy (2007)

<table>
<thead>
<tr>
<th>Model</th>
<th>Characteristics Nu, Re and Pr</th>
</tr>
</thead>
<tbody>
<tr>
<td>McAdams et al. 1950</td>
<td>0.8 0.33 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Bringer, Smith 1957</td>
<td>0.77 0.55 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Shitsman 1959, 1974</td>
<td>0.8 0.8 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Krasnoshchekov,1959</td>
<td>0.8 0.3 0 0.11 0.33 0.35 0 0</td>
</tr>
<tr>
<td>Swenson et al. 1965</td>
<td>0.923 0.613 0.231 0.231 0 0 0 0</td>
</tr>
<tr>
<td>Kondrat’ev 1969</td>
<td>0.8 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Ornatsky et al. 1970</td>
<td>0.8 0.3 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Ornatsky et al. 1972</td>
<td>0.8 0.4 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Yamagata et al. 1972</td>
<td>0.85 0.8 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Dyadyakin, Popov 1977</td>
<td>0.8 0.7 0.45 0.2 0 0 0 1</td>
</tr>
<tr>
<td>Kirillov et al. 1990</td>
<td>0.8 0.33 n₁ 0 0 n₂ 0 0</td>
</tr>
<tr>
<td>Gorban’ et al. 1990</td>
<td>0.9 0.12 0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

Model Jackson (2012)

The following forms apply to defining the pseudocritical region and forced convective heat transfer in the pseudocritical region using Jackson model [7]:

- the wall temperature does not exceed the pseudocritical value:

\[
Gr_b \frac{Re_b^{2.7} \cdot Pr_b^{0.5}}{< 10^{-5}} \quad ;
\]

(24)

- the wall temperature exceeds the pseudocritical value:

\[
Gr_b \frac{Re_b^{2.7}}{< 10^{-5}} \quad ;
\]

(25)

\[
\frac{Nu}{Nu_0} = 1 \pm 10^3 \cdot \frac{Gr}{Re_b^{2.7} \cdot Pr_b} \left[ \frac{N_b}{Nu_0} \right]^{-2} \quad 0.46
\]

(26)

Figure 5 – The effect of heat transfer in the pseudocritical region [7]

The following markings are present in the equation (1) to (27):

68

TECHNICS – MECHANICAL ENGINEERING (2017)
Nu - Nusselt number \[ \frac{\alpha L}{\lambda} \];

Pr - Prandtl number \[ \frac{\mu c_p}{\lambda} \];

Gr – Grashof number \[ \frac{g \beta (T_m - T_a) D^3}{v^2} \];

Re – Reynolds number \[ \frac{v L}{\nu} \];

\( c_p \) – specific heat \[ \frac{J}{kg \cdot K} \];

\( \alpha \) - heat transfer coefficient \[ \frac{kW}{m^2 \cdot K} \];

\( \lambda \) - heat conductivity coefficient \[ \frac{W}{m \cdot K} \];

\( \mu \) – dynamic viscosity of the fluid \[ \frac{N \cdot s}{m^2} \];

\( \beta \) – coefficient of volume expansion \[ \frac{1}{K} \];

\( \rho \) – density \[ \frac{kg}{m^3} \];

\( k \) - thermal conductivity \[ \frac{kW}{m \cdot K} \];

\( T_b \) – mean fluid temperature [°C];

\( T_w \) – wall temperature [°C];

\( T_{pc} \) – pseudocritical temperature [°C];

\( D \) – diameter [mm];

\( L \) – length [mm];

\( v \) – velocity [m/s];

\( g \) – acceleration due to gravity [m²/s²];

\( C \) = 0.0026 for water;

\( Nu_0 \) – local value of Nusselt’s number;

\( \xi \) – friction coefficient of Nusselt’s number;

\( n_1, n_2 \) – coefficient of Prandtl’s number;

4. CONCLUSION

In order to achieve the best solution, both from the technical and the economic point of view, the newer generation thermal power plants are required to reduce the emission of pollutants apart from increasing the utility rates.

One of the ways to achieve a higher degree of utility is using supercritical (SC) or ultra-supercritical steam parameters (USC) when operating the plants.

However, achieving high parameters depends on incorporating new materials that have better properties at high temperatures and pressures, using new welding technology and solving corrosion problems.

The process of steam production in the field of supercritical parameters belongs to a group of very sensitive heat exchange regions. In the region of parameters, close to the critical point of the thermophysical water size, there are leapfrog changes which, under the conditions of large thermal loads, lead to the impaired heat exchange and pipe material overheating. By studying these processes and on the basis of exponential data, the criteria for the region of the impaired heat exchange in this area have been established. Many scientists have developed heat exchange models in the pseudocritical region and, as a result, established these criteria. Their application mitigates the risks of material overheating and pipe fractures they are exposed to in the zone of high specific heats.

**REMARK**

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 4.

**REFERENCES**


REZIME

MODELI RAZMJENE TOPLOTE KOD TERMEOLEKTRA NA SA ULTRA-SUPERKRITIČNIM PARAMETRIMA PARE

Trenutno se u svijetu sve više razvijaju i grade termoenergetska postrojenja sa nadkritičnim početnim radnim parametrima pare. Rad postrojenja sa ovim parametrima karakteriše viši stepen korisnosti što i jeste jedan od osnovnih razloga za njihovu primjenu. Proces isparavanja se odvija u pseudo-kritičnoj oblasti, odnosno pri dostizanju pseudo-kritične temperature kada započinje kontinuiran prelaz vode iz tečnog u gasovito stanje. Ovu promjenu faze karakteriše nagla promjena termofizičkih karakteristika kao što su: specifična toplota, gustina, dinamički viskozitet, toplotna provodljivost i dr. Problematika pogoršane razmjene toplote proučava se u oblasti konvektivne razmjene toplote i iz uslova sličnosti temperaturnog polja za strujanje bez unutrašnjeg izvora toplote između kojih je uspostavljena funkcionalna zavisnost nazvana Nusseltov kriterijum sličnosti.

Ključne riječi: superkritičan fluid, pseudokritična oblast, prenos topline, Nusseltov kriterijum sličnosti
TECHNICS

ELECTRICAL ENGINEERING

Elektrotehnika – Constructions électrotechniques – Elektrotechnik – Електротехника


EDITOR-IN-CHEF

Prof. Vujo Drndarević, D.Sc, University of Belgrade, School of Electrical Engineering, Belgrade

EDITORIAL COUNCIL

Ljiljana Hadžibabić, Energy Agency of the Republic of Serbia, Belgrade

Rade Filipović, D.Sc, Thermal Power Plants “Nikola Tesla”, Obrenovac

Prof. Ninoslav Stojadinović, D.Sc, University of Niš, Faculty of Electronic Engineering, Niš

Prof. Vladimir Katić, D.Sc, University of Novi Sad, Faculty of Technical Sciences, Novi Sad

Gojko Dotlić, M.Sc, Public Enterprise for Electric Energy Transmission and Transmission System Control "Elektromreža Srbije", Belgrade

Prof. Ilija Vujosević, D.Sc, University of Montenegro, Faculty of Electrical Engineering, Podgorica

Prof. Boris Lončar, D.Sc, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade

EDITORIAL OFFICE: Union of Engineers and Technicians of Serbia, 11000 Belgrade, Kneza Miloša 7a/1, Tel, +381/0111 32 35 891, Fax +381/011/32 30 067
Statistical Analysis of the First Order of \( \alpha-q \) Model of Fading

**DOKO V. BANDUR**, University of Pristina, Faculty of Technical Sciences, Kosovska Mitrovica  
**BRANIMIR S. JAKŠIĆ**, University of Pristina, Faculty of Technical Sciences, Kosovska Mitrovica  
**MILOŠ V. BANDUR**, University of Pristina, Faculty of Technical Sciences, Kosovska Mitrovica

*Original scientific paper*

**UDC:** 621.391.812  
**DOI:** 10.5937/tehnika1701077B

In this paper, an improvement of the well-known Nakagami-\( q \) model of fading is proposed by introducing an additional flexibility in the form of a power of the modulus of a complex Gaussian process. The aim is to achieve better match between theoretical and experimental results, i.e. between theoretical and values measured in a real environment. The statistical analysis of the first order of the proposed \( \alpha-q \) model of fading is presented in this paper. That includes derived analytic expressions for the probability density function (PDF), the cumulative distribution function (CDF), the \( n \)-th order moment, the variance, and the corresponding moments-generating function (MGF). Probability density function and the cumulative distribution function of the \( \alpha-q \) process are graphically presented.

**Key words:** \( \alpha-q \) fading, probability density function, cumulative distribution function, \( n \)-th order moment, variance, moments-generating function.

1. INTRODUCTION

Nakagami-\( q \) model of fading is the most commonly used in describing the envelope and phase statistics of the narrow-band mobile channels. It is also used in describing the envelope distribution of the signal transmitted by satellite links subject to strong ionospheric scintillation, as well as in the performance analysis of mobile communications systems.

This model of fading is defined by the modulus of a complex Gaussian process, whose real and imaginary parts are known as uncorrelated zero-mean in-phase and quadrature components, respectively. Moreover, their variances are different from each other.

The Nakagami-\( q \) model represents a generalization of the Rayleigh model, where variances of the Gaussian components are mutually equal [1], and therefore suitable for applications in systems where there is no optical visibility between transmitter and receiver, as well as in the satellite channels that are subject of strong ionospheric scintillation [2]. Moreover, due to greater flexibility, the Nakagami-\( q \) model provides better match between analytical and experimental values compared to the Rayleigh model [3].

In this paper we propose a generalization of the Nakagami-\( q \) model by introducing a non-linearity in the form of a power of the modulus of the complex Gaussian process. Thus, the intensity of the resulting signal is not equal to the modulus of a complex Gaussian process, as it is the case with the Nakagami-\( q \) model, but to the modulus raised to the power of \( \alpha>0 \). This new model of fading is called \( \alpha-q \) model, where \( \alpha \) symbolizes the newly introduced non-linearity, while \( q \) symbolizes the Nakagami-\( q \) model that is in the core of the proposed model.

This generalization is an enhancement of the flexibility of the existing Nakagami-\( q \) model, aiming to enable even better match between analytical and experimental values, i.e. values measured in the real environment.

The results of the first order statistical analysis of the \( \alpha-q \) model of fading are presented in this paper. That is, the analytical expressions for the probability density functionality (PDF) [1, 4], the cumulative distribution function (CDF) [1, 5], the \( n \)-th order moments [1, 6], the variance [1] and the moments-generating function (MGF) [1] of a \( \alpha-q \) distributed random variable are presented. The analytic expression for the
probability density function is presented in a closed form, while the analytical expressions of other parameters mentioned above are presented in the form of infinite series.

2. α-q MODEL OF FADING

Let \( r(t) \) denotes the resulting envelope of the Nakagami-\( q \) multipath fading channel. The envelope \( r(t) \) can be written as a function of the Gaussian uncorrelated zero-mean in-phase \( X(t) \) and quadrature \( Y(t) \) components of variances \( \sigma_1 \) and \( \sigma_2 \), respectively [3]

\[
r(t) = |X(t) + jY(t)| = \sqrt{X^2(t) + Y^2(t)}
\]  

(1)

The PDF of this Nakagami-\( q \) distributed random variable (RV) \( r(t) \) is given by the following expression [2, Eq. (2.10)]

\[
p_r(t) = \frac{(1+q^2)r^2}{q\Omega} \exp\left[\frac{(1+q^2)r^2}{4q^2\Omega}\right] 
\times \frac{I_q\left(\frac{(1+q^2)r^2}{4q^2\Omega}\right)}{2\pi\sigma_1\sigma_2}
\]  

(2)

where \( I_0(\cdot) \) is the zeroth order modified Bessel function of the first kind, while \( q \) is a parameter that ranges between 0 and 1.

Let’s denote by \( R(t) \) the resulting envelope of the multipath \( \alpha-q \) fading channel. As we pointed out in the introduction section, the \( \alpha-q \) distributed RV is obtained by raising the modulus of the complex Gaussian variable to the power of \( \alpha > 0 \), from which it follows that

\[
R(t) = |X(t) + jY(t)|^\alpha
\]  

(3)

The introduced non-linearity, in the form of a power \( \alpha \), can be justified from the physical point of view by the argumentation used in [7], which basically explains the physical foundation and reasonableness of introducing the Weibull model. Namely, in the afore mentioned work, the authors aiming to generalize the Rayleigh model, also by introducing a non-linearity in the form of a parameter that is the power of a complex Gaussian process, generated a multi-dimensional Weibull distribution based on correlated Gaussian processes.

\[
Z = |X(t) + jY(t)|^{1/\beta}, \quad \beta > 0
\]  

(4)

3. PROBABILITY DENSITY FUNCTION

Since \( X(t) \) and \( Y(t) \) are independent, in-phase and quadrature, zero-mean Gaussian random variables with variances \( \sigma_1 \) and \( \sigma_2 \), respectively. It follows that their joint probability density function (PDF) is given by the following expression

\[
p_{XY}(X,Y) = \frac{1}{2\pi\sigma_1\sigma_2} \exp\left[\frac{-x^2}{2\sigma_1^2} - \frac{y^2}{2\sigma_2^2}\right]
\]  

(5)

Bearing in mind (3), and introducing the corresponding transformation formulas

\[
X = R^\alpha \cos \theta, \quad Y = R^\alpha \sin \theta
\]  

(6)

the joint PDF can be expressed in the polar coordinate system as follows

\[
p_{R\theta}(r,\theta) = \left| J \right| p_{XY}\left(\frac{1}{\alpha} R^\alpha \cos \theta, \frac{1}{\alpha} R^\alpha \sin \theta\right)
\]  

(7)

where the Jacobian transformation is given by

\[
J = \left| \frac{\partial(X,Y)}{\partial(R,\theta)} \right| = \frac{1}{\alpha} R^{\alpha-1}
\]  

(8)

By substituting (6) and (8) in (5) we obtain

\[
p_{R\theta}(r,\theta) = \frac{1}{\alpha} R^{\alpha-1} \times
\times \exp\left[-\frac{r^2}{2\sigma_1^2} \cos^2 \theta - \frac{r^2}{2\sigma_2^2} \sin^2 \theta\right]
\]  

(9)

Integrating the previous expression by \( \theta \)

\[
p_R(r) = \int_0^{2\pi} p_{R\theta}(r,\theta) d\theta
\]  

(10)

the expression for the PDF of the \( \alpha-q \) distributed RV \( R(t) \) is given by

\[
p_R(r) = \frac{1}{\alpha} R^{\alpha-1} \times \exp\left[-\frac{r^2}{2\sigma_1^2 (1-q^2)} \left(\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2}\right)\right]
\]  

\times I_0\left(\frac{r^2}{4q^2\Omega}\right)
\]

(11)

where \( I_0(\cdot) \) is the zeroth order modified Bessel function of the first kind. By using the following identities

\[
\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2} = \frac{(1+q^2)^2}{q^2\Omega}, \quad \frac{1}{\sigma_1^2} - \frac{1}{\sigma_2^2} = \frac{1-q^4}{q^2\Omega}
\]  

(12)

and substituting them in (11) the expression for the PDF of the \( \alpha-q \) distributed RV \( R(t) \) can be rewritten as

\[
p_R(r) = \frac{(1+q^2)^{\frac{1}{2}-1}}{\alpha q^2\Omega} \times \exp\left[-\frac{(1+q^2)^{\frac{1}{2}} r^2}{4q^2\Omega}\right]
\]  

\times I_0\left(\frac{(1-q^4)^{\frac{1}{2}} r^2}{4q^2\Omega}\right)
\]

(13)
It can be noted that the expression for the PDF of $R(t)$, given by (13), for the special case of $\alpha=1$, reduces to the well-known Nagakami-q PDF, i.e. the equation (2). The PDF of $R(t)$ for various values of the parameters $\alpha$ and $q$ is shown in Figure 1.

![Figure 1 – Probability density function of $R(t)$.
](image)

It can be seen from the Figure 1 that when the parameter $\alpha$ increases the PDF of $R(t)$ declines faster. In other words, for larger values of the parameter $q$, the PDF of $R(t)$ shows a significantly slower change compared to lower values of the parameter $q$.

4. CUMULATIVE DENSITY FUNCTION

By definition, the cumulative distribution function (CDF), $F_R(r)$, is given by the following expression

$$F_R(r) = \int_0^r p_R(r) dr$$

(14)

By replacing (13) in the previous equation and expressing the zeroth order modified Bessel function of the first kind in the form of infinite series [8]

$$I_0(z) = \sum_{k=0}^{\infty} \frac{z^{2k}}{2^{2k} k! \Gamma(k+1)}$$

(15)

as well as by interchanging the order of summation and integration, the CDF of $R(t)$ can be expressed as

$$F_R(r) = \sum_{k=0}^{\infty} \frac{2^{-2k} q^{k+1}}{\Gamma(1+k)x} \times$$

$$\left( \frac{1+q^2}{\Omega} \right)^{2k} \left( -1 + \frac{q^2}{\Omega} \right)^{2k} \times$$

$$\times \left( \Gamma(1+2k) - \Gamma \left( 1 + 2k, \frac{(1+q^2)^2}{4q^2\Omega}R^2 \right) \right)$$

(16)

where $\Gamma(\cdot)$ is the Gamma function [9]. The CDF of $R(t)$ for various values of the parameter $\alpha$ is shown in the Figure 2.

![Figure 2 – Cumulative distribution function of $R(t)$.
](image)

From Figure 2 it can be seen that the CDF of $R(t)$ converges to 1 with an increase of the parameter $r$ which confirms the correctness of the equation (16). Moreover, the CDF converges much faster to 1 for lower values of the parameter $\alpha$.

5. N-TH ORDER MOMENT AND VARIANCE

By using (13), based on the definition [2], the $n$-th order moment of $R(t)$, can be expressed as

$$\mu_n = E[R^n] = \int_0^\infty r^n p_R(r) dr$$

(17)

where $E[\cdot]$ is expectation. By substituting (13) and (15) in (17), after integration, the $n$-th order moment of $R(t)$ can be expressed as

$$\mu_n = \sum_{k=0}^{\infty} \frac{2^{1-2k+n\alpha}}{\Gamma(1+k)2^2 q^{1+n\alpha}} \left( \frac{1}{1+q^2} \right)^{1+2k+n\alpha} \times$$

$$\left( \frac{1+q^2}{\Omega} \right)^{2k} \left( -1 + \frac{q^2}{\Omega} \right)^{2k} \times$$

$$\times \left( \Gamma(1+2k) - \Gamma \left( 1 + 2k, \frac{(1+q^2)^2}{4q^2\Omega}R^2 \right) \right)$$

(18)

By definition [2], the variance of $R(t)$ is given by the following expression

$$\sigma_R^2 = E[R^2] - (E[R])^2$$

(19)

Based on (17) and (18), the expressions for the moments of the first and second order of the $R(t)$, i.e. $E[R^2]$ and $E[R]$, can be easily obtained. Further, by
substituting them in (19), and after some straightforward mathematical manipulations, the following expression for the variance of \( R(t) \) can be obtained:
\[
\sigma_R^2 = \sum_{k=0}^{\infty} \frac{2^{1-4k+2q} q^{1+2q} (-1 + q^4)^2 \Omega^2}{(1 + q^4)^2 \Gamma(1 + k)^4} \nonumber \\
\times \left( -2q \left( 1 + \frac{1}{1 + q^4} \right)^{2(4k+1)} \left( -1 + q^4 \right)^2 \Gamma(1 + k) \left[ 1 + 2k + \frac{\alpha}{2} \right]^2 \right) + \\
+ 4 \left( 1 + q^2 \right)^{1+4k-2q} \Gamma(1 + k) \left[ 1 + 2k + \frac{\alpha}{2} \right] \right) 
\]

(20)

6. MOMENT GENERATING FUNCTION

The moments-generating function (MGF) of \( R(t) \) is defined as
\[
M_R(s) = E[\exp(-sR)] = \int_0^\infty \exp[-sr] p_R(r) dr 
\]

(21)

By substituting (13) in (21), and expressing the Bessel function in the form of an infinite series, i.e. by applying (15), the MGF can be expressed as follows
\[
M_R(s) = \sum_{k=0}^{\infty} a(k) \left( \frac{1 + q^4}{\alpha q \Omega k \Gamma(1 + k)} \left( \frac{1 - q^4}{8 q^2 \Omega} \right)^{2k} \right) \times \\
\times \int_0^\infty r^{b(k)-1} \exp[-r - c r^{2/\alpha}] dr 
\]

(22)

where
\[
a(k) = \frac{(1 + q^4)^2 \left( \frac{1 - q^4}{8 q^2 \Omega} \right)^{2k}}{\alpha q \Omega k \Gamma(1 + k)} 
\]

(23)

\[
b(k) = \frac{(2 + 4k)}{\alpha} 
\]

(24)

\[
c = \frac{(1 + q^4)^2}{4 q^2 \Omega s^{2/\alpha}} 
\]

(25)

The integral
\[
\Psi(\xi, v) = \int_0^\infty x^{v-1} \exp[-x - \xi x^5] dx 
\]

(26)

that appears in (22), where \( b(k)=v, c=\xi \) and \( \delta=2/\alpha \) is analytically solved in [10], provided that \( \delta \) is a rational number. The following is the solution:
\[
\Psi(\xi, v) = \frac{\lambda^{2v} k^{2v} \Gamma(2v)}{\Gamma(2v+1)^2} \times \\
\times G^{x,\xi}_{\kappa,\lambda} \left[ \frac{2 k^2 \xi^5 \Gamma(2v)}{\lambda^2}, \left( \frac{2 - \nu}{\lambda} \right), ..., \left( \frac{\lambda - \nu}{\lambda} \right), \left( \frac{0}{\nu}, 1, \kappa, ..., (\kappa - 1)/ \kappa, \right) \right] 
\]

(27)

where \( G[\cdot] \) is the Meijer G function, while \( \kappa \) and \( \lambda \) are positive integer values, such that the following expression holds:
\[
\frac{\lambda}{\kappa} = \delta 
\]

(28)

Depending on the value of the parameter \( \delta \), which is in our case
\[
\frac{\lambda}{\kappa} = \delta = \frac{2}{\alpha} 
\]

(29)

it is always possible to choose the appropriate set of minimum values for the parameters \( \kappa \) and \( \lambda \) (for example: if \( \alpha=0.8 \), it follows that \( \delta=2.5 \), which means that for \( \kappa \) and \( \lambda \) can be chosen values 5 and 2, respectively). The referred analytical solution of the integral given by (26) was used in [3] and [11].

7. CONCLUSION

The paper presents one part of the statistical analysis of a new model of fading derived from the well-known Nakagami-q model. The presented analysis sets the theoretical foundation for further statistical analysis of the newly proposed fading model. In the first place, it refers to analysis of the second order statistics [12, 13], as well as the performance analysis of various diversity techniques and systems used to neutralize negative impact of the so-called fast fading in wireless telecommunication systems, especially in the absence of direct optical visibility, as well as in the satellite channels exposed to strong influence of ionospheric scintillation.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 1.

REFERENCES


\section*{REZUME}

\textbf{STATISTIČKA ANALIZA PRVOG REDA $\alpha$-$q$ MODELA FEDINGA}

U ovom radu, polazeći od dobro poznatog Nakagami-$q$ modela fedinga predlaženo je njegovu unapređenje uvodenjem dodatne fleksibilnosti u vidu parametra koji je stepen modula kompaksnog Gauss-ovog procesa, a s ciljem boljeg podudaranja teorijskih rezultata sa vrednostima izmerenim u realnom okruženju. U okviru rada izložena je statistička analiza prvog reda novog $\alpha$-$q$ modela fedinga koja uključuje izvedene analitičke izraze za funkciju gustine verovatnoće, kumulativnu funkciju raspodele, moment n-tog reda, varijansu i karakterističnu funkciju jednog $\alpha$-$q$ procesa. Grafički su predstavljeni rezultati za funkciju gustine verovatnoće i kumulativnu funkciju raspodele $\alpha$-$q$ procesa.

\textbf{Ključne reči:} $\alpha$-$q$ feding, funkcija gustine verovatnoće, kumulativna funkcija raspodele, moment n-tog reda, varijansa, karakteristična funkcija.
Development of Methods for Traffic Simulation of Telecommunication Processes in IRITEL over last 45 years

ALEKSANDAR V. LEBL, IRITEL a.d., Belgrade
DRAGAN S. MITIĆ, IRITEL a.d., Belgrade
ŽARKO M. MARKOV, IRITEL a.d., Belgrade
TOMISLAV I. SUH, IRITEL a.d., Belgrade
MLAĐEN D. MILEUSNIĆ, IRITEL a.d., Belgrade
PREDRAG N. JOVANOVIĆ, MÜHLBAUER AG, Stara Pazova
VLADIMIR S. MARIĆ, IRITEL a.d., Belgrade
BRANIMIR M. TRENKIVIĆ, VISER, Belgrade
MIROSLAV V. POPOVIĆ, University of Novi Sad, Faculty of Technical Sciences, Novi Sad
ŽELJKA M. TOMIĆ, College of Applied Studies in Engineering, Tehnikum Taurunum, Belgrade
PETAR B. DAKOVIĆ, IRITEL a.d., Belgrade
IVAN LJ. VIDAKOVIĆ, IRITEL a.d., Belgrade
BORIVOJE B. MITROVIĆ, IRITEL a.d., Belgrade

This paper summarizes the programs intended for simulation of traffic processes in different telecommunications systems. These programs are developed, implemented and verified by the members of the Institute IRITEL through numerous scientific papers and doctoral dissertations taken during 50 years of the Institute activities. Two main areas of traffic simulations are related (but not limited) to the analyses of switching systems and mobile telephony systems.

Key words: simulations, telecommunication processes, switching systems, mobile telephony, loss probability

1. INTRODUCTION

Simulation, i.e. imitation of random processes which take place in telecommunications devices (in further text: simulation) is a powerful tool that contributes to better device design, implementation and maintenance. Simulation methods evolved along with the technology development in telecommunications.

Since the first applied systems for voice connection realization were implemented in switching systems area, simulation methods in their beginning were adapted to the application for switching systems. In recent times, with increasing implementation of mobile telephony in realizing voice (and other, new forms of) communication, simulation methods are adapted to new technological solutions in this area.

All properties of telecommunication devices as electrical/electronic/programming circuits may be determined in detail. Contrary, the properties of device users are in relation to application randomness. That’s why user impact is difficult to be determined precisely.

In the early days of telephone/switching techniques, the users characteristics, called traffic characteristics, were determined by measurements. It is clear that measurements are related to the use of different equipment, that they last long and that it is impossible to measure processes of exactly desired properties (as traffic load).

First simulation procedures implied imitating process of call arrival and serving on a computer. Simulation is often also called modelling, because
simulation model is developed for the considered real situation. There are three main objectives, which are achieved by simulation.

The first objective is to check the theoretical results. Previously this was realized by comparing to the measurement results.

The second objective is to investigate the properties of complex queueing systems for which there is no easy way to calculate them.

The third objective of the simulation is to investigate various influences affecting the well-known models.

Simulation process has three significant advantages in relation to the traffic measurement.

The first advantage is that the model may be freely selected while measurement is related only to the existing device. The second advantage is the short duration of the simulation. That is to say, the simulation process relates to imitation of arrival and service process but the process duration significantly decreases.

The third advantage of the simulation over measurement is procedure commodity. It is necessary to be with the device to perform measurement on it and, often, to have the equipment and software for measurement. The simulation results are, after the realized procedure, treated as measurement results.

In order to statistically process the results, always at least three simulation processes are performed. The statistical properties of the considered variable (call loss, waiting time, served traffic), the mean and the dispersion are determined.

The theoretical results are considered as confirmed if they do not differ by more than 5% from the mean of the simulation results with a probability of 95%. In this paper it will be presented how random process simulation is used in IRITEL in the development of switching devices.

2. HISTORY OF SIMULATION AND THE BEGINNING OF ITS IMPLEMENTATION IN IRITEL

The first simulation methods were implemented in the world in mid-20th century by companies which developed and produced large telephone exchanges i.e. large switching systems. The efficiency calculation of large, multi-stage switching fields was complex and all known methods were based on approximate formulas.

On the other hand, the serving modules in the exchange (switches and trunks) were expensive and installing more modules than the required number was not profitable. The first simulation methods had the simple goal: on the basis of the number of serving modules and the offered traffic to determine the throughput, i.e. the call loss. One of the first papers on simulation is [1]. The journal, available in Belgrade, which often presented papers on simulation, was Ericsson Technics. One of the common papers is [2]. The implementation of simulation in IRITEL started in 1972, after rejection of one professional paper in the international journal with editor comment that contributions, suggesting new calculation methods, are no longer published if the results have not been confirmed by simulation4.

![Traffic process simulation in switching system](image)

Figure 1 – Traffic process simulation in switching system

The first simulation programs were used for the main task: confirm the loss probability calculation in switching module of the exchange, [3], and besides their own computer program had no original parts. A general layout of the simulation program flow is presented in Figure 1. In this figure A is the offered traffic, N (i.e. Nj) is the number of channels, and j is the number of currently realized connections.

3. THE ORIGINAL SIMULATION METHODS DEVELOPED IN IRITEL

Simultaneously with the use of conventional main simulation method, in IRITEL have been developed the methods, which are used to verify the efficiency of some specific solutions.

3.1. Simulation method for Engset model

This model is used to verify efficiency of traffic serving, where number of users is not at least ten times greater than the number of serving modules. The difference between this method and classic method is presented in Figure 2.

---

4Simulations for the IRITEL purposes were performed by postgraduate students on the computer (IBM 1140) in the Computing Centre on the School of Electrical Engineering in Belgrade. It is interesting to emphasize that running simulation program (coded in programming language FORTRAN 4, using punched cards) took several tens of minutes. The time dedicated to one user was 60 minutes, so it often happened that simulation couldn’t be finished because of a few program „typing” errors.
In this figure $M$ is the number of users in the system and $a$ is traffic per each user. Given that the number of users in a system is limited, offered call intensity decreases with each realized connection, as presented in block 3.

![Traffic process simulation in the switching system where the number of traffic sources is limited](image1)

The results of this method are presented in [4] and [5].

### 3.2 Simulation method for queueing systems with waiting

The greatest difference between real and simulated random process is in the nature of time. In real process time is continual variable, and in simulation it is discrete variable. Time in simulation is measured in discrete time units, which are, in fact, time intervals between two successive random numbers generation. This fact is exploited in simulation program of queueing system with waiting. This simulation program is very well suited to estimate mean values (of waiting time, of service time), but for the estimation of time distributions very long (pseudo)random number series must be implemented, thus prolonging the simulation time.

![Traffic process simulation in waiting queueing system](image2)

### 3.3 Simulation method of the channel group including fault channels

The fact is that fault (but not unplugged) channel may be considered as the channel which is seized for very short calls. This fact is implemented to model switching system with fault channels, and the calculation is verified by simulation.

Flow-chart of simulation program is presented in Figure 4. It is supposed that channel number $N$ is faulty (its release is realized in blocks 10 and 11). Short-term connections on this channel are modelled in such a way that the random number area, provided for its release, is 10 times greater than for faultless channels (normalization factor in block 2).

The results of this simulation are presented in [7] and [8].

![Flow-chart of simulation program intended to the simulation of module group including a faulty module](image3)

### 3.4 Simulation method for call collision in a channel

Several tens of years ago telephone network of YUGEL and EPS consisted of exchanges, which were, mainly, connected by one channel, so called Power Line Carriers (PLCs). In order to achieve very high availability of this network, the question arose: is it possible, in the case of accident in power facilities, to transmit calls over one connection in the direction AB and in the direction BA?

It is, obviously, possible, but it was necessary to explain the phenomenon and to calculate its probability (i.e. call collision probability). Calculation
method and results verification are presented in [9] and [10].

The flow-chart of program, which explains collision on two way trunks, is presented in Figure 5.

![Flow-chart of program for collision simulation on both-way trunks](image)

**Figure 5 – Flow-chart of program for collision simulation on both-way trunks**

In this figure \(j_1\) is the number of trunks, which are seized in the first direction, and \(j_2\) is the number of trunks, which are seized in the second direction. Traffic process for each direction is independently generated, i.e. two random numbers are generated in blocks 1 and 2 for each program step. Possible events on trunks are determined by the event combination from both trunk sides. The most interesting situation for the simulation process is call set-up from both sides.

An idle channel is searched on the first side starting from the trunk with the smallest ordinal number and on the second side starting from the trunk with the greatest ordinal number. That’s why both connections will set-up if there are at least two idle channels (block 8). If there are no idle channels (block 6), both calls are blocked (block 14). If there is one idle channel (block 7), call collision happens (block 15).

Behaviour in the case of other event combinations on both trunk sides are not presented in detail, but everything is joined in the block Decide.

3.5. The method for power estimation in GSM

Based on years of experience in simulation modelling of problems in switching systems in IRITEL, we have recognized the possibility that this knowledge may be used for modelling mobile systems. Besides classical traffic process, for systems in mobile telephony is specific base station (BS) emission power control. It is characteristic that, especially in GSM systems, this power may be regulated in each traffic channel (power control). Power depends on mutual distance between base station (BS) and mobile station (mobile user) (MS), on surface user distribution in the area of BS cell and on environmental attenuation factor (\(\gamma\)).

![Diagram](image)

**Figure 6 – Simulation of traffic process and BS power estimation in the systems of mobile telephony**

The common characteristic of simulation in different analyzed systems of mobile telephony is that it includes the part of simulation intended for BS emission power determination. The main simulation method of traffic process and BS power estimation is presented in Figure 6, [11]. Besides classical steps of telephone traffic simulation, as in switching systems simulation (steps 1-5 and 11-13, where steps 4 and 5 correspond to new connection set-up, and steps 11-13 correspond to connection release), additional steps are intended to power estimation. In order to realize power estimation, a new, uniformly distributed random number is first generated in block 6. After that, this random number is used to determine distance \(r\) between MS and BS (block 7). The mathematical function, which is applied to convert generated random number to \(r\), depends on MS surface distribution. Blocks 7 and 8 in Figure 6 present procedure when users are uniformly distributed: it is enough to simply calculate square root of generated number.

Step 9 in the flow-chart considers attenuation coefficient \(\gamma\). The value of this factor is between 2 and 5, [12], and the BS power in the considered channel is calculated, approximately, by the formula:

\[
W_i = \nu(r) = b + a \cdot r^{\gamma}
\]

where \(r\) is mutual distance BS-MS, and \(a\) is factor of proportionality. Factor \(b\) is the power, which is necessary for MS, which is located in the BS proximity and usually may be neglected.

The total BS power is increased in step 10 taking into account the power necessary for the realized connection. In the case of connection release, the total
instantaneous BS power is decreased subtracting the power of released connection (step 14).

3.6. Procedure with intra-cell traffic

Intra-cell (or internal) traffic corresponds to connections, which are set-up between two MSs situated in the same BS cell. As opposed to the external traffic (which requires only one traffic channel, because only one of two connection participants is located in the area of considered BS), two traffic channels are necessary for each intra-cell connection.

![Flow-chart of simulation program for the system, which includes intra-cell traffic](image)

Intra-cell traffic usually has very small value. But in some cases (for example, if BS covers the whole area of one rural region, or the whole one greater company, the value of intra-cell traffic may be significant (even up to 30-40% of total traffic).

Simulation of the system with the intra-cell traffic is similar to the simulation of basic system with only the external traffic component, which is already presented in Figure 6. The flow-chart of the program with intra-cell traffic component included is presented in Figure 7, [13]. Comparing to Figure 6, the value of normalization factor in block 2 (which multiplies generated random number) is different. The value of this factor depends both on external traffic ($A_e$) and on intra-cell traffic ($A_i$). As for the verification of the range, where generated number is, there are two verifications, i.e. there are three ranges. In the block 3 is determined whether generated random number corresponds to the external traffic, while in the block 8 is marked off whether it corresponds to intra-cell traffic, or to connection release.

The way of external connection initialization is presented by blocks 4-7 in Figure 7, with recording external connection loss in block 22 if it is determined in block 4 that there are currently no idle channels in the system. This program part corresponds to the simulation of channel seizure in typical mobile system (Figure 6).

The way of intra-cell connection initialization is modelled by blocks 9-14, with recording intra-cell connection loss in block 23, if there are not at least two idle channels in the system (test in block 9). The reason is that intra-cell connection is realized between two users situated in the same cell. In the case of intra-cell connection two independent random numbers are generated (RN2 and RN3). Each of these two numbers is intended to determine the distance of one of two connection participants from BS. The way how distance is determined in both cases is the same as in the case of external connection, or in the case of system in Figure 6.

When system with intra-cell connections is simulated, it is necessary to memorize for each active channel whether external or intra-cell connection is realized in the considered channel. For intra-cell connections it is necessary to keep track of the number of the second channel, which participates in the connection. When the first generated random number (intended for determination whether the connection is set-up or released) corresponds to the active channel, this channel is released in block 17. Then in block 19 is tested whether released channel corresponds to intra-cell connection. The test is based on the data in table of established connection types. For the case of intra-cell connections the second active channel is released in block 20.

3.7. Procedure with different density distribution of mobile users in the cell

In the available literature from the area of mobile telephony it is usually supposed that MS’ user density distribution in BS cell is uniform. But, this condition is often not satisfied. Practical experience shows that linearly increasing or linearly decreasing distribution in the direction from BS towards BS cell rim may appear.

The distribution may also be exponentially increasing or exponentially decreasing, etc, [14]. When simulation is performed, in accordance with the specified user distribution density, it is always necessary to determine distance between MS and BS starting from the generated random number. This is achieved by determining the inverse function of the desired user distribution, [15].

82
Therefore, inverse function is always implemented to determine \( r \). It is often not easy to calculate inverse function, and sometimes it is even not possible to find closed mathematical expression for the inverse function. In that case, the inverse function is determined approximately, implementing programs MATLAB or MATHEMATICA. This expression for the inverse function may be, afterwards, implemented in simulation program, where it replaces expression in block 7 (square root of random number) in Figure 6, [14].

As a conclusion, flow-chart of simulation program in this case corresponds to the flow-chart in Figure 6, with a replacement that an inverse function of cumulative probability density function for MS distance from BS has to be implemented in block 7.

3.8. Procedure with CDMA technics

Power control in systems with CDMA (Code Division Multiple Access) technics is specific, because there is one significant cell part in the BS vicinity, where signal power is constant and independent of distance between BS and MS. According to [16], all users at the distance till \( r_0 = 0.55 \cdot R \) from BS, where \( R \) is radius of BS cell, receive power as they are situated at the distance \( r_0 = 0.55 \cdot R \). The relation \( r_0 \) to \( R \) may be different in some systems. Outside the circle with radius \( r_0 \), power control dependent on mutual distance between BS and MS is implemented.

The flow-chart of simulation program when CDMA technics is implemented is presented in Figure 8, [17].

It corresponds to the flow-chart from Figure 6, with the addition of blocks 9-13. It is first tested in block 9 whether the generated random number determines distance less than radius \( r_0 \). If this condition is satisfied, BS power for the considered user is calculated in the block 10. If not, BS power is determined implementing the expression in block 11.

There are two methods for power calculation in the program: the first one, where power control is implemented for all users in the BS cell, depending on the distance BS-MS (blocks 7 and 8) and the second one, where the same power is generated for all users located inside the ring around BS, whose radius is defined in advance (blocks 9-13). The reason of this division is BS power comparison in two cases of BS power control (block 17).

3.9. Procedure with half rate calls

The flow-chart of simulation program in the case that both full-rate (FR) and half-rate (HR) connections may be realized in a system is presented in Figure 9, [18]. The characteristic of half-rate codec in GSM systems is that it seize only half a channel. More precisely, in time multiplex (Time Division Multiple Access, TDMA) of one GSM system, signal for the first MS is transmitted in one frame and for the second MS in the following frame. In this way, necessary channel capacity and BS emission power are saved, at the price of worse voice signal quality. Characteristic of this system is that only FR connections (which seize complete traffic channel) are set-up till some, in advance defined number of busy channels (threshold \( K \) in Figure 9), and after that also HR connections are set-up with the probability \( \pi_0 \). In the flow-chart, instantaneous number of FR connections is designated by \( n_f \), and the number of HR connections by \( n_h \).

Figure 9 – Flow-chart of simulation program intended for the system with possibility to realize full-rate and half-rate connections

Normalization of the generated random number range is realized in the block 2 of the flow-chart. The value \( \pi_0 \) has the influence on the normalization factor.
After that in block 3 is decided whether in the following simulation part a new call is generated (if the necessary conditions are satisfied) or, eventually, the call, which is in progress, ends. The procedure of new call generation is presented by blocks 4 to 11, and the procedure of call release by blocks 12 to 15. If the number of instantaneously busy channels is less than the threshold \( K \), a new FR call is generated in the block 7 if the result of test in block 5 shows that at least one idle channel exists. If not so, the loss of FR call (loss) is registered in block 6.

In the case that the number of instantaneously busy channels is not less than threshold \( K \), it is necessary to determine whether a new FR or HR call will be generated. The desired HR call generation rate is adjusted by the test in block 8. The procedure with HR calls in blocks 9-11 is similar as with FR calls in blocks 5-7. The only difference is that HR call may be generated if there is at least half an idle channel (test in block 9). If there is not half an idle channel, the loss of HR call (loss) is registered in the block 10.

It is adjusted in block 12 that the probability of FR connection release rate is proportional to the number of instantaneously established FR connections, while in block is adjusted that the probability of HR connection release rate is proportional to the number of instantaneously established HR connections. The connection release is, then, realized and registered in blocks 14 and 15.

3.10. Procedure with VAMOS technics

VAMOS (Voice service over Adaptive Multi-user channels on One Slot) technics is implemented in GSM systems in order to increase their traffic capacity by dividing each channel of GSM system to two subchannels. It is possible to implement VAMOS technics for signal transmission in FR and HR channels, such that in each channel are transmitted two FR or 4 HR channels.

This is allowed by the implementation of special modulation methods. In the direction from BS to mobile telephone AQPSK (Adaptive Quadrature Phase-Shift Keying) (or \( \alpha \) – QPSK) modulation is implemented. AQPSK is based on pairing users, for whom necessary BS power difference is not greater than the predefined value, usually in the range 4-10dB. As BS power adjustment is performed in steps of 2dB each one, it means that the ordinal number of the steps intended to power level control for two users may differ by two to five. As necessary BS power for each MS is primarily defined by its distance from BS, it follows that, besides worse voice connection quality, possibility of not-pairing two MSs due to their too great difference in distance to BS is additional price, paid because VAMOS is implemented, [19].

**Figure 10 – Flow-chart of the program, which simulates system with implemented VAMOS technics**

The flow-chart of simulation program in the case of VAMOS technics implementation is presented in Figure 10. This simulation allows us, besides the loss caused by the lack of idle channels (block 14) to determine, also, probability that users can’t be paired (block 15).

The value of normalization factor when random numbers are generated (block 2) is conditioned by the fact that in each channel may be realized two connections. After that, it is decided in block 3 whether the program steps for new call initialization or for connection release are realized.

A new call is generated in steps 4-10. If there are idle channels (block 4), it is generated a random number, which is used to determine distance between the considered MS and BS (block 5). When we are trying to set-up a new connection, it is first tested whether there is pairing possibility with some already realized connection. That’s why the ordinal number of the step for BS power adjustment is determined in block 6. If there are idle subchannels in pairs, where one connection is already realized (block 7) and if the ordinal number of necessary step for new connection BS power adjustment does not differ more than it is defined by upper and lower threshold (UTAsc and DTA-sc in block 8) from the ordinal number of the step for
the already realized connection in the same channel, such a connection is established in block 10. Otherwise, test in block 9 tries to find completely idle channel. If there is at least one such a channel, the connection is, also, realized in block 10.

Blocks 11-13 are intended for connection release. This is realized in such a way that some channel is released (in block 13) if the first generated random number, which is intended to determine whether it is necessary to set-up or release a connection, corresponds to the subarea reserved for this channel (blocks 11 and 12).

Specificity of VAMOS technics system simulation comparing to other simulated systems is that the analysis at the end of simulation, besides traffic loss (block 16), should include also user unpairing possibility. This is not conventional traffic loss and that’s why possibility of this state is especially analyzed.

Besides development of simulation methods intended to verify calculation of some queueing system, several papers, which attempt to give contribution to simulation theory, are also published, [20] - [24].

3.11. Which tools are used, available literature and what is the simulation duration

In relation to the simulations from the initial period of their application, today there are specially developed programs designed for simulation (ns-1, ns-2, ns-3, etc.). These programs allow faster simulation execution and facilitate the process of writing simulation programs. But, simulation programs in IRITEL are written in conventional program languages (C++, MATLAB), even some less demanding simulations in Excel. For demands in the case of simulating systems presented in this paper, the aforementioned programming languages provide 'satisfactory execution speed. For example, simulation with 1.000.000 random numbers generation in C++ language does not last more than one minute.

3.12. What is expected in the future?

During years, simulation procedures are developed from the simplest models imitation to complex models that can estimate a number of features that depend on the randomness of user behaviour. These are estimations of: repeated call influence, serving time distribution, different models of offered traffic, power distribution, mobile user density distribution, mobile users moving influence, and so on.

The main feature of all these simulation procedures related to telecommunications traffic is that they are based on the randomness of call generation, i.e. on well-known simulation method Roulette or Monte Carlo. One can say with certainty that in future simulation will be used in parallel with the calculation.

For more complex models simulation will be often used as the only mean of effectiveness estimation. It can be also predicted that, with the development of more and more complex telecommunication devices, the simulation methods will also progress.

4. CONCLUSION

In this short review paper is once again emphasized that simulation methods are used already 45 years in our development of telecommunication systems. Besides first methods, which are taken from professional literature, original methods are developed in parallel. These original methods are intended to verify specificity, which appear in equipment development, use and maintenance. Significant number of these original methods is presented in professional papers published in national and international journals. Besides, several professional papers are devoted to the problems of simulation theory.

REMARKS

Paper is devoted to the 50th anniversary of Institute IRITEL.

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 3.

REFERENCES


[7] Markov Ž. Calculation of group of trunks containing faulty trunks by the theory of mixed traffic, Archiv


REZIME

RAZVOJ POSTUPAKA SIMULACIJE SAOBRAČAJNIH TELEKOMUNIKACIONIH PROCESA U IRITELU U TOKU POSLEDNJIH 45 GODINA

U ovom radu ukratko se prikazuju programi, namenjeni simulaciji saobračajnih procesa u različitim telekomunikacionim sistemima. Ove programe razvili su, primenili i verifikovali saradnici Instituta IRITEL-a kroz brojne naučne radove i odbranjene doktorske disertacije tokom 50-godišnje delatnosti Instituta. Dve glavne oblasti saobraćajnih simulacija vezane su (ali ne i ograničene) na analize u komutacionim sistemima i u sistemima mobilne telefonije.

Ključne reči: simulacije, telekomunikacioni procesi, komutacioni sistemi, mobilna telefonija, vervoatnoča gubitaka
TECHNICS

TRAFFIC

Saobraćaj – Traffic – Verkehr – Транспорт

YEAR 64 – 2017.

EDITOR-IN-CHEF

Prof. Jadranka Jović, D.Sc, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade

EDITORIAL COUNCIL

Prof. Vladeta Čolić, D.Sc, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade
Vladimir Depolo, D.Sc, Belgrade Land Development Public Agency, Belgrade
Imre Kerékš, M.Sc, City Planning Institute of Subotica
Prof. Milan Marković, D.Sc, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade
Prof. Petar Miroslavjević, D.Sc. University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade
Prof. Pavle Gladović, D.Sc, University of Novi Sad, Faculty of Technical Sciences, Novi Sad

EDITORIAL OFFICE: Union of Engineers and Technicians of Serbia, 11000 Belgrade, Kneza Miloša 7a/I, Tel. +381/11/ 32 35 891, Fax +381/11/32 30 607
Assessment of the Transport Process’ Overall Effectiveness

DUŠAN M. RADOVLJEVIĆ, College of Applied Technical Sciences, Niš  
ALEKSANDAR V. MANOJLOVIĆ, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade  
OLIVERA M. MEDAR, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade  
NEBOJŠA J. BOJOVIĆ, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade

Achieving sustainable road transport requires the existence of methods for assessing its effectiveness, i.e., for assessing the overall efficiency of the transport process, road transport vehicle fleets, vehicles and drivers. Transport companies and companies with fleets for their own needs aim to increase the effectiveness of the resources they have and increase the quality of transport services in order to achieve a competitive position on the market. The achievement of the world class level in assessing the overall efficiency of the transport process is the goal of the state, the owner of the fleet, as well as the educational, professional and scientific community.

The paper presents the importance of researching and managing the efficiency of the transport process, a literature review, and a method for calculating the OVE Human indicator are presented. OVE is used as a tool for assessing the overall efficiency of the transport process, and it can be corrected for implementation in the local environment. It was pointed out to the problems that were observed in the application of similar indicators and final conclusions were given.

Key words: fleet, availability, performance, quality, energy efficiency

1. INTRODUCTION

Economic and social development has contributed to raising awareness about the importance environmental preserving. A sufficiently high level of economic development has enabled timely action, adequate response and achievement of sustainable development promotion. Defining towards environmental protection and stable economic growth influence the awareness of business subjects to reduce their adverse environmental impact.

The mentioned influences refer to the population whose responsible behavior enables improvement of the quality of life for them and their children. In this context, the establishment of a sustainable living environment implies the sustainability of all activities and business subjects in it, and this also applies directly to transport.[1-5]

Sustainability of transport refers to the environmental impact of transport means, which implies direct negative impact on the environment (exhaust gas, waste, noise, etc.), but also energy consumption, infrastructure construction, production of transport means, etc. Society development leads to resource constraints, develops the awareness to consequences of action to the environment and the planet’s future.

In order to be sustainable, transport needs to increase the effectiveness of the transport process, which directly relates to: managing transport requirements, reducing energy consumption, using renewable energy sources, using resources with the least harmful environmental impact, reducing the number of traffic accidents i.e. reduction of their consequences, more effective management of transportation means, educating employees, eco driving, driver training, etc..

In order to examine the interdependence of sustainable development, sustainable transport and the effectiveness of the transport process, numerous strategies, studies and reports have been analyzed to increase the overall effectiveness of road transport vehicle fleets [6].
Different measures affect road vehicle manufacturers to produce energy-efficient vehicles, with less emissions of exhaust gases. At the same time, there are attempts to act in the field of fleet management (for public and for personal needs) in order to be more energy efficient [7]. Sustainable development includes, among other things, the development of methods for measuring the overall effectiveness of the transport process, i.e. the effectiveness of road vehicles, drivers and the quality of service provided, which is also the subject of this paper. Within the Total Productive Maintenance approach (hereinafter referred to as TPM) [8], a complex indicator of Overall Equipment Effectiveness (hereinafter referred to as OEE) has been developed. On the basis of the OEE, an indicator was developed that could be applied to assess the overall effectiveness of the vehicle's operation.

The aim of this paper is to develop and further adapt this complex indicator that would evaluate the effectiveness of the transport process, i.e. which would include the evaluation of driver’s effectiveness beside evaluation of vehicle fleet effectiveness. The paper defines the method for estimating the effectiveness of the transport process in order to increase the effectiveness of the vehicle fleet. In order to solve the problem, a review of literature in this field is presented. Expected problems are presented that follow the application of this method. Final considerations and the direction of further research is presented.

2. THE IMPORTANCE OF TRANSPORT AND TRANSPORT MANAGEMENT

Developed and accountable community strengthens awareness of the need for own sustainability and acts through the building of moral criteria and the adoption of legal guidelines. The aim is to develop a rational transport system that meets the achievable criteria that are simultaneously set up by the social community and the business environment. This developed transport system can be encouraged [6]:

- increasing the energy efficiency of the fleet,
- reducing the share of transport costs in the price of the product,
- increasing traffic safety,
- reducing dependence on non-renewable energy sources,
- increase in Gross Domestic Product (GDP),
- a better life environment,
- cleaner and healthier environment
- safer future for new generations.

Achieving a sustainable transport process is an objective that can be achieved by the interaction of several factors, which are especially stand out:

- the state, i.e. social community
- vehicle feet owners,
- educational, professional and scientific community.

The state as a social and political community creates the most favorable solution for its citizens based on the current state of affairs, and in interaction with the environment. The state determines the policy, guidelines, and time limits for their implementation, while defining the limits, the level of freedom and the environment for the realization of sustainable transport.

It creates an environment in which transport process factors will operate. Institutions of the system, in accordance with the goals of the development policy, shape laws, regulations, tax policy and development strategies. An appropriately established ambiance guides transport to sustainable development.

Vehicle fleet owners as the main goal have an increase in the benefits, or maximizing profits. They adapt their activities to a defined ambiance and through rationalization seek the path to greater profits.

The educational, professional and scientific community has a task to point to the consequences of development in the coming period, which enables the state to correct politics and make a quality decision. On the other hand, it is necessary to manage the transport process in a given environment and to improve it in accordance with the sustainability goals. Transport process management involves adapting to modern and future technological requirements related to:

- production and packing of goods,
- production and purchase of vehicles,
- exploitation and maintenance of vehicles,
- transport service,
- infrastructure etc.

In order to efficiently manage the transport process and economy functioning of the society as a whole, all actors must be connected with information flows and activities. Vehicle feet owners work and collect information about their work. Educational, professional and scientific community develops new solutions, collects foreign experiences and best practices, improves methods and processes, processes them, and helps other actors in reaching the goal set by the state. The state, based on data of the results of fleet operations and research, reviews the set goals and takes adequate measures taking into account all the goals of the social community.

The significance of research in this area is that for seemingly opposing goals of the social community and business entities from the transport sector, they develop models and tools that can be monitored to reach
them in a unique way. These models and tools should be clear for application both in the management of individual vehicle fleet owners, as well as in the analysis of transport processes and the sector as a whole. There is a need to present modern methods and technologies in order to solve the problems they are facing in today’s environment. State authorities need to present the importance of managing the transport process, which brings with it the development of the transport sector, the economy and the society as a whole.

3. LITERATURE REVIEW

The customers expect transport service providers to provide excellent quality, reliable delivery and competitive pricing. In such case, it is expected from the transport service providers to increase resource availability utilization, maximize resource performance rate as well as increase quality of service rate. Transport process resources are vehicles, drivers, dispatchers, but also energy, infrastructure, capital, etc. For measuring transport process performance, a reliable tool based on a set of transport process operation indicators is needed.

Measurement of indicators in road freight transport at level observed shown in this paper was the first time used in study performed for the Great Britain government [9]. The study presents key indicators for the realization of transport process for fleets operating freight distribution. Based on the indicators presented, study showed the direction of further action needed for achieving higher goals of society. After that, the same authors conducted similar studies in other sectors of road freight transport.

Another group of authors continued to explore the vehicle fleet indicator system using the approach that represents the basis for maximizing the effectiveness of technical resources (equipment), by setting and maintaining an optimum relationship between people and technical resources (equipment) – TPM approach [8]. Originally, TPM uses the effectiveness of process (resources) to indicate the value of operators and people working in the production and maintenance, that is, using the OEE indicator as a quantitative indicator for measuring performance in the production process. The goal is to keep the equipment in optimal condition in order to prevent unplanned jams, speed losses, failures, quality losses, etc. which occur in the production process or in the provision of services. There are three endpoints of TPM: zero errors, zero accidents and zero delays [8].

Overall effectiveness indicator relating to the transport process (vehicle utilization) based on TPM methodology, OEE indicator, expert knowledge and best practice examples results in the Overall Vehicle Effectiveness (hereafter referred to as OVE) [10]. Since its inception and its first appearance in literature [10], OVE has been constantly improving [11-13]. OVE indicator implies measurement of losses during determination of availability value, effect (performance) and quality of transport process (Table 1). The OVE indicator names five losses inherent to the transport process: driver breaks, excessive loading and unloading time, fill loss, speed loss and quality delays [11].

### Table 1. Losses included in the methods OVE, MOVE and TOVE

<table>
<thead>
<tr>
<th>Losses in the transport process</th>
<th>OVE</th>
<th>MOVE</th>
<th>TOVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver breaks</td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Excessive loading / unloading</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Preventive maintenance</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Corrective maintenance</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Operative availability</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Administrative availability</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Speed losses</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Fill losses</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Route efficiency</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Delivery delays</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Load damage</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Losses of load</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>User complaints</td>
<td></td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

OVE methodology implementation represents a simple, complete, applicable and improved approach to measuring transport process effectiveness. The measuring itself of the OVE indicator and actions towards transport process improvement directly ensure enhancement potentials in energy efficiency and environmental protection. Possible contribution of OVE is at the national and at the level of business entities (vehicle fleets) [9]; at the national level, can contribute to monitoring the effectiveness of road freight transport, and at the level of management of the operation of the vehicle fleets, it can be an indicator of profitability, because its monitoring can reduce costs.

According to OVE calculation methodology, activities in transport process are divided into those with added value for the end customer and those not adding any value [10]. Early OVE calculation methodologies [10, 11] have appointed larger OVE values to less energy efficient routes in case where deliveries were made to significant number of destinations. Such problem has been identified for round journeys [12]. OVE, in its original form, does not consider the energy efficiency while making the route selection. In order to solve the mentioned issue, a new component measuring the route effectiveness is introduced into the OVE equation. The OVE takes up new shape and is named...
Modified Overall Vehicle Effectiveness (hereafter referred to as MOVE) [12].

The deficiencies observed in the OVE and MOVE method, which refers to the observation of the total calendar time in relation to the time when the company's working time, was overcome in the paper [13]. This problem is particularly pronounced in companies owning their own fleets. In [13] there is a measure of the overall effectiveness of the transport process, which is called the Transport Value stream map (hereafter referred to as TVSM). For the needs of companies that have their own fleets, the calculation of the OVE meter at the level of the total calendar time is recommended [13]. Procurement of a vehicle represents a great investment and the engagement rate of vehicles becomes crucial. Less utilization of vehicle availability causes higher costs of the transport process.

According to TVSM, the indicator of OVE is calculated according to the total calendar time, thus obtaining Total Overall Vehicle Effectiveness (hereafter referred to as TOVE) [13] (Table 1). The TOVE methodology considers some new losses referring to: vehicle availability time, preventive and corrective maintenance, breakdowns, excessive delays caused by customers, quality of service, etc. [13]. In the TOVE calculation, the transport process effectiveness is expressed through administrative or strategic availability, operational (working) availability, performance and quality rates. TOVE indicator is obtained by multiplying administrative availability, operational availability, performance and quality rates [13].

The MOVE method uses energy efficiency during the route path selection, other methods presented did not considered the problem of energy efficiency of the vehicle fleet. Energy efficiency is another vehicle fleet indicator, an indicator of realization of transport process in whole, so it is necessary to include it in method for calculating overall effectiveness of transport process. The energy efficiency indicators in road freight transport are defined by the directives of the European Parliament [14, 15].

Energy efficiency represents consumed energy level while realizing transport operations. Transport process energy efficiency represents the ratio of transport volume and energy consumption, and is expressed in tonne-kilometers per KWh (tkm/KWh). The expression may be inverted as well resulting in (KWh/tkm), which is consistent with the methodology presented hereafter. Other indicators expressing energy efficiency are: energy intensity (MJ/tonne), fuel efficiency (koe/tonne), emission efficiency (g of CO2/tonne), as well as CO2 efficiency (tkm/kg of CO2). A liter of diesel fuel has a constant energy density (approx. 10.1 KWh/l, 36.3 MJ/l or 0.87 koe/l) and while burnt in an internal combustion engine produces a constant amount of CO2 (2.66 kg/l) [14,15].

4. OVE HUMAN METHOD

In methods developed for calculating the complex vehicle fleet indicator (OVE, MOVE and TOVE) it was noticed that they do not take into account the energy efficiency vehicles, as well as that they do not treat other elements of the transport process and, above all, the effectiveness of the driver's work. Therefore, the further elaboration of one such indicator (its extension) went in that direction and an indicator of the effectiveness of the vehicle fleet called OVE Human was developed. OVE Human presents a mathematical statement in which vehicles, drivers and energy are figured, as vehicle fleet resources that affect the effectiveness of the transport process. Increasing the effectiveness of vehicles and drivers, as well as increasing energy efficiency (reducing energy consumption) increase the OVE Human Indicators value and contribute to the transport process improvement.

OVE Human is applicable in all forms of transport process, regardless of purpose: international and national freight transport, distribution, etc.

The goal is to use OVE Human as an indicator in the field of transport so energy efficiency and effectiveness of the transport process could be increased. The task is the same as for all previous studies: to eliminate losses in the fleet and increase the effectiveness of the transport process. Transport process effectiveness evaluation depends on the available resource utilization rates, the calculation is based on determining the utilization of vehicle and driver availability, the performance of vehicles and drivers, the quality of service provided and the quality of service rendered. Energy efficiency is included within the quality of the transport process.

OVE human indicator depends of:
Availability utilization ($\alpha$):
- vehicles ($\alpha_v$);
- drivers ($\alpha_d$);

Effect (Performance) ($\beta$):
- vehicles ($\beta_v$);
- drivers ($\beta_d$);

Quality of transport process ($q$):
- quality of service provided ($q_s$);
- vehicle fleet energy efficiency ($q_e$);
- the accuracy of the driver's work ($q_d$).

The formula for calculating OVE Human is given in the equation (1). The value of OVE Human moves in the interval between 0 and 1 ($0 \leq {OVE \text{ Human}} \leq 1$), expressed in percentage ranging from 0 to 100%.
\[ \text{OVEHuman} = \alpha \star \beta \star C = \]
\[ = \alpha_v \times \alpha_d \times \beta_v \times \beta_d \times q_s \times q_u \times q_d \quad (1) \]

Using resource availability (\(\alpha\)) is the product of using the vehicle’s availability (\(\alpha_v\)) and driver availability utilization (\(\alpha_d\)).

Vehicle availability utilization rate depends on vehicle roadworthiness and administrative conditions that vehicles should comply with. The entirety of vehicles in the fleet is denoted by (\(A_i\)) and is named total number of vehicles in inventory. There are two components of this inventory fleet size (\(A_i=\bar{A}_i+\bar{A}_d\)), where (\(A_i\)) stands for number of operational (roadworthy) vehicles, i.e. ready for operation, while (\(A_d\)) represents the number of defective vehicles, i.e. unready for operation.

Upon operational function, roadworthy vehicles (\(A_i\)) (\(A_i=\bar{A}_i+\bar{A}_d\)) are then further subdivided into vehicles in operation (\(A_d\)) and vehicles ready for operation but not engaged in operation (\(A_i\)). Every vehicle that is kept in the inventory fleet is in the observed period of \(D_i\) days (\(D_i\) - calendar number of days), and in accordance with the technical and administrative conditions available for the work of \(D_i\) days, that is, according to technical correctness or administrative conditions, is not available for work on days \(D_v\). For a certain period of time \(D_v\), the vehicle can be in the technically correct state of \(D_s\) days, that is, in a technically correct state and at the work of \(D_d\) days, in a technically correct state, not at work but available for the work of \(D_v\) days and unavailable for operation \(D_r\) days (\(D_v=D_s+D_d+D_r\)).

The use of vehicle availability (\(\alpha_v\)) is a coefficient that represents the utilization of the availability of vehicles that are capable or available for operation. This coefficient (Equation 2) indicates the ability of the organizational structure to employ vehicles that are technically correct and fulfill the administrative requirements, i.e. they are available for exploitation.

\[
\alpha_v = \frac{\sum_1^n A_{i\lambda} \lambda_i}{\sum_1^n A_i \lambda_i + \sum_1^n A_{i\lambda} \lambda_i} \quad (i=1, \text{n-th vehicle}) \quad (2)
\]

The availability of drivers depends on the number of days of annual leave, the number of days that drivers spend on sick leave, the number of days spent by drivers on serving internal disciplinary penalties and the number of days on serving sentences issued by state authorities, due to the protective measures for the prohibition of driving a motor vehicle. Drivers that are available for work can be:

- assigned to work tasks - effective work,
- deployed as a reserve - active on-call time,
- unallocated, due to lack of work, poor organization, etc. i
- attending training, additional training, etc.

Drivers who are unavailable for work are located at:
- annual leave,
- sick leave,
- serving internal disciplinary penalties,
- serving sentences issued by state authorities due to the protective measures for the prohibition of driving a motor vehicle.

The coefficient (\(\alpha_d\)) represents the utilization of the driver’s availability and represents the ratio of the total number of days the drivers spend at work and the total number of days when drivers are available for operation (equation 3).

\[
\alpha_d = \frac{\text{broj dana koji vozači provedu na radu}}{\text{ukupan broj dana kada su vozači raspoloživi za rad}} \quad (3)
\]

The total number of days when drivers are available for work is obtained when the total number of days in the year is deducted: weekends (Saturday and Sunday), days provided for annual leave, public holidays that are reunion and days reserved for celebrating religious holidays.

The effect (\(\beta\)) is the product of the vehicle's effect (\(\beta_v\)) and the driver's effect (\(\beta_d\)). Vehicle performance (\(\beta_v\)) depends on the volume of transport work and represents the ratio of Net Transport Work and Gross Transport Work (equation 4). Transport work is expressed in tonne kilometers [tkm].

\[
\beta_v = \frac{U_n}{U_b} = \frac{\sum_1^n (q_{\lambda_i} \times K \lambda_i)}{q_1 (\sum_1^n A_{\lambda i} + \sum_1^n A_{\lambda p i})} \quad (4)
\]

The net transport work during the transport of goods (\(U_n\)) represents the product of the quantity of cargo carried during each freight journey (\(q_{\lambda i}\)) and the length of the crossed road of each individual \(K\lambda\) load. The net transport work in passenger transport is the product of the number of passengers carried (\(N\)) and the passengers length level (\(L\)), is expressed in [putkm]. Gross transport work during the cargo transport (\(U_b\)) represents the product of the offered vehicle capacity (\(q\)) and collects the transit road with the AK load and the freeway without load AKo. Gross transport work for passenger transport is the product of the offered capacity of place in vehicles (\(m\)) and the length of the vehicle traveled on the line (\(L\)), is expressed in [putkm].

The effect of a driver depends on the time taken by drivers to work. The driver’s effect is the ratio of driving hours (\(\text{AH}_{\text{da}}\)) and car hours (\(\text{AH}_{\text{dr}}\)) (equation 5).

\[
\beta_d = \frac{\text{AH}_{\text{da}}}{\text{AH}_{\text{dr}}} = \frac{\sum_1^n \text{AH}_{\text{ui}}}{\sum_1^n \text{AH}_{\text{ri}}} \quad (5)
\]

Vehicle driving hours (\(\text{AH}_{\text{da}}\)) represent the total driving time that drivers spend driving a motor vehicle. This time includes the driving time from vehicle garage
to the first loading point and from the last unloading point to the garage, the loaded driving time between the loading and unloading point and the time of driving empty between the place of unloading and loading. Vehicle driving hours are the total driving time of all drivers.

Vehicle hours at work (AH) represent the driver’s working hours and includes the time from the moment of arrival to the workplace until the moment of leaving the workplace. In this time, the time of vehicle and driver preparation is inculcated, time of driving, time spent on loading and unloading, waiting time at the service (loading, unloading, waiting at the border crossing in the queue, etc.), the time of work for securing the cargo, i.e. receiving and dispatch passengers in passenger transport.

At this time, preparation and dispatch of accompanying documentation, debiting and disassembling vehicles and drivers with the necessary means for work, handing over the daily market to the cash register and etc.

The quality of the transport process (q) consists of three parameters. The first quality parameter is a service provided to the user (q_s), the second quality parameter is the energy efficiency of the vehicle fleet (q_v) and the third quality parameter is the driver’s performances (q_d).

The quality of service provided to the user (q_s) is the ratio of dissatisfied users and satisfied users from the total number of (N) users to whom the service is provided (equation 6). Information on the quality of the service provided is received directly from the users in the form of complaints and reclamations (recipient of the service provided is received directly from the users provided (equation 6)

\[ q_s = \frac{N_{\text{off}} + N_{\text{delay}} + N_{\text{damage}} + N_{\text{bag}}}{N} \]  

The quality parameter (q_s) refers to achieving the desired energy efficiency of the vehicle fleet. It is calculated as the ratio of the desired unit energy consumption for achieving the maximum transport operation, expressed in MJ per tonne kilometer (MJ/tkm), and realized unit energy consumption for the realized net transport operation (equation 7).

\[ q_v = \frac{E_{\text{setjen}}}{E_{\text{neto}}} \]  

Compliance with regulations in the field of transport and internal acts by the driver is represented by the q_d parameter. It is calculated as the ratio of the total number of rides without violation and the total number of journeys (equation 8).

\[ q_d = \frac{A_{\text{zak}} - N_{\text{in}} - N_{\text{vra}}}{A_{\text{zak}}} \]  

Based on the records of internal control, the number of violations of the internal regulations N_{vra} is determined. These violations relate to violation of internal procedures, technological procedures, internal acts, etc.

The number of violations in the field of traffic and transport N_{vra} is determined on the basis of records of misdemeanors issued by the competent authority when controlling the road and at the premises of the company.

5. APPLICATION OF THE OVE HUMAN INDICATOR AND ITS LACKS

The number of companies that have successfully applied one of the methods for calculating the effectiveness indicators is considered relatively small. There are several successful applications, and there are numerous documented failure cases. TPM and the application of complex performance indicators require not only commitment, but also a defined structure and direction.

Some of the prominent application problems include cultural resistance in accepting change. A complex indicator of effectiveness is used in accordance with social norms and not as a tool for reaching the world class of production [15]. The reasons for the inefficiency of the application of the meter are as follows:

- inertia (change in organizational culture);
- partial application;
- insufficient commitment to the problem;
- too optimistic expectations;
- lack of education and training;
- underestimating the importance of knowledge;
- resistance to change and new practises;
- selective management support (middle management level);
- trade union environment (workers are afraid that there will be a reduction in workforce and an increase in workload) etc.;

Different barriers that prevent organizations on the path to achieving the initiative are classified as: organizational, cultural, behavioral, technological, operational, financial and persistence [15].

6. CONCLUSION

By reviewing literature and examples of good practice on one side and modifying the OVE indicator
presented by [9] on the other hand, a method for measuring the effectiveness that can be applied in local conditions was obtained.

The OVE Human method represents an overview of the activities in the transport process that add or subtract value. It points to the possibility of increasing profitability because the largest costs are generated in the transport process (vehicles, labor, energy, etc.). The methods presented in the paper can measure the effectiveness of certain elements of the transport process. OVE Human is a complete meter, applicable to assessing the effectiveness of vehicles and drivers. The state provides the opportunity to monitor the activities of the transport economy through the OVE Human method, to identify the omissions, to examine the utilization of capacities, energy efficiency, environmental pollution, and the like, giving the possibility of management.

OVE Human focuses on the effectiveness of the transport process and can be a catalyst for new vehicle and driver performance standards. Within the transport process's effectiveness, there is potential for profit in competitiveness and improvement of environmental performance with the aim of sustainable transport. Further research is needed in order to test and establish the sustainability and significance of these improvements, not only for fleets, transport processes in general, but also for the wider economy and society. There are many factors that can contribute to the failure of the organization to successfully implement the presented model and realize the real potential. Therefore, the application of the model requires a long-term commitment to achieving the benefits and effectiveness of vehicles and drivers. In order to successfully apply the OVE Human model in the working environment, staff training, knowledge management, training, management support and team work are required, which are the basis for the successful implementation of the effectiveness indicators in the transport process.

It is therefore important to develop support, leadership, vision, strategic planning, knowledge management, more functional trainings, employee involvement, cultural change in organizations involved in the transport process. In this way, continuous improvement, motivation, development of incentive mechanisms can be achieved and in this way we can contribute to the development of a sustainable transport process, and to the transport economy we will provide a world class level that will guarantee sustainability.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 5.

REFERENCES


REZIME

Ocenova ukupne efektivnosti transportnog procesa

Postizanje održivog druganskog transporta zahteva postojanje metoda za ocenu njegove efektivnosti, odnosno za ocenu ukupne efektivnosti transportnog procesa, voznih parkova u drugom transportu, vozila i vozača. Transportna preduzeća i preduzeća sa voznim parkom za sopstvene potrebe teže podizanju efektivnosti resursa koji raspolažu kao i podizanju kvaliteta transportne usluge u cilju postizanja konkurentne pozicije na tržištu. Postizanje nivoa svetske klase prilikom ocenjivanja ukupne efektivnosti transportnog procesa je cilj države, vlasnika voznog parka, kao i obrazovne, stručne i naučne zajednice.

U radu je izložen značaj istraživanja i upravljanja efektivnošću transportnog procesa, prikazan je pregled literature i predstavljen je metod za izračunavanje pokazatelja OVE Human koji se koristi kao alat za ocenu ukupne efektivnosti transportnog procesa, a koji se može primrnuti u lokalnoj sredini. Ukazano je na probleme koji su uočeni prilikom primene sličnih pokazatelja i data su zaključna razmatranja.

Ključne reči: vozni park, raspoloživost, učinak, kvalitet, energetska efikasnost
The Research on Weather Impact on Trip Generation in European Cities

DRAGANA D. PETROVIĆ, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade

JADRANKA J. JOVIĆ, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade

VLADIMIR D. ĐORIĆ, University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade

Climate change and weather conditions’ change have the impact on the entire transport system. Weather changes cause changes in the transport supply, as well as in the transport demand. The first studies on weather impact on transport demand in the cities were carried out at the end of the nineties but they have been intensified in the last ten years. Most of the studies on weather impact on trip generation were carried out in the Northern Europe countries. In recent years studies are also conducted in European countries that have climate conditions and population habits significantly different from Northern European countries. This paper presents an overview of the areas where weather impact on the trip generation was researched. The most important conclusions of the conducted studies are presented and the weather components that have the greatest influence on the trip generation are indicated.

Key words: climate change, weather, transport demand, trip generation, transportation planning

1. INTRODUCTION

Climate change and sudden weather changes are not future generations’ concern. Climate change has already taken place and it was likely that their effects would be more expressed in the upcoming years. Still, different areas are expected to experience a different climate change impact [1].

Slightly higher increase in average temperatures, compared to the global average, is predicted on the territory of Europe. Snow periods will be shortened in all parts of Europe, so the snow cover is expected to decline in the greater part of Europe [2].

Higher temperatures during the winter, an increase in mean rainfall and in the greatest daily precipitation levels, and probably the increase of wind speeds, are expected in Northern Europe. The increase of the highest summer temperatures, increase of mean rainfall levels during the winter and decrease during summer, as well as the increase of the summer drought risk, is expected in Central Europe.

Greater warming during the summer, the decrease of mean precipitation values, reduction in the number of days with precipitation per year, and an increase in the risk of summer drought is expected in South Europe. The decrease of the average precipitation level, as well as greater warming during the summer, is expected in the greater part of the Mediterranean.

The average and extreme wind speeds are likely to increase in Southern and Central Europe. The duration of the snowy period and the amount of snowfall will probably decrease [2]. Average precipitation is expected to decrease, while average temperatures are expected to increase in the area of South-eastern Europe [1].

There is a great social interest to mitigate the climate change impact in the well-developed countries. The number of studies that consider the climate change impact and the weather impact, as a result of climate change, is increasing within the various scientific disciplines. The interest in the weather impact on transport demand, in particular on the trip generation, has
increased in the last decade. Increased interest in the weather impact on the travel behaviour is confirmed by numerous papers published in the previous two years [3, 4, 5, 6, 7, 8, 9, 10].

So far, studies have shown that weather affects the trip generation. However, it has been shown that weather did not affect the transport demand in the same way in different climate regions. The differences between the findings of various studies may be the result of the area in which studies were carried out, climate and habits of the population [11]. That is why the weather impact on transport demand needs to be explored at a local level. The transport demand in different weather conditions can be predicted only on the basis of the research conducted at a local level. Transport demand forecast has to be based on the special behavioural procedures for transport demand modelling in order to be reliable. In this case, it involves knowledge about user behaviour in different weather conditions [12, 13].

2. RESEARCH AREAS

Adverse weather conditions lead to traffic flow reduction on the road network. The recorded traffic flows were decreased by 1.3% during rainy days compared to the days without precipitation. It was found that daily traffic flow decreases by 0.08% with each millimetre of precipitation. The greatest rain effect on the traffic flow reduction is during the weekend and holidays. Snowfall has a far greater impact on the traffic flow on the road network, in some cases up to 50% [14, 15, 16, 17].

Adverse weather impact on transport demand is somewhat different on the street network, primarily because trips are shorter and because different transport modes are used. Numerous studies in cities have shown that adverse weather affects the trip generation. The extreme adverse weather has been found to be the second reason, after the illness, why the planned trip was not undertaken in Sweden [15]. The lowest mobility in Switzerland was recorded on Sundays during the winter, because more than a quarter of the population spent the entire day at home, i.e. did not make any trip [18].

Weather impact on travel behaviour and trip characteristics in cities has been explored in some regions of America, Australia, Europe and Asia. The most numerous are studies in Europe, more precisely in the countries of Northern Europe where studies about weather impact on travel behaviour have continuity. One of the main reasons for thoroughly weather impact investigation is the large share of non-motorized trips since users of non-motorized modes are most exposed to adverse weather conditions. In recent years, this type of research has begun to be carried out in European countries that are significantly different from the Northern Europe countries according to climate and population habits. On the Europe territory, studies about the weather impact on the trip generation were carried out in the territory of Belgium, the Netherlands, Serbia, Scotland, Switzerland, and Sweden.

The first studies about the weather impact on trip generation in cities were carried out at the end of the nineties. One of the pioneering studies on the weather impact on the travel behaviour was carried out in the territory of Belgium. Khattak and De Palma (1997) conducted research aimed at monitoring the travel behaviour in usual and in adverse weather conditions. The greater part of the sample was made by passenger car users. It was found that half of the passenger car users changed travel patterns in adverse weather and that adverse weather mostly affected the departure time [19]. De Palma and Rochat (1999) investigated the usual and adverse weather impact on the travel behaviour in Switzerland. The study found that most passengers changed their departure time to avoid congestion due to adverse weather [20]. Hassan and Barker (1999) concluded that in the territory of Scotland there was a difference in changes in traffic volume during adverse weather, depending on whether it was a weekend or a working day. It was noted that the decrease in traffic volume in adverse weather was greater during the weekend [21].

Cools, Moons, Creemers and Wets (2010) investigated the weather impact on transport demand in the territory of Belgium. The research has shown that the weather conditions affect the likelihood of a change in passenger behaviour and that changes depend on the trip purpose [22]. Cools, Moons and Wets (2010) showed that the same weather conditions had the different influence on transport demand at different locations on street network. It was concluded that the weather impact intensity depended on traffic volume [23]. Cools and Creemers (2013) investigated the impact of weather forecasts on passenger behaviour in the area of Belgium. Several aspects of the passengers’ behaviour, trip purpose and type of weather have been taken into account. It was concluded that travellers adjusted their activities to forecasted weather which primarily related to travel purposes such as shopping, leisure, and recreation [24].

Bergström and Magnusson (2003) examined the attitude of the residents in Sweden about cycling during the winter. It has been shown that the temperature, precipitation, and road condition were the most important factors for those who cycle to work during summer, but not during the winter. Physical activity was the most important factor for those who cycled to work during the winter, while travel time was the most
important factor for those who never cycled to work. [25] Liu, Susilo and Karlstrom (2014) conducted a study in Sweden with the aim to analyse the impact of changing weather conditions on the non-commuters’ travel behaviour. Authors selected this group for research because the commuters’ travel behaviour was less adaptable to weather changes. This study has especially pointed to the fact that weather changes may have a different impact on the trip characteristics in different regions [5].

Berkum, Weijermars and Hagens (2006) presented the weather impact, especially rain impact on travel behaviour in the Netherlands’ cities. The bicycle was the most represented transport mode in addition to car and public transport which was characteristic of cities in the Netherlands. This survey provided data about changes in the traffic volume and traffic flow in rainy conditions. It was concluded that the rain had a great influence on the trip generation for trips shorter than 7.5 km and that rain caused trip delay and trip cancellation [15].

The weather impact on transport demand in the Netherlands was also studied by Sabir, Ommeren, Koetse and Rietveld (2010). Transport demand was expressed by the total number of trips as well as by the total distance travelled during the day. It was concluded that weather conditions, particularly high and low temperatures, snow, and intense precipitation affected transport demand. It has been shown that weather almost did not affect work trips. [26] Sabir (2011) has shown that weather has less impact on commuting and business trips than on trips with other purposes [27].

Nikolić (2011) conducted the first research about weather impact on passengers’ decisions before and during the trip in the territory of Serbia. The research in Belgrade was aimed at determining the weather impact on the route change, departure time and the travel mode in the case of obligatory and non-obligatory trips. It was concluded that most passengers changed the departure time, while they least changed their established route. Respondents who were informed about weather conditions started their trips earlier in adverse weather [28].

Petrović, Ivanović and Đorić (2015) began extensive research about weather impact on transport demand in Belgrade during 2014. Pilot studies on travel demand have been carried out using the "stated adaptation" technique for different weather scenarios. The target population in the survey was employed Belgrade residents since they represented the majority of transport system users. The research has shown that adverse weather affects the cancellation of non-obligatory trips (leisure, recreation), while adverse weather does not affect the cancellation of trips to work [29]. Petrović (2017) continued investigations about the weather impact on the trip generation within doctoral dissertation. The method of "stated adaptation", as well as the method of "revealed preferences", showed that weather had the impact on the employed residents’ mobility in the territory of Belgrade. It was found that the employees made the largest number of trips during warm mostly dry days, and the least during the cold days with heavy precipitation. The mobility of Belgrade employees during the cold days with high precipitation was 15% lower than mobility during warm mostly dry days [30].

3. THE IMPACT OF WEATHER COMPONENTS ON TRIP GENERATION

Most studies point out that weather components that have the greatest impact on the travel behaviour are precipitation, temperature, and wind. Considering weather impact on the trip generation, effects of precipitation, temperature, and wind are also the most researched. Studies show that snow, rain, and strong wind reduce traffic flow, while high temperatures increase traffic flow [23]. In addition to the weather components, the season and the presence of certain weather component in the days prior to a survey may also play a significant role in explaining the changes that occur in the daily travel behaviour [7, 24].

Precipitation

The conducted studies showed that during the day with adverse weather, especially with precipitation, non-obligatory trips were delayed or shortened. Studies showed that the number of trips was lower during rainy days, especially during the weekend when sensitivity to precipitation was higher. A smaller decline was recorded in the number of trips on weekdays (on average 2.9%) compared to the weekend (7.9% for the Saturday, 5.2% for the Sunday) [31]. It has been shown that the intensity of impact to a large extent depended on the rain or snowfall intensity [17, 21, 32]. Also, studies have shown that snow affected the decrease in the number of passengers' trips [26, 27]. An analysis of the trip chains indicated an increase in the likelihood of chained trips in rainfall conditions for obligatory purposes, while for non-obligatory purposes less planned activities during rainy days were indicated [8].

Heavy rains and storms have an impact primarily on departure time since a certain number of passengers delay their travel to the occurrence of favourable weather conditions [22]. In order to avoid rainfall when walking or cycling one of the respondents' reactions is short-range trips postponement [15]. In the case of snow, more than 50% of respondents postpone
their travel. Snow has an impact on trips to work and on trips for shopping, whereby the most common reaction is trip postponement or cancellation in the case of non-obligatory purposes. In the case of snow, about 70% of respondents cancel the trip with non-obligatory purposes, and in the case of rain about 50% of respondents [22]. Precipitation has a major impact on the number of walking and cycling trips [33]. As the rainfall increases, the distance travelled is reduced, which is not valid for journeys to work [34].

Roadway covered with snow is the most influential factor in the number of trips in the chain [8]. Snow has the greatest influence on choosing the departure time. A survey in the territory of Belgrade has shown that during snowfall the use of a passenger car was decreasing [28]. The adverse weather impact is greater during the weekend, which is confirmed with a 15% traffic volume reduction when there is snow on the roadway, while the reduction in traffic volume is 10% during working days under the same conditions [21].

It has been shown that weather forecast affected the travel behaviour [15], although the effect was less than the impact of the current weather conditions. Most of the trip changes are caused by the announcement of snowfall [24].

Temperature

Temperature is perceived differently in different regions and in different seasons, especially in the case of non-motorized mode users, while in the case of motorized mode users the perception differs to a lesser extent [35]. Temperature and seasons have an impact on all trip characteristics [15]. With the temperature increase, there is an increase in the total number of trips, as well as in the number of trip chains at the individual level, which is especially true for non-commuters [5].

There is no significant difference in the mobility of employed residents in different temperature conditions [36]. High temperatures do not affect departure time, while low temperatures have an effect [28]. Extremely high and low temperatures are at least likely to affect work trips [22]. The effect of average temperature on non-commuters is far greater than the effect on commuters [5].

Wind

Studies have shown that in conditions of strong wind 45% of respondents cancelled their trip. Under storm conditions, one part of passengers postponed their trip until the appearance of favourable weather conditions [22]. In the papers analysing the influence of the wind, the most frequently analysed are changes in the transport demand under the influence of wind in combination with precipitation or low temperature.

4. CONCLUSION

The impact of climate change on the transport system cannot be reliably estimated unless the reaction of the transport system users in different weather conditions is assessed.

Presented studies pointed to the fact that weather had a significant impact on the number of trips that inhabitants made during a day. Conclusions about the trip generation in different weather conditions are especially important for traffic planning and traffic management procedures.

The results of relevant studies on the weather impact on the trip generation indicate the importance to develop measures for adaptation to climate change in the field of transport.

Studies carried out both in the territory of Belgrade and in the territory of other European cities have shown that favourable weather conditions influenced the greater mobility of the population, which was an important conclusion since the decrease in average precipitation and an increase in average temperatures were expected in the territory of Europe.

It is important to take into account the conclusions of the presented studies in the process of the transport demand modelling since travel behaviour is different in different weather conditions.

5. ACKNOWLEDGEMENT

This paper is the result of the research conducted within the project funded by the Ministry of Science, Education and Technological Development of the Republic of Serbia, Project number: TR36021.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 2.

REFERENCES


[33] Saneinejad S. Modelling the Impact of Weather Conditions on Active Transportation Travel Behaviour (Master Thesis), University of Toronto, Toronto, 2010.

[34] Aaheim HA, Hauge KE. Impacts of climate change on travel habits, Center for International Climate and Environmental Research, Blindern, Oslo, 2005.


REZIME

ISTRAŽIVANJE UTICAJA VREMENSKIH USLOVA NA NASTAJANJE KRETANJA U GRADOVIMA EVROPE

Klimatske promene i promene vremenskih uslova imaju uticaj na celokupan transportni sistem. Promene vremenskih uslova dovode do promena kako u transportnoj ponudi, tako i u transportnoj potražnji. Prva istraživanja uticaja vremenskih uslova na transportne zahteve u gradovima sprovedena su krajem devedesetih godina prošlog veka, a intenzivirana su u poslednjih deset godina. Najveći broj istraživanja o uticaju vremenskih uslova na nastajanje kretanja sproveden je u zemljama Severne Evrope. Poslednjih godina istraživanja počinju da se sprovode i u evropskim zemljama koje su po klimatskim uslovima i navikama stanovništva značajno drugačije od severnoevropskih zemalja. U radu je prikazan pregled područja u kojima je istraživan uticaj vremenskih uslova na nastajanje kretanja. Predstavljeni su najvažniji zaključci sprovedenih istraživanja i ukazano je na komponente vremenskih uslova koje imaju najveći uticaj na nastajanje kretanja. Poznavanje uticaja vremenskih uslova na transportne zahteve neophodno je za sprovodenje procedura planiranja saobraćaja u uslovima najavljenih klimatskih promena.

Ključne reči: klimatske promene, vremenski uslovi, transportni zahtevi, nastajanje kretanja, planiranje saobraćaja
ISSN 1450-9911

TECHNICS

MANAGEMENT

Menadžment – Gestion – Management - Управление


EDITOR-IN-CHEF
Prof. Vujadin Vešović, D.Sc, Engineering Academy of Serbia, Belgrade

EDITORIAL COUNCIL
Prof. Petar Jovanović, D.Sc, Project Management College, Belgrade

Academician Prof. Leonid Avramovič Baranov, Moscow State University, MIIT, Moscow

Prof. Sanja Petrović, D.Sc, Nottingham University Business School, Nottingham, UK

Prof. Dejan Petrović, D.Sc, University of Belgrade, Faculty of Organizational Sciences, Belgrade

Prof. Ilija Ćosić, D.Sc, University of Novi Sad, Faculty of Technical Sciences, Novi Sad

Prof. Nebojša Bojović, D.Sc, University of Belgrade, Faculty of Traffic and Transport Engineering, Belgrade

Prof. Vesna Spasojević Brkic, D.Sc, University of Belgrade, Faculty of Mechanical Engineering, Belgrade

EDITORIAL OFFICE: Union of Engineers and Technicians of Serbia, 11000 Belgrade, Kneza Miloša 7a/I, Tel. +381/11/ 32 35 891, Fax +381/11/ 32 30 067
Assessing the Recycling Costs in the Product Development Phase

VLADIMIR V. TODIĆ, University of Novi Sad, Faculty of Technical Sciences, Novi Sad
ILIJA P. ĆOSIĆ, University of Novi Sad, Faculty of Technical Sciences, Novi Sad
ZDRAVKO M. TEŠIĆ, University of Novi Sad, Faculty of Technical Sciences, Novi Sad
BOJAN B. LALIĆ, University of Novi Sad, Faculty of Technical Sciences, Novi Sad
NEMANJA Z. TASIĆ, University of Novi Sad, Faculty of Technical Sciences, Novi Sad

Assessing the recycling costs in the product development phase significantly affects the product management at the end of its lifetime. Allowing managing the product at the end of its lifetime, recycling greatly contributes to protection of the environment. Assessing the recycling costs for individual alternative solutions of preliminary and conceptual design in the product development phase, including the possibility of opting for different materials for individual product components, makes the basis for managing the costs of recycling.

On the example of single-row cylindrical roller bearings, the paper presents the application of fuzzy-neural networks in the assessment of recycling costs in the product development phase.

Key words: recycling, costs, fuzzy-neural networks

1. INTRODUCTION

The development of new products and services, as a process inspired by the desire of people to increase the quality of their living, has simultaneously endangered two basic factors of sustainable living standard relating to a quality environment and sufficient amount of energy. Products at the end of their life cycle, or not in use, should be used as secondary raw materials and additional source of energy. Using modern recycling technologies, these products can be converted into raw materials for further processing or for the production of new products.

Recycling is a process of processing materials, products and components that are withdrawn from use at the end of their life with the goal of obtaining new materials for the production of the same or other products.

Recycling can refer to treating waste generated in the process of production or processing products withdrawn from use. In doing so, two important effects can be achieved [1]:

- reduced exploitation of sources of primary raw materials and energy, as waste is used as raw material, and
- reduced amount of waste that needs to be disposed.

At the beginning of the 1970s, the EU has conceived decisions and directives for managing products not in use, known in the literature as waste, as a result of which Serbia also recognized waste management and environmental protection as a matter of national interest.

Therefore, in Serbia waste management is defined by law, which implies collecting, sorting and recycling waste in an organized manner, which has been achieved by developing and establishing a number of recycling facilities. In accordance with EU directives, the most acceptable strategies for managing products...
at the end of their life cycle have been adopted, such as [2]:
- reuse of used products,
- reconstruction of used products,
- use of used products for spare parts,
- recycling with disassembling,
- recycling without disassembling, and
- disposal of used products.

Reusing used products means returning discarded products which are still operational and which can be used as spare parts, while the reconstruction of used products implies modernizing or improving their performances.

Recycling with disassembling is a strategy consisting of separation of components made from different materials before re-reprocessing in the recycling process. An example of recycling with disassembling is the German approach to recycling old cars [1]. Components which are separated in the process of disassembling based on the type of material are re-processed and used for the production of the same or other products.

Recycling without disassembling is the procedure in which the products are pressed and crushed, and sorted based on the type of material. An example of recycling without disassembling is the American approach to recycling old cars [1]. From the ecological point of view, land filling is the most unfavorable strategy of product deposition.

2. BASIC TYPES OF RECYCLING

Depending on the type of waste, recycling processes cover the most important types of materials, including paper, glass, pneumatics, plastics, construction waste, medical waste, wood, metal, electronic and electrical waste, old vehicles, batteries, and household appliances. By type, recycling technologies can be mechanical, chemical and biological [1, 3]. In addition to collecting, the most important activities in the mechanical recycling processes, also common to all types of recycling, are:
- disassembling,
- classification,
- cutting, crushing and grinding,
- pressing,
- agglomeration, and
- washing.

The basic characteristics of recycling technologies relating to these types of waste are presented in a number of literature sources, for example [3], while in this paper only the basic activities of the recycling process of metal waste are presented.

2.1. Recycling metal waste

Metal products, which are excluded from use at the end of their life cycle, can be made from various metals and their alloys, which need to be grouped in the process of classification, primarily based on the type of material.

The wide range of materials used for these products requires various recycling technologies, or their combinations, depending on the materials of components [4].

The processing of primary and secondary raw materials, i.e. waste, based on pyrometallurgical, combined and hydrometallurgical treatment, along with the corresponding activities, is shown in Figure 1.

![Figure 1 - Joint processing of primary and secondary raw materials [3]](image-url)
Pyrometallurgical processing includes metallurgical methods for obtaining metals from ores placed at higher temperatures, while hydrometallurgical treatment is essentially based on a melting process, in which one or several components of metal changes its state from solid waste to solution.

3. RECYCLABILITY AS PART OF THE QUALITY OF THE NEW PRODUCT

Designing a new product in modern conditions, which arises as a result of the work of an elite design team, most often organized on the concept of simultaneous engineering, implies devising a solution for the new product which is suitable to all phases of its life cycle, from development through recycling. Such designs is supported by the use of DFx tools [5] intended for designing for excellence (Figure 2).

The three basic DFx methodologies, related to product design, production, use, recycling and environmental protection, enable new products to be developed and designed, which are suitable for:

- manufacturing (DFM),
- assembling (DFA),
- manufacturing and assembling (DFMA),
- disassembling (DFD),
- quality (DFQ),
- recycling (DFR),
- environment (DFE), etc.

Figure 2 - Designing for excellence [5]

In the development phase, costs of disassembling in the recycling phase and the permanent removal of products are often "hidden". Therefore, the authors [6] propose the following elements for testing product recyclability: disassembly, separation of components and materials for reuse, sorting, cutting and permanent waste removal. Thus, all elements determining the design of the product's life cycle need to be incorporated as early as the phase of conceptual design (Figure 3).

In the analysis of DFx methodologies related to the design of a new product from the aspect of recyclability, the following important elements of recyclability can be highlighted [2]:

- suitability of materials of product components for melting,
- usability of the recycled metal for producing the same or other products,
- reusability of components that are not recycled,
- efficient disassembly of complex products to subassemblies and components,
- low recycling costs, etc.

In all phases of product design, from conceptual design and shaping to detailed design, appropriate software tools are used for visualization, simulation, mathematical modeling, 3D modeling, 2D designing, with specific methods and models being used in the product development phase for assessing recyclability, especially in terms of recycling costs.

Recyclability and recycling costs in the product development phase can be assessed within the framework of cost assessment for all phases of the product life cycle [7, 8, 9], or in the framework of cost assessment for individual phases of the product life cycle [10, 11, 12].
In modern conditions of application of DFx tools, costs of recycling in the product development can be assessed and managed using phase fuzzy-neural networks.

Figure 3 - Life cycle design concept [6]

4. ASSESSING RECYCLING COSTS USING FUZZY-NEURAL NETWORKS

Artificial intelligence is part of computer science and deals with the design of intelligent computer systems, that is, systems that exhibit features similar to human behavior in terms of learning, reasoning, problem solving, and language understanding. The main goal of artificial intelligence is to simulate human behavior which is based on knowledge and using knowledge.

Artificial intelligence uses a number of techniques, including neural networks and fuzzy logics. Compared to traditional computer programs, their use is reflected in the independent management of symbols as concepts and ideas [13].

Artificial neural networks represent a family of statistical models of machine learning based on a large number of input dimensions. Some of the basic features and possibilities offered by artificial neural networks are adaptability, non-linearity and the level of confidence in decision making. Fuzzy logic, or fuzzy systems, which are based on the fuzzy set theory, can be considered as the generalization of conventional rule-based expert systems.

In theory, it is possible to combine all traditional techniques of artificial intelligence, but so far the best results have been obtained using hybrid techniques, created by combining traditional techniques of artificial intelligence. In this paper, fuzzy-neural networks were used as a combination of artificial neural networks and fuzzy logic.

4.1. Training, testing and validation of fuzzy-neural networks

The training, testing and validation of the selected fuzzy-neural network was conducted using the Gaussian membership function (gauss2mf), with parameters (1 3 3 4), based on the data for recycling costs of the selected group consisting of 93 structurally similar bearings. The recycling costs of these products, which were collected in specialized companies dealing with recycling of metal waste, were based on the costs of recycling activities for this type of waste, such as:

- Collecting,
- Disassembling,
- Sorting,
- Separation of parts for use,
- Washing and degreasing,
- Crushing,
- Melting,
- Removing permanent waste, etc.

In the framework of disassembling, bearings are separated from various types of complex products and then disassembled before recycling. Costs of disassembling related to the separation of the bearing from a complex product depend on the type of product, location of the bearing, level of automation of disassembly, as well as the dimensions and weight of the bearing. Sorting includes grouping steel and plastic components, as well as components for reuse, i.e. screws and seals.

The collected data on recycling costs are systematized and shown in Table 1 as a function of bearing dimensions and weight. These costs represent the average cost of all recycling activities mentioned above. The trained fuzzy-neural network was tested using the data for ten bearings from the above group and validated using the other group consisting of ten bearings.

The group of similar bearings has been characterized by the same input parameters: bore diameter (d), outer diameter (D), width (B) and weight (m). The range of these parameters of the selected group of bearings is:

- d = (12-120) mm,
- D = (35-240) mm,
- B = (11-141) mm, and
- m = (0.04-17) kg/bearing.

Based on the input parameters and the data on recycling costs of the selected group of roller bearings, the correlation factors between the input parameters and the recycling costs have been determined as 0.85 for bore diameter, 0.90 for outer diameter, 0.81 for width and 0.90 for weight.
The accuracy of training, testing and validation of the neural network are shown in Table 2.

Figure 4 shows the graphical presentation of recycling costs ($T_{rec}$) of the trained fuzzy-neural network as a function of the input data relating to bore diameter (d), outer diameter (D), width (B) and weight (m).

Table 1. Recycling costs of similar products

<table>
<thead>
<tr>
<th>BEARING DIMENSIONS AND WEIGHT</th>
<th>LABEL</th>
<th>Recyling</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>17</td>
<td>40</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>47</td>
<td>14</td>
</tr>
<tr>
<td>25</td>
<td>52</td>
<td>15</td>
</tr>
<tr>
<td>30</td>
<td>62</td>
<td>16</td>
</tr>
<tr>
<td>35</td>
<td>72</td>
<td>17</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>18</td>
</tr>
<tr>
<td>45</td>
<td>85</td>
<td>19</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>20</td>
</tr>
<tr>
<td>55</td>
<td>100</td>
<td>21</td>
</tr>
<tr>
<td>60</td>
<td>110</td>
<td>22</td>
</tr>
<tr>
<td>65</td>
<td>120</td>
<td>23</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>22</td>
</tr>
<tr>
<td>20</td>
<td>47</td>
<td>25.5</td>
</tr>
<tr>
<td>25</td>
<td>52</td>
<td>27.2</td>
</tr>
<tr>
<td>30</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>35</td>
<td>72</td>
<td>33</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>45</td>
<td>85</td>
<td>37</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>38.8</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>27.4</td>
</tr>
<tr>
<td>25</td>
<td>52</td>
<td>34.1</td>
</tr>
<tr>
<td>30</td>
<td>62</td>
<td>38.1</td>
</tr>
<tr>
<td>35</td>
<td>72</td>
<td>42.9</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>49.2</td>
</tr>
<tr>
<td>45</td>
<td>85</td>
<td>49.2</td>
</tr>
<tr>
<td>50</td>
<td>90</td>
<td>51.6</td>
</tr>
<tr>
<td>55</td>
<td>100</td>
<td>55.6</td>
</tr>
<tr>
<td>60</td>
<td>110</td>
<td>65.1</td>
</tr>
<tr>
<td>65</td>
<td>120</td>
<td>68.3</td>
</tr>
<tr>
<td>70</td>
<td>125</td>
<td>69.9</td>
</tr>
<tr>
<td>75</td>
<td>130</td>
<td>73.3</td>
</tr>
<tr>
<td>80</td>
<td>140</td>
<td>77.8</td>
</tr>
<tr>
<td>85</td>
<td>150</td>
<td>81</td>
</tr>
<tr>
<td>90</td>
<td>160</td>
<td>89</td>
</tr>
<tr>
<td>100</td>
<td>180</td>
<td>98.4</td>
</tr>
<tr>
<td>110</td>
<td>240</td>
<td>117</td>
</tr>
<tr>
<td>120</td>
<td>215</td>
<td>73.5</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>28.6</td>
</tr>
<tr>
<td>20</td>
<td>47</td>
<td>31</td>
</tr>
<tr>
<td>25</td>
<td>52</td>
<td>31</td>
</tr>
<tr>
<td>30</td>
<td>62</td>
<td>35.7</td>
</tr>
<tr>
<td>35</td>
<td>72</td>
<td>38.9</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>43.7</td>
</tr>
<tr>
<td>45</td>
<td>85</td>
<td>43.7</td>
</tr>
</tbody>
</table>

$T_{ODIĆ}$ V. et al. ASSESSING THE RECYCLING COSTS IN THE PRODUCT DEVELOPMENT...
5. ASSESSING THE RECYCLING COSTS FOR A NEW PRODUCT

The assessment of recycling costs of the roller bearing from Figure 5 with the dimensions given in Table 3 was carried out using a trained fuzzy-neural network.

Figure 5 - Single-row cylindrical bearing

The single-row roller bearing, as a new product, belongs to the group of the aforementioned similar products and is characterized by the same input parameters.

The recycling costs of these products were determined using the trained fuzzy-neural network and setting the corresponding input parameters for the single-row roller bearing (Table 4).

Table 3. Dimensions of single-row cylindrical roller bearings

<table>
<thead>
<tr>
<th>No.</th>
<th>BEARING DIMENSIONS AND WEIGHT</th>
<th>LABEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>d</td>
<td>D</td>
</tr>
<tr>
<td>1.</td>
<td>35</td>
<td>72</td>
</tr>
<tr>
<td>2.</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>3.</td>
<td>45</td>
<td>85</td>
</tr>
<tr>
<td>4.</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>5.</td>
<td>55</td>
<td>100</td>
</tr>
<tr>
<td>6.</td>
<td>70</td>
<td>150</td>
</tr>
<tr>
<td>7.</td>
<td>75</td>
<td>115</td>
</tr>
<tr>
<td>8.</td>
<td>80</td>
<td>140</td>
</tr>
<tr>
<td>9.</td>
<td>110</td>
<td>200</td>
</tr>
<tr>
<td>10.</td>
<td>130</td>
<td>230</td>
</tr>
</tbody>
</table>
ASSESSING THE RECYCLING COSTS IN THE PRODUCT DEVELOPMENT...

The present example of cost assessment for single-row cylindrical bearings takes into account only one version of the engineering solution and one type of material used for individual components, because the requirements regarding the solution and the type of material for individual bearing components are determined by standards for this product type.

6. CONCLUSION

Assessing the recycling cost in the product development phase makes the basis for managing the recycling costs at the end of the product life, because the cost assessment for individual solutions of conceptual and preliminary product design enables to select the solution with the lowest recycling costs.

Managing recycling costs in the product development phase is conducted within the cost management of other phases of the product life cycle as well, primarily, the costs of manufacturing and use. The trained fuzzy-neural networks for assessing and managing recycling costs in the development phase of the new product represent a significant part of the knowledge base, which is not suitable for the application of the DFx product design from the aspect of recyclability.

The presented concept of recycling cost management allows the recycling costs to be assessed in the product development phase, while the management of these costs is only possible when alternative solutions for product materials or components can be set up in the product development stage. The basic directions for future research will be to explore the possibility of automated recognition and selection of similar products for which recycling costs are known, as well as the possibility of applying other artificial intelligence methods for assessing the recycling costs.

7. ACKNOWLEDGMENT

The research for this paper was carried out within the project "Development of software for managing the repair and installation of brake systems of rail vehicles", Ministry of Science and Technological Development, No. 035050, for the period 2011-2016.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, No 1.

REFERENCES


Table 4. Recycling costs for single-row cylindrical roller bearings

<table>
<thead>
<tr>
<th>No.</th>
<th>Label</th>
<th>Bore diameter</th>
<th>Outer diameter</th>
<th>Width</th>
<th>Weight</th>
<th>Manufacturing costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>d</td>
<td>D</td>
<td>B</td>
<td>m (kg/pc)</td>
<td>Tm (€/pc)</td>
</tr>
<tr>
<td>1.</td>
<td>NU 207 EM</td>
<td>35</td>
<td>72</td>
<td>17</td>
<td>0.304</td>
<td>0.78</td>
</tr>
<tr>
<td>2.</td>
<td>NU 208</td>
<td>40</td>
<td>80</td>
<td>18</td>
<td>0.38</td>
<td>1.03</td>
</tr>
<tr>
<td>3.</td>
<td>NU 209</td>
<td>45</td>
<td>85</td>
<td>19</td>
<td>0.44</td>
<td>1.24</td>
</tr>
<tr>
<td>4.</td>
<td>NU 210</td>
<td>50</td>
<td>90</td>
<td>20</td>
<td>0.49</td>
<td>1.41</td>
</tr>
<tr>
<td>5.</td>
<td>NU 211 EM</td>
<td>55</td>
<td>100</td>
<td>21</td>
<td>0.67</td>
<td>1.74</td>
</tr>
<tr>
<td>6.</td>
<td>NU 314 EM</td>
<td>70</td>
<td>150</td>
<td>35</td>
<td>2.89</td>
<td>8.64</td>
</tr>
<tr>
<td>7.</td>
<td>NU 1015 M</td>
<td>75</td>
<td>115</td>
<td>20</td>
<td>0.75</td>
<td>1.69</td>
</tr>
<tr>
<td>8.</td>
<td>NU 216 EM</td>
<td>80</td>
<td>140</td>
<td>26</td>
<td>1.60</td>
<td>4.88</td>
</tr>
<tr>
<td>9.</td>
<td>NU 222 E</td>
<td>110</td>
<td>200</td>
<td>38</td>
<td>4.80</td>
<td>13.00</td>
</tr>
<tr>
<td>10.</td>
<td>NU 226 E</td>
<td>130</td>
<td>230</td>
<td>40</td>
<td>6.80</td>
<td>12.00</td>
</tr>
</tbody>
</table>

The basic directions for future research will be to explore the possibility of automated recognition and selection of similar products for which recycling costs are known, as well as the possibility of applying other artificial intelligence methods for assessing the recycling costs.


REZIME

PROCENA TROŠKOVA RECIKLAŽE U FAZI RAZVOJA PROIZVODA

Procena troškova reciklaže u fazi razvoja proizvoda, ima značajan uticaj na upravljanje proizvodom na kraju njegovog životnog veka. Reciklaža koja obezbeđuje upravljanje proizvodom na kraju životnog veka, ima značajan doprinos očuvanju životne sredine. Procena troškova reciklaže za pojedina alternativna rešenja preliminarog i konceptualnog dizajna u fazi razvoja proizvoda, uključujući i mogućnost izbora različitih materijala za pojedine delove proizvoda, čini osnovu za upravljanje troškovima reciklaže. U radu je prikazana primena fazi-neuronskih mreža za procenu troškova reciklaže u fazi razvoja proizvoda na primjeru valjkastih jednorednih kotrljajućih ležaja.

Ključne reči: reciklaža, troškovi, fazi-neuronske mreže
Bullwhip Dependency of Participants' Risk Preferences in the Supply Chain

BILJANA V. PANIĆ, University of Belgrade
Faculty of Organizational Sciences, Belgrade

DRAGANA D. MAKAJIĆ-NIKOLIĆ, University of Belgrade
Faculty of Organizational Sciences, Belgrade

MAJA D. HADŽIAHMETOVIĆ, Nimble Software Systems, Inc, Belgrade
MIRKO B. VUJOŠEVIĆ, University of Belgrade,
Faculty of Organizational Sciences, Belgrade

This paper examines the causes of risk preferences, as one of the personality traits, of the participants in the supply chain on inventory and backorder costs. Based on test results the participants are divided into two groups: risk-seeking and risk-averse. Two teams are formed who simulated a beer game. It is shown that there are differences in costs between these teams.

Key words: risk preferences, bullwhip effect, supply chains

1. INTRODUCTION

The supply chain (SC) includes all the participants who are directly or indirectly involved in the process of satisfying consumer needs [1]. A lack of information and a lack of coordination [2] can lead to the bullwhip effect which implies a distortion of information within the SC, as different stages in the chain have different calculations on the size of the demand, so the demand varies more as it goes from the retailer to the manufacturer.

The bullwhip effect was first recognized in work by [3]. Later on, the bullwhip effects were described as "systematic irrational behavior of players" or "misinterpretation of feedback" [4, 5]. A retailer interprets a small change in consumer demand as a trend of growth, which leads him to increase his order. The higher it goes up the chain, the higher is the increase in the size of orders.

The causes of the bullwhip effect are classified as operational and behavioral [6]. Authors in [4, 7] first examined only behavioral causes of the bullwhip effect by eliminating other causes in experimental conditions. Behavioral causes relate to the reduced rationality with the decision-makers, especially in the misinterpretation of feedback and delay, and can be grouped into five categories: coordination risk [6], mistrust [6], cognitive limitations [4, 8], negligence of inventory that has not arrived yet [7, 8, 9, 10, 11, 12] and personal characteristics [13, 14, 15]. The authors in [14, 15] prove that participants who are more cooperative in supply chains have lower costs.

The authors in [13] examined the correlation between personality traits and supply chain performances – backorder costs and inventory costs. The extent to which self-efficacy, the locus of control, tolerance for ambiguity and risk preferences can influence the decision-making and performance were examined.

The purpose of this research is to examine whether the participants’ proclivity towards risk can influence the bullwhip effect in the SC and whether it is possible to form a chain with participants with favorable traits. The assumption was that all participants could be divided into two groups: risk-seeking and risk-averse ones and based on this division, the participants will obtain different costs in the chain. If these assumptions prove to be true, then it would be possible to form a supply chain which contains participants with favorable traits only.

The participants were divided into two above mentioned groups based on a questionary and an experiment was conducted where the participants played the beer game created at Sloan School of Management, Massachusetts Institute of Technology - MIT [16].

The second part of this paper the literature review concerning the bullwhip dependency of participants’
risk preferences in the supply chain is presented. The third part of the paper describes the beer game and the experiment is described in the fourth section of this paper. The fifth section provides final considerations.

2. BULLWHIP DEPENDENCY OF PARTICIPANTS’ RISK PREFERENCES IN THE SUPPLY CHAIN

One of the first to examine risk-seeking and risk-averse behavior in SC were examined in [17] on a newsvendor model. Several authors [13, 18, 19, 20, 21, 22, 23] examined the impact of risk preferences of individual participants in the SC on their behavior. It is an interesting fact that in [22] the emphasis is on the importance of taking into account the attitude towards risk of all participants in the SC, not just the risk their own company. The authors in the [23] have proven that the more risk-averse the participants in the SC are, the more they tend to keep safety stock, and vice versa.

People who are risk-averse have higher costs of a stock than people who are moderately or very prone to risk [13]. One explanation may be that such persons are more cautious when ordering, so it happens that they do not have enough stock. Retailers who are less prone to risk tend to order more when compared to those who are more risk-seeking. At first glance, this may seem illogical, but probably people who are less prone to risk react slower to changes in demand, but when they do react they tend to order more. As a result of such behavior retailers who are risk-averse cause a greater bullwhip effect and have higher costs. On the other hand, wholesalers, distributors, and manufacturers who are risk averse and behave in the same way, cause a smaller bullwhip effect and have lower costs, because in these positions it is better to respond slowly to changes in demand. For retailers, the backorder is the most important factor since they have a direct relationship with the consumer. When it comes to distributors, they depend on more than one retailer since they are usually a part of a supply network. Risk-seeking persons react faster, which proved good in a retailer’s position, but bad in all other positions.

In the papers [20, 24] the authors have identified two extreme types of behavior called safe harbor and panic. When it comes to the safe harbor behavior, people tend to order more than they need to provide a certain level of safety stock. This leads to an increase in inventory but also forces their suppliers to increase their orders or pay for unmet demand. On the other hand, the panic means that the participant only forwards orders he had received, this way emptying his warehouse at the very beginning. It initially does not affect other participants, but if the consumer demand grows, the participant who acts this way must order more than the participant who has safety stock. This is when this strategy starts to have the same negative impact, as the previous one. Authors showed optimal values obtained only when the player is a computer. The more there is a human factor in the SC, the higher the costs are. If a player chooses the panic strategy, he pays higher penalties, and if he selects safe harbor, he pays more stock costs [24].

Risk preferences behavior in SC is included in mathematical models in [25, 26]. Risk preferences of the inventory management are included in the standard newsvendor model are shown in the [25]. In the [26] the authors developed a model with the risk-averse retailer and quantified the risk using an exponential utility function where they introduced the parameter risk tolerance factor. Their conclusion goes as follows: The optimal order quantity for the risk-averse retailer is always lower than that for a risk-neutral retailer. Moreover, the risk-averse retailer’s expected total cost is higher and cost variance is lower than those for the risk-neutral retailer.

In the [27] the authors simulated the functionality of the SC with risk-seeking and risk-averse participants using the Petri Nets. They have proven that risk-seeking participants have lower costs if they use the last period as a method for demand forecasting and risk-averse ones have lower costs if they use the moving average method.

3. THE BEER GAME

The game was created in the early sixties as part of research in industrial dynamics done by Jay Forrester. The event takes place at a table where the production and distribution of beer are being simulated [7]. Teams play a game with the objective to minimize the expenses of the overall supply chain. The winner is the team with the lowest expenses. Each of the participants is asked to invest $1 as a stake, where the winner takes the whole sum. Teams are divided into four sectors: Retailer, Wholesaler, Distributor, and Manufacturer. One or two persons manage each of the sectors. The game is usually played with chips and a deck of cards where the chips represent the cases of beer and a deck of card is the demand for those cases. A customer comes to a retailer to buy beer. The retailer meets customer needs by selling the beer from his inventory. Each unsatisfied demand remains for the following period as backlog. The retailer makes orders with the wholesaler who meets the demand from his inventory. The wholesaler places orders to a distributor, the distributor to a factory and the factory purchases raw materials from a supplier. It takes two weeks (two iteration simulations) for the product to be moved from one phase to the other. Holding costs are 0.50$ per case per week, and backorder costs are 1$ per case per week. At the start of the game, everyone is equal – each
participant has the inventory of 12 beer cases. Over the course of several weeks, players learn about the mechanisms of purchasing, how to deposit inventory etc. During that period, the demand is constant – 4 cases per week. During the first three weeks, the players can order only 4 cases per week, which is logical since the demand is also 4 cases. At the beginning of the fourth week, a player can order as much as he wants, and he is told that customer demand can vary. One of his tasks is to foresee the demand, according to the orders he makes, bearing in mind that the delivery period is two weeks. Thus, the player must foresee the demand in a two weeks’ time and place an order accordingly. The game lasts for 50 simulated weeks, but the desired effects are obvious far earlier.

Each player possesses valid local information (about his inventory, remaining orders, receiving amounts from his direct supplier and the amounts he has just delivered to the player he supplies), but he does not have global information. Only the retailer knows the demand of the last customer. The others can get this information only on the demand of the immediate customer. Communication between the participants is not allowed. Barriers to communication and lack of information lead to inadequate coordination in a supply chain.

4. THE EXPERIMENT

The participants in this experiment were students at the Faculty of Organizational Sciences as a part of their master studies Risk Management course. The students were asked to fill in the questionnaire [28] based on which they were divided into two groups: risk-seeking and risk-averse types. The game lasted for 23 iterations/weeks.

The results of the experiment are displayed in Table 1 and Table 2 as well as in the Figures 1, 2 and 3 where the following abbreviations are used: r – retailer, w – wholesaler, d – distributor and m – manufacturer.

Table 1. Risk-averse participants’ costs

<table>
<thead>
<tr>
<th>Costs</th>
<th>r</th>
<th>w</th>
<th>d</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backorder</td>
<td>174</td>
<td>136</td>
<td>104</td>
<td>21</td>
</tr>
<tr>
<td>Inventory</td>
<td>8</td>
<td>11</td>
<td>47.5</td>
<td>163</td>
</tr>
<tr>
<td>Total</td>
<td>182</td>
<td>147</td>
<td>152</td>
<td>184</td>
</tr>
</tbody>
</table>

Table 2. Risk-seeking participants’ costs

<table>
<thead>
<tr>
<th>Costs</th>
<th>r</th>
<th>w</th>
<th>d</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backorder</td>
<td>141</td>
<td>146</td>
<td>117</td>
<td>20</td>
</tr>
<tr>
<td>Inventory</td>
<td>35</td>
<td>179.5</td>
<td>216</td>
<td>441.5</td>
</tr>
<tr>
<td>Total</td>
<td>176</td>
<td>325.5</td>
<td>333</td>
<td>461.5</td>
</tr>
</tbody>
</table>

Figure 1 - Backorder Costs

If we presume that as in [13], risk-averse participants react more slowly to the changes of demand, that will correspond to the „panic“ type of behavior [20, 24]. This would mean that participants who are risk-averse would have higher backorder costs to risk-seeking participants. This has been confirmed in the case of retailers and manufacturers only (Figure 1).

Figure 2 - Inventory Costs

On the other hand, risk-seeking types react faster to changes in demand which corresponds with the „safe harbor“ behavior. This means that people who fall into this type of behavior are enlarging their order for the amount they owe, which leads them to higher inventory costs, which is confirmed with this experiment (Figure 2).

Figure 3 - Total Costs
It is possible to conclude that the total costs are higher with risk-seeking types (Figure 3), which has not been confirmed in the other research [13, 27], but the inventory costs are much higher when people are risk-averse, which is in accordance with the other research [13, 20, 24].

5. CONCLUSION

This paper confirms the hypothesis which says that participants in the supply chain can be divided into two groups: risk-seeking and risk-averse and that propensity to risk can affect the bullwhip effect. It is displayed that participants who are risk-averse have lower inventory costs to participants who are risk-seeking. It is also shown that risk-averse participants have higher backorder costs if they represent a manufacturer or a retailer. Risk-averse participants have lower total costs which could be a guideline when a supply chain is formed.

The main setback of this paper represents the small sample. Besides this, it is impossible to eliminate the presence of other personality traits of participants which could have a great deal of influence on the bullwhip effect. The sample was a group of students who participated in the experimental conditions and not real-life supply chain participants.

Further research can be done based on more participants in the chain and the focus could be on the propensity to risk in each position in the supply chain.

REMARK

This paper is translation in English of the paper published in the Magazine „Tehnika“, LXXII, 2017, № 3.

REFERENCES


**REZIME**

**ZAVISNOST EFEKTA BIČA OD SKLONOSTI KA RIZIKU UČESNIKA U LANCU SNABDEVANJA**

U ovom radu je ispitana uticaj sklonosti ka riziku kao osobine ličnosti učesnika u lancu snabdevanja na troškove skladištenja i troškove usled nezadovoljene tražnje. Učesnici su na osnovu rezultata testa podeljeni na sklene i nesklone riziku. Formirana su dva tima koja su simulirala pivsku igru. Pokazano je da postoje razlike u troškovima između ova dva tima.

**Ključne reči:** sklonost ka riziku, efekat biča, lanci snabdevanja
ENGINEERING CARD

28 percent of the European working force considers tapping into foreign labour markets. In the light of the current shortage of skilled workers, this group of professionally mobile and well educated employers needs to be addressed properly.

However, despite the rising need of skilled workers from foreign countries and despite the willingness of many Europeans to actually work in a different country, many barriers are in place impeding job changes within the EU. To overcome these barriers in the long run, the EU commission filed a bill at the end of the year 2011 to modernise the recognition of professional qualifications Directive 2005/36/EG. Through transparent, quick, and reliable mechanisms of recognizing professional qualifications, professional mobility is supposed to be enhanced and the collaboration between member states on the realization of a single EU market is supposed to be strengthened.

At the heart of the proposal is the introduction of a European professional card. This professional card, which will be issued by the native country, will attest professional qualifications and the right to pursue a profession EU-wide. According to the commission, the introduction of the professional card will also lower processing times and costs for the recognition of professional qualifications. Moving professionals such as four million engineers will benefit from these developments. At this time, the European Parliament and the Council of Ministers deliberate on the EU commission’s bill to modernize the professional qualifications Directive.

In 2010, the Association of German Engineers (VDI) took initiative and invited representatives of the German Federal Chamber of Engineers and of all other Engineering Associations to jointly work on the realization of a European Professional Card for engineers.

The Association of German Engineers (VDI), together with the European Federation of National Engineering Associations (FEANI), succeeded with its pioneering work: As the first European professional group, engineers can use a voluntary professional card: the engineerING card. All 32 FEANI member associations are convinced by the advantages of this card.

The engineerING card serves as a proof of professional qualifications, thus facilitating application processes, in the entire European Union.

The representatives of the Union of Engineers and Technicians of Serbia, a national member of FEANI from Serbia, in 2013 signed Cooperation agreement for the issuing of the Engineering card in Serbia.

As a result of this Agreement every Serbian engineering professional that holds an engineering degree from an officially recognised Serbia tertiary institution can apply for the engineerING card. An expert committee looks into certificates and, if desired, relevant professional experience, as well as further educational trainings and then decides whether these qualifications can be recognized. All results are compiled in a central database. All information is provided on an excerpt from the register of a cardholder and is available to the card owner at all times on the respective website. Card owners can prove all their engineering qualifications with the excerpt from the register in applications. Likewise, businesses benefit from the increased transparency and comparability amongst candidates for a vacant position.
TECHNICS

QUALITY- IMS,
STANDARDIZATION
AND METROLOGY

Kvalitet – IMS, standardizacija i metrologija, Quality
IMS, Standardization and Metrology


EDITOR-IN-CHEF

Zoran Pendić, M.Sc, United Association of Serbia for
Quality, Belgrade

EDITORIAL COUNCIL

Prof. Vidosav Majstorović, D.Sc, University of
Belgrade, Faculty of Mechanical Engineering,
Belgrade

Prof. Dragutin Stanivuković, D.Sc, University of
Novi Sad, Faculty of Technical Sciences, Novi Sad

Prof. Srdan Tanković, D.Sc, University of Belgrade
School of Electrical Engineering, Belgrade

Prof. dr Ljiljana Vujotić, University of Belgrade,
School of Medicine, Belgrade

Prof. dr Valentina Marininković, D.Sc, University of
Belgrade, Faculty of Pharmacy, Belgrade

Nebojša Veljković, D.Sc. Ministry of Environmental
Protection, Environmental Protection Agency,
Belgrade

Milovan Luković, “Sloboda”, Čačak

Bojana Jakovljević, Bs.C, Telekom Srbija ad,
Belgrade

Prof. Dejan Kostić, Ph.D. KTH Royal Institute of
Technology School of Information and
Communication Technology, Stockholm, Sweden

Prof. Ton van der Wiele, D.Sc, Erasmus Research
Institute of Management, University Rotterdam,
Netherlands

EDITORIAL OFFICE: Union of Engineers and Technicians
of Serbia, 11000 Belgrade, Kneza Miša 7a/I, Tel. +381/11/
32 35 891, Fax +381/11/ 32 30 067
Industrially Contaminated Areas in Serbia as a Potential Public Health Threat to the Exposed Population

BRANISLAVA I. MATIĆ, Institute of Public Health of Serbia, „Dr Milan Jovanović Batut“, Belgrade

Original scientific paper UDC: 504.5:628.4.045

UROŠ D. RAKIĆ, Institute of Public Health of Serbia, „Dr Milan Jovanović Batut“, Belgrade DOI: 10.5937/tehnika1703441M

SNEŽANA M. DEJANOVIĆ, Institute of Public Health of Serbia, „Dr Milan Jovanović Batut“, Belgrade

VERICA S. JOVANOVIĆ, Institute of Public Health of Serbia, „Dr Milan Jovanović Batut“, Belgrade

MARILA R. JEVTIĆ, University of Novi Sad, Faculty of Medicine, Novi Sad

NELA Ž. DONOVIĆ, University of Kragujevac, Faculty of Medical Sciences, Department of Hygiene and Ecology, Kragujevac

Mining and mineral processing is still a vital source of income in Serbia, due to mineral abundance in copper, lead, zinc, antimony. Copper mining and metal-processing are located in the east: Bor, Veliki Krivelj, Cерovo, Majdanpek. Abandoned sites from antimony mining and processing and secondary lead smelter are at the western border: Zajača, Krupanj, Stolice. Coal mining and power plants are surrounding Belgrade: Obrenovac (2 power plants), Grabovac (plant ash landfill), Kolubara and Kostolac. Main objective is to focus on potential public health hazards from industrial contamination in Serbia. Key public health issue is presence of As and Cd in ambient air PM10 close to industrially contaminated sites due to the fact that ores have high naturally occurring contents of heavy metals and metalloids. Data originate from Serbian Environmental Protection Agency, Mining and Metallurgy Institute Bor, Belgrade Institute of Public Health, as part of continuous measurement of air quality within State network of automatic stations. Concentration of As in PM10 are extremely above the limit value in Bor and Lazarevac, with Cd values slightly increased in Bor. Serbia lacks the legal framework for continuous and institutionalized follow-up of population groups vulnerable to hazardous environmental exposure, although measured concentration indicate urgent need for such activities.

Key words: industrially contaminated sites, public health, As, Cd, Pb

1. INTRODUCTION

The rapid growth of urbanization and industrialization, where the progressive expansion of the suburbs into closer proximity with industrial plants in certain areas, has led to the problem of air pollution [1]. As we know, human health is intimately connected to the surrounding environment. This is particularly the case of the health of people living in contaminated si-

Author’s address: Branislava Matić, Institute of Public Health of Serbia, “Dr Milan Jovanović Batut“, Belgrade, Dr Subotića starijeg 5
e-mail: damjanko98@yahoo.com
Paper received: 08.05.2017.
Paper accepted: 17.05.2017.
food chain, resulting or being able to result in human health impacts” [4]. Given this definition, an area affected by a single chemical contamination of a single environmental matrix (e.g., the soil contamination caused by a given pesticide) and a large area with soil, water, air, and food chain contamination by multiple chemicals (e.g., the contamination caused by longterm emissions of a petrochemical complex) can be both considered contaminated sites [2].

According to data collected by the European Environment Agency, Europe has hundreds of thousands of contaminated sites [5], many of them resulting from earlier industrialization and poor environmental management. Past and present activities can cause dispersion and accumulation of countless contaminants, mainly chemicals, to an extent that might affect human health by compromising air quality, altering soil functions, entering the food chain, and polluting groundwater and surface water. Typically, but not always, these stressors occur in localized areas near the point sources and affect local communities [6]. This issue is particularly challenging for several reasons: the hazards are very heterogeneous; reliable exposure data are sparse; most associations between industrially contaminated sites and health refer to conditions with multifactorial etiology; and the underlying social, economic and occupational framework is complex. Furthermore, industrially contaminated sites are often located close to urban areas, making exposure patterns more complex [4].

Mining and mineral processing has played a vital part in the history and economy of the Western Balkans. Being abundant with mineral resources, such as copper, chromite, lead, zinc, and antimony, it counts as some of the largest deposits in Europe. Naturally, environmental hotspots in Serbia are, principally, associated with mining, processing and smelting of mentioned metal ores [7-10]. Copper mines and its tailings dam are located close to the eastern country boundaries, in Bor, Veliki Krivelj, Cerovo and Majdanpek, while sites contaminated with antimony mining and processing and secondary lead smelter are located at the extreme western spot, bordering Bosnia and Herzegovina: Zajača, Krupanj, Stolice. Coal mining and power plants are surrounding Belgrade: Obrenovac (2 power plants), Grabovac (plant ash landfill), Kolubara and Kostolac (Figure 1). Coal was, and is will be most important source of primary energy in Serbia, regarding both the amounts and energy, regardless to any correction of existing reserves estimations. Largest consumers of coal in Serbia are thermal power plants, with consumption of 96% of total annual production, while remaining part is dried and screened for the industry and open market. Lignite power plants are providing some 60% of total electricity production, while in winter periods, during which demand for electricity is largest, this contribution increases up to 75% [10].

The key aim of this paper is to give an insight into the scope of industrial contamination in Serbia, together with types of its sources, focusing on heavy metals and metalloids present in the environment, primarily ambient air.

**Figure 1 - Location of ICS in Serbia** [9]

Specific aim of this paper is to focus on the presence of heavy metals and metalloids in ambient air PM10 particles measured by automatic measuring stations positioned in the vicinity of industrial pollution sources, as atmospheric particles with elevated metals may have serious impact on human health [11, 12]. Heavy metals are defined as metallic elements that have a relatively high density compared to water [13]. With the assumption that heaviness and toxicity are inter-related, heavy metals also include metalloids, such as arsenic, that are able to induce toxicity at low level of exposure [14].

In recent years, there has been an increasing ecological and global public health concern associated with environmental contamination by these metals. Environmental pollution is very prominent in point source areas such as mining, foundries and smelters, and other metal-based industrial operations [13].

2. METHODS AND DATA COLLECTION

In order to present the scope and type of environmental pollution caused by the defined industrial sources, we used the data on regular monitoring implemented by the Serbian Environmental Protection Agency (SEPA), Institute for Mining and metal-
processing in Bor, Belgrade Institute of Public Health. Continuous measurement of air quality is done through the State network of automatic stations established by the SEPA, part of which are located in Bor, Grabovac, Lazarevac, Veliki Crljeni, and Zajača [15-17]. Key coordinating stakeholder for these measurements is SEPA, while, Belgrade IPH is a legal holder of particular measuring stations within the network [15]. Results of air quality monitoring in Bor are also interpreted in the Annual Report on Air Quality Monitoring produced by the National Institute of Public Health, due to its potential grave public health effect on the exposed population [18,19].

Reasons for choosing the above listed CSs are as follows: Town of Bor suffers complex industrially originating pollution, as both mining for copper ore and smelting is present either in the town, or close to it; Lazarevac (a suburb of the capital city of Belgrade) and Veliki Crljeni are both part of the same coal mining and coal burning power plant complex (lignite mining in Lazarevac, lignite burning power plant in Veliki Crljeni), while Zajača, being a part of inter-connected mining-smelting antimony complex in western Serbia, now hosts a toxic shale landfill of approximately 60,000 tons of weight [20].

The tiniest of all numbered ICSs by its geographic coverage, Zajača village is located on the territory of the town Loznica, with 225 households and 600 inhabitants (Figure 2). It is an example of a typical mining habitat, whose development followed the on-site dynamics of mining-smelting activities. According to the terrain geographical conditions, there were no topographic capacities for the habitat to spread, as it was located in a narrow valley stuck in between steep hills, with River Štira running through it, on its flow towards River Drina (natural border with Bosnia & Herzegovina). Actually, this was the natural reason disabling better circulation of wind masses, on a terrain suffering continuous ambient air pollution from two defined sources, such as the battery recycling plant and shale landfill, nested on a hill above the village. Hence, population of Zajača has been exposed to long-term contamination generating from the mining-smelting activity, of multiple chemical exposure kind (simultaneous exposure of one population group to contaminants generating from multiple sources) [20,21]. Since 2013, SEPA has located its automatic measuring station close to the battery recycling plant in Zajača, with constant, on-line appearance of the data for monitored parameters (Figure 3).

Grabovac, a village close to Obrenovac (coal-fired power plant) hosts a large coal ash landfill, which is the reason why SEPA installed its automatic measuring station there. Besides monitoring PM$_{10}$ values, this station measures contents of heavy metals, as well.

![Figure 2 - Location of Zajača mining-smelting complex [17]](image)

3. RESULTS

In order to present key public health threats for the population exposed to emissions from diffuse and point sources of industrial contamination, we chose the presence of heavy metals in particulate matter (PM10), due to the fact that both coal and copper ore in Serbia, have substantial naturally occurring contents of heavy metals and metalloids, such as cadmium and arsenic. Results are given for the years 2012 and 2013, as due to the centennial flooding in 2014 all measurement activities were disrupted (Table 1).

<table>
<thead>
<tr>
<th>Geography/cal location</th>
<th>Sources of pollution</th>
<th>2012 (ng/m$^3$)</th>
<th>2013 (ng/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cd</td>
<td>As</td>
<td>Cd</td>
</tr>
<tr>
<td>Bor</td>
<td>Cu mines and smelting</td>
<td>5.07</td>
<td>97.0</td>
</tr>
<tr>
<td>Grabovac</td>
<td>Coal firing ash landfill</td>
<td>0.44</td>
<td>8.7</td>
</tr>
<tr>
<td>Lazarevac</td>
<td>Lignite mines</td>
<td>0.52</td>
<td>17.9</td>
</tr>
<tr>
<td>Veliki Crljeni</td>
<td>Lignite mines &amp; power plant</td>
<td>0.1</td>
<td>6.4</td>
</tr>
<tr>
<td>Zajača</td>
<td>Abandoned Sb mine, Pb smelter</td>
<td>27.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Limit value (ng/m$^3$)</td>
<td>5.0</td>
<td>6.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Limit values for PM$_{10}$ contents of arsenic, as defined by the legal act, have been breached at all sampling points, located in the vicinity of industrial hot spots, with the copper mining-smelting complex in Bor leads as the most contaminated urban setting among them. Mean annual value for arsenic in Bor for the year 2012 is more than 16 time higher than the limit value, while for 2013 mean concentration is some ten-fold the given limit value [Uredba].

On the other hand, abandoned antimony mining and smelting complex in Zajača, although out of work, is still being depicted as a pollution source, due to the fact that a slag landfill, rich in As,Cd,Sb is situated on
a hilltop, just above the village occupied by its dwellers. Fact that after the closure of the antimony mine, a battery recycling plant was installed on-site, justifies the occurence of cadmium, primarily in ambient air particles. The only automatic measuring station of the SEPA on that location belongs to the National Network of automatic stations (AMSs), and was installed on-site in 2013, with specific focus on lead concentration in PM10 particles, parallel to initial human biomonitoring activities, with measuring lead in blood of exposed children (Figure 3) [15, 17, 20].

4. DISCUSSION

4.1. Arsenic in copper ore

Contents of heavy metals and arsenic in PM10 is usually high in the vicinity of industrial sources of pollution. High concentration of arsenic in copper ore that is exploited in Bor and surrounding mines is an often proven quantitative fact, as mentioned in earlier findings [21, 22, 23]. The point that arsenic in ambient air PM10 is continuously monitored in Bor, and that its concentration is yet not dropping down, without any thorough investigation into the health impacts of exposure of domicile population, is a worrying sign. Until now, the only case-study providing data on human biomonitoring in population exposed to arsenic, was a study aiming to provide evidence of cardiological effects of naturally occuring arsenic in groundwater in Zrenjanin, Serbia [24], with no such a study provided for the exposed population of Bor.

4.2. Arsenic in coal and coal ash

Coal combustion is one of the main anthropogenic sources of toxic trace element emissions to the environment. Various species and oxidation states of the trace elements released from power stations may determine their ultimate environmental fate and health impacts [25]. Coal ash is the waste that is left after coal is combusted (burned). It includes fly ash (fine powdery particles that are carried up the smoke stack and captured by pollution control devices) as well as coarser materials that fall to the bottom of the furnace. Most coal ash comes from coal-fired electric power plants [26]. When speaking of coal ash in Serbia, it is estimated that, during last decade, in Central Serbia, some 5.5 million tons of ash were separated, i.e. 62.5 tons per square kilometer or 0.77 tons per inhabitant, listing Serbia at the top, when coal ash production is the case, proportionally speaking [27]. Three of our sites with mean annual arsenic values above the limits given by the Decree are linked to coal mining, coal firing and deposition of waste produce of combustion (coal ash deposition site). In Grabovac, hosting coal ash disposal site for coal brought from Kolubara lignite mines, arsenic in PM10 mean annual value was increased for 45% of the limit value (6.0 ng/m³ vs. 8.7 ng/m³), while in 2013 it was more tan a two-fold limit value (12.9 ng/m³). Fact is that directly next to the disposal site there are no dwellings, but some 3000 of inhabitants at the village Grabovac live in the vicinity, within the 3 km diameter from it [27].

4.3. Antimony mining and lead battery recycling

The village of Zajača is situated in western Serbian Macva County, with a population of barely 600, some 140 kilometers from the capital, Belgrade. It comprises solely of metallurgy industrial complex surrounded with residential homes of the employees. The battery recycling facility is located in the village’s center in a steep valley of the Jadar River, being geographically isolated.

Prior to opening of the battery recycling plant, this ICS hosted an antimony mining-smelting complex, for decades. Arsenic was used in production of refined antimony, in the smelting process, becoming a
continuous element of the toxic slag deposition, situated at the top of the hill above Zajača [20, 28]. Arsenic and cadmium were monitored at the ICS of Zajača (Mačva District) only in 2012, in our study. Mean annual concentration for cadmium at the site is a five-fold the value given by the regulation (5.0 ng/m³) [29]. On the other hand, mean value for arsenic is just slightly elevated. This numbers could be explained by the fact that battery recycling waste was deposited at the deposition site more recently, while use of arsenic in antimony smelting has a far more historic background [28].

Lead in ambient air PM10 was monitored in connection with the lead production process at the battery recycling plant in Zajača, by the AMS installed by the SEPA [17]. As Figure 3 shows, Pb concentration oscillates due to production discontinuity, with peaks above the limit value of 0.5 µg/m³ during months March - May 2013, a break in production in the period June to October 2013, when production of metallic lead was shortly revived, until it finally stopped in November, due to factory’s closure.

Similar to this monitoring, a study was performed in Zajača in the period 1998-1999, when a significant correlation was reached between daily production of lead and Pb in PM10, measured next to the plant [30].

5. CONCLUSIONS

Although Republic of Serbia is a signatory of Parma Declaration in 2010 at the 5th Ministerial Conference for Environment and Health in Parma, Italy, adopted CEHAP (Children's Environment and Health Action Plan) as its national legal act, both focusing on environmental health challenges for children's health and human biomonitoring as a tool for its monitoring [33], no further steps were made since in implementation of these international binding obligations [31, 32].

Republic of Serbia, with its health sector in a leading role, needs to organize and adopt human biomonitoring as a key public health measure, especially for the vulnerable population groups living close to recognized ICSs. Reason for such an urgent need in implementing this kind of preventive measures is in the nature of most highly toxic substances to which these vulnerable groups are being exposed, to be absorbed easily by pregnant mothers, and transferred transplacental to the offspring, making severe organic damage to the unborn child.

REMARK

This paper was published in the Magazine „Tehnika“, LXXII, 2017, No 1.

REFERENCES


[29] Decree on the air quality monitoring conditions and requested air quality (“Official Gazette of the RS”, No. 11/2010; 63/2013)


INDUSTRIJSKI KONTAMINIRANI LOkaliteti u Srbiji kao potencijalna javno-zdravstvena pretnja za izloženu populaciju

Rudarstvo i prerada metala je još uvek vitalni izvor prihoda u Srbiji, zahvaljujući značajnim mineralnim nalazištima bakra, olova, cinka, antimona. Rudnici i topionica bakra locirani su na istoku zemlje: Bor, Veliki Krivelj, Cerovo, Majdanpek. Napušteni rudarsko-topionički kompleks antimona i fabrika za reciklažu akumulatora blizu su zapadne državne granice: Zajača, Krupanj, Stolice. Rudnici uglja i termoelektrane, okružuju Beograd: Obrenovac (2 termoelektrane), Grabovac (pepelište TENT), Kolubara i Kostolac. Glavni cilj rada je fokusirati se na potencijalne javno-zdravstvene pretnje poreklom od industrijskih zagađenja u Srbiji. Usled činjenice da su teški metali (Pb, Cd) i metaloidi (As) prirodno prisutni u rudama i površinskom sloju tla, njihovo prisustvo u PM$_{10}$ frakciji ambientnog vazduha, predstavlja značajan javno-zdravstveni problem, u blizini industrijski kontaminiranih lokaliteta. Izvor podataka su Agencija za životnu sredinu Srbije, Institut za rudarstvo i metalurgiju Bor, Gradski zavod za javno zdravlje Beograd, koji čine integralni deo sistema za kontinuirani monitoring kvaliteta vazduha u sklopu Državne mreže automatskih mernih stanica. Koncentracije arsena u PM10 česticama ekstremno su iznad dozvoljenih vrednosti u Boru i Lazarevcu, dok koncentracije kadmiijuma u Boru nisu značajnije povećane.

U Srbiji nije usvojena regulativa kojom se omogućava kontinuirano i institucionalizovano praćenje štetnih uticaja iz životne sredine nan a njima izložene osetljive populacione grupe, iako su jasno definisane visoke koncentracije polutanata jasni pokazatelj da takve mere treba što pre preduzeti.

Ključne reči: industrijski kontaminirani lokaliteti; javno zdravlje, As, Cd, Pb
Physical Security of Water/Wastewater Infrastructure – Planning and Equipment Selection

DRAGOMIR V. MARKOVIĆ, Energoprojekt Entel a.d, New Belgrade

RADOJICA M. GRAOVAC, Energoprojekt Entel a.d, New Belgrade

Review paper

UDC: 628.144-759
628.21-759

DOI: 10.5937/tehnika1704612M

This paper discuss why drinking water supply systems and sewerage systems need to be physically protected, what threats should be considered, and points to the necessity of a good knowledge of technological processes in these systems and the possession of information about the essential characteristics of the equipment for the technical security (different physical protective barriers, different alarm systems, access control equipment, intruder detection equipment, optical cables, audio/video equipment, etc.) of the mentioned systems. The approach based on the application of ready-made solutions offered on the market, without prior analysis of the system and the adoption of security plans, is wrong. This paper suggests how to work in order to achieve an optimal solution to the technical protection of the mentioned systems.

Key words: water, wastewater, infrastructure, security, equipment, planning

1. INTRODUCTION

Water / wastewater systems provide life-important community services to people 24 h a day, 365(6) days a year, and these services are essential to quality and safety of life of the population of each country. Water resources, water / wastewater treatment, transport and distribution facilities are among the critical infrastructures of each country. The rapid development in the field of legislation and practice of water / wastewater infrastructure protection came after the terrorist attack in New York, September 11, 2001. In Serbia, the activities related to water quality protection are developed and world practice is followed.

On the other hand, there are no approaches or definitions regarding the protection of infrastructure, including facilities for water and wastewater, except for general quotes in the Emergency Situations Law, are not sufficiently defined. However, with regard to the EU Critical Infrastructure Directive (Directive 2008/114 / EC), the adoption of the Critical Infrastructure Protection Law can be expected. Together with the Law on Private Security and the standard SRPS

A.I2.002: 2015: "Social Security - Private Security Services - Requirements and Instructions for Conformity Assessment”, this will open approaches for adoption of by-laws and instructions for public water management and communal Companies how to plan physical and technical security [1]. In Serbia, the largest number of water infrastructure facilities is without technical protection equipment, while a smaller number of facilities are equipped with technical protection devices according to the technical solutions of the manufacturer or solutions have been applied as for the protection of general public facilities, mostly by using CCTV cameras. For only a small number of facilities, an elaborate of security analysis with the proposal of the equipment, had been made first, and on that basis equipment for technical security have been selected, contracted and installed. In this paper general approaches in evaluation of the security risk for water infrastructure facilities, with the emphasis on the sources, wells and pumping plants, planning guidelines, overview of the characteristics and possibilities of technical protection equipment, based on the global practice and concrete experiences from some of the countries of the Middle East is described.

2. ANALYSIS OF RISK AND THREATS FOR WATER INFRASTRUCTURE

The mostly reported mistakes in the operation of water infrastructure are grouped as: loss of water
pressure in most of the water supply system, loss of water supply over a longer time interval as a result of the termination of treatment or distribution of water, catastrophic use or theft of chemicals for water treatment which has a direct impact on public health, deliberate contamination of water or contamination as a result of an incident on the water supply system resulting in an impact on public health, longer periods of absence of treatment and collection of wastewater, use of wastewater at collection sites as a means of attacking other water infrastructure facilities.

The risks and threats that may manifest on the operation of water infrastructure facilities are the following:

- Risks due to natural disasters: earthquakes, floods, strong winds, risk of worker disease (pandemic), risk of retirement of employees who led the production process. Infrastructure errors.

- Threats to the water management system can be those that come from outside (sabotage, vandalism), those generated within a water management organization (employees dissatisfied with their status, failure to comply with technical protection procedures) and threats that arise as a result of incidents of uncontrolled access to facilities or frustrated activists. These threats can be further categorized as threats of low, medium and high levels.

- It is necessary for each water management facility to undertake risk and threat assessments and on the basis of this, to make a plan of technical protection of the facility, or to plan the appropriate technical means. When assessing risks, it is necessary to identify categories of persons who would perform unauthorized access to a water facility in order to stop the processing and distribution of water or contaminate water, or make a malicious act. The category of people potentially threatening critical infrastructure is defined as: vandals, criminals, saboteurs (or terrorists) and insiders.

It is necessary to create a threat matrix as well as an assessment table for the application of certain technical means for each plant / structure / object of the water infrastructure facilities.

3. BASIC ROLE OF PHYSICAL PROTECTION EQUIPMENT

Physical protection systems should ensure the effective implementation of the following measures [2-6]:

- Deterrence from access to the infrastructure are measures through providing lighting facilities, prominent and fully visible video surveillance cameras, fully visible infrastructure facilities with no visible obstacles, visible presence of staff, etc.

- Detection, under detection, is assumed security measures intended to detect the presence of a person accessing an object without the permission and knowledge of operational personnel of water facilities.

- Delay, are measures to set physical barriers so that the intruder (or intruders) that have already entered the zone of the protected object and which is covered by the detection measures slows down on the path of advancement towards the ultimate goal-protected object for the purpose of coming of the physical protection team.

- Response, means the response of the physical protection team in terms of stopping an intruder whose presence is detected in the protected zone of water objects. Figure 1 gives an illustrative overview of the above measures or activities, and Table 1 shows the calculation of individual time intervals.

![Figure 1 - Criminal activities during access to a water facility](image-url)
4. SELECTION OF PHYSICAL PROTECTION EQUIPMENT

An example of physical equipment selection for water wells and pumping stations is shown below [2-9]. Security measures in terms of delay of access to the facility are:

At the level of the fence or perimeter of the plant:
- Delay - It is possible to plan: a perimeter detection system; electronic control of passage through the gate (this is also a system of delay); illumination of perimeter; illumination of entrance gates.
- Detection - It is possible to plan: a perimeter detection system; electronic control of passage through the gate; the protection of steel grids of all gaps or passages at the perimeter of the plant.

Table 1. Calculation of activity extensions for unauthorized access to a water facility

<table>
<thead>
<tr>
<th>Activity</th>
<th>Task Time (minutes)</th>
<th>Cumulative Time (minutes)</th>
<th>Adversary Task description</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td></td>
<td>Climb over fence</td>
<td>1st Alarm</td>
</tr>
<tr>
<td>2</td>
<td>0.3</td>
<td>0.4</td>
<td>Run 80 м</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.8</td>
<td>1.2</td>
<td>Force door</td>
<td>2nd Alarm</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>1.6</td>
<td>Walk 45 м</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.2</td>
<td>1.8</td>
<td>Cut door lock</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.1</td>
<td>1.9</td>
<td>Walk to asset</td>
<td>Response Force Arrives</td>
</tr>
<tr>
<td>7</td>
<td>0.2</td>
<td>2.1</td>
<td>Disable asset</td>
<td>Stop Adversary</td>
</tr>
<tr>
<td>8</td>
<td>0.9</td>
<td>3.0</td>
<td>Escape</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.0</td>
<td>Total Time</td>
<td></td>
</tr>
</tbody>
</table>

a) Within plant, between the fence and the protected object
- Delay - It is possible to plan: the next fence-wall; reinforced fence-wall; special foundation for fence-wall against digging; massive obstacles to protect access to the facility; padlocks at the entrance gates of the next fence; protection of feeder substations with an additional fence-network; protection of diesel aggregates with additional fence-network; locks and padlocks on the door of a chemical store; shafts with reinforcement and locking system.

- Detection - It is possible to plan: a detection system on another fence; electronic control of entry into the warehouse of chemicals; electronic control of passage through the gate (this is also a system of delay); electronic detection of unlocking of padlock on shaft covers; arranging the terrain between the enclosure and the protected object so that the access to the object is completely visible or makes it impossible to access the protected object and that the intruder is not noticed.

b) At the level of a protected object
- Delay - It is possible to plan: installation of protective covers over the source / well and pipes that come out of the source / well; installation of protective cages around the entire source / well and pipes that come out of the source and are located nearby; protection of the covers of all valves; the installation of doors where it is not possible to remove hinges or to remove the door and which are secured by a lock; equipping the locks with the key of all the front doors; installation of explosion-proof exterior doors; setting obstacles for vehicles at the entrance gates; installation of bullet-proof windows on the windows; placing a protective lattice on blinds or louvers; setting pads on all openings for exit to the roof; protection of internal transformers, diesel generators and electric distribution plants by placing it in cages with padlock-key; access under the key for the chemical line.

- Detection - It is possible to plan: a detection system for access to main valves; an external door fitted with open-closed indication; electronic access for the front door; double entry doors equipped with a door-entry system (so-called door trap); glass breakers detectors on windows; detectors of persons moving within the space; additional gratings on the louver and grill openings with detection of passage; protection of the stairs for the roof with an obstacle and with the detection of passage through the stairs; locked access to an
external line for the addition of chemicals with the detection of access to the line; locked access to an internal line for the addition of chemicals with the detection of access to the line.

c) Water quality control system

It is possible to plan the detection of unauthorized access to the system for “on-line” water quality detection.

d) Video surveillance with fixed type CCTV cameras

It is possible for these cameras to be set up for video surveillance; of all external doorways; all covers and shutters on the shafts and valves. Selecting the number and quality of the camera as well as determining the position can be made to allow: Observation (the size of the display of the person or vehicle being watched should be 5% of the height of the monitor): detection: (the size of the display of the person or vehicle being viewed to be 10% of the monitor height): Recognition: (the size of the view of the person or vehicle being watched should be 50% of the monitor height): identification (the size of the display of the person or vehicle being viewed to be 120% of the supervisory monitor height), envisage local recording and remote alarming.

e) CCTV surveillance with motorized rotating cameras and motorized zoom capability (optical zoom)

It is possible to install these cameras for surveillance of: the main gate with identification of vehicle registration plates; main entrance doors; complete video surveillance of the perimeter of the facility; interior spaces, with the application of the above principles in the selection and positioning of cameras as well as local recording and remote alarming.

f) Electrical equipment supply and cabling methods

It is possible to plan: that all electric cabinets shall be equipped with key locks or padlocks; that the power supply of the equipment is so-called uninterruptible power supply (UPS); that the complete electrical installation will be carried out in pipes or below the plaster with spare routes for the technical protection system.

g) Equipment for operating wells and pumps - SCADA

It is possible to ensure that PLC cabinets are equipped with: key lock or padlock; special switches with contacts indicating that the door of the cabinet is open by force; that the complete wiring from the PLC to all encoders and measuring instruments on the well or to the pump is carried out in pipes so as to prevent direct access to the cables.

5. CONCLUSION

Certainly the preparation of the elaborate with the analysis of security risks and threats is an important step in the planning of physical protection for water / wastewater infrastructure. After that, it is possible to see the optimal solution and the choice of technical protection equipment and in order to achieve the goal of reducing these risks and threats. The author's intention was to present the basic approaches to the selection of this equipment, which can certainly help to review this issue by those who make decisions on investments for the construction or rebuilding of water infrastructure facilities.

REMARK

This paper was published in the Magazine „Tehnika“, LXXII, 2017, No 4.

REFERENCES


[9] Different security projects for water plants in the Middle East, Energoprojekt Entel.
REZIME

TEHNIČKA ZAŠTITA INFRASTRUKTURE ZA VODU/OTPADNU VODU – PLANIRANJE I IZBOR OPREME

U ovom radu se razmatra zašto bi vodovodni i kanalizacijski sistemi trebalo da budu tehnički zaštićeni, koje pretnje treba uzeti u obzir, i ukazuje na neophodnost dobrog poznavanja tehnoloških procesa u ovim sistemima i posedovanja informacija o bitnim karakteristikama opreme za tehničko obezbeđenje (različite fizičke zaštitne barijere, različiti alarmni sistemi, oprema za kontrolu pristupa, oprema za detekciju uljea, optički kablovi, audio / video oprema itd.) pomenutih sistema. Pristup zasnovan na primeni gotovih rešenja koja se nude na tržištu, bez prethodne analize sistema i donošenja bezbednosnih planova, je pogrešan. Ovaj rad sugeriše na koji način treba da se radi da bi se došlo do optimalnog rešenja tehničke zaštite posmatranih sistema.

Ključne reči: voda, otpadna voda, infrastruktura, zaštita, oprema, planiranje
CO-PUBLISHERS

SERBIAN CHAMBER OF ENGINEERS, BELGRADE

- FACULTY OF CIVIL ENGINEERING, BELGRADE
- FACULTY OF TECHNICAL SCIENCES, NOVI SAD
- FACULTY OF TRANSPORT AND TRAFFIC ENGINEERING, BELGRADE
- SCHOOL OF ELECTRICAL ENGINEERING, BELGRADE
- FACULTY OF MECHANICAL ENGINEERING, BELGRADE
- FACULTY OF MINING AND GEOLOGY, BELGRADE
- FACULTY OF TECHNOLOGY AND METALLURGY, BELGRADE
- FACULTY OF ORGANIZATIONAL SCIENCES, BELGRADE
- TECHNICAL FACULTY, BOR
- TECHNICAL FACULTY, ČAČAK
- IPIN – INSTITUTE FOR APPLIED GEOLOGY AND HYDRO ENGINEERING, BIJEĐINA

SPONSORS

- PUBLIC ENTERPRISE FOR ELECTRIC ENERGY TRANSMISSION SYSTEM CONTROL “ELEKTROMREZA SRBIJE”, BELGRADE
- PUBLIC ENTERPRISE ELECTRIC POWER INDUSTRY OF SERBIA, BELGRADE
- TERMAL POWER PLANTS “NIKOLA TESLA”, OBRENOVAC
- MAŠINOPROJEKT - COPRING, BELGRADE
- PE HIDRO POWER PLANTS „DRINSKO LIMSKE“, BAJINA BAŠTA
- PUBLIC UTILITY COMPANY “BELGRADE WATERWORKS AND SEWERAGE”, BELGRADE
- TRAFFIC INSTITUTE "CIP", BELGRADE
- INSTITUTE "MIHAJLO PUPIN", BELGRADE
- INSTITUTE "VINČA" BELGRADE
- BUSSINESS COMPANY THERMAL POWER PLANTS AND MINES, “KOSTOLAC”, KOSTOLAC
- PE “KOLUBARA” MINING BASSIN LAZAREVAC
SCADA DCS SISTEMI
INSTITUTA “MIHAJLO PUPIN”

Pouzdanost
Robustnost
Trajanje

Naše znanje traje...

View SCADA sistemiza:
- Upravljanje u prenosnim i distributivnim mrežama električne i toplotne energije
- Upravljanje tehničkim sistemima
- Sistemi upravljanja u komunalnim delatnostima
- Sistemi obaveštavanja i uzbunjivanja
- Upravljanje industrijskim procesima

DCS sistemi za:
- hidroelektranе
- termoelektrane
- na kopovima uglja

Volgina 15, 11060 Beograd, Srbija  Telefon: +381 11 6771 017
automatika@pupin.rs  www.pupin.rs  www.view4.rs  www.atlas-max.rs