

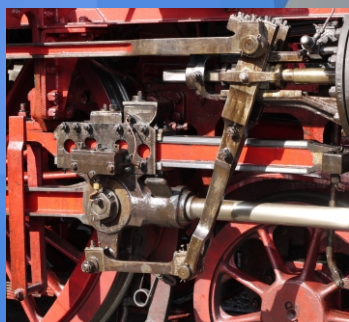
INTERNATIONAL SCIENTIFIC JOURNAL

INDUSTRY 4.0

ISSN (PRINT) 2534-8582

ISSN (WEB) 2534-997X

YEAR VIII ISSUE 5/2023



①



②



③



④

PUBLISHED BY
SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING
“INDUSTRY 4.0”, BULGARIA

INTERNATIONAL SCIENTIFIC JOURNAL

INDUSTRY 4.0

YEAR VIII, ISSUE 5 / 2023
ISSN (PRINT) 2534-8582, ISSN (WEB) 2534-997X

PUBLISHER

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING "INDUSTRY 4.0"

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90,
tel./fax (+359 2) 986 22 40,
office@stumejournals.com
WWW.STUMEJOURNALS.COM

EDITOR IN CHIEF

Prof. D.Sc. Georgi Popov, DHC, Technical University of Sofia, BG

EDITORIAL BOARD

Members:

Acad. Igor Bychkov, RU
Cor. member Alexey Beliy, BY
Cor. member Svetozar Margenov, BG
Prof. Alexander Afanasyev, RU
Prof. Alexander Guts, RU
Prof. Andrzej Golabczak, PL
Prof. Bobek Shuklev, MK
Prof. Boris Gordon, EE
Prof. Branko Sirok, SI
Prof. Claudio Melchiorri, IT
Prof. Cveta Martinovska, MK
Prof. Dale Dzemydiene, LT
Prof. Dimitar Yonchev, BG
Prof. Dimitrios Vlachos, GR
Prof. Dobre Runchev, NM
Prof. Dragan Perakovic, HR
Prof. Galina Nikolcheva, BG
Prof. Galina Zhavoronkova, UA
Prof. Gerard Lyons, IE
Dr. Giovanni Pappaletta, IT
Prof. Henrik Carlsen, DK
Prof. Idilia Bachkova, BG
Prof. Idit Avrahami, IL
Prof. Inocentiu Maniu, RO
Prof. Iurii Bazhal, UA
Prof. Jürgen Köbler, DE
Prof. Jiri Maryska, CZ
Prof. Katia Vutova, BG
Prof. Lappalainen Kauko, FI
Dr. Liviu Jalba, RO

Prof. Luigi del Re, AT
Prof. Majid Zamani, DE
Dipl.-Kfm. Michael Grethler, DE
Prof. Michael Valasek, CZ
Prof. Milija Suknovic, RS
Prof. Miodrag Dashic, RS
Prof. Mohammed Taleb Obaidat, JO
Prof. Murat Alanyali, TR
Prof. Nadežda Jankelová, SK
Prof. Nafisa Yusupova, RU
Prof. Nina Bijedic, BA
Prof. Ninoslav Marina, MK
Prof. Olga Zaborovskaia, RU
Prof. Pavel Kovach, RS
Prof. Petar Kolev, BG
Prof. Peter Korondi, HU
Prof. Peter Sincak, SK
Prof. Petra Bittrich, DE
Prof. Predrag Dasic, RS
Prof. Radu Dogaru, RO
Prof. Raul Turmanidze, GE
Prof. René Beigang, DE
Prof. Rozeta Miho, AL
Prof. Salloom A. Al-Jaboori, JO
Prof. Seniye Ümit Oktay Firat, TR
Prof. Sreten Savicevic, ME
Prof. Sveto Svetkovski, MK
Prof. Tomislav Šarić, HR
Prof. Vasile Cartofeanu, MD
Prof. Vjaceslavs Bobrovs, LV
Prof. Vladyslav Alieksiev, UA

TECHNICAL EDITORS:

M. Sc. eng. Radoslav Daskalov, Bulgaria
M. Sc. eng. Oleg Mihailov, Bulgaria

CONTENTS

TECHNOLOGICAL BASIS OF “INDUSTRY 4.0”

Mathematical modeling in psychology

Soloveva Olga 149

DOMINANT TECHNOLOGIES IN “INDUSTRY 4.0”

Quality evaluation of the welded joints made by robotic welding

Jakub Brezina 152

Testing of Innovative Composite Wall/Ceiling Panel

Ivan Palijan, Davor Grandić, Ivana Štimac Grandić, Paulina Krolo, Lazar lukačević, Antonio Bakran 155

Evaluation of the Erythrocyte Aggregation Index in Women With Preeclampsia by the Usage of the Microfluidic Device And Specially Developed Rheological Software

Anika Alexandrova, Velichka Strijkova, Emilia Abadjieva, Svetla Todinova, Ina Giosheva, Ariana Langari, Tihomir Tiankov..... 159

Absorbable Dressings Manufactured of Tropocollagen with Nanodiamonds

Anna Karczemska, Dariusz Witkowski, Radomir Magiera, Radosław Wach, Bożena Rokita, Alicja Olejnik, Zuzanna Nowak, Laura Ciosek, Łukasz Piwowarski, Andrzej Argalski, Katarzyna Mitura, Stanisław Mitura 164

Anomalies in the Earth rotation and Syzygies in Perigee

Leonid Zotov 166

BUSINESS & “INDUSTRY 4.0”

Web-based Business Process Management System

Milena Karova, Iliyan Boychev 169

Application of Innovation in the Event Tourism in Azerbaijan

Rana Sultanova, Hikmat Hasanov 173

Bulgaria's long journey from consumer to producer of energy equipment

Boyan Asparuhov 175

SOCIETY & “INDUSTRY 4.0”

Intellectual factor of the new economy: Formation features

Olga Avdeychik, Vasily Struk, Alexander Antonov, Alexander Lesun, Wan Xuemin 178

Influence of environmental factors of long-term operation and effectiveness of SMFC-based biosensors for heavy metal polluted waters

Rosen Ivanov, Petia Genova, Polina Velichkova 182

Personal noise exposure level and the impact on the employee's performance in the automotive industry

Teodora Topcheva, Marija Hadzi-Nikolova, Dejan Mirakovski, Simeon Simoeonov, Zlatko Petreski 186

State and characteristics of the vehicle fleet of Montenegro with special reference to fuel consumption and electric vehicles

Marko Lučić 190

Trend Analysis of Using of Green Energies in Georgia until 2040

Raul Turmanidze, Giorgi Popkhadze 193

Mathematical modeling in psychology

Soloveva Olga M.

Candidate of Physical and Mathematical Sciences, Candidate of Legal Sciences, lecturer.

St. Petersburg State University of Telecommunications named after Prof. M.A.Bonch-Bruевич, St. Petersburg College of

Telecommunications named after E. T. Krenkel.

Saint Petersburg, Russia.

Corresponding author: olgams02@mail.ru

Abstract: *The development and use of mathematical models is of great importance not only in the research field, but also in the practical field. Mathematical research in psychology is based on the construction of an image of the studied object or group of objects, fixing the basic properties and relationships. The complexity lies in the heterogeneous nature of individuals, in the diversity of their behavioral characteristics, interests, and features of social behavior. Statistical models can be divided into separate groups; models that consider processes that affect individual behavior at the micro level, that is, at the level of low-level human thinking processes; meso-level models; macro-level models that consider and predict general trends in the behavior of people in a group, for example, in a crowd.*

KEYWORDS: MATHEMATICAL MODELING, PSYCHOLOGY, ANALYSIS, ALGORITHMS, TYPES OF MODELS, MODELING LEVELS, CROWD BEHAVIOR.

Introduction. Prerequisites

Currently, more and more widespread use in various scientific and practical fields. Including in psychological research received mathematical modeling. Mathematical modeling is convenient to use to analyze the functioning, study properties, predict the further behavior of a system or object. Modeling in the most general form can be defined as the study of an object, in which not the object itself is studied, but its theoretically constructed model, which is in accordance with the object or system under study, reflects certain properties of the object or system, is able to replace the object under study in the study, provides information about the modeled object.

The development and use of mathematical models is of great importance not only in the research field, but also in the practical field. According to the author, their application is of particular relevance at the intersection of scientific and practical fields. For example, developed, implemented in software and used in practice models and algorithms for interrogation, the development and use of various interrogation tactics depending on the situation [2,3].

Basic provisions

The basis of mathematical research is the construction of an image of the object or group of objects under study, fixing its main properties and relationships. Mathematical models are based on the results of a physical study of the behavioral processes of the objects under study, determining the conditions for regulating behavior and activities based on observation, experiment and other methods of psychological analysis, as well as on the results of statistical studies, in which again mathematical models can be used. As a result, the mechanism of the studied phenomenon is formulated in the form of a model, then the functioning of the model is observed and compared with the behavior recorded in the experiment. After the analysis of the obtained data, the mathematical model is refined and refined. Thus, the mathematical methods of data processing correspond to certain studies preceding the modeling stage.

There are models of various types that are used in the area of knowledge under consideration. I will give a number of examples. Stochastic models include probabilistic methods, development of game theory, dynamic programming. These methods also analyze the process in dynamics, however, if the state of the system before the experiment (or interaction) and after is important, the dynamics of the process of change itself is not studied in this case. Therefore, an urgent task in this direction is the creation of formal mathematical models of human behavior depending on his subjective experience, personal characteristics and motivation.

Synergistic models that are sensitive to initial conditions and have a large scatter in the possible final data of the system, as well as the randomness of the original system. Disorder may precede the

appearance of a new structure, so mathematical solutions that describe self-organizing structures will help come to an understanding of the psychological mechanisms of self-organization.

When constructing mathematical models in the field of psychology, in addition to a rigidly deterministic algorithm and a probabilistic algorithm, the so-called heuristic algorithm, the value of which was previously underestimated, is of great importance.

Mathematical models can be used as a means of implementing a systematic approach that provides opportunities not only for fixing in a quantitative form the relationships in the systems under consideration, but also for use in their in-depth qualitative analysis, as well as for predicting properties. In each system under consideration, it is necessary to single out the structures that correspond to the objectives of the study, the main properties of the structure, the main factors that affect the structure, and also use the methods relevant to them.

The use of mathematical methods in psychology is carried out in various cases, for example, in the statistical processing of observational results, in the choice of equations that describe the relationship between the variables studied in the experiment, and in the creation and testing of mathematical models.

Mathematical models are used to study a wide range of mental processes: perception, problem solving, learning, etc. The range of questions is rapidly expanding. The study of methods of mathematical modeling in psychology will make it possible to more clearly and unambiguously determine the processes of perception, memory, thinking, creativity, play, learning, etc.

However, here it is necessary to point out the problem of solving the following methodological issue - the question of the relationship between the object and the model in psychology. That is, what can be a modeled object here. The specificity of mental phenomena lies in the fact that they are various forms of subjective reflection of objects and phenomena of objective reality: the main function of the mental is the regulation of behavior and activity.

The very nature of the psyche is such that in the process of studying it, we are faced with the need to consider relations of different orders. All these relations are realized in a single process, the dynamics of which depends on the specific conditions of its course of the mental process.

In addition, a feature of the area of application of mathematical research is that the area under study is not a closed system that exists in isolation from other systems of the material world (physical, biological, social, and so on). This is the peculiarity of the application of mathematical modeling methods.

When it comes to mathematical models in psychology, one must bear in mind that in such models only one particular aspect of the consideration of those phenomena, processes, etc., which are studied by psychology, is taken.

It is possible to distinguish models of different levels, depending on the field of application and the object of study.

According to the author, it is possible to single out statistical models based on the statistical processing of the data obtained into a separate group. The results of using these models can be used in other types of modeling.

Further, models of the so-called micro-level are considered, which describe and predict the processes of the flow of human intellectual activity at a low-level analysis of the processes of human thinking, that is, at the level of neural connections.

Next comes the so-called meso-level, when the behavior of a person and his behavior is studied depending on one or another frame of reference - the system in which the given object of study is located, and on external initial and boundary conditions.

And the next level is the macro level. Related models study and predict the behavior of a group of people. It seems to the author that at present the models of this group are the most interesting for real practical application. For example, let's pay attention to the analytical model of crowd behavior [1]. There are social forms of behavior in which the manifestations of the will, desires and needs of an individual are very limited by the influence of other people in the group. The peculiarity of the behavior of the crowd lies in the specifics of the socio-psychological phenomena that determine the uniformity of the behavior of the individuals of this group as a whole. At the same time, a certain problem is created by the heterogeneity of the nature of individuals, the diversity of their behavioral characteristics, interests, and features of social behavior. The dominant mechanism for the formation of the crowd and the development of its specific qualities is the growing mutually directed emotional infection. A crowd is an unstructured accumulation of people, devoid of a clearly perceived commonality of goals, but mutually connected by a similarity of emotional state and a common object of attention. Growing in numbers, infected by the general mood and interest, people gradually turn into a discordant, unorganized cluster, or crowd. The crowd does not reason or think. Individuals, not even experiencing psychic pressure from other individuals, but only perceiving the behavior of these other individuals, are infected by their behavior, obey and follow it. The main stages in the formation of the crowd are the formation of the core of the crowd, the process of circulation, the identification of a common object of attention, the activation of individuals through arousal. Let's stop at the last step. Stimulation of the activation of individuals through exciting impulses occurs most often as a result of the leadership of the leader. This can induce the individuals who make up the crowd to take concrete action. The accumulation of individuals in the crowd instinctively submits to the authority of the leader. The leader in the crowd can appear as a result of a spontaneous choice, and often - and controls the crowd consciously in a predetermined direction. In this way, it is possible to direct or redirect the behavior of the crowd by injecting a suitable leader into it. Or neutralize the crowd by introducing several leaders with different orientations of emotional impact.

So the crowd does not reason or think. The crowd does not tolerate any disputes or contradictions. The judgments of the "average" individual from the crowd are always imposed and never the result of a comprehensive discussion. In the crowd there is such a socio-psychological phenomenon as emotional resonance. Psychological "infection" determines the direction of the special properties of the crowd. People from the crowd infect others and become infected from them. Crowd members, when exchanging emotional charges, gradually inflame the general mood. The feeling inherent in the crowd spreads and intensifies quickly through suggestion and "infection". Whatever the feelings of the crowd, good or bad, their characteristic feature is one-sidedness. The crowd lacks a critical attitude towards itself.

In the temperamental sphere, the psychological characteristics of the crowd are manifested in activity and diffuseness. Of course, disobedience of individual individuals (the so-called "negatively" oriented subjects) is also possible.

One of the important issues is the prediction of crowd behavior in real conditions. It is not possible to carry out full-scale tests. Therefore, there is a need for a theoretical study and prediction of the properties of crowd behavior. Mathematical modeling with further computer implementation can help to solve the problem. In the model under consideration, Individuals in a crowd can be considered as some local "volumes", initially differently oriented, for correct prediction of the behavior of the crowd, it is necessary to take into account the micro-characteristics of these local objects, which are subjected to a directed impact with the aim of their further favorable reorientation. The organization of carriers of "emotional charges" from individual (chaotic) distribution to the hierarchical organization of processes, including local instabilities, is an illustration of the internal connections of what is happening in the crowd.

Organization from individual (chaotic) distribution to hierarchical organization of processes - an illustration of the internal connections of what is happening in the crowd, in a single object of a discrete structure.

Based on the foregoing, let's consider an analytical model of crowd behavior. Analytical relations are proposed to predict the behavior of such real macroscopic objects as a crowd. Ratios are developed based on the available real data on the behavior of the crowd in various conditions. The methods of mathematical analysis of crowd behavior should allow, on the basis of a unified approach, to predict the behavior of an object with any internal structure, the behavior of any type of crowd, reflect its scale and characteristic properties in the process of evolution of behavior. In this regard, the following tasks were solved. Development of a scenario for a multi-level process of behavior of an object of study with an arbitrary and changing in the process internal structure under arbitrary influence. Formulation of the principles of building a model. Creation of mathematical methods in order to obtain the necessary tools for modeling multi-level processes.

The model is based on the following principles.

In the human community there is a homogeneous "local" volume corresponding to the individual, in which the processes that cause his reaction with subsequent action are possible.

"Local" volume can be considered as a mathematical point in a continuous continuum. Changing the behavior of the crowd, its emotional intensity is a multi-level process that takes place in the conditions of constant interaction of local objects with the external environment.

A two-level model of the property formation process is chosen: applied stresses generate microstresses that cause acts of emotional "transfer" and micro-actions that turn into changes on a macroscopic scale.

The driving force in a continuum with a structure is the effective stress field σ^*_{ik} , determined through the applied σ_{ik} , oriented p_{ik} (p_{ik} are associated with the macroscopic impact of the crowd) and undirected λ_{ik} stresses as a consequence of the orientation effect: $\sigma^*_{ik} = \sigma_{ik} - p_{ik} + \lambda_{ik}$.

At the macroscale level, the results of crowd behavior in various modes of exposure that simulate real conditions are concentrated [1].

Reorientation of the original objects of the hit system using the rotation tensor. The properties of a tensor are a particular set of its components and the relationships between them. the rotation tensor is a tensor of the second rank and its components appear as a matrix. With a defeat rotation tensor, an orthogonal triplet of vectors. The first vector in this trio of violations when applied to an unmanaged rotation operator, it can be changed as the axis of rotation.

The reorientation of local objects of the system can be described using the rotation tensor, which is associated with an orthogonal triple of vectors. The first vector in this triple can be considered as the axis of rotation. The connection between the old position of these vectors in space and the new one is determined using the Euler relations.

The rotation tensor P , which is not equal to E (the identity matrix), can be uniquely represented as

$$P = m \cos \alpha + (-m \sin \alpha) \cos \alpha + m \sin \alpha \sin \alpha$$

Here α is the angle of rotation, and the unit vector m defines a straight line in space, called the axis of rotation; the positive direction of the rotation angle α is consistent with the direction m in accordance with the accepted orientation of space.

A matrix in an orthonormal basis has the form

$$\begin{pmatrix} \cos \alpha & -\sin \alpha & 0 \\ \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

For K^* we take the so-called effective temperature of emotional intensity, which depends on an external driving force, and not only on the initial emotional intensity and the emotional intensity of differently oriented individuals. The effect of the effective "stress field" σ^*ik depends on the orientation of individual local subjects, that is, their local bases. The elementary act of the result of the impact is implemented according to the "shift + turn" scheme. Translational and rotary modes of the direction of reorientation of structural objects are organically interconnected in the concept. The effective "temperature" of emotional intensity (K^*) is determined as follows:

$$dK^* = dK - K_0 \text{ Dik} \sigma_{ik}/q_0$$

Here, K is the "temperature" of emotional intensity, K_0 is the "temperature" of emotional "equilibrium", Dik is the distortion tensor as a consequence of the impact of the applied "forces", q_0 is the reaction effect associated with the internal reaction and the degree of "uncertainty" of the elements of the structure. σ_{ik} is a characteristic of the stress field, a_{ik} is a set of coordinates characterizing the orientation of local subjects. In general, values are characterized by some conventional units. But with further details of the model, for example, the temperature of emotional intensity can be associated with the physical characteristics of individual components of the crowd

A change in the phase state F (the degree of readiness for specific physical actions as a consequence of the impact of the general emotional "heat" of the crowd) of the emotional state of the subject, depending on its own orientation and external influence, as well as on the total normalized phase, the emotional "temperatures" of the beginning of the reaction K_s and the maximum intensity $K_{\max}$ (that is, the transition to specific physical actions) the increase in effective emotional tension is described by the ratio:

$$dF = (H(1-F_{\max})H(dK^*))dK^*/(K_{\max}-K_s),$$

where $H(x)$ is the Heaviside function [1]

The general phase state of the crowd is determined by integrating the phase state of individual subjects according to a set of coordinates characterizing the orientation of separate local bases - individual subjects.

If several leaders are "embedded" in the crowd, the crowd structure can be considered as "grainy". In modeling, this means that a "grain" with some orientation cannot cover volumes related to another "grain".

Conclusions

According to the author, mathematical modeling in the field of psychology is promising and of great practical importance. Mathematical modeling is not only a means of implementing a systematic approach, which makes it possible not to fix relationships in a quantitative form in the systems under consideration, but also a means of in-depth qualitative analysis, as well as a means of predicting properties. The results of mathematical modeling in the area under consideration are of particular interest and effectiveness in their software implementation.

Literature

1. Soloveva Olga Mikhailovna. Analytical model of crowd behavior. Mathematical modeling proceedings. 07-10 Decemder, 2022, Bulgaria. Published: Scientific technical union of mechanical engineering "Industry-4.0", 45-47.
2. Соловьева О.М. Специфика алгоритмизации следственного осмотра. Судебная реформа и эффективность деятельности органов суда, прокуратуры и следствия: Тезисы научно-практической конференции. – СПб: Изд-во СПб юридического института Генеральной Прокуратуры РФ, 2001, с. 164-165
3. Вандер М.Б., Соловьева О.М. Возможности алгоритмизации следственных действий. Труды Санкт-Петербургского Юридического института Генеральной Прокуратуры Российской Федерации. № 1. – СПб, 1999, с.72-77.

Quality evaluation of the welded joints made by robotic welding

Jakub Brezina

Technical University of Košice, Faculty of Mechanical Engineering, Košice, Slovakia

jakub.brezina@tuke.sk

Abstract: This paper presents the results of an investigation aimed at evaluating the geometric and material characteristics of welds, such as dimensions, shape, pores, cracks and other imperfections. An automated weld inspection workstation has been designed which includes suitable sensors, equipment and software solutions for data acquisition and processing. Tests were performed on selected welds to determine the material superheat and weld quality.

Keywords: ROBOTIC WELDING, WORKPLACE DESIGN, INSPECTION OF WELDS

1. Introduction

Increasingly more and more manufacturers are directing their investments into the introduction of modern industrial automation and information systems in order to maintain competitiveness, to be able to respond to changing market requirements or simply to work efficiently. These trends did not bypass the field of welding either. As is well known, welding innovation has been created and advanced from the first hand-worked specialty to the advanced systemic specialized science. Examining and simulating intelligent activity and capacity of welder's operation is critical for improvement of mechanical welding. Therefore, simulation and understanding a welder's activities by some clever machines, e.g., industrial welding robot is one of the most vigorously researched issues in the advanced welding technology. Welding as one of the methods of joining materials that is used in many industries is very often represented among the energy industry, construction, engineering industry and, last but not least, the automotive industry. It is the automotive industry that includes a wide range of welding methods. In addition to the resistance welding, electric arc welding with an electrode in the protective atmosphere is also widespread. These welding methods can be performed by welding robots. Robotic workplaces and lines are an integral part of the car production process and their components. With increasing demands for efficiency and welding quality, robotic welding becomes preferred method of connecting materials such as low carbon, micro-alloyed and stainless steel as well as aluminum and alloy. Robotic welding process allows higher accuracy, higher speed and repeatability with high quality of production, leading to cost reduction. The weld control is an important and integral part of the process in mass production of welds. Weld control area is currently a great emphasis. Experimental part of paper is aimed at two parts. First is the workplace design for automated weld control. Second part is macro weld control first part to rest in the designed workplace for automated control of the frame of the rear seat frame construction of the rear seat which is seen in Figure 1 and 2. The operator of one control cell checks 150 welds on one set. This means that operator checks 1950 welds per hour, which is an enormous amount and, of course, in this case the NOK welds are overlooked. For this reason, we decided to deal with camera weld control with a camera placed on a robot. [1-8].

2. Robotic systems

Robotic systems often include various feedback mechanisms to assist the control system in adjusting welding parameters without operator intervention to accommodate unforeseen changes in weld joint geometry or location. These changes include variables such as manufacturing tolerances beyond specifications, etc. Some robotic systems use real-time digital images of the weld pool to alter welding parameters such as current, feed rate, and wire feed to avoid poor quality.[4] Cartesian robots equipped with joints are used for welding. In addition to X, Y, Z movements, they allow wrist movement and welding torch rotation. Articulated robots equipped with a wrist are used for shaped welds. A robotic welding system can work with higher repeatability than a manual welder and thus we achieve higher performance. However, robots require regular recalibration or reprogramming. [5]

It is important to correctly set the welding parameters, such as welding speed and intensity, to ensure the desired quality of the welds in robotic welding. Most robotic welding systems also enable automatic quality control of welds and their documentation. When designing a robotic welding workplace, accuracy and repeatability, the number of axes, reliability, welding fixtures, programming, weld monitoring systems, and maintenance are taken into account. Accuracy and repeatability are specified on an application basis. Continuous production line interruptions can be minimized by properly designing the robotic system. Proper welding fixtures will ensure that distortion after welding is reduced to a minimum. Formed welds can require complex programming involving multiple axes. Complex welding applications require weld positioners for part handling and part placement.

With the development of advanced technologies, robotic welding is becoming more and more advanced. Robotic welding workplaces not only have stable and high welding quality, but also can improve work efficiency.

The paper presents the results of work focused on:

- Workplace design for automated inspection of welds of the rear seat frame structure
- Macroscopic inspection of welds

3. Technical solution of the workplace

A workplace was designed for the automated inspection of the welds of the rear seat frame structure, Fig1.

The operator of one control cell checks 150 welds on one set. That means it will check 1950 welds per hour, which is an enormous amount. In this case, defective welds are overlooked. For this reason, a camera inspection of welds with a camera placed on the robot was proposed. The technical solution is based on the requirement to check 150 welds in a maximum time of 85 seconds, approximately 0.5 s/weld.

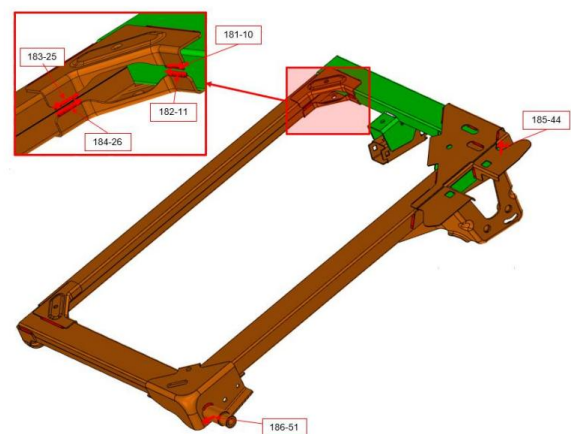


Fig. 1 Detail of the part with marked welds for visual inspection

Two ABB IRB1600 robots were designed so that all welds could be checked without the need to rotate the parts. The parts are inserted into preparations for precise fastening of the parts. Fig. 2 shows the ground plan of the proposed workplace with dimensions. Also shown is a dimensional solution that meets not only the standard, which specifies the minimum distances of machines from the walls of the workplace, but also the dimensions that are limited by the customer.

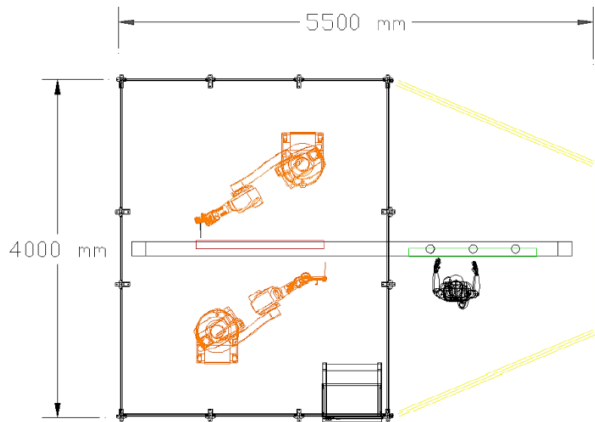


Fig. 2 Ground plan of the robotic workplace

The operator of the workplace with camera control and the actual loading and unloading is performed by a worker. Since the automated workplace is dependent on the loading and unloading of controlled pieces, it is necessary to combine it with the necessary human work. Camera systems are installed on the robot arm. Fig.3 shows a 3D visualization and ground plan of the workplace.

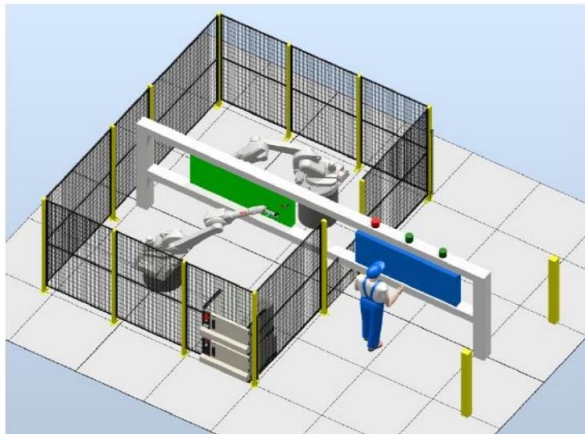


Fig. 3 Visualization and ground plan of the workplace

Fig.4 shows a weld that meets all the customer's requirements for weld quality. In Fig.5, an unsatisfactory weld is evaluated by a camera system, which identified insufficient length, porosity and deformations outside the values required by the customer.

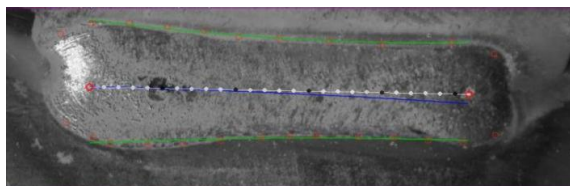


Fig. 4 A satisfactory weld with the right parameters

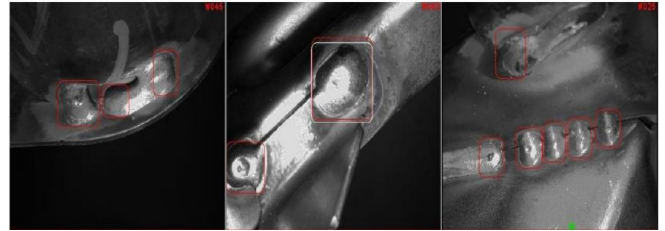


Fig. 5 Detected weld defects

It can be seen in Fig. 6 that the camera system can also capture spatter in the area of the thread, which is a frequent reason for the impassability of screws and nuts.

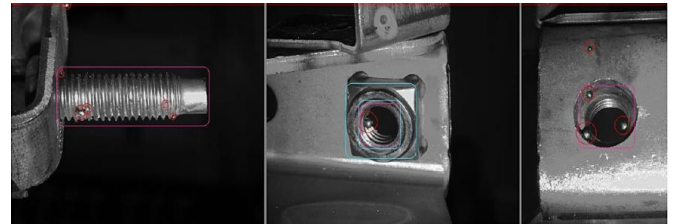


Fig. 6 Camera inspection of threads

The inspection of the welds with a camera system is followed by a macroscopic analysis of the welds. Fig.7 shows a macro image of a welded joint that is slightly damaged by corrosion with a visible HAZ (heat affected zone). The height of the weld is 3.2 mm and the penetration in both material thicknesses is satisfactory for the quality of the weld joint. Fig. 8 shows another of the well-made welds with satisfactory parameters, correct pre-welding in accordance with the standard and customer requirements.

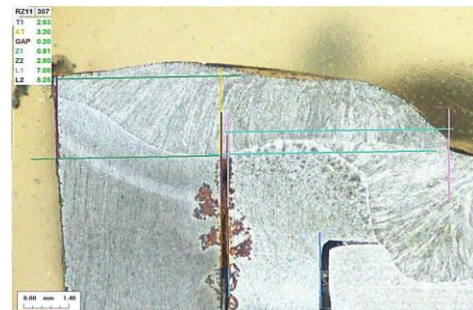


Fig. 7 Macroscopic analysis of a compliant weld

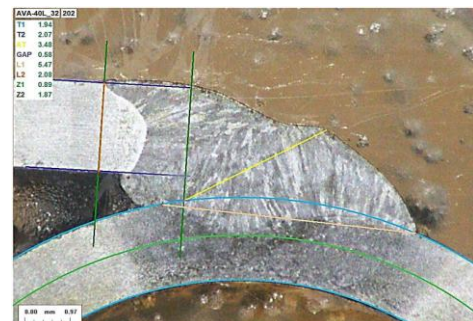


Fig. 8 Macroscopic analysis of a compliant weld

4. Conclusions

The weld inspection process is an important part of the manufacturing process. Visual evaluation of welds is provided by operators who evaluate welds based on experience. The human factor, the high number of inspected welds and the speed of the process lead to incorrect evaluation or overlooking some of the errors that are undesirable from the point of view of the quality of the welded joint. The use of cameras for automatic evaluation of welds appears to be one of the solutions to this problem. Inspection system with the help of cameras that take photos and compare them with the set parameters of the weld. The entire system can be "taught" and thus adapted to the specifics of individual welds. After the end of the production of the given product, the robotic workplace can be adapted to a new type of product, which significantly reduces costs. The error rate of the robotic workplace when the welding control parameters are correctly set is practically zero. The very parameters for the evaluation of the weld are compared with the metallographic evaluation of each inspected weld before starting the workplace and, if necessary, they are fine-tuned. A workplace prepared and debugged in this way can be put into continuous operation. Defective welds are noted and repaired in the next process step. The implementation of an automated welding inspection workplace would bring a number of advantages for the company, such as the reliability of the inspection, the quality of production and the elimination of complaints. The design of a robotic inspection workplace can be the basis for further research and development in the field of welding joint inspection automation.

Acknowledgments: This contribution is the result of the project implementation: "Innovative approaches to the restoration of functional surfaces by laser weld overlaying" (APVV-20-0303), supported by the Slovak Research and Development Agency and supported by the Ministry of Education of Slovakia Foundation under grant projects VEGA No. 1/0497/20 "Application of progressive technologies in restoration of functional surfaces of products" and KEGA 036TUKE-4/2021 "Distance form of education in the field of engineering technologies using modern IT tools for foreign students".

5. References

1. NEE, Andrew Y C. Handbook of manufacturing engineering and technology. New York: Springer, 2014. ISBN 9781447146711.
2. Kuss, A., Diaz P., J.R., Hollmann, R., Dietz, T., Haegle, M. Man- ufacturing knowledge for industrial robot systems: Review and synthesis of model architecture. 12th IEEE Conference on Automation Science and Engineering 2016.
3. P. Maropoulos, Z. Yao, H. Bradley, K. Paramor
An integrated design and planning environment for welding: Part 1: Product modelling
Journal of Materials Processing Technology, 107 (1) (2000), pp. 3-8
4. Reeves RE (1988) Expert system technology—an avenue to an intelligent weld process control system. Weld J 67(6):33–41
5. Zha X. F., Du H., 'Generation and simulation of robot trajectories in a virtual CAD-based off-line programming environment' Int. J. Advd Mfg Technol. 17 (8) (2001): 610–624.
6. Reeves RE (1988) Expert system technology—an avenue to an intelligent weld process control system. Weld J 67(6):33–41
7. G. Vosniakos, A. Chronopoulos
Industrial robot path planning in a constraint-based computer-aided design and kinematic analysis environment. in: Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 223 (5) (2009), pp. 523-533
8. . Pan, J. Polden, N. Larkin, S. Van Duin, J. Norrish
Recent progress on programming methods for industrial robots
Robotics and Computer- Integrated Manufacturing, 28 (2) (2012), pp. 87-94

Testing of Innovative Composite Wall/Ceiling Panel

Ivan Palijan¹, Davor Grandić², Ivana Štimac Grandić², Paulina Krolo², Lazar lukačević², Antonio Bakran²

Palijan d.o.o., Zagreb, Croatia ¹

University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia²

ipalijan@palijan.hr

Abstract: The company Tehnoplast profili d.o.o. from Zagreb, in cooperation with the Faculty of Civil Engineering University of Rijeka and the company Palijan d.o.o. from Zagreb, is conducting a scientific research project dealing with buildings of near-zero energy produced in an industrial way. The construction system of these buildings consists of ceiling and wall panels, which are integrated into the building's construction system. The structural wall/ceiling panels consist of external gypsum-fibreboard, thin-walled steel structure in the panel core and polymer foam in between. To enable the practical application of the innovative wall/ceiling panel system as a load-bearing structural element, the design model based on the comprehensive experimental and numerical investigation must be defined. In the research presented in this paper the performance of the composite wall/ceiling panels and the steel core wall/ceiling structure during out-of-plane to failure tests is shown.

Keywords: COMPOSITE WALL/CEILING PANEL, GYPSUM-FIBREBOARD, FOAM FILL, THIN-WALLED STEEL STRUCTURE

1. Introduction

Recently, the concept of green building has become very popular worldwide [1]. The use of recycled materials and/or highly thermal efficient materials in construction is one of the main objectives for green building requirements. Composite wall panels including profiled steel components and various types of infill have been manufactured and tested around the world [2-4]. Some popular infill materials in energy efficient buildings are foamed concrete, rubberized foamed concrete, or polyurethane foam [2,4]. Composite panels with a core of polyurethane foam and facing materials such as gypsum, wood-based materials, or some composites have been used as structural elements in building construction for many years. In the last decade, the number of relevant studies has increased dramatically compared to the previous similar periods, indicating that the attention and focus of researchers have been directed towards the importance of the structural performance of foam-filled composite panels [4].

The company Tehnoplast profili d.o.o. from Zagreb, in cooperation with the Faculty of Civil Engineering University of Rijeka and the company Palijan d.o.o. from Zagreb, is conducting a scientific research project entitled: Prefabricated buildings of near-zero energy produced in an industrial way (grant no. KK.01.2.1.02.0046.) financed by the European Regional Development Fund.

Since 2010, Tehnoplast profili d.o.o. has been engaged in the development of elements for prefabricated buildings with near-zero energy. It has developed the concept of innovative elements of prefabricated buildings with near-zero energy through its own and joint development research activities. It has also developed the concept of technology for industrial production of prefabricated houses with near-zero energy. The construction system of these buildings consists of ceiling and wall panels, which are integrated into the building's construction system with connecting elements. To enable the practical application of the innovative wall/ceiling panel system as a load-bearing structural element of the building, a design model for the resistance must be defined. Therefore, extensive experimental researches are required, including testing of the materials of the panel components, testing of the connections and fasteners, and testing of the panels themselves. In recent years, extensive experimental studies of the materials of panel components have been carried out [5-10], as well as tests of connections between materials (polymer foam/gypsum-fibreboard; polymer foam/steel) [11-14] and bracket connection in steels C-profiles [15]. This paper presents the performance of (i) the composite wall/ceiling panels and (ii) the core wall/ceiling structure consisting only of thin-walled steel C-profiles during out-of-plane to failure tests.

2. Basic concept

The structural wall/ceiling panels consist of external fire-resistant gypsum-fibreboard (claddings), open thin-walled steel C-

profiles in the panel core (steel core structure), and polymer foam filling the space between the gypsum fibreboard and the steel core structure (Figure 1).

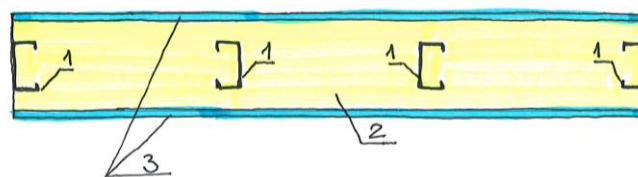


Fig. 1 Cross-section of the structural wall/ceiling panel (1- open thin-walled steel C-profiles in the panel core, 2- polymer foam filling, 3-external gypsum-fibreboard)

In this innovative composite panel, the three different materials are combined into one structural element, each contributing to the panel's favorable properties. An experimental study of composite panels under out-of-plane loading have been designed to test the hypothesis about the favorable effect of polymer foam fillings on the composite panels' mechanical resistance.

3. Materials and specimens

Laboratory tests have been performed on two groups of specimens: composite panels and the steel core structure itself.

The steel core structure (specimens B0; Table 1) is an 2D-truss system made of cold-formed, thin-walled C-profiles. Four vertical elements (C1, C2, C3 and C4) with a length of 2000 mm are connected to three horizontally placed elements (C5, C6 and C7) with a length of 1800 mm. The dimensions of the steel core structure specimen are 1800 × 2000 × 89 mm (Figure 2).

Table 1: Testing specimens.

Specimen	Specimen notation	Total number of specimens
Steel core structure	B0-x	4
Composite panel	B-x	6

NOTE: x indicates number of specimen (1-4 for steel core structure and 1-6 for composite panel)

The specimens of composite panels (specimens B; Table 1) consist of a steel core structure, cladding of gypsum-fibreboard and infill of polymer foam (Figure 1). The dimensions of the composite panel specimen are 1800 × 2000 × 160 mm.

The cross sectional and material properties of C-profiles in the core steel structure of the panes are all the same. C-profiles are made of cold formed steel S 550 GD ($f_y = 550 \text{ N/mm}^2$, $f_u = 570 \text{ N/mm}^2$), according to HRN EN 10346 [16] and protected from corrosion by hot galvanizing, 275g/m² (Z275). Polymer foam has a nominal density of 45 kg/m³.

The panel cladding consists of two 12.5 mm thick fermacell® gypsum-fiberboards attached to each side of the core.

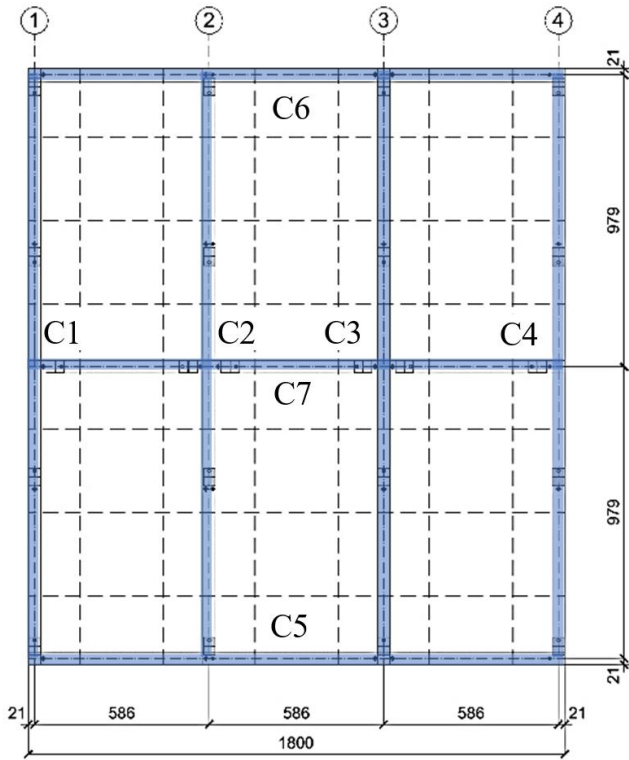


Fig. 2 Geometry of steel core structure (measures in mm)

Figures 3 and 4 show the test specimens B0-1 and B-1 before testing.

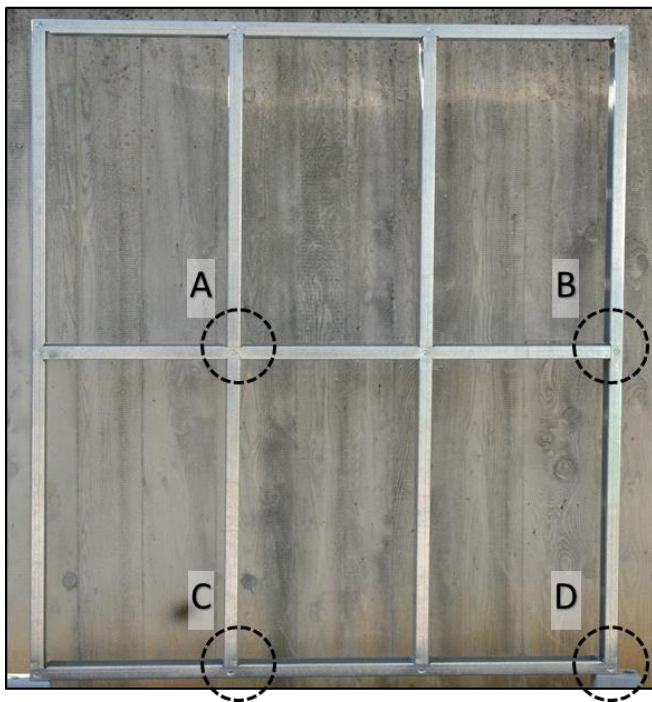


Fig. 3 Specimen B0-1 prior testing



Fig. 4 Specimen B-1 prior testing

4. Test and measurement equipment setup

The specimen testing equipment consists of a loading system and supports (Figure 5).

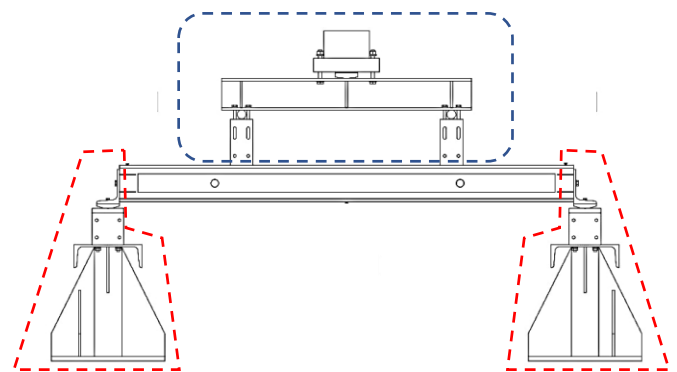


Fig. 5 Testing equipment: loading system (blue) and supports (red)

The loading system consists of two loading beams through which the load is transferred to the specimen. The loading beams are spaced 925 mm apart, which is approximately one quarter of the span of the specimen. Another beam is placed over the loading beams and perpendicular to them, through which the load is transferred from the actuator to the loading beams. A plate with a circularly machined bottom surface was placed under the actuator, achieving centric input of the load (Figures 4-6).

The loading setup ensures that the maximum bending moment on the specimen is the same as the maximum bending moment due to continuous load obtained by dividing the total loading force by the span.

The supports are made of steel beams standing on rigid "legs". The testing boundary condition of specimen corresponds to the boundary conditions of wall/ceiling panel in real building structure (Figures 5-7).

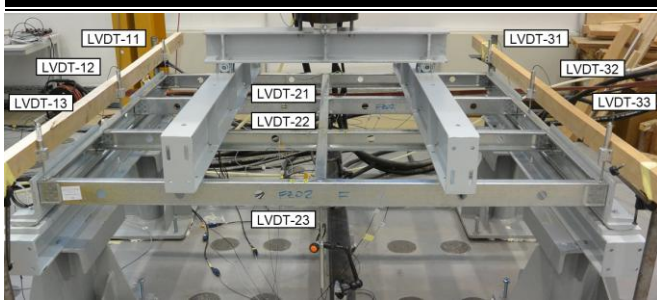


Fig. 6 Testing setup for steel core structure

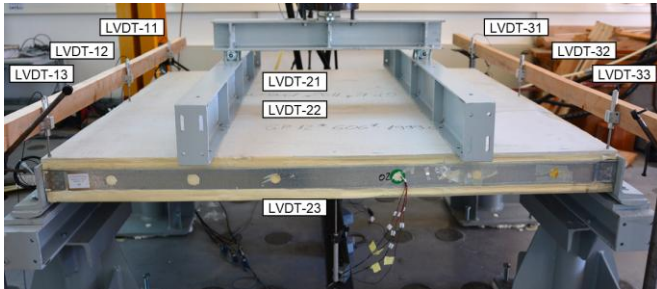


Fig. 7 Testing setup for composite panel

Displacements were to be measured on all specimens. The displacements were measured with LVDT (OMEGA LD320-25 at the supports and OMEGA LD320-50 at mid-span). The setup of the measuring devices can be seen in Figure 8.

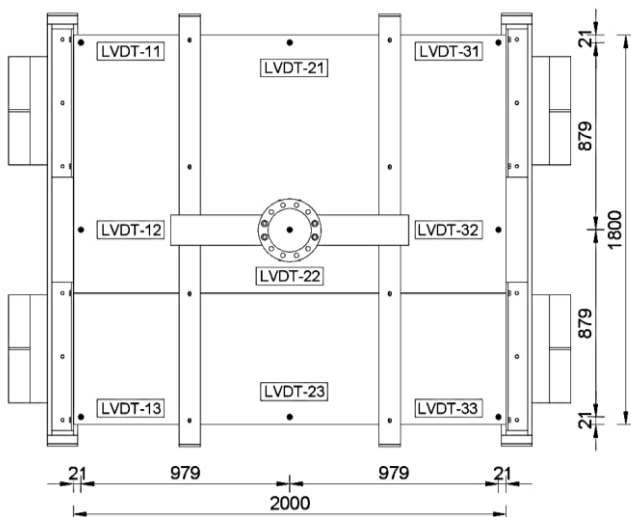


Fig. 8 LVDT setup (measures in mm)

5. Test results

The flexural tests on the specimens were performed in the Structure Laboratory of the Faculty of Civil Engineering in Rijeka using a Zwick/Roell hydraulic actuator with a capacity of 500 kN. The room temperature during the test was 21.3°C, and the relative humidity was 63.8%. Test management and data registration were carried out using TestXpert II software.

The tests were performed by loading the specimens to failure.

Visual inspection of the steel core structure specimens after testing revealed the failure mechanism manifested by the protrusion of the C-section compression flanges (Figure 9). The mentioned failure mechanism occurred in all specimens.

The failure in specimens B0-1 to B0-4 occurred at a force between 26 and 27 kN, while the deflection in the middle of the bay (position of LVDT-22) was between 22 and 23,4 mm. The average initial stiffness of specimens B0-1 to B0-4 is 1,53 kN/mm. [17].



Fig. 9 Failure mechanism in steel core structure specimen

Visual inspection of the composite panel specimens during and after testing revealed the relevant failure mechanism manifested by the tensile failure of the gypsum-fiberboards at an approximate force of 40 kN and a deflection of 7 mm for all specimens (Figure 10).

After the tensile failure of the gypsum-fiberboards, there is a gradual tensile failure of the polymer foam, followed by cracks in the gypsum-fiberboards in tension and expansion of the cracks (Figure 11). At forces between 56 and 65 kN, tensile failure of one of the outer C-profiles (C4 or C1) occurs, whereupon the force decreases. The indicated failure mechanism occurred in all specimens (Figure 12). The average initial stiffness of specimens B-1 to B-6 is 4,56 kN/mm. [17]



Fig. 10 Tensile failure of the gypsum-fiberboard



Fig. 11 Failure of the polymer foam



Fig. 12 Tensile failure of one of the outer C-profile

6. Conclusion

During the comparative out-of-plane to failure tests of composite panel specimens and steel core structure specimens the following conclusions can be seen:

- The values of the failure force for the composite panel are more than 2 times higher than the values of the failure force for the steel core structure test.
- The initial stiffness of composite panel specimens is about 3 times higher than that of steel core structure specimens.

The preliminary results of the out-of-plane to failure tests presented here show that the mechanical resistance of composite panels is greater than that of the steel core structure, which can be attributed to favourable effect of the polymer foam fillings on the mechanical resistance of the composite panels.

7. References

1. Zuo, J. et al. Green building evaluation from a life-cycle perspective in Australia: a critical review *Renew. Sustain. Energy Rev.* 70, 358-368 (2017)
2. Eltayeb, E., et al. Composite walls Composed of profiled steel skin and foam rubberized concrete subjected to eccentric compressions, *Journal of Building Engineering*, 46, 103715 (2022) <https://doi.org/10.1016/j.jobbe.2021.103715>.
3. Yi, O. et al. Case Study of the Structural Performance of Composite Slabs with Low Strength CRC Delivered by Concrete Truck, *Case Studies in Construction Materials*, 13, e00453 (2020) , <https://doi.org/10.1016/j.cscm.2020.e00453>
4. Samali, B., Nemati, S., Sharafi, P., Tahmoorian, F., Sanati, F. Structural Performance of Polyurethane Foam-Filled Building Composite Panels: A State-Of-The-Art. *J. Compos. Sci.* 3, 40 (2019) <https://doi.org/10.3390/jcs3020040>
5. Krolo, P., Bakran, A., Lukačević, L., Bede Odorčić, N., Palijan, I., Prlić, T., Bulić, M. Istraživanje ponašanja komponenti kompozitnog panela s integriranom čeličnom jezgrom. *Zbornik radova* (Građevinski fakultet Sveučilišta u Rijeci), 25 (1), 221-236 (2022) doi:10.32762/zr.25.1.14.
6. Bakran, A., Krolo, P. & Lukačević, L. Experimental Determination of Shear Modulus of Polyurethane Foam Using Two Test Procedures. U: Skozrit, I., Sorić, J. & Tonković, Z. (ur.) *10th ICCSM International Congress of Croatian Society of Mechanics Book of Abstract*. (2022)
7. Krolo, P., Bakran, A., Lukačević, L., Grandić, D., Palijan, I., Prlić, T., Bede, N., Štimac Grandić, I., Šćulac, P. & Bulić, M. Experimental study of innovative building panel system, U: Balac, M., Dragicevic, A. & Mladenovic, G. (ur.) *International Conference of Experimental and Numerical Investigations and New*

Technologies CNN TECH 2022 - Programme and The Book of Abstracts. (2022)

8. Bede, N., Krolo, P., Grandić, D. & Palijan, I. Ponašanje magnezij-oksidskih kompozitnih ploča izloženih jednoosnom tlaku. U: Damjanović, D., Kozak, D., Konjatić, P. & Katinić, M. (ur.) *Zbornik radova desetog susreta hrvatskog društva za mehaniku*. (2020)
9. Krolo, P., Bede, N., Grandić, D. & Palijan, I. Ponašanje magnezij-oksidskih kompozitnih ploča izloženih jednoosnom tlaku. U: Damjanović, D., Kozak, D., Konjatić, P. & Katinić, M. (ur.) *Zbornik radova desetog susreta hrvatskog društva za mehaniku*. (2020)
10. Krolo, P., Bede, N. & Grandić, D., Palijan, I. Influence of density on tensile and compressive properties of polyurethane foam. U: Šajna, A., Legat, A., Jordan, S., Horvat, P., Kemperle, E., Dolenc, Sabina, Ljubešek, Metka & Michelizza, M. (ur.) *Proceedings of the 2nd International Conference CoMS 2020/21*. (2020)
11. Lukačević, L., Krolo, P. & Bakran, A. Experimental Investigation of Face-to-Core Bond Strength between Gypsum Fibreboard and PU Test and measurement equipment setup Rigid Foam. U: Skozrit, I., Sorić, J. & Tonković, Z. (ur.) *10th ICCSM International Congress of Croatian Society of Mechanics Book of Abstract*. (2022)
12. Bakran, A., Krolo, P. & Čeh, N. Utvrđivanje svojstava prionjivosti između čelika i polimerne pjene provedbom testa savijanja kompozitnog panela. U: Brčić, M., Skobla, A. & Ribarić, D. (ur.) *Zbornik radova 11. susreta Hrvatskog društva za mehaniku*. (2021)
13. Lukačević, L., Krolo, P. & Čeh, N. Ispitivanje kompozitnog panela na savijanje s ciljem utvrđivanja svojstva prionjivosti obloge i jezgre panela. U: Brčić, M., Skobla, A. & Ribarić, D. (ur.) *Zbornik radova 11. susreta Hrvatskog društva za mehaniku*. (2021)
14. Bakran, A., Krolo, P. & Čeh, N. Utvrđivanje svojstava prionjivosti između čelika i polimerne pjene provedbom testa savijanja kompozitnog panela. U: Brčić, M., Skobla, A. & Ribarić, D. (ur.) *Zbornik radova 11. susreta Hrvatskog društva za mehaniku*. (2021)
15. Lukačević, L., Krolo, P.; Bakran, A. Experimental Investigation of Novel Angle Bracket Connection in Cold-Formed Steel Structures, *Buildings*, 12(8); 1115, 17 (2022) doi:10.3390/buildings12081115
16. HRN EN 10346:2015 Continuously hot-dip coated steel flat products for cold forming -- Technical delivery conditions (EN 10346:2015) Croatian standard institute, Zagreb, Croatia (2015)
17. *Izveštaj o ispitivanju panela* (Laboratorij za konstrukcije, Građevinski fakultet u Rijeci, Rijeka 2022)

Funding: This research was funded by the project “Predgotovljene zgrade gotovo nulte energije proizvedene na industrijski način/Prefabricated buildings of near-zero energy produced in an industrial way”, Grant no. KK.01.2.1.02.0046, financed from the European Regional Development Fund.

Acknowledgments: The authors would like to thank the company Tehnoplast profili d.o.o. and the company Palijan d.o.o. for their help in producing specimens and test tools.

Evaluation of the Erythrocyte Aggregation Index in Women With Preeclampsia by the Usage of the Microfluidic Device And Specially Developed Rheological Software

Anika Alexandrova^{1,2}, Velichka Strijkova^{3,4}, Emilia Abadjieva^{1,2}, Svetla Todinova^{2,3},
Ina Giosheva^{3,5}, Ariana Langari³, Tihomir Tianskov^{1,2}

Institute of Mechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria¹

Center of Competence at Mechatronics and Clean Technologies – MIRACle, Sofia, Bulgaria²

Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences, Sofia, Bulgaria³

Institute of Optical Materials and Technologies "Acad. Yordan Malinovski", Bulgarian Academy of Sciences, Sofia, Bulgaria⁴

University Obstetrics and Gynecology Hospital "Maichin Dom", Sofia, Bulgaria⁵

e-mail: anikaalexandrova@abv.bg

Abstract: In this pilot study, microfluidic flow analysis and atomic force microscopy (AFM), are used, to determine microrheological properties of the blood – aggregation, and deformability of erythrocytes in women with preeclampsia (PE). The aggregation of red blood cells (RBCs) is evaluated with the microfluidic system BioFlux, by applying an experimental approach and image analysis created by the authors of this study. The elastic properties of erythrocytes are defined by Young's modulus, using AFM. The aggregation index of erythrocytes and their elastic modulus are statistically significantly increased in patients with PE, in comparison to healthy normotensive pregnant women. In addition, it is found that the RBCs are less deformable and the interaction between them in aggregates is stronger in women with preeclampsia as compared with healthy pregnant women.

Keywords: MICROFLUIDIC SYSTEM, ATOMIC FORCE MICROSCOPE, IMAGE ANALYSIS, ERYTHROCYTE AGGREGATION, RBC DEFORMABILITY, PREECLAMPSIA

1. Introduction

Preeclampsia (PE) is a complex systemic syndrome that occurs after the 20th week of gestation and is characterized by maternal de-novo hypertension and/or significant proteinuria. The disease is also accompanied by organ dysfunction in a previously normotensive woman [1].

The erythrocytes (red blood cells, RBCs), the most abundant cells in the bloodstream, suffer greatly from the effects of PE [2]. The disease is associated with significant changes in erythrocyte morphology [3, 4, 5], with early degeneration and de-structuring of its membrane, leading to lysis in the blood stream [5, 6].

Abnormal blood rheology found in preeclampsia is related to a reduction in blood flow, which is an important factor in determining the amount of oxygen and nutrients carried across the placenta [7]. Deterioration of microrheological properties of the blood related to erythrocyte aggregation and deformability, results in impaired microcirculation.

In PE patients elevated RBC aggregation and decreased deformability are observed [2, 6, 7, 8]. These changes in the microrheological properties of the blood lead to increased viscosity, which can prevent proper tissue perfusion in the intervillous space of the placenta. Therefore, erythrocytes are unable to provide adequate oxygen delivery to the fetus. Damaged erythrocytes may enhance the progression of endothelial dysfunction and maternal circulatory disorders [2, 8].

RBC aggregation is known as the rouleaux formation of erythrocytes under low flow conditions. The erythrocyte aggregations in general are based upon a force balance between fluid forces and the natural adhesion forces between them [9]. The elevated erythrocyte aggregation in women with PE, compared to healthy pregnant women, can be determined by different techniques and methods: a photometric device Myrenne aggregometer [2, 10, 11, 12], a counter-rotating cone-plate Rheoscope system [13], zeta potential sedimentation technique [13, 14], a Laser-assisted Optical Rotational Cell Analyzer (LORCA) [2, 8, 15].

Another method for analyzing erythrocyte aggregation is microfluidic technologies [16]. It is possible to study the in vitro aggregation of erythrocytes in microchannels, under conditions similar to those in blood vessels, by using a high-speed video system connected to a microscope and a micropump [17, 18].

Erythrocyte deformability is described as the ability of red blood cells to adapt by deformation in response to mechanical forces to facilitate their passage through narrow capillaries and ensure sufficient tissue oxygenation [17, 18]. The decreased RBC deformability in PE is evaluated by the positive pressure filtration method [7, 20, 21, 22] and by laser diffractometer (ektacytometer) - LORCA [2, 6, 8].

In recent years atomic force microscopy become a powerful high-resolution method for studying the topography and biomechanical properties of blood cells [5, 23, 24, 25, 26]. The elastic characteristics of the erythrocytes, estimated by Young's modulus, can be used as an indicator reflecting their state [23, 24, 25]. Higher values of Young's modulus correspond to an increase in stiffness, i.e. a decrease in the elasticity and deformability of the cells [25, 26].

This study aims to evaluate erythrocyte aggregation and membrane deformability in patients with preeclampsia and to compare with healthy pregnant women, using microfluidic flow analysis and atomic force microscopy.

2. Materials and Methods

In this study, two groups of women are enrolled: patients with preeclampsia (PE group), and healthy normotensive pregnant women (PC group). Experiments are realized with peripheral blood samples from 4 pregnant controls in the third trimester of pregnancy and 13 pregnant women with PE. The human blood samples are collected from volunteer donors in accordance with ethical norms of medicine, and all of them gave written informed consent. Blood samples are drawn by venepuncture and collected in 6 ml tubes with K₂EDTA.

The erythrocytes are isolated by centrifugation of the whole blood (by centrifuge Universal 320 R, Hettich) at 1200 g for 15 min, and the yellowish supernatant (plasma and white blood cells) is discarded. A 40% hematocrit erythrocyte suspension is prepared (by centrifuge Haematokrit 200, Hettich). From this erythrocyte suspension, 10 µl is taken and added to 200 µl of Dextran 70 solution (at a concentration of 4 g/dl), to stimulate erythrocyte aggregation.

The erythrocyte aggregation is studied using the air pressure-driven microfluidic system BioFlux. It is a high-quality imaging platform for conducting in-flow rheological analyses [27]. The microfluidic system consists of a BioFlux 200 electro-pneumatic

flow control pump system; BioFlux microfluidic plates; inverted fluorescence microscope Lumascope 620; and computer configuration with operational and analysis software. For experiments of evaluation of the erythrocyte aggregation, BioFlux plates 24-well 0-20dyn/cm², containing 8 microfluidic channels with cross-sectional dimensions of 350 µm in width and 75 µm in height are used.

The microfluidic channels are filled with 200 µl of the prepared diluted erythrocyte suspension in Dextran 70. The erythrocyte suspension is perfused through the microfluidic channels at shear stress of 5 dyn/cm², for 5 min. Next, the flow in the channels is reduced to low shear stress at 0,1 dyn/cm², for 5 min. After stopping the flow, the formed erythrocyte aggregates are imaged, using the inverted microscope, working in the Phase Contrast mode. The aggregates formed in the channel are put to shear stress 5 dyn/cm², again for 5 min. The images of the remaining erythrocyte aggregates not destroyed by the flow, using the Phase Contrast mode of the microscope, are taken.

The RBC aggregation determined with the microfluidic system BioFlux is evaluated by image analysis created by the authors of this study. The obtained images of the erythrocyte aggregation, after usage of a microfluidic device are imported as input data in the software environment Image J [28], and after that the obtained results are further processed in an elaborated program in IntelliJ IDEA [29]. For every image with erythrocyte aggregation, the number of aggregates is determined; the aggregate size is identified, and the total area of the erythrocyte aggregates, as well.

After the image analysis, the Erythrocyte Aggregation Indexes, of the two studied groups of women with normal pregnancies and patients with PE, are established. The first EAI_1 represents the power of erythrocyte aggregation under low flow conditions. It is calculated by the formula:

$$EAI_1 = \frac{S_2}{S_1},$$

where S_2 (in pixels) is the total sum of areas of the aggregates (after the flow of 0,1 dyn/cm²), and S_1 (in pixels) is the total observed area of one visual field of the microscope.

The second EAI_2 shows that part of the formed erythrocyte aggregates, which are not destroyed at high flow conditions. It is calculated by the formula:

$$EAI_2 = \frac{S_3}{S_1},$$

where S_1 (in pixels) is the total observed area of one visual field of the microscope, and S_3 (in pixels) is the total sum of areas of erythrocyte aggregates with high shear stress (after the flow of 5 dyn/cm²).

The isolated erythrocytes from every blood sample are mixed with plasma (in a ratio of 1:1) to prepared smears (according to the procedure described in Dinarelli et al.) [30]. The cells deposited on the poly-L-lysine slides are further observed using an optical and atomic force microscope (AFM).

AFM imaging and force measurements of smears of RBCs are performed with an atomic force microscope (MFP-3D, Asylum Research, Oxford Instruments, Abingdon, UK) at room temperature. Force-distance curves are measured at room temperature in contact mode using silicon nitride probes (Nanosensors, type qp-Bio) with a spring constant of 0,06 N/m, resonant frequency of 16 kHz, conical shape, and nominal tip radius of 8 nm. The force mapping is performed on a grid of 32 × 32 points. The images are collected at a scanning speed of 2 s/row. Before the measurements, the tip is calibrated on a clean glass substrate using the special software Igor Pro.

Young's modulus (E) is determined by analyzing the force-distance curves applying the Hertz model [31]:

$$E = \frac{\pi \cdot F}{2 \tan(\theta) \cdot \delta^2} (1 - \nu^2),$$

where F is the loading force, δ is the indentation depth, E is the apparent Young's modulus, θ is the open-angle of the type, and ν is Poisson's ratio. The Poisson's ratio of the cell is set as 0,5 in this study for its incompressibility.

Data analysis is accomplished by using the software package Sigma Plot 11.0. All data are presented as means ± SD (standard deviation). The significance of differences between the two studied groups pregnant women - healthy individuals and those with PE, are evaluated using a t-test or Mann-Whitney Rank Sum Test. Differences are accepted as significant at $p < 0,05$.

3. Results

The main clinical characteristics and hematological indices of erythrocytes derived from patients with preeclampsia (mean age $30,2 \pm 10,5$ years), and healthy pregnant women (mean age $24 \pm 1,4$ years) are presented in Table 1.

A statistically significant increase in RBC count and hematocrit (Hct), by 4% and 6% respectively, in the blood samples of patients with PE, in comparison to the control group is established. The red blood cell distribution width (RDW) significantly increases by 6% in PE patients, compared to the results of PC group. The mean value of fibrinogen (Fg) increases statistically significantly in patients with PE, in comparison with the results of healthy normotensive women. The other hematological parameters of erythrocytes (Hb, MCV, MCH, MCHC) for the studied groups are not statistically significant.

Table 1. Mean values and standard deviations of hematological parameters of the patients with preeclampsia (PE group), and healthy normotensive women with normal pregnancies (PC group).

Hematological parameters	PC group n=4	PE group n=13
RBC, T/l	$3,77 \pm 0,48$	$3,93 \pm 0,5^*$
Hb, g/L	$110,5 \pm 6,58$	$119,72 \pm 10,08$
Hct, L/L	$0,34 \pm 0,04$	$0,36 \pm 0,03^{\#}$
MCV, mmol/L	$89,03 \pm 5,33$	$92,01 \pm 5,45$
MCH, pg	$29,3 \pm 1,7$	$30,57 \pm 1,9$
MCHC, g/L	$329 \pm 10,4$	$337,82 \pm 20,72$
RDW, %	$13,07 \pm 1,67$	$13,8 \pm 2,24^*$
Fg, g/l	$5,4 \pm 0,27$	$5,57 \pm 1,12^{##}$

t-test * $p < 0,05$; ** $p < 0,01$; *** $p < 0,005$;

Mann-Whitney Rank Sum Test # $p < 0,05$; ## $p < 0,01$; ### $p < 0,005$.

RBC – red blood cells count, Hb – hemoglobin; Hct – hematocrit, MCV – mean cellular volume, MCH – mean cellular hemoglobin, MCHC – mean cellular hemoglobin concentration, RDW – red blood cell distribution width; Fg – fibrinogen

Images of erythrocyte aggregates obtained with the BioFlux microfluidic system demonstrate a strong difference between the aggregation of RBCs in healthy pregnant women and patients with PE, is observed (Fig. 1). The small single erythrocyte aggregates (rouleaux) formed in women with normal pregnancies (Fig. 1A). Large aggregates (rouleaux) that form branched networks (Fig. 1B) are observed in the erythrocyte suspensions of patients with PE (Fig. 1B).

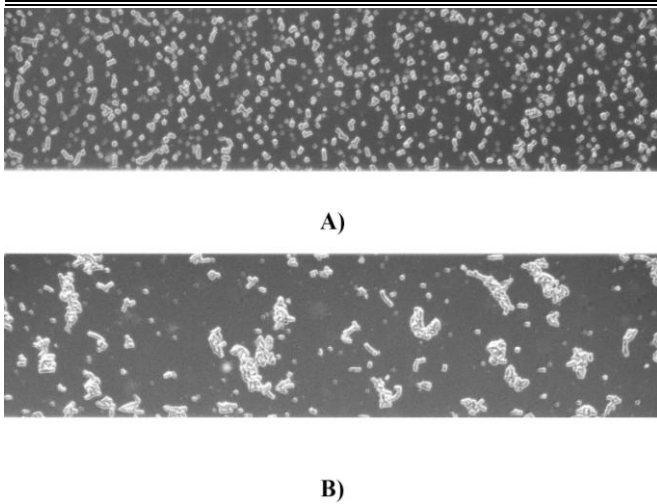


Fig. 1. Images of erythrocyte aggregates obtained with the BioFlux microfluidic system under low flow condition (after shear stress 0,1 dyn/cm²): A) healthy pregnant women; B) pregnant women with preeclampsia.

Based on the images obtained with the BioFlux system, and analyzed using software environments Image J [28] and Intellij IDEA [29], the erythrocyte aggregation indexes are evaluated. A statistically significant difference of RBC aggregation between the control group and patients with PE is found (Table 2). The erythrocyte aggregation index EAI_1 is increased in patients with PE (by 98 %; $p=0,009$), as compared to healthy pregnant ones.

Table 2. Mean values and standard deviations of Erythrocyte Aggregation Indexes of the control group of healthy pregnant women and patients with preeclampsia.

Erythrocyte Aggregation	Healthy Pregnant n=4	Patients with PE n=13
EAI_1	0,064±0,028	0,127±0,048 ^{##}
EAI_2	0,005 ± 0,002	0,008 ± 0,003

Mann-Whitney Rank Sum Test # $p<0,05$; ## $p<0,01$; ### $p<0,005$

By the application of a new methodology, elaborated by the authors of this study, through images analysis is evaluated how much of the erythrocyte aggregates formed at low flow conditions remain intact at high shear stress (Fig. 2).

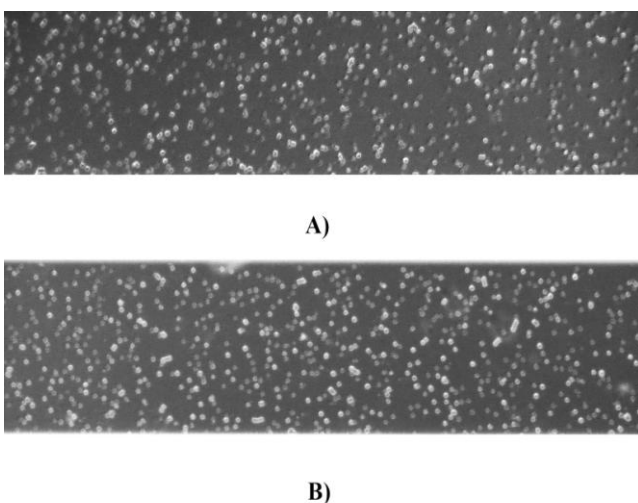


Fig. 2. Images of erythrocyte aggregates obtained with the BioFlux microfluidic system under high flow condition (after shear stress of 5 dyn/cm²): A) healthy pregnant women; B) pregnant women with preeclampsia.

The EAI_2 in patients with PE is higher (by 37,5 %), compared to healthy pregnant women (Table 2). This means that after high shear stress (5 dyn/cm²), fewer aggregates are broken down in patients with PE compared to control pregnant women. This is possibly related to greater adhesion forces between erythrocytes forming aggregates in PE group.

Using AFM the Young's modulus (E) of RBCs derived from the two studied groups of women is evaluated from the force-distance curve after applying the Herz model. The mean value of E for the PC group is estimated to be about 1,5 MPa until the mean value for PE group (2,1 MPa) is higher than that of control ones (Fig. 3).

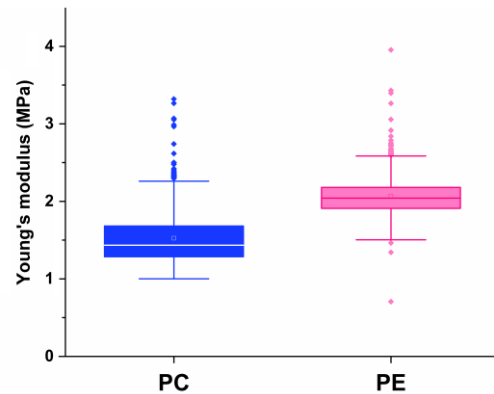


Fig. 3. Box-plot of Young's modulus evaluated for all red blood cells derived from control pregnant women in the third trimester of pregnancy (PC), and patients with preeclampsia (PE). Outliers of the interquartile range are presented by diamonds for each group.

For a more detailed study of the distribution of Young's modulus for the RBCs of each of the studied groups, the values of elastic modulus are presented in the form of histograms (Fig. 4). The multicomponent Gaussian distribution of elastic modulus data shows the presence of populations with different values in the control group, a dominant one with a maximum centered at 1,35 MPa. After applying a test for the normality of the data distribution (via the Shapiro-Wilk test), it was found that the values of Young's modulus of erythrocytes for the patients with PE consisted of a normally distributed population. The Young's modulus of RBCs in the PE group is established to be statistically significant compared to that of the PC population.

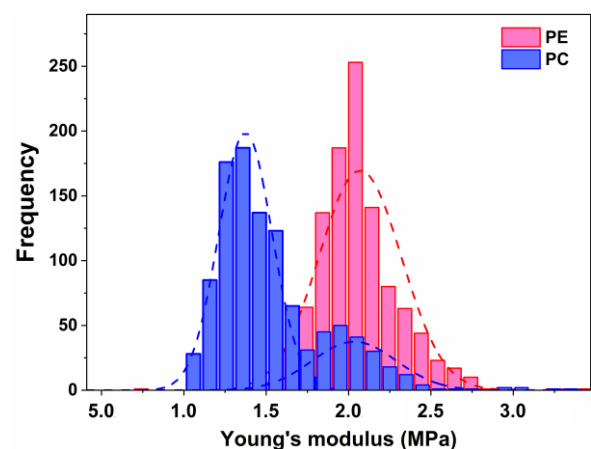


Fig. 4. Histograms of the distribution of Young's modulus determined for all red blood cells derived from control pregnant women in the third trimester of pregnancy (PC), and patients with preeclampsia (PE).

4. Discussion

Preeclampsia (PE) is a heterogeneous disorder that has a significant impact on the maternal and fetal organism [32, 33]. The complex pathophysiological background of PE, including inflammatory, genetic, immunological, hemodynamic changes, and oxidative stress, leads to vascular endothelial injury, vasospasm, and hypertension. These pathophysiological mechanisms alter the biophysical properties of red blood cells, including their abilities to aggregate and deform [2, 5].

Altered RBC aggregation and deformability can be considered as the cause or the result of complex circulatory disorder. Endothelial damage leads to microthrombus formation and erythrocyte fragmentation or hemolysis due to vascular mechanical forces in PE [3]. The blood viscosity at low shear conditions in the placental intervillous space is mainly determined by increased values of RBC aggregation, and this potentially deteriorates placental microcirculation [34]. Enhanced RBC aggregation may have an additional impact on peripheral vascular resistance, and endothelial dysfunction may in turn further increase blood pressure, thereby provoking a vicious cycle [35].

The reason for reduced RBC deformability in PE can be chronic inflammation and hypoxia, which leads to an elevated concentration of free radicals inducing changes in RBC membrane properties and subsequent increase of intracellular Ca^{2+} [36]. In addition, an increased Ca^{2+} pump activity leads to adenosine triphosphate (ATP) depletion in RBCs resulting in poor deformability [15].

The relatively rapid improvement of deformability in the postpartum period in PE may presumably occur due to the termination of gravidity, which has maintained the disease. It can, therefore, be hypothesized that RBC deformability may be a sensitive and early marker of the normalization of maternal microcirculation after delivery [2].

In this pilot study, results on microrheological properties of the blood for a group of women with PE and healthy pregnant controls, are presented. The RBC aggregation at flow conditions is determined with the microfluidic system BioFlux. The image analysis is elaborated by using the Image J software environment [28], and then the obtained results are further processed in an elaborated program in IntelliJ IDEA [29]. The results show that the power of erythrocyte aggregation - estimated by EAI_1 , is statistically significantly higher in patients with PE, compared to the control group of pregnant women. By determining the parameter EAI_2 , at high flow conditions, it is found that, in women with PE, a smaller part of RBC aggregates are disrupted compared to the healthy normotensive women. The reason for this can be the adhesion forces between the erythrocytes in the aggregates, which are greater in the pathological state - PE, compared to healthy pregnant controls.

The Young's modulus determined by AFM in PE patients increases statistically significantly compared to healthy pregnant women, showing decreased elasticity of patients' RBC membranes. This leads to a reduction in their deformability compared to the mechanical properties of erythrocytes in healthy controls.

The elastic modulus can be a reliable indicator of the mechanical state of blood cell membranes [23, 24, 25]. Therefore, Young's modulus becomes the important biomarker determining the status of red blood cells in a pathological condition – PE.

The results in this study, for the elevated erythrocyte aggregation and the decreased RBC deformability in the patients with preeclampsia, are consistent with the obtained outcomes in other research [2, 6-8, 10-15, 20 - 22]. We confirm the changes in the microrheological properties of blood in patients with preeclampsia by means of relatively new technologies - microfluidic flow analysis and AFM, which have not been used for their research so far. New additional information on the elastic properties of erythrocytes (estimated by Young's modulus) and on

the force of interaction between them in erythrocyte aggregates in pregnant women with PE is given by the usage of these technologies.

A more accurate understanding of changes in microrheological properties of the blood, i.e. erythrocyte aggregation and deformability, for maternal red blood cells would help to identify new therapeutic perspectives aimed at restoring erythrocyte function and improving oxygen-carrying capacity. The parameters of erythrocyte aggregation and deformability determined in our study can be used as biomarkers for the diagnosis of pregnant women with PE.

5. Conclusion

In this pilot study, microfluidic flow analysis and AFM are used to determine the aggregation and deformability of erythrocytes in patients with preeclampsia compared to those of healthy pregnant women. The aggregation of RBCs is evaluated with the microfluidic system BioFlux, by applying an experimental approach and image analysis created by the authors of this study. The erythrocyte deformability is defined by Young's modulus using AFM. Statistically significant differences in erythrocyte aggregation index and elastic modulus of RBCs between groups of pregnant women with PE and healthy controls are found. In addition, our results demonstrated that the RBCs are less deformable and the interaction between them in aggregates is stronger in women with preeclampsia. This study can be a basis for further research on microrheological properties of the blood for early diagnosis and possible prevention of this pathology.

Acknowledgment

This work has been accomplished with the financial support by the Grant No BG05M2OP001-1.002-0011-C02 financed by the Science and Education for Smart Growth Operational Program (2014-2020) and co-financed by the European Union through the European structural and Investment funds.

References

1. Report of the American College of Obstetricians and Gynecologists' Task Force on Hypertension in Pregnancy. Hypertension in pregnancy. *Obstet Gynecol* 122: 1122–1131, (2013).
2. B. Csiszar, G. Galos, S. Funke, et al. Peripartum Investigation of Red Blood Cell Properties in Women Diagnosed with Early-Onset Preeclampsia. *Cells*, 10, 2714 (2021).
3. J. D. Hernandez Hernandez, O. R. Villaseñor, J. Del Rio Alvarado, et al. Morphological changes of red blood cells in peripheral blood smear of patients with pregnancy-related hypertensive disorders. *Arch Med Res* 46: 479–483. 17 (2015).
4. F. G. Cunningham, T. Lowe, S. Guss, R. Mason. Erythrocyte morphology in women with severe preeclampsia and eclampsia. Preliminary observations with scanning electron microscopy. *Am J Obstet Gynecol*. 153(4):358-63 (1985).
5. I. Giosheva, V. Strijkova, R. Komsa-Penkova, et al. Membrane Lesions and Reduced Life Span of Red Blood Cells in Preeclampsia as Evidenced by Atomic Force Microscopy. *Int. J. Mol. Sci.*, 24, 7100 (2023).
6. L. Heilmann, W. Rath, K. Pollow. Hemorheological changes in women with severe preeclampsia. *Clin Hemorheol Microcirc* 31: 49–58 (2004).
7. G. D. Lang, G. D. Lowe, J. J. Walker, et al. Blood rheology in pre-eclampsia and intrauterine growth retardation: effects of blood pressure reduction with labetalol. *Br J Obstet Gynaecol*. 91(5):438-43 (1984).
8. D. J. Pepple, M. R. Hardeman, A. M. Mullings, H. L. Reid. Erythrocyte deformability and erythrocyte aggregation in preeclampsia. *Clin Hemorheol Microcirc*. 24(1):43-8 (2001).
9. C. Murali, P. Nithiarasu. Red blood cell (RBC) aggregation and its influence on non-Newtonian nature of blood in

- microvasculature. *J of Modeling in Mechanics and Materials*, 1 (1), 20160157 (2017).
10. A. L. Tranquilli, G. G. Garzetti, G. De Tommaso, et al. Nifedipine treatment in preeclampsia reverts the increased erythrocyte aggregation to normal. *Am J Obstet Gynecol*. 167(4):942-5 (1992).
11. G. F. von Tempelhoff, E. Velten, A. Yilmaz, et al. Blood rheology at term in normal pregnancy and in patients with adverse outcome events. *Clin Hemorheol Microcirc*. 42(2):127-39 (2009).
12. R. Csorba, A. Yilmaz, P. Tsikouras, et al. Rheological parameters in the umbilical cord blood in moderate and severe forms of preeclampsia. *Clin Hemorheol Microcirc*. 55(4):391-401 (2013).
13. P. Ozanne, F. C. Miller, H. J. Meiselman. RBC Aggregation in Diabetic and Pre-eclamptic Pregnancy. *Clin Hemorheol Microcirc*. 3(2):145 – 154 (1983).
14. M. N. Karemore, J. G. Avari. Alteration in zeta potential of erythrocytes in preeclampsia patients. In: *Prediction of maternal and fetal syndrome of preeclampsia* (2019).
15. B. Schauf, U. Lang, P. Stute, et al. Reduced red blood cell deformability, an indicator for high fetal or maternal risk, is found in preeclampsia and IUGR. *Hypertens Pregnancy* 21(2):147-60 (2002).
16. G. V. Grigorev, A. V. Lebedev, X. Wang, et al. Advances in Microfluidics for Single Red Blood Cell Analysis. *Biosensors*, 13, 117 (2023).
17. Y. J. Kang. Microfluidic-based effective monitoring of bloods by measuring RBC aggregation and blood viscosity under stepwise varying shear rates. *Korea Aust. Rheol. J.*, 32, 15–27 (2020).
18. R. Mehri, C. Mavriplis, M. Fenech. Controlled microfluidic environment for dynamic investigation of red blood cell aggregation. *J. Vis. Exp.* (100):e52719 (2015).
19. V. Pretini, M. H. Koenen, L. Kaestner, et al. Red Blood Cells: Chasing Interactions. *Front Physiol*. 10: 945 (2019).
20. P. Gresele, R. Gueriolini, G. G. Nenci. Erythrocyte deformability changes in normal pregnancy and pre-eclampsia. *Br J Haematol*. 52(2):340-2 (1982).
21. T. C. Inglis, J. Stuart, A. J. George, A. J. Davies. Haemostatic and rheological changes in normal pregnancy and pre-eclampsia. *Br J Haematol*. 50(3):461-5 (1982).
22. J. Thorburn, M. M. Drummond, K. A. Whigham. Blood viscosity and haemostatic factors in late pregnancy, pre-eclampsia and fetal growth retardation. *Br J Obstet Gynaecol*. 89(2):117-22 (1982).
23. A. Alexandrova-Watanabe. Study of rheological, mechanical and morphological properties of blood, its formal elements and parameters of hemocoagulation in type 2 diabetes mellitus. Ph.D. thesis, Institute of Mechanics, Bulgarian Academy of Sciences, Sofia, Bulgaria (2021).
24. A. Langari, V. Strijkova, R. Komsa-Penkova, et al. Morphometric and Nanomechanical Features of Erythrocytes Characteristic of Early Pregnancy Loss. *Int. J. Mol. Sci.*, 23, 4512 (2022).
25. V. Sergunova, S. Leesment, A. Kozlov, et al. Investigation of Red Blood Cells by Atomic Force Microscopy. *Sensors* 22, 2055 (2022).
26. M. E. Dokukin, N. V. Guz, I. Sokolov. Quantitative study of the elastic modulus of loosely attached cells in AFM indentation experiments. *Biophysical Journal* 104, 2123-2131 (2013).
27. C. G. Conant, M. A. Schwartz, J. E. Beecher, et al. Well plate microfluidic system for investigation of dynamic platelet behavior under variable shear loads. *Biotechnol Bioeng* 108: 2978- 2987 (2011).
28. <http://imagej.nih.gov/ij/>
29. <https://www.jetbrains.com/idea/>
30. S. Dinarelli, G. Longo, G. Dietler, et al. Erythrocyte's aging in microgravity highlights how environmental stimuli shape metabolism and morphology. *Sci. Rep.* 8, 5277 (2018).
31. B. Briscoe, K. Sebastian, M. Adams, The effect of indenter geometry on the elastic response to indentation. *J. Phys. D Appl. Phys.* 27, 1156–1162 (1994).
32. H. Valensise, B. Vasapollo, G. Gagliardi, G. P. Novelli Early and late preeclampsia: two different maternal hemodynamic states in the latent phase of the disease. *Hypertension* 52: 873–880 (2008).
33. M. A. R. de Freitas, A. V. da Costa, L. A. Medeiros, et al. The role of the erythrocyte in the outcome of pregnancy with preeclampsia. *PloS ONE* 14(3): e0212763 (2019).
34. R. Gamzu, G. Barshtein, F. Tsipis, et al. Pregnancy-induced hypertension is associated with elevation of aggregability of red blood cells. *Clin. Hemorheol. Microcirc.* 27, 163–169 (2002).
35. O. K. Baskurt, H. J. Meiselman, Erythrocyte aggregation: Basic aspects and clinical importance. *Clin. Hemorheol. Microcirc.* 53, 23–37 (2013).
36. E. Friederichs, H. J. Meiselman, Effects of calcium permeabilization on RBC rheologic behavior. *Biorheology* 31, 207–215 (1994).

Absorbable Dressings Manufactured of Tropocollagen with Nanodiamonds

Anna Karczewska^{1,*}, Dariusz Witkowski¹, Radomir Magiera¹, Radosław Wach², Bożena Rokita², Alicja Olejnik², Zuzanna Nowak¹, Laura Ciosek¹, Łukasz Piwowarski⁴, Andrzej Argalski⁴, Katarzyna Mitura⁵, Stanisław Mitura⁶

Institute of Turbomachinery, Lodz University of Technology, Poland¹

Institute of Applied Radiation Chemistry, Faculty of Chemistry, Lodz University of Technology, Poland²
Sancoll, Poland⁴

Department of Biomedical Engineering, Koszalin University of Technology, Poland⁵

State University of Applied Sciences in Kalisz, Poland⁶

anna.karczewska@p.lodz.pl

Abstract: The aim of this research is to obtain nanodiamonds-containing collagen sponges (lyophilisates) for wound healing. The purpose is to create an antimicrobial barrier on the dressing based on active tropocollagen. The research problem in this task is the use of antibacterial properties of nanodiamonds to modify new collagen-based materials being the products of this investigations.

Keywords: TROPOCOLLAGEN, NANODIAMONDS, ABSORBABLE WOUNDS DRESSINGS

1. Introduction

Lodz University of Technology with collaboration with Nicolaus Copernicus University in Toruń – Collegium Medicum in Bydgoszcz and with Sancoll company is implementing the project “Development of an Absorbable Dressing Based on Active Exogenous Tropocollagen from Fish Skin with the Addition of Modified Carbon Nanopowders” No POIR.04.01.04-00-0077/20.

The main goal of the project is to develop an innovative absorbable dressing based on exogenous tropocollagen with the addition of modified nanodiamonds in the form of a gel, lyophilisate, membrane, non-woven fabric and registration as a medical device. The aim of the project is also to develop modifications of nanodiamonds so that they create antibacterial properties of the dressing and the ability to interfere with the formation of biofilm on the wound surface and devices for the production of dressings, and to transfer production to a semi-industrial scale.

The project aims to develop and parameterize a technology for the production of an absorbable dressing based on active tropocollagen of fish origin and a carbon nanostructure dressing modified for the needs of the application environment.

For this purpose, the necessary tasks have been defined, which allowed to determine the elements necessary to produce the dressing at each stage. In the initial stages, the collagen parameters for the production of the dressing have been determined, the method of modifying the nanodiamonds in terms of anti-inflammatory, anti-allergic and bacteriostatic properties and the target forms of the dressing. Detonation nanodiamonds showing high biological activity related to their electronic structure, crystallographic structure and developed reaction surface are used.

At the same time, devices have been developed to produce a non-woven fabric and a collagen membrane, and to apply a nanodiamond layer to a collagen non-woven fabric. An important element is the development of a method and process for dressing sterilization. The dressing forms prepared in this way is subjected to in vitro tests to determine compliance with the ISO 10993-1:2018 standard for a medical device used for more than 30 days and to be analyzed in terms of measuring the degree of proliferation, cellular migration, cellular viability, vascularization of the new tissue formed and monitoring changes on protein and gene/protein mRNA levels.

Then, the production will be transferred to a semi-industrial scale. This will allow the start of certification of the medical device.

Collagen is a natural fibrous protein of the extracellular matrix. The triple helix structure consists of three proteins wrapped around each other. This triple helix protein molecule is forms the major part of the extracellular dermal matrix, together with the

glycosaminoglycans, proteoglycans, laminin, fibronectin, elastin and cellular components. Is involved in the process of wound healing, in scar formation during the healing of connective tissues. Collagen is used in tissue engineering and regenerative purposes, because of its biocompatible properties.

Collagen is the most abundant protein in animal tissues. Collagen molecules can be divided into subfamilies based on their supramolecular assemblies. The subfamilies and collagen molecules most relevant to the arterial wall are fibril-forming or fibrillar collagens (types I, III, V), basement membrane network collagens (type IV), beaded filament forming collagen (type VI), network forming collagens (type VIII), transmembrane collagens (type XIII), and fibril-associated collagens with interrupted triple helices (type IX, XII, XIV). There are at least 16 types of collagen. The body is consists approximately 80 – 90 percent of the collagen types I, II, and III. In early healing wounds, type III is laid down first, with the proportion of type I increasing as scar formation progresses and is remodelled. Collagen deposition and remodelling contribute to the increased tensile strength of the wound, which is approximately 20% of normal by three weeks after injury, gradually reaching a maximum of 70% of that of normal skin. Although epithelial structures can heal by regeneration, connective tissues cannot and depend on the process of repair mostly by the formation of collagenous scar tissue, predominantly of type I, which serves to restore tissue continuity, strength and function. Collagen is a brittle substitute for unwounded tissue, and scar tissue rarely exceeds 70% of unwounded tissue strength. Collagen type I can be found in bones, tendons, organs, collagen type II in found mainly in cartilage. Collagen type III can be found mainly in reticular fibres (fine fibrous connective tissue occurring in networks to make up the supporting tissue of many organs). Collagen type IV can be found in the basement membrane of cell membranes (a thin noncellular layer located between epithelial cells and the connective tissue that underlies them, composed of collagen and other proteins and having a variety of functions including support and filtration). In hair, nails there is collagen type V. The various collagens and the structures they form all serve the same purpose, to help tissues withstand stretching.

Collagen enables better absorption of minerals, increasing bone density (the bone extracellular matrix consists of 90% of collagen and its connections with calcium, magnesium and phosphorus). It also supports protective and repair processes in cartilage tissue, reduces the activity of enzymes responsible for inflammation and pain. The role of collagen in wound healing is to attract fibroblasts and encourage deposition of new collagen to the wound bed.

Collagen has a key role in the control of the inflammatory response to injury and subsequent repair with functions that influence cellular mitogenesis, differentiation and migration and protein synthesis in the extracellular matrix (ECM). Collagen is

really important in synthesis and release of inflammatory cytokines and growth factors and interactions between enzymes which remodel the ECM, including matrix metalloproteinases (MMPs) and their tissue inhibitors (TIMPs).

Many collagen dressings have been developed to enhance wound repair, particularly of non-infected, chronic, indolent skin ulcers.

Collagen is a very important material in biomedical engineering, due to its various applications it is a very important biopolymer [1-4]. Nowadays, there are many collagen dressings available on the market, such as gels, creams, sponges, which are designed to support wound healing. A hard-to-heal wound has been defined as one that fails to heal with standard therapy in an orderly and timely manner. This definition applies equally to both acute and chronic wounds. A wound is considered chronic if it has not healed significantly in four weeks or completely in eight weeks. Especially in the elderly and people with chronic diseases, slower healing of wounds can often be observed. Collagen dressings are intended to speed up this process.

Many collagen dressings have been developed to enhance wound repair, particularly of non-infected, chronic, indolent skin ulcers. Collagen wound dressings are gels, pads, particles, pastes, powders, sheets or solutions derived from bovine, equine, porcine, fish or avian sources.

Natural collagen is widely used in pharmacy and medicine as a biomaterial and has a huge impact on the development of such fields as regenerative medicine and tissue engineering. The primary function of collagen proteins is to maintain the structural integrity of tissues and organs. It not only fills the space between cells, but also ensures the mechanical strength of the tissue. Collagen binds water in tissues, is involved in the blood clotting process, in regenerative processes: wound healing, scar formation, and bone fusion after fractures.

The aim of this research is the development of novel wound dressing with the addition of nanodiamonds.

2. Collagen/NDs lyophilisates

Nanodiamonds, which are nanometer-sized carbon allotropes, possess exceptional physical, chemical and biological properties [5-6]. Together with their biocompatibility and the possibility to modify their properties with surface chemistry, it is interesting to explore nanodiamonds in the field of wound healing.

Nanodiamonds (ND) powder RT-DND Ray Techniques was produced by detonation method. NDs are purified, graphite and metal free. Manufactured for various applications in bioengineering. Average grain size is between 3,5 – 6,0 nm. For investigations the active exogenous tropocollagen from fish skins, manufactured by Sancoll Company, was used. Different concentrations of nanodiamonds have been added to collagen and lyophilisates samples have been manufactured for further investigations. NDs are dispersed in the volume of collagen gel before its lyophilisation or alternatively are sprayed on the surface of the lyophilized sponge of dressing, to have direct and instant contact with possible bacteria.

Figures 1-2 show the examples of the obtained samples. The technology of collagen materials manufacturing needs controlled conditions. Especially temperature is critical because tropocollagen obtained from sweet water fish denaturizes in temperatures below 30°C.

Sterilization is a critical technological step, but thermal methods and chemical methods cannot be applied. It is due to respectively thermal instability of the protein and its physical state (porous sponge), and possible reactions of a sterilization active compound with polypeptide chemical groups. Therefore, radiation method of sterilization was employed. Some denaturation of collagen was

observed due to irradiation, but in general the protein preserved its ordered structure, stabilized with hydrogel bonding.

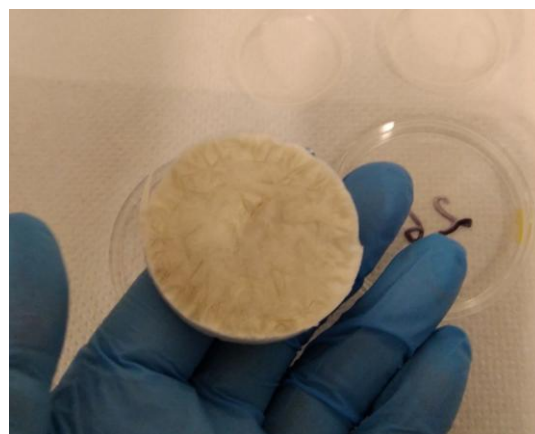


Fig. 1 Lyophilized Collagen with nanodiamonds.

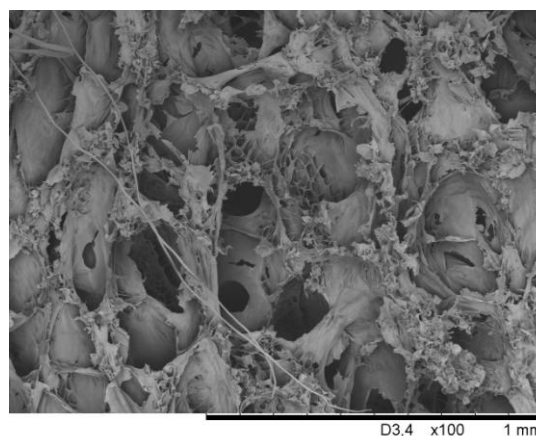


Fig. 2 SEM picture of Tropocollagen/NDs lyophilizate sponge.

3. Conclusions

The integration of nanodiamonds with collagen presents a promising avenue for development of wound healing materials.

4. References

1. A. Sionkowska, *Materials Science Forum* 706–709 (2012) 595–599.
2. A. Sionkowska, K. Adamiak, K. Musiał, M. Gadomska, *Materials* 13 (2020) 4217.
3. S. Chattopadhyay, R.T. Raines, *Biopolymers* 101 (2014) 821–833.
4. H. Lodish, A. Berk, S.L. Zipursky, P. Matsudaira, D. Baltimore, J. Darnell, *Journal of Cell Science* 113 (2000) 2925–2926.
5. K. Mitura, A. Karczewska, P. Niedzielski, J. Grabarczyk, W. Kaczorowski, P. Louda, S. Mitura, *International Journal of Nanomanufacturing* 2 (2008) 29.

Acknowledgments

The work was realized as a part of the project POIR.04.01.04-00-0077/20 financed by Polish National Centre for Research and Development NCBiR.

Anomalies in the Earth rotation and Syzygies in Perigee

Leonid Zotov^{1,2*}Institute of Electronics and Mathematics National Research University Higher School of Economics, Moscow, Russia¹Sternberg Astronomical Institute, Lomonosov Moscow State University, Russia²

wolftempus@gmail.com

Abstract: In 2022 the Earth rotation velocity reached its maximum and in 2017-2020 the Chandler wobble of the rotational axis disappeared for the second time in the history of observations. Unexplained modulations of 90 and 20-25 year periods are observed. They reflect geophysical processes in the atmosphere, ocean, and Earth's interior and can be linked to climate. It is important to understand their causes and predict them for navigation etc. We found out, that the orientation of the lunar orbital plane and position of perigee revolves in such manner, that their mutual positions repeat with 90-year semi-periods at the minimum of the Chandler wobble. At the same time synodic period of syzygies in perigee (every 412 days) with respect to the position of the Chandler pole (433 days) rotates within ~22-23 years. We have collected arguments in favor of the hypothesis that the mass flows and redistribution within the Earth systems under the influence of apsidal-nodal effects of luni-solar tide could be responsible for the above mentioned modulations in the Earth rotation.

Keywords: EARTH ROTATION, CHANDLER WOBBLE, LOD, LUNAR ORBIT

1. Introduction

The rotation of the Earth is the subject of research in geodesy, astrometry, and geophysics. In the 19th century, an increase in the accuracy of observations made it possible to detect changes of latitudes (the polar motion, PM). With the advent of quartz clocks in the first half of the 20th century, the variations of the angular velocity of the planetary rotation also manifested itself [1,2]. Fig. 1 shows the anomalies of the length of the day, LOD, reflecting how much (in milliseconds of arc) the length of the day has changed due to acceleration (LOD decreases) or deceleration of the planet. Against the background of long-term (20-25 years) variations, annual and interannual fluctuations are observed.

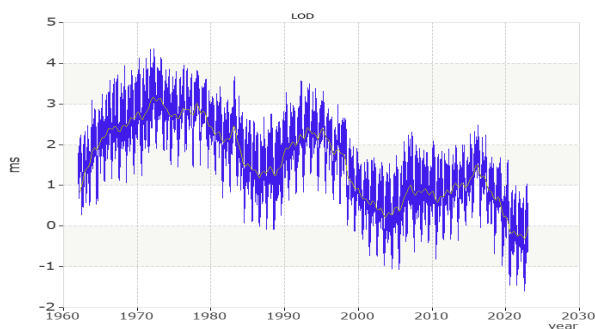


Fig. 1 Variations of LOD from EOP CO4 bulletin.

Figure 2 shows the trajectory of the Earth's pole since 1842 in the terrestrial reference frame (TRF). Its main components are the pole drift, the annual wobble, and the Chandler wobble (CW) with the period of 433 days and variable amplitude of about 100 ms of arc (3 m on the planet's surface). In the 1930s and 2020s, the CW disappeared.

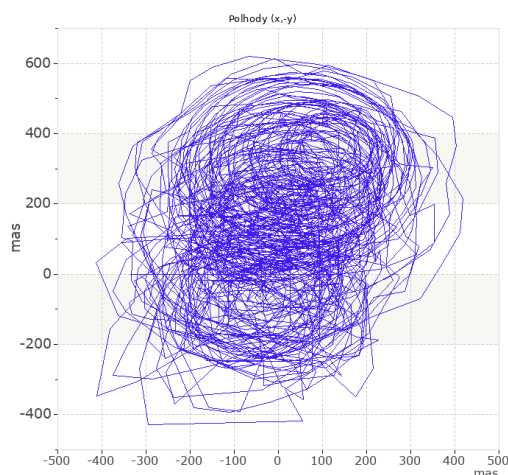


Fig. 2 Polar motion from EOP CO1 bulletin (X up, -Y right).

The Earth is a spinning top located in the gravitational field of the celestial bodies surrounding it. The moment of forces from the Moon and the Sun causes precession and nutation of its axis in the inertial frame, well modeled by the IAU 2000 model [3] (former name MHB 2000). Observations show minor deviations of the real position of the planetary rotation axis in the celestial reference frame, CRF. These deviations are called Celestial Pole Offsets, CPO (dX, dY), and, along with LOD, x and y coordinates of the pole, constitute five Earth rotation parameters, ERP. Fig. 3 shows the CPO dX coordinate since 1985. Against the background of noise, a 430-day period of Free Core Nutation FCN appears. Its amplitude is at the level of ~0.3 milliseconds of arc, but in 2000 and 2022 it noticeably decreases [4].

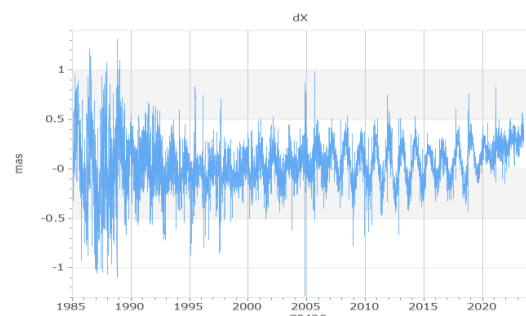


Fig. 3 CPO dX from EOP CO4 bulletin.

From the presented ERP data, it can be concluded that a number of anomalies appeared in the Earth's rotation in the 2020s. The LOD reached minimum in 2022, comparable only with the minimum of 1930s, the Chandler oscillation died out, and the free core nutation signal disappeared. Features in the Chandler wobble of the pole can be revealed more clearly by filtering out other components of the polar motion. Figure 4 shows the CW extracted by various methods on example of its x-coordinate. One can see amplitude fluctuations with quasi-40- and 90-year periods [5].

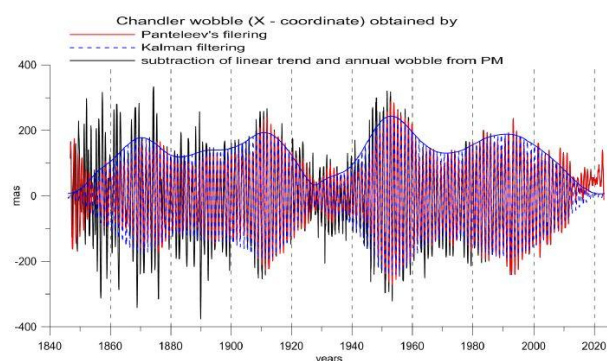


Fig. 4 Chandler wobble filtered from EOP CO1 bulletin.

2. Approaches used to explain ERP variations and geometry of the tide

If the Earth were an absolutely rigid body, it would not change its shape and moment of inertia. Under the action of centrifugal forces, the planet acquired a spheroidal shape with a polar radius 21 km smaller than the equatorial one. The presence of many layers makes the Earth a complex system with viscoelastic properties.

Under the action of moments of external forces, the compressed top undergoes precession-nutation motions. The IAU 2000 theory allows to calculate them by passing the nutations of the solid Earth at different frequencies through the transfer function of the real Earth with resonant frequencies calculated theoretically in advance. Of these two, CW and prograde FCN eigen oscillations, are actually observed, while the inner core wobble (ICW) and near diurnal free wobble (NDFW), have not yet been detected [6].

Astronomers have divided the variations in the Earth's rotation into two frequency bands: precession and nutation and polar motion, PM. The first two processes are analyzed in the celestial reference frame CRF having periods more than two days. The PM lies outside the range from -0.5 to 0.5 cycles per day in CRF, but is conventionally considered in the rotating terrestrial reference frame TRF, which means that all the frequencies are shifted by one cycle per day. In TRF, the PM frequencies are outside the range from -1.5 to -0.5 cycles per day [3].

This was done taking into account that all the planets, the Sun and the Moon have slow motions in the celestial system and the components of their influences (torques) on the Earth are low-frequency in CRF. These effects can be studied both in Euler angles and in more general coordinates, for example, Andoyer variables, using the Lagrange or Hamilton equations.

It is more difficult to construct a theory of polar motions, since they occur mainly under the influence of geophysical factors, i.e. redistribution of the masses of the Earth, changes in the ocean currents, atmospheric winds, etc. Seasonal changes associated with the movement of the Earth around the Sun, causing variations in insolation and hemispheric heat transfer, are fairly regular and predictable. But difficult-to-predict phenomena, such as earthquakes, the El Nino climate oscillation, the passage of cyclones, also interfere and forces PM. It is very difficult to calculate the energy of these processes and construct the Lagrange equations for them. An approach based on the conservation of angular momentum, AM, law is used. If in one of the shells AM has changed, for example, increased, then the solid Earth should reduce its rotational speed. The Euler-Liouville equations for the motion of the pole and Earth's rotational velocity changes are trying to take into account in the form of excitaton functions all the redistributions of mass and proper motion in the shells, as well as changes in the inertia tensor components caused by deformations of the Earth's figure.

However, the question remains open: how the Sun, the Moon and other celestial bodies can influence the circulation in the ocean and atmosphere, processes in the depths and other geophysical phenomena, influencing the movements of the pole. We do not raise the question of why there are no clear manifestations of the 11-year solar cycle in meteorology, or why the 433-day Chandler period has not been revealed in other geophysical phenomena. We neither are trying to return to those views that existed at early steps of the scientific understanding of the world, when the influence of the planets on the fate of the world was of interest to astrologists. But we rise the following question as legitimate: is it possible that the precession-nutation theory, although taking into account the moments of forces from the planets that change the orientation of the axis of the gyroscope – Earth in inertial space, ignored the problem of the influence of celestial bodies on geophysics contributing to the PM? Here we meet the problem of divergence of the scientific branches, when even within one field the separate

directions of the studies are isolated and do not elaborate the interdisciplinary problem.

The influence on the Earth from the celestial bodies comes through the tides. They attracted attention of many scientists: from Newton and Galileo to Laplace, Darwin, Lord Kelvin, Schrödinger, Jeffreys, Melchior, and others. The theory of the Earth's response to the tidal potential, taking into account Love numbers, is well developed. The Laplace expansion of tides is a kind of approximation, when the ellipsoidal (second order) form of the tidal potential is approximated by a series of zonal, sectorial and tesseral harmonics [7]. In the harmonic theory of tides many frequencies arise in the diurnal, semidiurnal and long-periodic ranges. The complex nature of the Moon's movements is taken into account in the arguments of harmonics, including all the six orbital parameters changing in a long-period inequalities. Among them, the movement of the ascending node of the lunar orbit with a period of 18.6 years to the west and the 8.85-year drift of the perigee to the east.

Our attention was drawn to the combination of these processes by the works of N.S. Sidorenkov [8]. Obviously, depending on the location of the ascending node, the orientation of the lunar orbital plain and the declinations the moon reaches in its monthly course across the sky depend. The position of the perigee on orbit, when the Moon is moving faster and is closest to the Earth, determines both the time it takes for the moon to reach maximal declination and the strength of the tide. In syzygy, when the Sun, Moon and Earth are aligned along the same line, the tides from these two luminaries add up, leading to the maximum amplitude of the tidal wave. If at the same time the Moon is in perigee, then it will be even stronger.

Yu. N. Avsyuk [9] drew attention to the fact that the full moons, FM, in perigee (the same for new moons, NM) are separated by an interval of 412 days, very close to the 433-day period of the Chandler wobble. We plotted these events by blue (FM) and yellow (NM) stars in Fig 5. We noticed that the mutual synodic period of these two processes is about 22 years. If we take at every midnight (thereby demodulating the rotation of the planet) the direction in which the instantaneous pole of the Earth is displaced in the Chandler motion and determine the angle it makes with the direction to the perigee, then it turns out that the angle between them opens with 22-year period, i.e. directions along which the perigee full moons and new moons occur wrt CW shifts across the sky, describing a circle in 22-23 years. Similar quasi-periodicity is observed the decadal oscillations of LOD (Fig. 1) and antinodes (humps) of the amplitude of the Chandler oscillation (Fig. 4).

Considering the ascending node of the lunar orbit motion along the ecliptic, which determines the lunar orbit orientation relatively to it and equator, it turns out that in 22 years the perigee goes twice into one (for example, northern) hemisphere and thrice into the other. Vice versa in the next cycle. This leads to idea that the antinodes of the CW amplitude, which just reflect the untwisting of the axis in the interval of ~22 years and spiraling in the next interval [5,10], can be a consequence of the geometry of the tidal wave movement along the Earth's shells.

The axis of symmetry of the tidal potential is directed from the center of the Earth to the tide-forming body (the Moon). Moving across the sky, the Moon deforms the Earth in different directions like pastry, changing its shape and the currents in the shells. The whole complex of accompanying redistributions of masses, friction of the material dragged by the tide is very complex, heterogeneous across the hemispheres and depends on the amplitude of the tide. The latter depends on how close the Moon is to the Earth and how the tides from the Moon and the Sun are mutually summed up. That is why syzygies in perigee attracted our attention: they reflect the sequence of mutual positions of the Moon, Sun, perigee and nodes.

Assuming that the Chandler wobble lows near 1927 and 2022 are not accidental, we have noticed from Fig. 5 that in 1927 the ascending node of the lunar orbit, located at the point of the summer solstice, formed a quadrature (right angle) with perigee, located at a point ~6° north of the autumn equinox (due to the tilt of the lunar

orbit). This year, the big full moon occurred near the date of the vernal equinox. Due to the fact that two rotations of the perigee $8.85 \times 2 = 17.7$ years last one year less than the precession cycle of 18.6 years, the ascending node lags behind and does not have time to return to the same point on the ecliptic, when the perigee again comes to where it was two cycles before. Therefore, the relative positions of the node and perigee grows, turning around the sky with a synodic period of ~ 180 years. Due to this, the dates of big full moons (in perigee) drift and after 90 years, a perigee new moon comes to the place (in a year) of the perigee full moon (compare tow panels of Fig. 5). Therefore, 90 years later - in 2020, when the node came back to the point of the summer solstice, the perigee came to a point 6° south of the autumnal equinox (since this sector of the lunar orbit is inclined under the ecliptic) and formed a quadrature with the node again. The Chandler wobble has faded. The decay of the CW, as follows from the analysis of observations [4,5,10], is also accompanied by its phase change of 180° , so, it flips. We found that due to the peculiarities of the inclination of the lunar orbit during the first 90 years, the series of big full moons go to the northern hemisphere sequentially to quite higher and lower declinations, while in the southern hemisphere they reach only the same very moderate ones. In the era of the disappearance of the CW, the situation reverses. This means that the described phenomenon be responsible for the changes in the amplitude of the polar motion. How this is synchronized with the LOD is not yet clear, but, in our opinion, the synchronization is seen from observations [10].

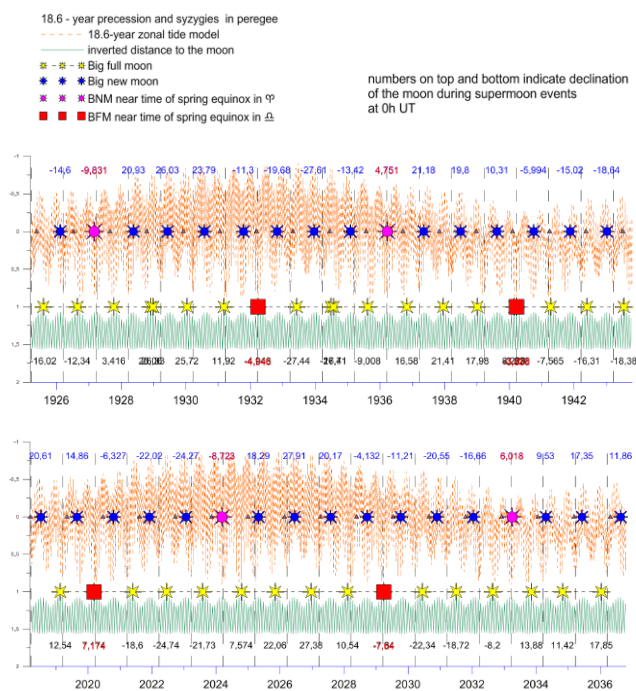


Fig. 5 Syzygies in perigee sequence on the background of 18.6-year cycle of tides.

3. Conclusions and Discussion

We presented considerations regarding the possible reasons of the appearance of 90-year and 20-25-year decadal modulations in the ERP: amplitude of the Chandler oscillation, LOD and CPO. The geometry (inclination) of the lunar orbit and its elongation are changing cyclically in the sky, and the interchange of syzygies in perigee reflects (measures) it. The revealed changes in mutual configurations of the Sun, Moon, perigee and nodes correspond to the epochs of anomalies appearance in the ERP. For a more convincing proof, it is necessary to carry out a detailed calculation of the components of inertia tensor changes, taking into account the subtle effects of the passage of a tidal wave over asymmetric (in terms of the distribution of water and land) hemispheres, the mutual addition of the lunar and solar tides, dissipation, and, possibly, the

action of external moments of forces on the tidally elongated figure of the Earth.

Despite the fact that the movement of the nodes of the lunar orbit and perigee have been known for centuries and are taken into account in the harmonic theory of tides, the IAU2000 theory of precession and nutation, the tide models for LOD, etc., the author admits that the interaction of lunar orbital precession and perigee movement can cause unaccounted changes in the Earth's shells that affect the ERP. The mechanics of heaven, acting on the deformable Earth - a gyroscope, synchronizes the course of geophysical processes in the atmosphere, ocean, core on time scales of tens of years, causing long-term anomalies in the planetary rotation.

Long-term observations just started to allow us to identify such effects and their causes. The various superimposed irregularities hide from us what may be associated with the impact of regular cycles of the cosmic origin. The rotation of the Earth studies are at the intersection of astronomy and geophysics. Here we can expect a more noticeable manifestation of astronomical factors, which will make possible to trace their role in the local processes of meteorological, climatic, and hydrological nature [6,10]. In the near future, our specialized publication will appear, where we hope to give development of the presented impetus.

References

1. Bizouard C., *Geophysical modelling of the polar motion*, De Gruyter, (2020).
2. Gross R., *Theory of Earth Rotation Variations, VIII Hotine-Marussi Symposium on Mathematical Geodesy*, (2015), <https://doi.org/10.1007/978-3-319-30530-1>
3. Dehant V. & P. M. Mathews, *Precession, Nutation, and Wobble of the Earth*, Cambridge University Press. 554 p. (2015), ISBN 9781107092549
4. Malkin Z, Belda S, Modiri S. Detection of a New Large Free Core Nutation Phase Jump, *Sensors*, **22**(16):5960, (2022), <https://doi.org/10.3390/s22165960>.
5. Zotov L., N. Sidorenkov, Ch. Bizouard, Anomalies of the Chandler Wobble in 2010s, *Moscow University Physics Bulletin*, **Vol. 77**, N. 3, pp.55-58, (2022), <https://doi.org/10.3103/S0027134922030134>
6. Zotov L. *Earth rotation and climate processes*, 306 p., MIEM HSE, (2022)
7. Lowrie W., *A students guide to geophysical equations*, Cambridge Univ. press, (2011).
8. Sidorenkov N.S., Synchronization of terrestrial processes with frequencies of the Earth-Moon-Sun system, *Astronomical and Astrophysical Transactions (AAPT)*, **Vol. 30**, Iss. 2, pp. 249-260, (2017).
9. Avsyuk Yu. N., Tidal forces and natural processes, Shmidt IPE RAS, Moscow, (1996).
10. L. Zotov, Ch. Bizouard and N. Sidorenkov, Chandler Wobble and Lod Anomalies in 2010–2020s, *Proceedings of the 19th Annual Meeting of the Asia Oceania Geosciences Society (AOGS 2022)*, p. 153-155 (2023). <https://www.worldscientific.com/doi/epdf/10.1142/13385>
11. Zotov L., Bizouard C., Shum C.K., A possible interrelation between Earth rotation and climatic variability at decadal time-scale, *Geodesy and Geodynamics*, **Vol. 7**, Iss. 3, pp. 216-222, KeAi, China, (2016), [tps://doi.org/10.1016/j.geog.2016.05.005](https://doi.org/10.1016/j.geog.2016.05.005).

Web-based Business Process Management System

Milena Karova^{1,*}, Iliyan Boychev²
 Technical University of Varna, Varna, Bulgaria¹
 Technical University of Varna, Varna, Bulgaria²
 m.karova@tu-varna.bg

Abstract: The report presents a developed Web-based information system for managing business processes. The system includes system design and development, database design and development, and Web interface design. A special encryption algorithm was used to generate the key. The main purpose is to provide protection, both at the system's entrance and during data transfer and storage. For the web platform, the main protections are 1) Control of access to the system by filling in a username and password, individual for each external user; 2) Ensuring protection of input data by irreversible hashing of the password with a randomly generated key from the system; 3) Using resource protection i.e. without authorization it is not possible to review and change the information in the database 4) Using of special unique identifiers to access the database information; 5) Using a token to send requests to the API.

Keywords: web-based information system, business process, password protection, authorization, encryption algorithm, tasks, secure communication

1. Introduction

Creating a web platform for a business, regardless of industry, can have a huge impact on its success and greatly improve productivity. Allowing third parties to monitor and even participate to some degree in a company's work process would attract more customers. In the development of a web platform, an important role is played by the programming interface. Such a well-defined interface enables a secure and easy exchange of data streams with customers and partner systems. This, in turn, makes it possible to provide different functions and services in different forms - desktop applications, mobile applications, websites, and others.

Nowadays, having a web platform and API plays an important role in business development. They provide the opportunity to integrate modern functionalities and services to attract more customers and partners. An important part of creating an API, in addition to selecting and implementing an architectural model, is good documentation and building strong system defenses against various types of cyber attacks.

There are a lot of software products [1][2][3] that offer services related to personnel management. Research has been done on what some of the better-known software has to offer and based on the research a comparative feature has been made with the current development.

"BambooHR" is a well-designed software solution that helps automate a company's operational tasks. The software collects and provides useful information for employees to streamline work processes and improve efficiency. "Workday" provides a modern and easy-to-use interface similar to BambooHR[4]. The software offers a wide variety of robust features that help companies with financial management, human capital management, service automation, talent management, recruiting, compensation management, and analytical reporting. "IceHRM" is one of the most simplified and effective information systems due to its security and accessibility [5]. Most companies prefer the product because of its centralized support, which makes managing the company and its resources easy. The app has a rich user interface that makes it extensible and customizable.

All three products have unique functionalities such as employee time tracking, automatic payroll process, insurance addition, email system integration, the ability to integrate third-party software products via API, and many more operations. The products have various implemented protections like, hashing, encryption, and tokens on APIs. By integrating APIs, applications easily manage to modernize their content while also managing to implement new up-to-date functionalities. In this way, they remain competitive in the market and manage to develop cross-platform. Despite their modern look, this software is dependent on cloud space and requires a constant internet connection, or their offline version is limited to functionalities.

2. Design of Web System

A) Employee tasks management

The main functionality supporting the management of the work of employees is the creation of tasks. To create a task, at least two users are needed - one who assigned the task and one to whom it was assigned. It is necessary to determine the priority of the task so that the manager can plan the tasks properly and the more urgent ones are done first. Status is also needed, which can be changed during the execution of the task. All this data should be stored in one centralized database. Thus, managers and directors will have access to information based on which they can properly plan the work process. This process is shown in Fig. 1

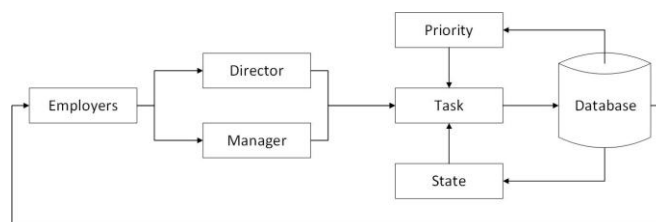


Fig. 1. Create task process

To integrate communication with third parties, having a separate table with authorized users is good. An API compliant with modern architectural requirements is also needed. RESTful APIs stand out as having the most advantages. They, in turn, require additional security measures such as a sufficiently secure authorization token for each request, limiting the number of requests received per unit of time, encrypting communication, creating an external representation of identifiers so that foreign resources cannot be accessed, requiring certificates, and others. A well-secured web platform should have protection on every page, whether the user trying to access the resource is authorized. Accordingly, when logging in, it is good to keep this authorization, whether it is in the form of an API key or the protected version - a token.

Privileges need to have a name and a number, an index that shows the priority. For the states, in addition to the name, it is necessary to note whether each is finite. If it is finite, backups will need to be provided (See Fig. 2), since running tasks carry more useful information than closed ones, and the total number of tasks can become too large and difficult to load for a simple machine. Archived tasks must have their table in the database, analogous to a current tasks table.

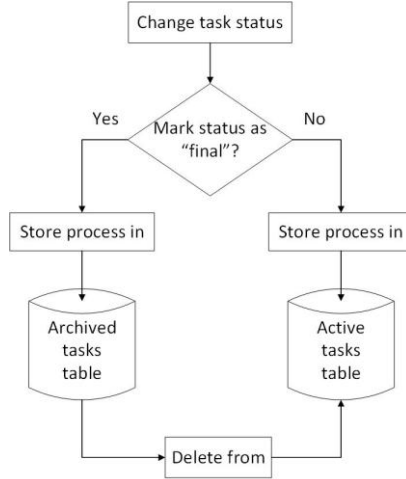


Fig. 2. Archive complete task steps

B) Web system

Fig. 3 is shown a UML-case diagram of the development Web system

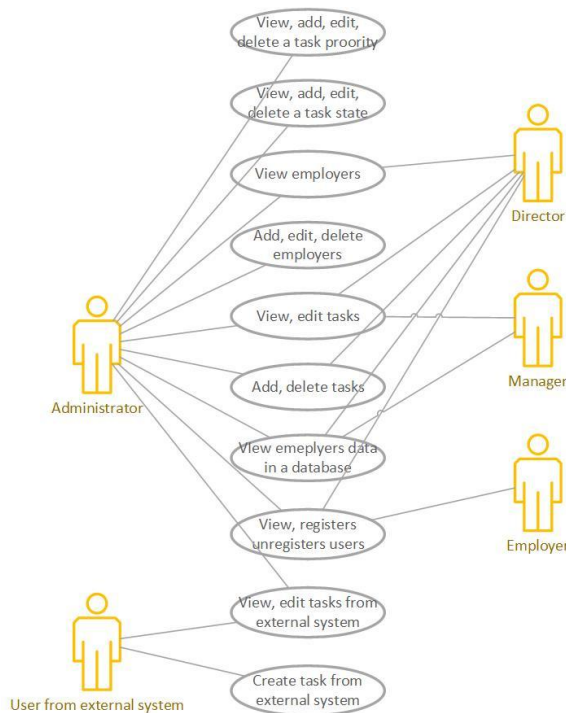


Fig. 3. UML-case diagram of Web system

Four different levels of access are available in the system (Fig. 3):

- administrators
- directors
- managers
- employees

The administrator is responsible for the various settings in the system as well as servicing new or existing employees. He has the highest level of privileges and for him, all the functionalities of the system are unlocked. The administrator can view, add, edit, and delete the states and priorities that can be selected when creating a task. When setting states, a state can be marked as final by marking the backup option. This way, changing the status to final for the task will remove it from the current task table and move it to the archived task table. Administrators can view, add, edit, and delete tasks and employees, register and delete external users, and view,

delete, and change only the status and status of tasks entered by external systems. To be able to assign tasks in the system, there must be at least two employees, at least one entered priority and at least one entered status. Admin can also change the status of registered employees and view their profile in the system. Only the administrator cannot delete his profile. In this way, at least one administrator is always provided.

The director can view information about registered employees and current tasks. It can monitor the status of tasks, assign tasks to managers, register and delete external users, and view, delete, and change only the status and status of tasks entered by external systems. It can also edit and remove tasks entered by the main system, reassign them to another employee, and change their status. To be able to assign tasks in the system there must be at least two employees, at least one priority entered and at least one status entered by an administrator.

Managers, in turn, can only view tasks assigned to them and change their status. Based on this information, they can make decisions about the work process, such as what will be the tasks of the day that the employees will have to complete. The system clearly shows by priority which tasks are more urgent than others and should be completed first. With statuses that indicate a task as completed, it is archived. This backup is deleting the task from the current task table and moving it to the archive task table as well. The task is removed from the manager's task list and is no longer loaded. Managers can also review the information entered for them in the system.

Employees can review their data entered into the system

C) Optimistic approach

The system loads data from the database into the memory of the machine on which it is launched. This gives rise to a certain problem related to the actuality of the data being worked with. If a director-level employee edits the title of a task and at the same time a manager-level employee has already changed the status of the task and saves it in the database, the director would be working with out-of-date data. If attempted to write, this would compromise the already existing information on the server, as the director would unknowingly change the title and status without intending to. This kind of problem is easily solved with an optimistic approach. It is implemented by adding column in the system tables. This column indicates the number of changes made so far. In the example described above, if the director tries to save the task by changing the title only, the system will go to the database, and read the counter recorded there. Then the values of the newly read counter and already read and stored in memory will be compared. If the values do not differ, the change will be written to the database and the counter will be incremented by one. But if the values don't match, it means that the record was changed prematurely, as, in the example above, the manager changed the status of the task before the director saved his change. In such a case, any actions with the record are terminated until it is reloaded and updated in memory (See Fig. 4).

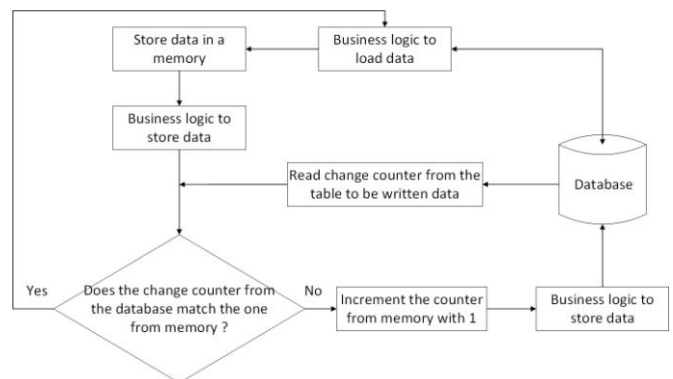


Fig. 4. A summary of the optimistic approach.

D) Web System Architecture

The system architecture is based on the Document-View model. The document stores the data, manages its printing, and coordinates the updating of multiple data views. The view displays the data and manages the employee's interaction with it, including selecting, adding, editing, and deleting.

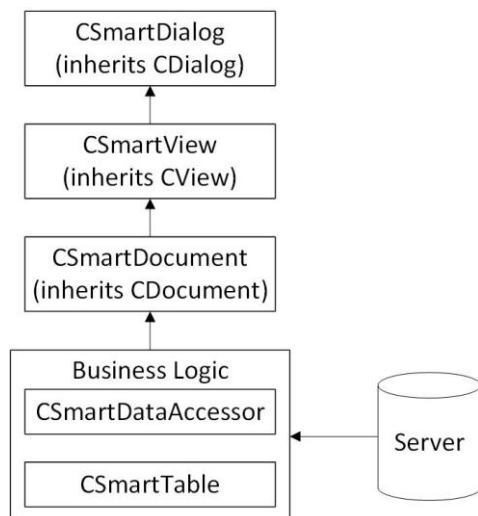


Fig. 5. Web System Architecture

The architecture is based on the following classes:

- CDocument – class for supporting objects used to store or control program data and provides the basic functionality of documents defined by the programmer.

- CView – provides the basic functionality of views. A view is attached to a document and acts as an intermediary between the document and the user. The view renders the document data on the screen and interprets user input as operations on the document. In the current development, the CListView class, a descendant of CCtrlView, which in turn is a descendant of CView, is used for data visualization. CListView simplifies the use of the list control and CListCtrl, the class that encapsulates the list control functionality, with the MFC document view architecture

- CFrameWnd – supports objects that provide the frame around one or more document views. In current development, it is inherited from CMDIFrameWnd, which in turn is inherited from CMDIFrameWndEx. CFrameWnd's successors build on its base functionality.
- CDocTemplate – maintains an object that coordinates one or more existing documents of a given type and manages the creation of the correct document, view, and frame window objects for that type. It can be either CSingleDocTemplate or CMultiDocTemplate, depending on whether the system uses one or several different documents for different data.

In the current system, "Smart" classes have been developed, inheriting the base classes and upgrading them according to the needs of the application (Fig. 5). Additional classes added:

- CSmartTable to work with the data (read, add, edit, and delete) directly from a specific table in the database.

- CSmartDataAccessor takes care of the conditions under which it is read, written, and delete, and takes care if changes are required on the other tables, except the one that is the main one for the class

An advantage of this type of architecture is that in the presence of multiple views, the data used is kept in the same document. This allows individual views to work with the same code common to all views. This code is in the document. It, in addition to storing and processing the view data, also takes on the task of updating all views when the data changes from any of the views using the document.

The implementation of the Document-View architecture separates the data itself from its display and user operations on it. All data changes are managed through the document class. The

view calls this interface to access and update the data. Documents, their associated views, and the frame windows that frame the views are created from the document template. The document template is responsible for creating and managing all documents of a single data type.

3. Tests

According to the set goals and objectives, the following functional tests were performed on the desktop and the web system:

- User registration by an employee with the role of administrator or director through the desktop system (Fig. 6). Registration is easy by entering a username.

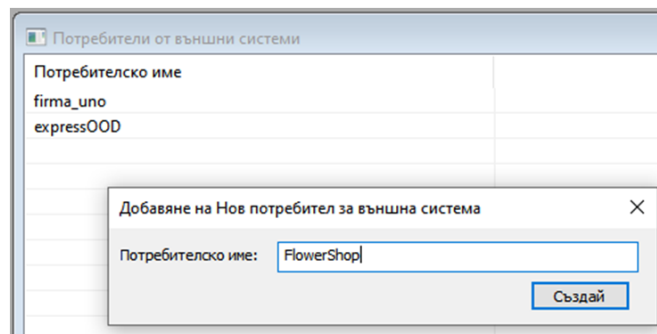


Fig. 6. Registration screen

After authorization, the web platform client receives a JWT with its ID. The token is stored in the browser's Local Storage. After registration, the user can change his password. Warning messages appear when passwords do not match.

- After logging in, all entered tasks of the user are loaded. In Fig. 7 demonstrates how, of all tasks visible through the desktop system, only those registered by "FlowerShop" are loaded.

Наименование	Приоритет	Статус	Редакция	Изтрй
Доставка на цветя	Не толкова важна, но спешна	Незапочната	Редакция	Изтрй
Изпращане на цветя на г-н Иванов	Важна и спешна	В процес на изпълнение	Редакция	Изтрй
Получаване на тор	Необработен	Необработен	Редакция	Изтрй
Доставка на цветя	Необработен	Необработен	Редакция	Изтрй

Име	Приоритет	Състояние	Назначена от
Доставка на цветя	Не толкова важ...	Незапочната	FlowerShop
Изпращане на цветя на г-н Иванов	Важна и спешна	В процес на изп...	FlowerShop
Получаване на тор	Необработен	Необработен	FlowerShop
Доставка на цветя	Необработен	Необработен	FlowerShop
Доставка на гуми	Необработен	Необработен	expressOOD
Смяна на масло	Необработен	Необработен	expressOOD

Fig. 7. All table tasks entered by the logged-in user.

The User can create and edit tasks. Every single task can be deleted. When logging out of the web system, the token is deleted.

The Administrator and Director role employees can view, edit and delete tasks entered from an external system (Fig. 8). Editing can only be done on the status and status of a task.

4. Conclusion

Based on the tests performed, the development fulfils all the set goals and tasks. The web system allows viewing, creating, editing, and deleting tasks, with various protections applied to the available resources. The API provides security by encrypting the access

password with a key, limiting the number of requests that can be received per unit of time, and requiring authorization with each request. The desktop system has four different levels of access, each of which is tailored to the functionality it needs to perform. Additional services related to creating and deleting users to access the web interface and viewing, editing, and deleting tasks entered from an external system have been implemented. Through the web system, transparency is achieved in the work of a company. Its customers are allowed to monitor and even participate in the work process by managing tasks entered by them and monitoring their completion. The programming interface allows flexibility in developing different client applications with which to exchange data securely. Despite the available functionalities, the development could be further developed, such as the implementation of an option to send leave requests from employees to management or send emails.

Име	Приоритет	Състояние	Назначена от
Доставка на цветя	Не толкова важ...	Незапочната	FlowerShop
Изпращане на цветя на г-н Иванов	Важна и спешна	В процес на изп...	FlowerShop
Получаване на тор	Необработен	Необработен	FlowerShop
Доставка на цветя	Не толкова важ...	В процес на изп...	FlowerShop
Доставка на гуми	Необработен	Необработен	expressOOD
Смяна на масло	Необработен	Необработен	expressOOD

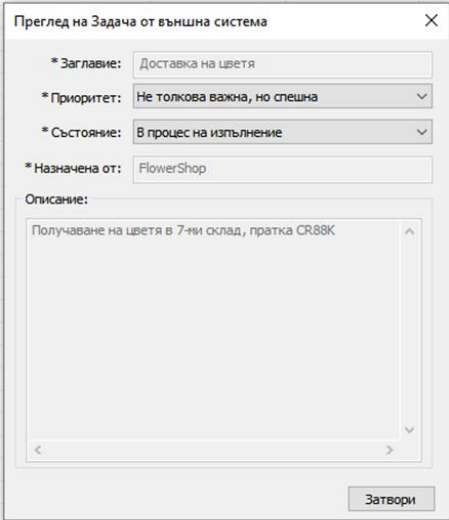


Fig. 8. Register of tasks entered from an external system.

5. References

1. E. Medvedeva, S.Kroshilin, Sergey. Transformation of Personnel Management Process: Reshaping Responsibilities of Non-Medical Personnel. City Healthcare. 4. 60-72. 10.47619/2713-2617.zm.2023.v.4i2;60-72. (2023)
2. Y. Tokareva, E. Gasparovich, E. Uskova, A. Zotov, (2023). Personnel Development Management at the Enterprise With Mixed Labor Organization. Management of the Personnel and Intellectual Resources in Russia. 12. 5-12. 10.12737/2305-7807-2023-12-2-5-12,(2023)
3. A. Litvinyuk, L. Babynina, L. Kartashova, L. Ivanova-Shvec, E. Novikova, Z. Troska, E. Kuzub, S. Kartashov, (2023). Modern technologies of personnel management. 10.12737/1863127. (2023)
4. K. E. Pearlson, C. Saunders, D. F. Galletta, Managing and Using Information Systems: A Strategic Approach, 7th Edition, Wiley, ISBN: 978-1-119-56115-6, (2019)
5. K. Sousa, Effy Oz, Management Information Systems, Seventh Edition, Cengage Learning EMEA, ISBN: 9781305172180, (2014)

Application of Innovation in the Event Tourism in Azerbaijan

Rana Sultanova¹, Hikmat Hasanov²

Azerbaijan National Academy of Sciences¹

Azerbaijan Tourism and Management University, Baku, Azerbaijan²

rena-sp@mail.ru, Hikmat.hasanov@outlook.com

Abstract: The role of event tourism in Azerbaijan is increasing each year slightly by taking place in sports events, festivals, musical competitions, and tourism fairs. Since 2012 when Eurovision Song Contest was held in Baku, Azerbaijan has become one of the event centers in the world. As the number of events held in Baku increases, tourist arrivals also increase slightly. By mentioning event tourism, festivals, seminars, meeting events, and some other events are taken into consideration.

As different events are held in Azerbaijan every year, there is a huge need for the application of innovative approaches. In this article, different innovation examples, as well as the impact of event tourism have been researched.

KEYWORDS: EVENTS, NEW STRATEGIES, SOCIOECONOMIC DEVELOPMENT, A NEW TYPE OF TOURISM, SUSTAINABLE DEVELOPMENT, INNOVATIVE APPROACH

1. Introduction

Various types of events have always been an important part of society. The structure of events has transformed and modernized since ancient times. Events are now considered a great motivator in the field of tourism, and it has an impact on the development of destinations [2]. Countries are trying to take advantage of events in order to attract tourists, and as a result, events have been used to gain popularity, and reputation and support economic development [6]. As a result, some cities have already been branded. the solid state.

The role of event tourism in Azerbaijan is increasing each year slightly by taking place in sports events, festivals, musical competitions, and tourism fairs [1]. Since 2012 when Eurovision Song Contest was held in Baku, Azerbaijan has become one of the event centers in the world, and because of that, Azerbaijan started to create a new and better brand. Within five years, Azerbaijan hosted many local and international events such as Eurovision Song Contest (2012), Baku European Games (2012), the 42nd Olympiad (2016), Judo Grand-Prix (2016), Baku Solidarity Games (2017) and so on (<http://tourismboard.az/>). Baku is already known as a sports center, and in the nearest future, some sports events, UEFA European League Final (2019), and European Football Championship (2020), will be held in Baku. Developing the tourism industry in Azerbaijan has already been a priority for the country to decrease dependency on the oil sector. However, event tourism is still a new type of tourism in Azerbaijan. Developing event tourism and achieving sustainable tourism development is required to find out and apply new strategies, programs, and plans. If Azerbaijan applies new and better strategies and plans, it can help to improve the socio-economic situation of the country.

Azerbaijan has been ranked and the country has increased its credit ranking through international credit rates such as "Fitch Ratings," "Moody's," and "Standards & Pauvres." The status of Azerbaijan in the World Bank and International Finance Corporation report "Doing Business" has also changed. In the "Global Competitiveness Study," published by the World Economic Forum, Azerbaijan is also one of the leading countries in the CIS and the regional countries. According to the World Bank, Azerbaijan has a 'high-average revenue' list.

The rapid development of the economy, increasing the influence of Azerbaijan, attracts tourists from all over the world. As a meaningful result of this, incoming tourism develops year by year. In according with the recent statistic, tourist arrival has already reached around three million. As tourism develops, turnover lets develop tourism, and by that, usage of tourism resources and potential of tourism are used effectively. Besides generating income, the development of tourism allows to the country show off its culture and traditions to the world [3]. To increase tourism potential and tourism itself, the year 2011 was announced as a "tourism year". Tourism does not only develop in Baku. At the same time, in the region of Azerbaijan, positive tourism growth was

recorded. For this purpose, tourism agencies, hotels, tourism complexes were created in the regions of Azerbaijan. In accordance with this strategy, more 35 five stars hotels were created.

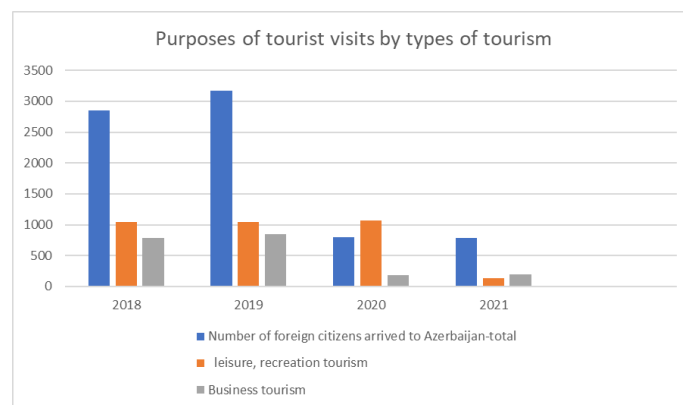


Fig. 1 Purpose of tourist visits by types of tourism

Figure 1 displays the purpose of tourist visits. Leisure and business tourism are the main types of tourism. Business events play a significant role in increasing the number of business travelers. However, COVID had very negative effects on tourism industry of Azerbaijan.

2. Innovative approaches in event tourism

Event tourism refers to the travel and participation in events, conferences, trade shows, festivals, and other organized gatherings held in different locations. It involves individuals or groups traveling to attend or participate in these events, often combining leisure, business, and cultural experiences.

In recent years, event tourism has witnessed significant innovations that have transformed the way events are organized and experienced. These innovations encompass a wide range of technological advancements and sustainable practices that aim to enhance attendee engagement, streamline event management, improve sustainability, and create memorable experiences [2].

The introduction of mobile applications, virtual and augmented reality, live streaming, and webcasting has revolutionized the way events are accessed and experienced. Attendees can now access event information, interact with other participants, and engage with event content through their smartphones, tablets, or virtual reality headsets. This enhances convenience, connectivity, and the overall event experience.

Technological innovations such as RFID and NFC technology, social media integration, artificial intelligence, and chatbots have transformed event operations, making processes like ticketing, access control, payments, and attendee assistance more efficient and seamless.

Smart venue technology utilizing IoT devices, gamification techniques, and sustainability initiatives have also become

prominent in event tourism. These innovations enhance event venues with features like intelligent lighting, climate control, crowd management systems, interactive displays, and sustainable practices like waste reduction and renewable energy sources.

These innovations not only enhance the attendee experience but also provide event organizers with valuable data and insights through data analytics and crowd management technologies. This information can be used to improve event planning, marketing strategies, and decision-making for future events.

Furthermore, event tourism is constantly evolving, and new innovations continue to emerge, driving the industry forward. These innovations aim to create immersive experiences, foster engagement, improve operational efficiency, and promote sustainability in the dynamic world of event tourism [5].

In recent years, several innovations have been utilized in event tourism to enhance the overall attendee experience and improve event management. Here are some notable innovations:

1. **Mobile Applications:** Event-specific mobile applications have become increasingly popular. These apps provide attendees with event schedules, maps, speaker information, real-time updates, networking opportunities, and interactive features. They enhance communication, engagement, and convenience for participants.
2. **Virtual and Augmented Reality:** Virtual reality (VR) and augmented reality (AR) technologies have been employed to create immersive experiences for event attendees. VR can transport participants to virtual event environments, while AR can overlay digital information on the physical surroundings, providing additional context and engagement.
3. **Live Streaming and Webcasting:** Event organizers now leverage live streaming and webcasting technologies to reach a broader audience beyond the physical event venue. This allows remote attendees to participate virtually, ensuring wider engagement and accessibility.
4. **RFID and NFC Technology:** Radio Frequency Identification (RFID) and Near Field Communication (NFC) technologies have been used for various purposes, such as ticketing, access control, cashless payments, and interactive experiences. These technologies streamline event operations, enhance security, and enable personalized interactions.
5. **Social Media Integration:** Social media platforms play a crucial role in event promotion and engagement. Integrating social media features into events allows attendees to share their experiences, interact with other participants, and amplify the event's reach through user-generated content.
6. **Artificial Intelligence (AI) and Chatbots:** AI-powered chatbots have become prevalent in event tourism to provide instant assistance, answer inquiries, and offer personalized recommendations. They can handle routine queries, provide event information, and enhance attendee engagement.
7. **Smart Venue Technology:** Event venues are incorporating smart technologies, including Internet of Things (IoT) devices, to improve operational efficiency and enhance the attendee experience. This includes features such as smart lighting, climate control, crowd management systems, and intelligent signage.
8. **Gamification:** Gamification techniques are used to increase attendee engagement and participation. Event organizers integrate game elements, such as challenges, leaderboards, and rewards, into the event experience to make it more interactive and enjoyable.

9. **Sustainability Initiatives:** Event tourism has witnessed a growing focus on sustainability. Organizers are implementing innovations like eco-friendly practices, renewable energy sources, waste reduction measures, and carbon offset programs to minimize the environmental impact of events.

3. References

1. Alirzayev, A. Turizmin İqtisadiyyatı və İdarəedilməsi, Azərbaycan Dövlət İqtisad Universiteti, 2011, 28 s
2. Backman et al. (1995) Event tourism: an examination of motivations and activities, pp. 15-24
3. Bramwell, B. (1993). Planning for tourism in an industrial city. *Town and country planning*, 62, (1 /2), pp.17-19.
4. Bramwell, B. (1997) Strategic planning before and after a mega-event
5. Crompton, J. (1997). Motives of Visitors Attending Festival Events, *Annals of Tourism Research*, 24(2), s. 425-439.
6. Getz, D. (2008). Event Tourism: Definition, Evolution and Research. *Tourism Management*, Vol. 29, No.3, pp.403-428.

Bulgaria's long journey from consumer to producer of energy equipment

Boyan Asparuhov

University of library studies and information technology, Sofia, Bulgaria¹
b.asparuhov@unibit.bg

Abstract: *The development of energy in our country is one of the good examples, thanks to which it can be claimed that Bulgaria is growing into an industrial country. The study of the stages in this development shows a different attitude towards this industry during the first half of the previous century and then, until the end of the socialist period. Until the middle of the century, energy was extremely underestimated as an area on which the general industrial growth depended, it was neglected financially as a secondary area, for which the differences remained from investments in other directions. A quite natural consequence of this was the weak technical training of the intelligentsia and the inability to develop its own energy production, which led to technological dependence on more developed countries. After the middle of the century, a reversal is noticeable, thanks to which the negative trends are abandoned. There are results that speak for the prioritization of energy policy.*

In addition to being singled out as a separate industry, the energy industry also robs the largest capital funds. The leading understanding is that without the development of energy, there would be no development at all. Undoubtedly, Bulgaria's great achievements in engineering, metallurgy, transport and other industrial sectors would not have been possible without the successful development of the Bulgarian energy industry.

KEYWORDS: HISTORY, ENERGY, DEVELOPMENT, MACHINE-BUILDING

1. Introduction

The industrial development of any society in the 20th century would not have been possible at all without the assimilation of technological abilities to build more powerful and more productive means to ensure higher consumer indicators in energy. Failure to understand that energy is the basis of any economy striving for industrial development condemns any society to technological backwardness. Until 1944 there is practically no energy industry in Bulgaria. The electrification known to bourgeois Bulgarian society is a technological and mechanical import, and the system is maintained and repaired by foreign specialists, mainly from Germany and Austria. In legal and regulatory terms, energy issues and problems are not considered from their own point of view, but only when solving specific issues within the competence of three separate ministries - of public works, of water and agriculture, and of mines. The Bulgarian energy industry will not have its own state department until the middle of the century. This is the reason why the idea of optimal use of water power for the production of electricity was not realized in time, although it was advocated among a small circle of people from the technical intelligentsia in Bulgaria already in the second decade of XX. After the middle of the 20th century, a real turnaround took place in our country. Gradually, the Bulgarian society grew from a consumer to a producer of the energy industry. A specific model is emerging that combines the simultaneous use of exhaustible and non-exhaustible energy sources in the production of electricity. Efforts to build highly efficient thermal power plants, even in conditions of lack of adequate raw material supply, alternate with the development of water power plants using the power of water.

2. Solutions

The socialist government inherited 127 MW of capacity installed in 121 small power plants with an annual production of 311 million kWh. This production covers the electrification needs of 13% of the total number of settlements in our country and 32% of the population. These indicators rank our country in the penultimate place in Europe at the end of the World War II. [1] The data reveal a very low level of energy development, and the production based on foreign projects, imported technologies and machines is grossly insufficient to meet the energy needs of the Bulgarian society, both for domestic consumption and for the development of other industrial branches. The reason for this lag is the lack of an adequate regulatory framework to regulate the development of the energy sector and the absence of unified management. Only in 1928 a separate department of electricity was created under the umbrella of the Ministry of Public Works, although the Society of Engineers and Architects had declared itself the sole legislation and management of the sector a full decade earlier. [2]

In 1929 by order of the Minister of Agriculture and State Properties, D. Hristov, a commission was appointed to draw up a general plan for electrification of the country, using its thermal and hydraulic resources. This commission sat until 1933 without achieving its goals, and the electrification plan was not completed until the 1950s. [ibid]

Only in 1946 the government in its program statement announces that special attention will be devoted to the rapid overcoming of the energy supply crisis by building a comprehensive electrification system based on powerful steam and water plants. [3]

With the establishment of the Ministry of Electrification in 1946, and the Law on Electricity Industry adopted by the National Assembly in 1948 begins the successive construction of a more powerful energy base to overcome the economic backwardness of our country. Increasing the production of existing plants and building new energy capacities are the two main directions of the new energy policy. [1,p.372]

The facilities and the energy base with which Bulgaria crossed the first half of the 20th century are morally outdated and extremely insufficient for the needs of the new industrial development. Our most powerful thermal power plant, left as a legacy from the period before 1944 - the one in the village of Kurilo - reached 14.5 mW, and most of the others were below 1 mW. In 1948, its power was increased to 18 mW. In 1951 and 1955 expansions were carried out at the Pernik TPP, the V. Kolarov", TPP "Yanko Kostov", etc., new diesel generators have also been installed in Northern Bulgaria. At the same time, new thermal power plants are being built - TPP Sofia, TPP "Republika" in Pernik, TPP "Maritsa 3" in Dimitrovgrad. By the mid-1950s, electricity production increased 7 times compared to 1944. [ibid]

This shows that the needs characteristic of the industrial growth of a society have already become inherent in the Bulgarian economy. The registered higher production of electricity gives confidence for setting more distant goals, such as the policy for accelerated economic development of Bulgaria. In a report of the Committee on Industry to the Council of Ministers, delivered in 1960 the need for additional construction of 1 million kilowatts of electric power by 1970 is substantiated. [4] Data from the current consumption of electricity are indicated and a forecast is made for future needs. In 1959 the annual consumption was 3.895 billion kWh. In 15 years, consumption has increased 12 and a half times. It is planned that in 1962 the consumption will reach nearly 8 billion kWh, and in 1970 - 22 - 24 billion kWh. [ibid]

A reference to the data of the Central Statistical Office shows that in 1970 the electricity produced was 19.5 billion kWh, and the consumption was 15 billion kWh. [5] Regardless of the fact that the planned figures were not reached in the desired period, the increase in electricity consumption in our country was a permanent trend until 1989, although a decrease in growth was noticed after 1975, due to the gradual transition to a more economical and efficient use

of energy resources. In order to satisfy the ever-growing needs for electrical energy, the construction of production facilities, which has not been undertaken until now, is underway. In 1960, the first large thermal power plant in our country, Maritsa Iztok 1 (TPP MI 1), was put into operation. In order to reach its planned capacity of 500-550 mW, 8 turbo units with a total capacity of 800 mW were delivered from the USSR in succession, of which 4 pcs. 50 mW and 4 units of 150 mW. (two for TPP MI 1 and two for TPP MI 2).[6] Powers of such a scale in the energy sector were not known in our country so far. Only TPP MI 1 could generate more electricity than all power plants put together to date! With its commissioning, it suddenly turns out that only one new plant increases energy efficiency. This is a technological step forward for the Bulgarian energy industry, a new level of production, promising unlimited consumption and removal of restrictions for further industrial development. This positive amplitude was most noticeable in the decade between 1950 and 1960. The total installed power capacity at the beginning of this decade was 176 mW, and at the end - 929 mW. New capacities were then introduced, providing an additional 730 MW, or 79% of all existing capacities were newly built and equipped with modern equipment. [7] In this case, we observe, on the one hand, the utilization of much more powerful technical facilities, having greater energy indicators, operating at much higher parameters (only one of the two turbounits in TPP MI 1, which has a power of 150 mW, exceeded the entire power generated by all power plants combined from the time until 1944!) On the other hand, there is a new technological moment - construction, through consolidation - 4 turbo units of 50 mW and two more of 150 mW. - united in one headquarters. The consolidation of production facilities and separate units, as a result of which higher indicators have been reached, is a sign that Bulgaria is becoming part of the world's technical progress.

The MI1 TPP emerged as the largest source in our power system and remained a major producer until the mid-1960s, when the first unit of the new MI2 TPP was commissioned. Until 1968 three more units of 150 mW each come into operation and the new plant adds another 600 mW to the national energy system. TPP MI 2 reaches a higher power at the very first stage of its construction and operates with 4 turbine units of 150 mW each. In addition, the newly built capacities, although with greater energy indicators and parameters, create opportunities to reduce fuel costs. (ibid)

Probably the biggest achievement of all is the creation of our own base for the development of energy construction. In fact, the construction of the large thermal power plants in the Marishka basin was realized according to technical projects prepared in the USSR, but Bulgarian engineers participated in their preparation. In a report to the Secretariat of the BKP, the director of Energoproekt reports that in our country hydrotechnical objects, power lines, substations, factory thermal plants and the construction-constructive part of large thermal plants are independently designed. Only the machine-technological and electrical parts of the thermal power plants with medium and large power are not designed independently. [8]

But the report draws attention to the possibility that their design could begin to be carried out entirely by Energoproekt, which would significantly reduce investment costs. Then it was also noted that the benefits of independent design would be complemented by the effect of adopting more economical solutions when solving technical and constructive issues, according to our conditions. (ibid) At a meeting of the Electricity Commission held in Leningrad in May 1963, the needs of the countries (from Eastern Europe) for equipment were determined and recommendations were made for specialization in production. Our nomenclature includes the main thermal power equipment - steam turbine units, steam boiler units and turbogenerators. We insist that the electromechanical equipment - synchronous compensators, capacitors and cables - be included there. The Bulgarian delegate Huben Ovcharov reports that the production of auxiliary equipment, which is expensive, requires a lot of labor and few materials, which our country can benefit from. [8, p.29]

Until 1980 the production of electrical energy from thermal power plants is developed as a priority, because of their high productivity,

although this is not a sufficient motive. Bulgaria's energy policy for the period is guided by the principle of building such capacities that use local primary energy resources as fuel, which unfortunately turn out to be extremely insufficient.

By the middle of the 1950s, quality coal was exhausted and the use of low-calorie lignite coal from the Eastern Mariskie basin began, which until that moment had not been used as a raw material for combustion in general practice worldwide, due to its poor qualities. Bulgaria was the first to start using them for energy purposes by constructing devices for their more efficient burning. [1,p.373]

In 1964, Bulgarian-Soviet studies were launched to establish a scheme for burning coal in the new TPP MI 3, which has a total capacity of 840 MW. The boiler unit of the power plant, constructed entirely by Bulgarian Research Institute of Energy [9], works according to the scheme launched by engineer N. Todoriev for direct burning of lignite coal, significantly reducing the costs of building facilities for drying the fuel raw material. This scheme proved its advantages and in 1980 was also introduced in TPP MI 2. [1, p.550]

The "Maritsa - East" complex is shaping up to be the most powerful center of thermal power plants in our country. Characteristic of the development of thermal power plants is the significant concentration of production capacities. In 1950 the average power was 4.4 mW, in 1960 it increased to 100 mW and reached 1260 mW in 1980. [ibid]

In parallel with the expansion and construction of new thermal power plants, the hydro potential of Bulgaria was also developing. In the master plan for electrification, realized in the 1950s, hydroelectric plants were given a primary role. By 1945 in our country there were several hydroelectric power plants with running water with a total installed capacity of 47 MW. In 1948, the Energohydroproject was established, which began research and design of future sites

The following year, the Hidrostroy administration was created, which was entrusted with the construction. After many years of activity related to geological, hydrological, topographic, etc. studies of the rivers in our country, in 1956 the country's hydropower potential has been determined. [1, p. 374]

Given the natural circumstances, the construction of long collecting derivations and numerous water intakes began according to original solutions. The goal is maximum utilization of the high falls in the mountainous regions. [ibid]

The decade between 1950 and 1960 it turned out to be particularly strong for the development of hydropower. Large dams "Stalin", "Batak" and the power plants connected to them "Batak", "Peshtera", "Aleko", "Pasarel", "Kokaliane" and others were put into operation. In 1960 75 units have already been built in our country. hydroelectric plants and the first 11 large dams were built, the main purpose of which was the production of electricity. [10]

What strongly distinguishes Bulgarian energy before the middle of the century from the period after is the inclusion of our country in the production of energy equipment. Until 1944 the energy base such as facilities, projects and installation was the work of foreign companies and foreign technical personnel. [1, p. 371]

In his book with memories of electrification before September 9, engineer Teodor Tsonev summarizes that the German-oriented policy of our government before 1944 rested on the basis that Bulgaria should not develop industrially, but should remain a faithful producer and supplier of agricultural products attached to the highly developed German industry. [2, p. 245]

The state of consumption was interrupted in the middle of the century to begin a new stage - of building the production of energy equipment. Our own production of energy equipment for hydroelectric power plants began in 1952. Then the engineers I. Pehlivanov, V. Konstantinov and A. Nikolov started the water turbine project for the Batoshevo 2 HPP (3 turbines x 6.6 mW) and the Studena HPP (2 turbines x 3.7 mW). In a few months, the constructions were completed, and in 1 year they were made in DMZ N. Vaptsarov, Pleven.

Meanwhile, the cast iron spirals and flywheels with a unit weight of 1 ton came out ready from the first casting, and the working wheels

were cast by the chief engineer of the "Electrometal" steel foundry in Sofia V.I. Dimitrov. According to the project, they should have been made of bronze, but Dimitrov experimented and made a casting from the classic chrome-nickel stainless steel with the necessary physical and mechanical properties. So, in 1956 Bulgaria is included in the list of energy equipment manufacturers. [11] In 1958, China ordered 30 sets of turbogenerators from Energohydroproject. The value of the contract was \$50 million. For three years, the Bulgarian plants have been working on the implementation of this order, and Bulgaria was included in the list of energy equipment exporters. [ibid]

In 1959 by decree of the Ministry of Justice No. 1368 of 20.8.1959, the "Antonivanovtsi" hydroelectric junction was included for construction during the third five-year plan. The rainbow dam that was built is the highest in the Balkans - 144 m, with a crown length of 440 m and a reservoir volume of 218 million cubic meters. The conceptual design of the dam was subjected to a model static-mechanical study in Italy and proved to be correctly designed. [12]

In 1959 one of the most important hydropower projects in our country has been completed - the Batashkiy hydropower road. In essence, it is a cascade between two main dams and three power plants located on them with a total power of 232 MW. In 1965 "Arda" cascade with a total power of 277 mW was also completed. [1p. 374]

Compared to those built before 1944 water plants with capacities well below 1 MW, these engineering projects impress with their scale and are testimony to the technological transition that Bulgarian society made.

In the period 1950-60 the unified high-voltage system was built and the main part of the electrification of the settlements was completed. During this period, 2,200 km of high voltage, 13,000 m of medium voltage and 21,200 low voltage networks were built. [7] Until 1965 in our country we created (designed and built) water turbines, their shut-off devices and generators for 14 HPPs. There are 24 hydro units in operation in these HPPs, with a total capacity of about 50 mW. This number does not include the 32 hydro units and their facilities exported to China, and later to Vietnam, with a total capacity of 46.6 MW. In this period, the maximum power of the unit achieved was 7.5 mW. [13]

In DMZ "N. Vaptsarov", Pleven, and in STZ "V. Kolarov", Sofia using models and technical assistance from Soviet specialists, our engineers construct the turbines for the hydro facilities in a local production environment. The regulators and part of the automation elements remain imported, but for the rest a complete production environment is being developed in our country. Initially, this was done without the presence of a hydraulic laboratory, which led to some design flaws affecting the quality, the price of the machines and the delivery times. In terms of efficiency, our machines are at an average level, in terms of speed they are inferior to those produced in the West. [ibid]

In 1967 the turbines, equipment and generators for another 9 HPPs with a total capacity of 349 MW are in production or in the process of construction. The maximum achieved power of one unit is already 62 MW - Momina Klisura HPP [ibid]

The factory in Pleven was already working on the production of turbines with a maximum weight of the processed parts of 70 tons, and in STZ "V. Kolarov" in Sofia, 8 units were produced. Synchronous generators with a total weight of 670 tons and 663 synchronous and asynchronous motors over 100 kW with a total weight of 1264 tons. The equipment allows the processing of single parts up to 40 tons. [ibid]

The planned in 1960 construction of new means of energy production, which would satisfy the ever-increasing needs of electricity consumption, was ahead of schedule by 2 years, being implemented as early as 1968 and exceeding the additional 1,000 mW capacity indicated by the Planning Committee as necessary. In 1970, the total power reached only by the thermal power plants was 3300 mW, and by hydropower plants 816 mW [5]

The desire to continuously increase electricity production continues to grow in the next decade. The master plan for hydropower construction of the Ministry of Energy and Fuels envisages

construction by 1980 on new 37 medium and large HPPs, on various small HPPs and on 6 pumped storage HPPs. (PAVEC)[13] It is planned to install 85 units of three different types - Francis, Pelton and Kaplan - with a total capacity of 2,700 MW in the medium and large plants. The value of the turbine part amounts to BGN 57 million, of the generators – BGN 67 million, or a total of BGN 124 million. BGN 40 million are additional expenses for the hydro units of the PAVEC. In order to save BGN 164 million in costs to the state budget, expansion of the turbopumping workshop at DMZ N. Vaptsarov, Pleven, construction of a generator workshop at STZ V. Kolarov, Sofia, and construction of a test laboratory for researching model water turbines were planned. [ibid]

Only the units of the Belmeken HPP and the Sestrimo HPP are planned for import due to the insufficient preparation (as of 1967) for the production of large turbines and generators, but despite this, negotiations are underway to manufacture part of the equipment in our country according to the company's construction documentation provider [ibid]

In the period 1960-1970, in connection with the intensive development of the energy-intensive branches of industry, mechanized agriculture, transport and the household, the need for electricity increased. The need is also reinforced by insufficient efficiency in the use of resources, by the structure and quality of raw materials. [1, p.548]

In the following decade - 1970-1980 - the growth of energy consumption gradually decreased, since the material base of the Bulgarian industry was already built to a considerable extent and it gradually moved to less energy-intensive productions. Nevertheless, the targeted rates of economic and social development cannot be achieved by maintaining the rate of import of energy resources.

The development of electricity production is oriented towards nuclear energy. With the signing of a cooperation agreement with the USSR in 1966, the construction of a nuclear power plant near Kozloduy began, which was built in three stagesq till 1990-es with a total planned capacity of 3760 MW.

Conclusion

Bulgaria's way of energy development keeps pace with world trends, draws on the rich technological experience of developed Western countries and uses the help of Soviet specialists. In 1988, the power generation capacities in our country were nearly 80 times more, and the power generation 145 times greater than in 1944. [1,p.548]

This giant technological step, although it does not look so impressive against the background of the general energy development on a planetary scale, but it impresses above all with the desire to create our own base for the design and construction of energy plants, with the development of state production of energy equipment, of technical and scientific potential, which ennoble Bulgarian society and creates conditions for its transition from an agrarian to an industrial environment.

References

1. Todoriev, N., Development of Industry in Bulgaria, NI, Sofia, 1990, p.371
2. Tsonev, T., My memories of electrification in Bulgaria before the 9th, 1938, ASA, F. 521, des. 1, a.u. 339, p.177
3. Ivanov, D. Rise and fall of socialism, Sofia, 2009, p. 124
4. ASA, F.517, op.1, a.e. 10, p. 40
5. CSO, Republic of Bulgaria '89, Brief Statistical Collection, Sofia 1990)
6. Chairman's report of the Committee on Industry to the Council of Ministers regarding the technical and economic construction of a thermal power plant, ASA, F.517, des. 1, a.u.10, p. 40
7. SCTP, Characteristics of the technical of the industry 1961-1980, ASA, F. 517, des.1, a.u. 16
8. Energoproekt, ASA, F. 521, des. 1, a.u. 91, p. 101
9. ASA, F. 521, des.1, a.u. 400, p. 43
10. SCTP, Report, 1960, ASA, F.517, des.1, a.u.16
11. Pehlivanov, I., Witness to History, Sofia, 2005, p. 18
12. SCTP, ASA, F.517, des.1, a.u.10, p. 179
13. Minister of Mechanical Engineering Marii Ivanov's report, ASA, F.531, op.3, a.e. 47, p.209

Intellectual factor of the new economy: Formation features

Olga Avdeychik¹, Vasily Struk², Alexander Antonov², Alexander Lesun², Wan Xuemin²
 Grodno State Agrarian University¹ – Grodno, Belarus,
 Yanka Kupala Grodno State University² – Grodno, Belarus,
 E-mail: antonov.science@gmail.com

Abstract: *The new economy requires the creation of a methodology for training a new type of worker – a “knowledge worker”, whose activities will ensure the innovative development of business entities and social security of workers for a comfortable and safe life. An innovatively receptive specialist with pronounced creative thinking during the formation of a new economy and its subsequent sustainable functioning with a characteristic vector of social development has the intellectual potential for the development and practical use of highly effective innovations that ensure the achievement of strategic goals declared at the state level. To form such a specialist, it is necessary to transform methodological approaches to the intellectual support of educational processes, professional activities and advanced training based on the concept of “lifelong education” (“education through life”).*

The features of the functioning and development of the domestic education system in the context of the requirements of the state strategy for sustainable economic development are considered. The need to improve methodological approaches to the educational process with an increase in research and socio-humanitarian components is shown. Education in all forms of its manifestation like as a target process or self-learning is a systemic process in which professional skills and abilities are an important, but not a determining component of a harmonious member of society, which, through its activities, contributes to its progressive development. The fundamental goal of education is to form a harmonious personality, in which the talents laid down at the gene level are manifested and developed to the full extent in adequate accordance with moral criteria based on universal human values and national mentality.

KEYWORDS: NEW ECONOMY, INNOVATION STRATEGY, EDUCATION, INTELLECT, PERSONAL HARMONY, SCIENTIFIC COMPONENT, ACADEMIC LITERACY

1. Introduction

The practical implementation of the state strategy for sustainable economic and social development for the period up to 2020 and the long-term period [1, 2] involves the expansion of the use of high-level technologies in production and social activities, including convergent technologies (NBIC) [2–10]. This aspect of the innovative functioning and development of industrial and social complexes of various levels, forms of ownership and departmental subordination involves the possession by employees at all stages of the product life cycle of modern methods of managing a new type of economy, positioned as a “knowledge economy”, “intellectual economy”, “digital economy” [11, 12]. The prevailing form of training of professional workers for various areas of the functioning of the economy, the most important factor in the formation and development of which are intellectual products implemented in new materials, designs, management technologies, manufacturing, sale, maintenance and recycling, is the implementation of the educational process in higher educational institutions (HEIs) in accordance with the current regulatory legal documentation governing List of educational programs, their content, forms of control and terms of implementation in accordance with the Educational Code.

The new economy requires the creation of a methodology for training a new type of employee – a “knowledge worker” [13], whose activities will ensure the innovative functioning of a business entity.

An innovatively receptive specialist with pronounced creative thinking [14] during the formation of a new economy and its subsequent sustainable functioning with a characteristic vector of social development has the intellectual potential for the development and practical use of highly effective innovations that ensure the achievement of strategic goals declared at the state level. To form such a specialist, it is necessary to transform methodological approaches to the intellectual support of the processes of training, professional activity and advanced training on the basis of the concept of “education through life”.

In studies devoted to the process of formation of innovation-receptive specialists at the stage of the educational process in basic specialties that determine effective economic and social development, various aspects of its implementation are considered, taking into account the requirements of the knowledge economy [14–19, 26–35]. So in [15] as a “guarantor of the success of society” consider the “dialogization of the educational process”. In [15] it is noted that in the implementation of educational of the process “with the traditional reliance on lectures”, the specialist does not acquire “effective management skills” in full. Shrubenko A. G. believes [16] that it is necessary to move to the “individually-oriented” principle of building the educational process. Some trends in the

transformation of the educational process in the interests of the new economy with an innovative nature of functioning are considered in more detail in [15–19].

An analysis of studies devoted to various aspects of improving the educational process in the interests of the neo-industrial economy clearly indicates its multifactorial nature with the decisive influence of the intellectual component in various forms of manifestation. The trend of simplifying higher education through the preferential formation of students’ professional skills, instead of a comprehensive assessment of problems based on the scientific component and a complex of socio-humanitarian disciplines, reducing the duration of training, the increasing role of the economic component in the activities of universities, which has manifested itself in the last decade, requires an integrated approach to the development of a methodology for the functioning of higher education during the formation of a new economy.

It is of significant scientific and practical interest to assess the role of the intellectual factor in the educational process of higher education to determine the directions for the formation of methodological approaches to the systematic training of specialists for the domestic economic complex, taking into account its features.

2. Results and discussion

Trends in the development of the economy at the global, state and regional levels are characterized by an increase in the share of services of various types and its prevalence over the production of material objects that ensure the functioning of basic industries and the system of comfortable and safe life [5, 10, 20, 23]. Therefore, the educational process of higher education should transform the content of educational programs for the training of specialists in all branches of industrial production with taking into account the features of new systems of marketing, service, permanent updating of the product range with changing consumer demand [20–22]. At the same time, the educational process should take into account the peculiarities of the Belarusian economy, which is in the process of transition from IV, V to VI technological order [23].

The characteristic tendencies of the Belarusian economy in transition are inefficient innovative functioning, which predetermines the process of stagnation. Belarus, like most countries of the post-Soviet space, belongs to the “countries with incomplete industrialization” [23], therefore, “... the essence of the technological problem ... consists in the fact that the third and fourth technological modes are a fundamentally different type of production than the fifth and sixth So, in the industry of the Republic of Belarus ... up to 1/3 of all labor is manual, 1/5 is manual labor with a mechanical tool, 1/3 is machine labor and only 1/10 is semi-automated and automated” (emphasis added – O.A.,

V.S., A.A., A.L., X.W.) [23, p. 27]. Further in this work it is noted: "... the main body of the employed population (up to 80%) in Belarus is made up of representatives of mass professions associated with traditional branches of the economy and forming a hierarchy of socio-professional groups similar in occupation (hired labor of a physical and mental nature), property status ..., scope of rights ... and sharing non-market values in the economic and social spheres ... In order for employees to be able to reproduce new social strata, to become effective owners of their labor power, it is necessary to reorganize both external conditions that change the position of workers in society, and internal ones - overcoming paternalistic stereotypes. focus on continuous improvement of professional education, the formation of social responsibility for one's life" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [23, p. 28].

In our opinion, it is obvious that "the focus on continuous improvement of professional education and the formation of social responsibility" occurs at the primary stages of the educational process, focused not on an employee with a set of professional skills (even a high level), but on an employee with harmonious development, whose need for intellectual improvement is not based on the need to ensure comfortable living, but is its basic the need to improve oneself as a person with characteristic individual characteristics. The concept of "lifelong learning" is the individual's desire for harmonization, including through the development of professional skills and abilities within the framework of possible competencies.

A characteristic trend in the economic and social development of the post-Soviet states is "globalization - the second stage of urbanization - expressed in the migration of the population of small towns to regional centers, large cities and capitals, which ... Strengthened... negative trends" in the regions, including "... A sustained slowdown in economic growth ... degradation of the material and technical base of enterprises, organizations, institutions and infrastructure" (emphasis added by us – O.A., V.S., A.A., A.L., X.W.) [24, pp. 7–8]. In the same work, it is noted that "... According to the UN, the Republic of Belarus is among the countries with a high level of human development, being in 53rd place in the world out of 173 countries surveyed annually" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [24, p. 9]. At the same time, many effective approaches in economically developed countries to intensify innovative functioning using the latest, including convergent technologies, through the formation of cluster structures and digitalization of the economy, have not been properly developed and their real contribution to the economy of Belarus is insignificant. For example, in [24] it is noted that "Examples of effective digitalization, effective interaction of the Hi-Tech Park (HTP) with enterprises of the real sector are not numerous. For the first time since 2018, revenue from the sale of HTP services reached USD 1.4 billion. USA, of which 380 million are in the domestic market" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [24, p. 11]. A similar situation is typical for the development of the nanoindustry as the main component of NBIC technologies.

A characteristic feature of the development of the industrial complex of Belarus is the phenomenon called in [26] "technological uncertainty": "... Technological uncertainty is characterized by a multiplicity of options for choosing technologies that arise from the inability to assess the probability of potential results from their use. Such uncertainty is a natural limitation of the controllability and stability of the organizational and economic system as a whole and the industrial complex in particular. Currently, a large amount of accumulated knowledge is the foundation for the emergence of new ones, the volume of technologies is constantly increasing, and the speed with which new technologies arise and is being introduced is growing. As the dynamics of technological evolution accelerate, technological uncertainty grows" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [25, p. 53].

In our opinion, it is more reasonable for Belarus to talk about "technological lability", i.e. about the mobility of sectors for the use of high-tech and traditional technologies, depending on the type of innovative products.

This lability is due to the expansion of the range of new technologies for the production of innovative products and their consumption, taking into account the concept of the life cycle.

In the processes of industrial production of commercial products, "technological uncertainty" does not exist, since based on the totality of the parameters of the material, technical, technological, personnel and investment base, the business entity unambiguously determines the set of technologies that will be used in the production of innovative products in accordance with the current regulatory and technical documentation.

The whole question is the level of novelty of the innovative development and the degree of its protection against unauthorized use and production. With a high level of innovation (conceptual, breakthrough), the lability of technologies does not play a predominant role.

With mass industrial production of innovations with similar parameters of functional (consumer) characteristics, the role of the technological lability factor increases, since it affects the price parameters and production productivity.

At the same time, it should be noted that the noted characteristic features of the development of industry in Belarus, as the main factor determining economic and political sovereignty, require the development of new methodological approaches to the organization of the educational process for the training of engineering and managerial personnel adequate to the requirements of the new economy with a pronounced trend of innovative functioning. A qualified specialist should not only possess the essence ("know-how") of high technologies developed and used in the leading countries, have practical skills to adapt them to the existing industrial production, but also apply them in their original or modernized form in combination with domestic technologies to achieve synergistic effects. This aspect involves obtaining not a highly specialized educational complex sufficient for the implementation of professional competencies, but systemic ideas about the development of technologies in accordance with the requirements of neo-industrialization with the prevalence of reasonable actions that preserve the environment and harmonize society. A highly qualified worker of neo-industrial development is a "knowledge worker", owns the technologies of creative thinking within the scope of his professional activity and development of the social environment.

An analysis of studies devoted to the methodological aspects of the educational process during the formation of a new technological order in Belarus [18, 19, 25–35] allows us to identify characteristic trends in the approaches used in domestic higher education.

In the work of Professor Kirvel Ch.S. it is rightly stated that "... In modern conditions of global competition for resources, territories, financial power, the main goals of information wars are the destruction of the consciousness and self-consciousness of peoples, their life-meaning values, ideals and guidelines" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [18, p. 79].

Gustave Le Bon noted: "... The only important changes from which the renewal of civilizations follows are in ideas, concepts and beliefs. Major historical events are only visible consequences of invisible changes in people's thoughts" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [18, p. 81].

Therefore, "... the more primitive a person's education, the easier it is to lure him into a network and, as such, connect him to one of the global networks or to all networks at once" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [18, p. 85]. A systematic purposeful substitution of the concept of "education" with the concept of "training" is carried out with the help of the so-called "educational services", implemented mainly on a commercial basis.

An educated person is not a "highly specialized" person, but a person with a high professional level in a particular field of activity, who adequately assesses the trends in the development of societies and his position in them.

Therefore, the scientific and socio-humanitarian components of education in all specialties are not only necessary, but also decisive in the formation of a specialist's ability to assess all the

consequences (and not just economic) of the solutions developed by him.

In [19] a well-founded opinion is expressed about the direction, goals and objectives of the transformation of the educational process in the Belarusian higher school: "... To indicate the general orientation of the processes that are unfolding in full swing in the education system and higher education in particular, it is appropriate to use the prefix "de-", indicating decomposition and decay: "defundamentalization", "dehumanization", "deconcretization", "dehumanization" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [19, p. 60].

The authors consider "econocentrism" to be a stable, defining trend in the development of education, noting that: "*The lie of econocentrism lies in the fact that it declares education to be a private interest of individual stakeholders (individual employers and potential employees) and reduces the fullness of the benefits created by the education system to only one thing – narrow professional training*" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [19, p. 63].

The educational process within the framework of econocentrism is replaced by a set of various kinds of flash mobs and smart mobs, startups, etc., imitating scientific research, preparation of essays, course and diploma projects that make up the essence of the educational process within the specialty. The number of participants in this process in the educational environment is rapidly increasing and "... The scale of this phenomenon of steel is substantial, which has made it possible to ... I. Huizinga to declare the emergence of a special type of personality – Homo Ludens – "a person playing" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [19, p. 71].

It is obvious that Homo Ludens are participants in the process of providing educational services, which replaced classical higher education – both students (trainees) and teachers. The observed change of the teaching staff, former graduates of universities who did not receive a full-fledged professional education due to the use of modern forgiven educational programs, forms the prerequisites for the rapid degradation of the educational process. Significant part of the new generation of teaching staff does not have its own idea of the essence of the subject taught, since they have neither the experience, nor the results, nor the desire to carry out systematic scientific research within the framework of their profession, therefore the process of "teaching" is replaced by the process of "reading" lecture courses that are the result of direct or indirect plagiarism and compilation of sources borrowed from information content. Precariat teachers fill in the former an educational space with high requirements for professional training and a directed criterion, displacing from it the very essence of higher education as an elitist, developing person in all aspects of a harmonious personality. Precariat teachers "successfully" train "precariat specialists", for whom the concepts of professional duty, dedication to the cause, enterprise, integrity, patriotism are replaced by the concept of "tolerance", "political correctness", etc.

The change in the professional content of the teacher due to the absence or insufficiency of their own scientific base within the framework of the disciplines taught necessitates the search for new parameters to maintain their status in the educational society. So, Prokhorova L.V. [30] believes that "... To achieve ... a harmonious set of qualities requires the teacher to be conscious of actions, which in turn is impossible without reflection: the teacher needs to know what requirements the student audience and colleagues impose on him" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [30, p. 18]. The author [30] believes that "... A university teacher is a person who, by the nature of his activity, must have a number of universal qualities: the abilities of a psychologist, organizer, analyst, speaker, – to master the methods of teaching and education, to be not only a competent specialist in his field, but also a polymath in other fields of knowledge" [30, p. 18].

In the studies of L.Y. Donskoy, the image of a teacher of higher education is determined by a dynamic model that includes three levels [31]. Primary attention is paid to the natural component (external data, physical and psychophysiological characteristics, temperament, gender, age), the internal component (communicative

qualities, charm, professional knowledge, individual style, etc.), symbolic characteristics (visual, auditory, kinesthetic, olfactory components) [30].

All the actions of the teacher, according to the author of the work [30], should be aimed at *pleasing students*, since, in particular, Socrates noted that "they learn from someone they like" [30, p. 19]. In our opinion, this is a simplified understanding of the meaning of the Socratic statement, since it refers not only to the ability to communicate and charm, but to the intellectual level of teaching, which students "like" with its depth professional knowledge, versatility, scientific potential, realized in significant achievements – textbooks, monographs, patents, scientific school, effectiveness of practical innovation, etc.

Therefore, the concept of "educational violence", proposed by us in the works [14, 17], does not reduce the ability of the teacher to "like", since adequate (professionally oriented) students understand the need to expend a large amount of effort to achieve a high real (and not formalized) professional level.

According to the concept of D. Bell, the university is presented as an "axial social institution" [28] of post-industrial society: "*The university is increasingly becoming the main social institution of post-industrial society, which has assumed the functions of fundamental research, training of highly qualified personnel, and the development of general education*" (emphasis added – O.A., V.S., A.A., A.L., X.W.) [28, p. 37].

For higher education in Belarus, D. Bell's concept requires transformation due to the relatively low level of research work, especially characteristic of regional and non-state universities, and their scientific status. Therefore, the formation of the modern status of the university is impossible without integration interaction with academic science with mutual diffusion (percolation) of personnel and convergence of research, educational and applied innovation projects based on the concept of intellectual support with a certain infrastructural embodiment.

Only the permanent generation of high-level knowledge in the integration cluster "Higher educational institution – Academy of Sciences – Industrial enterprise" will ensure the development of educational and methodological complexes adequate to the post-industrial economy for training specialists in strategic programs for innovative development of high-tech sectors of the economic complex, ensuring its sustainable development [14, 17]. This will preserve the basic functions of the classical university, in which the permanent updating of the content of educational and methodological materials will be carried out on the basis of scientific fundamental and applied knowledge with a high level of novelty and relevance.

In the economy of the transition period, with the formation of new relationships between producers of goods and services and consumers, universities of the classical type mainly provide support for existing industries and management organizations, administration of research institutions of various departmental subordination by training personnel in a wide range of specialties. With an increase in the share of knowledge-intensive, including convergent, technologies in the real sector of the economy and social security, the role of the university should be proactive, ensuring the adequacy of specialists to the requirements of the labor market with a predominant intellectual component. Achieving this state is possible only with a change in the share of the research component in the educational process through the convergence of research and educational technologies taking into account the changing range of specialties demanded by innovative enterprises specializing in the field of nanomaterials science, information technology, development of biological objects and cognitive systems. In the presence of their own developments in the field of high, including convergent, technologies carried out within the framework of large state and interstate projects, universities will have an effective original scientific base for the development of educational and methodological support for popular specialties, while maintaining their leading position in the global educational space, characterized by the free exchange of information flows and developed communicativeness.

3. Conclusion

An analysis of studies devoted to the consideration of various aspects of the educational process in the national higher education indicates the lack of a systematic approach to assessing its effectiveness in the implementation of the State Strategy for Sustainable Socio-Economic Development for the period up to 2020 and the long term. The emerging trend of reducing the share of the scientific component with a reduction in the cycle of socio-humanitarian disciplines and the total duration of training leads to the formation of specialists with certain professional skills without understanding the multifactorial nature of the development of the world society with pronounced consumer guidelines.

The expediency of developing a research component in the educational process of higher education and intensifying the interaction of the faculty and students in the framework of high-level scientific programs is shown.

4. References

1. The National Strategy for Sustainable Development for the Period to 2020 of the Republic of Belarus, Minsk (2004).
2. The National Strategy for Sustainable Development for the Period to 2030 of the Republic of Belarus, Minsk (2015).
3. A. Lazarevich (2014). The horizons of technosocium, *The Science and Innovations*, 3(133), 22–28. (in Russian).
4. A. Miroshnichenko (2014). Systems of enterprises continuous improvement based on knowledge management, *The Science and Innovations*, 2(132), 55–60. (in Russian).
5. Yu.S. Solodovnikov (2019). Modern structural policy of the Republic of Belarus in terms of Eurasian economic integration, *Business. Innovation. Economy*, 3, 17–25. (in Russian).
6. A. Shumilin (2014). Formation of the backbone interactions in the innovative development of economy, *The Science and Innovations*, 7(137), 29–34. (in Russian).
7. L. Vainshtein (2014). Scientific support of the human factor in various technological structures, *The Science and Innovations*, 7(137), 8–12. (in Russian).
8. V. Baynev (2017). The fourth industrial revolution as a global innovative project, *The Science and Innovations*, 3, 38–41. (in Russian).
9. M.V. Kovalchuk, O.S. Naraikin and E.B. Yatsishina (2012). Convergence of science and technology and creation of new noosphere, *Nanotechnologies in Russia*, 7, 1–5. (in Russian).
10. Ya.P. Hilo, V.V. Goncharov (2013). Directions of intensification of innovative development of the Republic of Belarus in the conditions of formation of innovative economy, *Bulletin of the Gomel State Technical University named after P.O. Sukhoi*, 3, 117–123. (in Russian).
11. B.N. Panshin (2019). Genesis and hierarchy of key concepts in the digital economy, *Business. Innovation. Economy*, 3, 142–146. (in Russian).
12. B. Melnikas, et al. (2013). *The Knowledge Economy: Internationalization and Systematics of Innovation*, Lithuanian Innovation Center, Vilnius. (in Russian).
13. I. Nonaka and H. Takeuchi (1995). *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press, New York.
14. O.V. Avdeychik, L.P. Nehorosheva, V.A. Struk (2016). Fundamentals of scientific and innovative activities, *Law and Economics*, Minsk. (in Russian).
15. A.D. Korol (2015). Dialogueization of education as a guarantor of the success of society, *Problems of management. Ser. A and B.*, 2, 155–159. (in Russian).
16. A.G. Shrubenko (2016). The flagship of management education: the path of innovative development in a quarter of a century, *Ser. A and B.*, 1(58), 6–16. (in Russian).
17. O.V. Avdeychik, G.A. Khatskevich, V.A. Struk, L.N. Nehorosheva (2019). Fundamentals of innovative activity of industrial enterprises, *GrSU, Hrodna*. (in Russian).
18. Ch.S. Kirvel (2012). Socio-humanitarian knowledge and education in the context of modern information wars and the global competition, *Journal of the Belarusian State University. Sociology*, 2, 79–91. (in Russian).
19. Ch.S. Kirvel, S.Z. Semernik, Modernization of education: a miser pays twice, *Belaruskaia dumka*, P. 1, 8, 60–65 (2012); P. 2, 9, 69–75 (2012). (in Russian).
20. E.E. Golovchanskaya, L.S. Shakhovskaya (2019). Intellectual needs as a marketing category, *Business. Innovation. Economy*, 3, 184–189. (in Russian).
21. V. Shumilin (2014). Consumer-Driven Innovation: The Web X.O Phenomenon, *Science and Innovations*, 12(142), 24–25. (in Russian).
22. Yu. Pravik (2013). Marketing methods in the implementation of state strategies for innovative development, *Science and Innovations*, 7(125), 48–51. (in Russian).
23. G. Sokolova (2013). Modernization as a technological and social phenomenon: Belarus – Russia, *Science and Innovations*, 6(124), 24–28. (in Russian).
24. G.A. Khatskevich, N.G. Zabrodskaia (2019). Socio-economic factors that justify the actual changes of administrative and territorial division of the Republic of Belarus, *Business. Innovation. Economy*, 3, 7–16. (in Russian).
25. Yu.V. Meleshko (2019). Ontological nature of the economy of neoindustrial production, *Business. Innovation. Economy*, 3, 49–57. (in Russian).
26. Ch.S. Kirvel (2018). Modern education «in the clutches» of liberal market extremism, *Journal of the Belarusian State University. Sociology*, 4, 88–96. (in Russian).
27. N.V. Smirnova (2015). Academic literacy and writing in the university: from theory to practice, *Higher education in Russia*, 6, 58–64. (in Russian).
28. D.G. Dobrorodny (2019). Distance learning as a global perspective and challenge for a classical university, *Higher school*, 5, 36–39. (in Russian).
29. I.B. Strelkova (2019). Expert assessment of the originality of scientific works with the help of the "Antiplagiat" system in the structure of the formation of academic literacy of young researchers, *Higher school*, 5, 3–7. (in Russian).
30. L.V. Prokhorova (2019). The image of higher school teacher in the context of intercultural interaction, *Vysheishaya shkola*, 5, 18–21. (in Russian).
31. L.Yu. Donskaya (2004). Psychological conditions of forming the image of a high school teacher, *Dis. ... kand. psikh. nauk*, Stavropol, 212. (in Russian).
32. K. Titayev (2012). From what Russian universities become "fence-building institutions", *Domestic notes*, 2, 1–12. (in Russian).
33. L. Yu. Shilin, A. A. Navrotsky, L. S. Strigalev (2019). Modern aspects of intellectualization of educational technologies, *Higher school*, 1, 25–26. (in Russian).
34. V. V. Tsepikalo (2013). HTP: high technologies of education, *Science and Innovations*, 7, 57–59. (in Russian).
35. E. T. Polupanova (2020). Evaluation by students of university teachers: world experience, *Higher school*, 1, 41–44. (in Russian).

Influence of environmental factors of long-term operation and effectiveness of SMFC-based biosensors for heavy metal polluted waters

Rosen Ivanov, Petia Genova, Polina Velichkova
University of Mining and Geology, Sofia, Bulgaria
r.ivanov@mgu.bg

Abstract: Sediment microbial fuel cells are relatively new devices, originally designed to generate electricity from the degradation of organic matter in the soil by microorganisms. Currently, SMFC-based biosensors are attracting scientific interest as new and promising devices for rapid real-time monitoring of water quality and water pollutants. Compared with conventional biosensors, SMFC-based biosensors show advantages such as low cost, simple design, and the possibility of IN SITU operation and self-powered monitoring. SMFC-based biosensors are expected to be used for remote environmental monitoring, therefore evaluating their long-term performance is crucial for their usability. In this paper, we present new data needed to establish the long-term performance of SMFC based biosensors. The present study presents the effect of various environmental factors such as temperature, pH and microbial activity on the performance and effectiveness of the SMFC based biosensor for monitoring water contaminated with heavy metals. The results show stable long-term performance of these devices under various environmental conditions.

Keywords: SMFC BASED BIOSENSORS, HEAVY METALS DETECTION, ENVIRONMENTAL FACTORS

1. Introduction

The development of on-line and in situ water sensors is critical for monitoring heavy metal discharge and taking emergency response. Conventional water quality monitoring depends on sampling and lab analysis, which often lags behind the discharge of wastewater, moreover, sampling and analysis cost long process time, making it impossible to alert heavy metal pollution when it is happening. [1,2]

In recent years, MFC based sensors have been envisaged as a promising low-cost and energy-efficient tool for online monitoring of pollution events in water and soil. [3] The use of exoelectrogenic bacteria to sense contaminants had a serious drawback, as the sensors could not monitor repeated pollutions unless exoelectrogenic bacteria were recovered or re-inoculated and acclimated after each pollution event. Unfortunately, recovery from disturbance or acclimation usually took several weeks. [4,5]

To overcome the drawback, SMFC-based biosensors can be used for monitoring water pollution with heavy metals. Sediment microbial fuel cells generate electricity from the electro-potential difference between aerobic water and anaerobic sediments. [6] Most sediment microbial fuel cells are open systems with anodes embedded in sediment and cathodes placed in water layer. The microorganisms in the sediment consume organic substrates and transfer the electrons to the anode. [7] Dissolved oxygen is utilized as electron acceptor and combines with protons to form water and generate electricity. The advantages of the SMFC biosensor include:

- the cathode instead of exoelectrogenic bacteria in the sediment senses heavy metal contaminants discharged into the water. [8] The sediment adsorbed a large proportion of heavy metals and protect exoelectrogenic bacteria from being inhibited by heavy metals ions, thus the sensor could work normally after a shock. [9]
- the sensor employs native exoelectrogenic bacteria in sediment to generate a baseline voltage, therefore, the inoculation process can be omitted. [10]
- the sensor's components are assembled into an integrated and rigid system; thus, monitoring is conveniently started by inserting the sensor into the flooded soil. [11]

The performance of SMFC is affected by many factors, such as temperature, pH, organic matter of the sediment and others. [12]

In this study, a SMFC-based biosensor was constructed to investigate its long-term performance for heavy metals monitoring. The sensitivity of the biosensor under conditions of varying temperature and pH was also investigated. The SMFC based biosensor was operated for a period of one year in the field

environment and a group of heavy metal solutions ranging from 0.5 to 50 mg/l were repeatedly applied in different seasons.

2. Materials and methods

Soil Sampling

For the purpose of the study, river sediment was taken from Ivanyanska river, Bulgaria (42°42'27.1"N 23°11'46.4"E), from a depth of 20-30 cm. After taking the river sediment, the larger pieces were removed by sieving through 2 mm. In order to carry out physicochemical analyses, part of the sieved soil was air-dried. Soil pH was measured by pH-meter HANNA HI-9021 determined at 1 : 2.5 (soil:water). Soil electrical conductivity (EC) was measured by WTW LF 197-S determined at 1 : 5 (soil:water). The main soil physicochemical properties were as follow pH 6.89, EC 142.31 $\mu\text{S cm}^{-1}$. The soil was classified as sandy clay loam, the Kjeldahl-N content were 0.214% and dissolved organic carbon 68.34 mg kg^{-1} .

Construction of SMFC biosensor

The sediment microbial fuel cell is a plastic container with a volume of 800 cm^3 . At the bottom of the vessel is a stainless steel electrode with an area of 32 cm^2 . The vessel was filled with river sediment with a volume of 550 cm^3 . The cell was then filled with pure water and a second 32 cm^2 stainless steel electrode was placed in the surface layer of the water. The physicochemical characteristics of water was pH 7.08, Eh 363 mV and EC 62 $\mu\text{S cm}^{-1}$ measured by Vernier LabQuest Mini. On Figure 1 is shown a scheme of the laboratory model of the SMFC-biosensor.

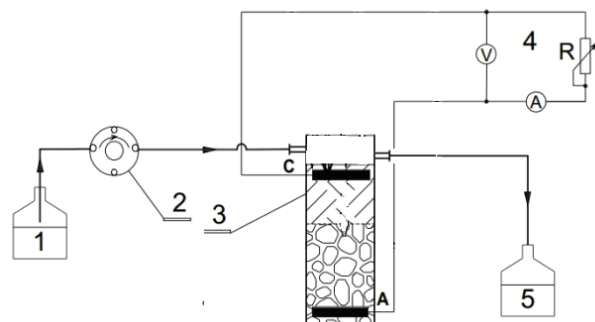


Fig. 1 The schematic diagram of the SMFC-based biosensor

1 – Inflow, 2 – Peristaltic pump, 3 – Sediment microbial fuel cell, 4 – Digital multimeter, 5 – Outflow, A – Anode C – Cathode

The test solutions pass through the cathode zone, where heavy metals ions play the role of an additional electron acceptor and increase the voltage of the cell by changing the electrochemical parameters. Four identical SMFC-based biosensors were made. The

anode and cathode of each biosensors were connected with an external 1000Ω resistor using copper wire. Then they had been acclimated, until the base voltage is reached and the electroactive microorganisms acclimatize. The SMFC based biosensor was operated for a period of one year in the field environment in area with Moderate continental climate.

The abundance of exoelectrogenic microorganisms was quantified by 16S rRNA gene. In the sediment *Geobacter* and *Clostridium*, were dominant exoelectrogenic bacteria. *Anaeromyxobacter*, *Bacillus*, *Pseudomonas* and *Desulfolobus* was also detected.

Heavy metals pollution

For the purposes of the study, synthetic solutions containing copper ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$), zinc ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$), nickel ($\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$) and chromium ($\text{K}_2\text{Cr}_2\text{O}_7$) with different concentrations were prepared. Solutions were prepared in seven concentrations – 0.5, 1, 2.5, 5, 10, 25, 50 mg/l. The solutions were repeatedly applied in different seasons with various temperature and pH conditions.

Electrochemical analysis

Polarization and power curves of the individual SMFCs were obtained by varying external resistances sequentially from 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1.5, 1.3, 1, 0.7, 0.5, 0.3 to 0.1 KΩ using MCP lab electronics BXR-04 ResistorBox.

To determine the response of voltage signals to Cu^{2+} shock, the biosensors' voltage was measured and recorded with Vernier LabQuest Mini and Logger Lite software.

3. Results and discussion

The open circuit voltage of the four sediment microbial fuel cells was monitored for one year. The cell voltage was almost the same throughout the period, with the graph showing the average cell voltage over a year (Figure 2).

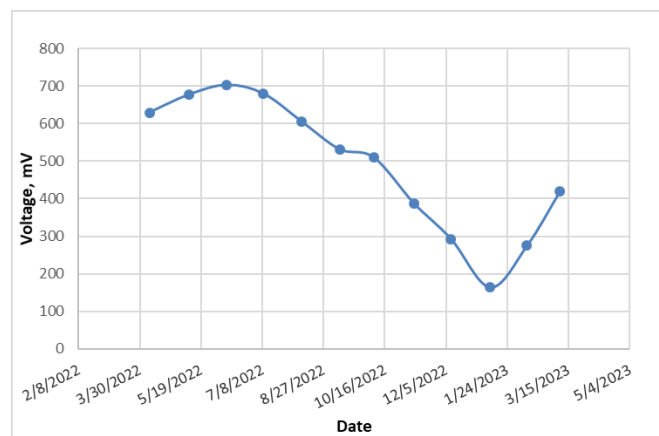


Fig. 2 Dynamics of open circuit voltage of SMFCs during one year

From the data in front of the graph, it can be seen that the voltage of the cells is significantly higher in spring and summer, when the average daily temperatures are also higher.

Temperature

The next experiment aimed to establish the effectiveness of the SMFC-based biosensors at different ambient temperatures. From the preliminary data in figure 3, it is clear that the voltage generated by the cells is directly dependent on the average daily temperatures. Higher ambient temperatures enhance the metabolic activity of exoelectrogenic bacteria, leading to an increase in the generated voltage. When average daily temperatures decrease in winter, the activity of microorganisms in the sediment becomes lower and the cell voltage decreases.

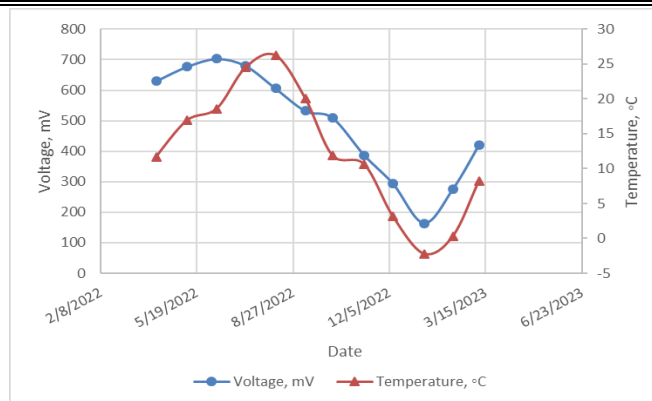


Fig. 3 Dynamics of open circuit voltage of SMFCs during one year

The experiment was conducted at three different temperatures, characteristic of the different seasons in a Moderate continental climate zone. The study was conducted in summer, autumn and winter at respective average daily temperatures of 25, 15 and 5°C. The results of the study are presented in Figures 4, 5, 6 and 7.

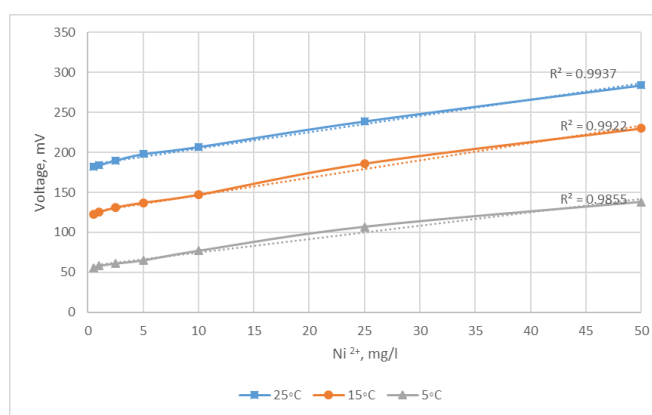


Fig. 4 SMFC-based biosensors standard curves Ni^{2+}

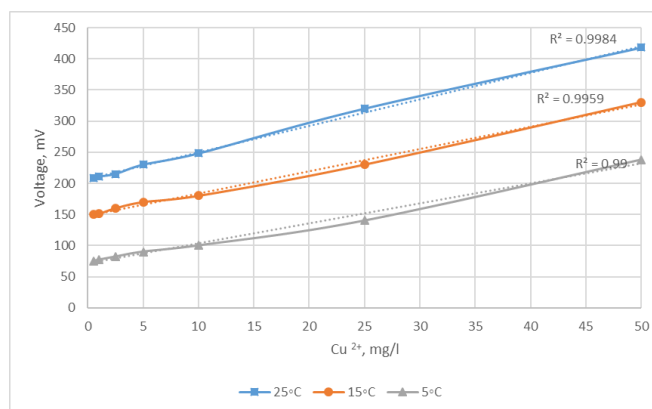


Fig. 5 SMFC-based biosensors standard curves Cu^{2+}

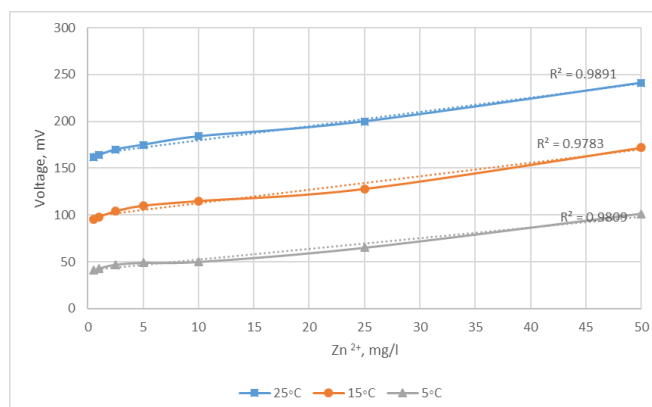


Fig. 6 SMFC-based biosensors standard curves Zn^{2+}

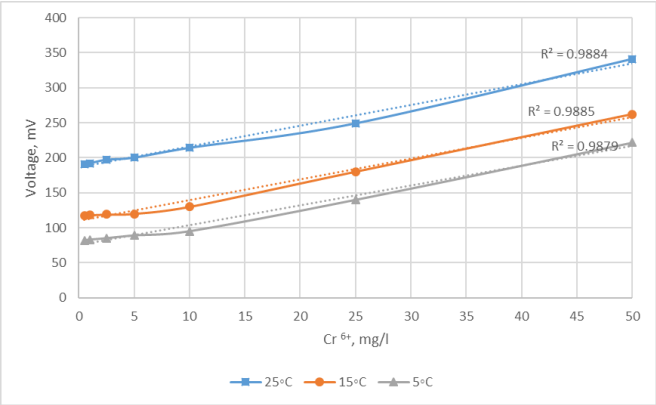


Fig. 7 SMFC-based biosensors standard curves Cr⁶⁺

Regardless of the ambient temperature, the results show a very high coefficient of determination - R^2 for all four investigated metals. Temperature affects only the base voltages of the cells, as it is largely formed by the activity of exoelectrogenic bacteria. The voltage increase after the addition of the heavy metal solutions is exclusively based on a change in the electrochemical parameters, namely the addition of an additional electron acceptor in the cathode region. Therefore, the efficiency of the SMFC-based biosensor for heavy metals monitoring remains high coefficient of determination ($R^2 = 0.9783 - 0.9984$) at all three investigated temperatures.

pH

The next experiment aimed to establish the influence of pH on the performance of SMFC-based biosensors for monitoring water pollution with heavy metals. Heavy metal solutions have pH values of 2.5, 4 and 5.5. The investigated pH values were chosen so that the investigated metals were in soluble form.

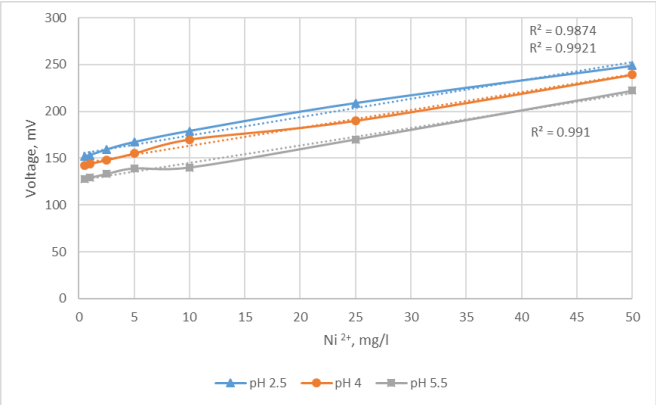


Fig. 8 SMFC-based biosensors standard curves Ni²⁺

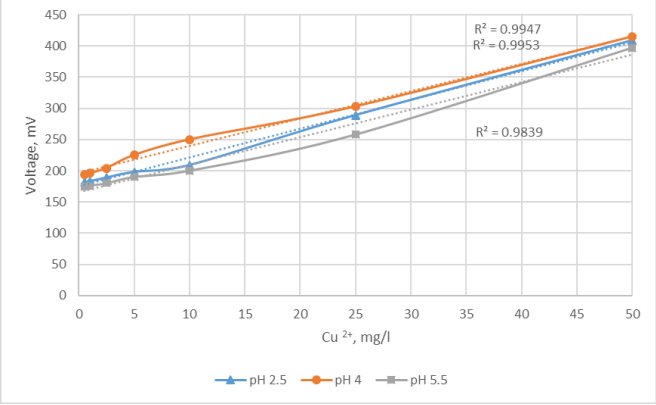


Fig. 9 SMFC-based biosensors standard curves Cu²⁺

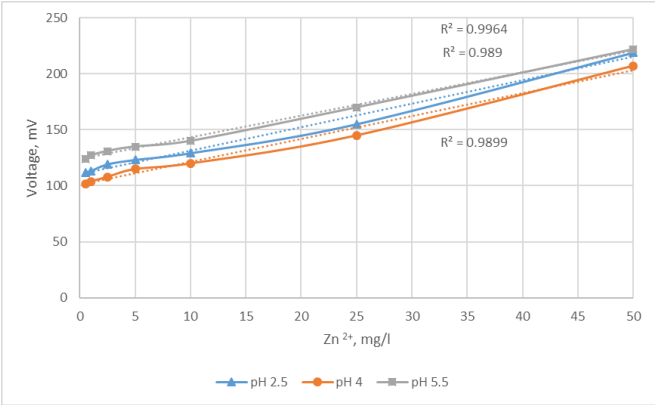


Fig. 10 SMFC-based biosensors standard curves Zn²⁺

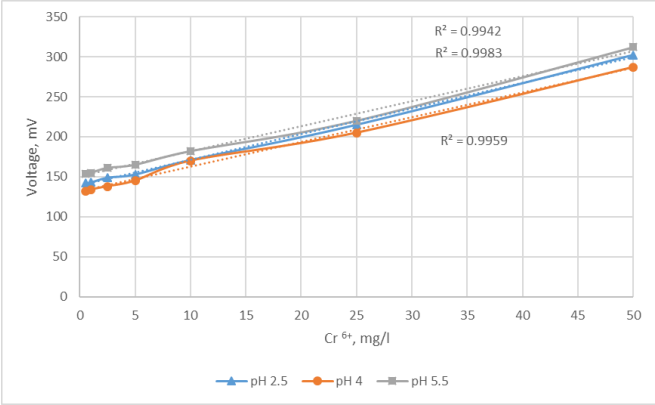


Fig. 11 SMFC-based biosensors standard curves Cr⁶⁺

The results of the study show a very high coefficient of determination - R^2 for all four investigated metals regardless of the pH of the incoming solutions. The coefficient of determination varies between 0.9839 and 0.9964.

Inhibition of exoelectrogenic bacteria

The next experiment aimed to establish the inhibitory effect of heavy metals on exoelectrogenic bacteria in long-term operation. We have found that *Geobacter* and *Clostridium* are dominant exoelectrogenic bacteria in Starting soil. Therefore, they were selected as representatives of exoelectrogenic bacteria for qPCR assay. After one year of operation of the SMFC based biosensor, the abundance of *Geobacter* and *Clostridium* in the anode area was determined. The results are shown in Table 1.

Table 1: Copies of 16S rRNA gene for *Geobacter* and *Clostridium*

	Geobacter				Clostridium			
	copies of 16S rRNA gene (10 ⁹)				copies of 16S rRNA gene (10 ⁹)			
	Ni ²⁺	Cu ²⁺	Zn ²⁺	Cr ⁶⁺	Ni ²⁺	Cu ²⁺	Zn ²⁺	Cr ⁶⁺
Starting soil	0.31	0.31	0.31	0.31	0.49	0.49	0.49	0.49
After one year	0.27	0.29	0.25	0.22	0.47	0.46	0.48	0.45

The abundance of *Geobacter* and *Clostridium* were determined with copies of 16S rRNA gene. The copies of 16S rRNA gene for *Clostridium* were approximately two times higher than those for *Geobacter*. In the anodic zone, there was no significant difference between the initial soil and the soil after one year of operation in the copies of the 16S rRNA gene for *Geobacter* and *Clostridium*. This is probably because the surface layer of soil adsorbs heavy metal ions abundantly and is thus prevented penetration into deeper soil

layers. It can be concluded that the exoelectric bacteria were not inhibited in the deeper soil layer and hence the influence of heavy metal ions on exoelectric bacteria is limited.

3. Conclusion

In order to determine the influence of environmental factors of long-term operation and effectiveness of SMFC-based biosensors for heavy metal polluted waters, four sensors were constructed. The influence of temperature, pH and the toxic effect of heavy metal ions on the performance of the biosensor was investigated. The results showed that temperature only affects the base voltage of the biosensor, but not its sensitivity to heavy metal ions. The pH of the inlet solution did not affect the performance of the biosensor, and high values of the coefficient of determination were achieved for all four heavy metals investigated. The surface layer of soil adsorbs heavy metal ions abundantly and is thus prevented penetration into deeper soil layers. This results in minimal inhibition of exoelectrogenic bacteria and allows the biosensor to be used for monitoring recurring water pollution with heavy metals. The results proved the long-term effectiveness of the SMFC-based biosensors when working in different environmental conditions.

Acknowledgements

This work was funded by The Bulgarian National Science Fund, KII-06-M57/I – 2021

4. References

1. S. Wu, H. Deng, C. Han, L. Liu, W. Zhong, A novel sediment microbial fuel cell based sensor for on-line and in situ monitoring copper shock in water, *Electroanalysis* 30 (2018) 2668-2675, <https://doi.org/10.1002/elan.201800424>
2. T. K. Sajana, M. M. Ghangrekar, A. Mitra, Effect of operating parameters on the performance of sediment microbial fuel cell treating aquaculture water, *Aquacultural Engineering* 61 (2014) 17-26, <https://doi.org/10.1016/j.aquaeng.2014.05.004>
3. Q. Zhao, M. Ji, R. Li, Z. J. Ren, Long-term performance of sediment microbial fuel cells with multiple anodes, *Bioresource Technology* 237 (2017) 178-185, <https://doi.org/10.1016/j.biortech.2017.03.002>
4. S. Z. Abbas, J. Wang, H. Wang, J. Wang, Y. Wang, Y. Yong, Recent advances in soil microbial fuel cells based self-powered biosensor, *Chemosphere*, 303 (2022) 135036 <https://doi.org/10.1016/j.chemosphere.2022.135036>
5. L. Liu, T. Chou, C. Lee, D. Lee, A. Su, J. Lai, Performance of freshwater sediment microbial fuel cells: Consistency, *International journal of hydrogen energy* 41 (2016) 4504-4508, <https://doi.org/10.1016/j.ijhydene.2015.07.139>
6. T. Ewing, P. Ha, H. Beyenal, Evaluation of long-term performance of sediment microbial fuel cells and the role of natural resources, *Applied Energy* 192 (2017) 490-497, <https://doi.org/10.1016/j.apenergy.2016.08.177>
7. H. Wang, Y. Ye, J. Zhang, H. Ning, Y. Xiang, X. Song, W. Zhao, F. Guo, Power performance improvement in sediment microbial fuel cells: Recent advances and future challenges, *International journal of hydrogen energy*, 48 (2023) 24426-24446, <https://doi.org/10.1016/j.ijhydene.2023.03.291>
8. T. Ewing, P. Ha, J. T. Babauta, N. Tang, D. Heo, H. Beyenal, Scale-up of sediment microbial fuel cells, *Journal of power sources* 272 (2014) 311-319, <https://doi.org/10.1016/j.jpowsour.2014.08.070>
9. J. Dziegielowski, M. Mascia, B. Metcalfe, M. Di Lorenzo, Voltage evolution and electrochemical behaviour of Soil microbial fuel cells operated in different quality soils, *Sustainable energy technologies and assessments* 56 (2023) 103071, <https://doi.org/10.1016/j.seta.2023.103071>
10. L. Liu, Y. Lu, W. Zhong, L. Meng, H. Deng, On-line monitoring of repeated copper pollutions using sediment microbial fuel cell based sensors in the field environment, *Science of total*

- environment* 748 (2020) 141544, <https://doi.org/10.1016/j.scitotenv.2020.141544>
11. K. Zhang, H. Cao, J. Chen, T. Wang, H. Luo, W. Chen, Y. Mo, L. Li, X. An, X. Zhang, Microbial fuel cell (MFC)-based biosensor for combined heavy metals monitoring and associated bioelectrochemical process, *International journal of hydrogen energy* 47 (2022) 21231-21240, <https://doi.org/10.1016/j.ijhydene.2022.04.225>
 12. N. Song, H. Jang, Effects of initial sediment properties on start-up times for sediment microbial fuel cells, *International journal of hydrogen energy*, 43 (2018) 10082-10093, <https://doi.org/10.1016/j.ijhydene.2018.04.082>

Personal noise exposure level and the impact on the employee's performance in the automotive industry

Teodora Topcheva¹, Marija Hadzi-Nikolova², Dejan Mirakovski², Simeon Simoeonov¹, Zlatko Petreski³.

¹Goce Delcev University, Faculty of Mechanical Engineering, Stip, North Macedonia

²Goce Delcev University, Faculty of Natural and Technical Sciences, Stip, North Macedonia

³University Ss. Cyril and Methodius, Faculty of Mechanical Engineering Skopje, North Macedonia

E-mail: teodora.3263@student.ugd.edu.mk, marija.hadzi-nikolova@ugd.edu.mk, dejan.mirakovski@ugd.edu.mk, simeon.simeonov@ugd.edu.mk, zlatko.petreski@mf.edu.mk

Abstract: In today's demanding market environment the companies need to deliver high quality product to their customers and in parallel to maintain an ergonomic workplace for their employees to increase the productivity. The purpose of this paper is determination of the personal noise exposure level caused by the machines and equipment installed in all organization units in an auto part production plant. The noise level was measured and analysed with noise measurements equipment – dosimeters and software tool at 25 measurement points across the plant. In addition, the strength between the variables, noise levels and concentration, is presented with correlation coefficient.

KEYWORDS: NOISE LEVEL, PERSONAL EXPOSURE, AUTOMOTIVE INDUSTRY

1. Introduction

The implementation of ergonomics design on the workplace can improve the productivity, safety, physical and mental well-being, and employee satisfaction. Many studies done in the past years have shown positive effects of adopting ergonomics principles to the work environment. It is very important that the production system designers should not be focused only on the productivity but also on providing comfortable workplace for the employees.

Many different factors have impact on the work environment: noise, vibration, lightening, heating, and cooling, air pressures, etc. The current research studies consider three types of effects of these factors: effects on employee health, comfort, and performance [1]. Continuous and dynamic interaction between people and their environment has its effects on personality. This can lead to a direct impact on performance and productivity as well as affecting the employee health and safety.

One of the key factors contributing to ergonomic workplace is the noise exposure level. Noise is defined as unwanted or harmful sound that can damage the hearing and cause many other adverse health effects. It can also be the cause of injuries at work. The effects can be short and long term. Short term effects of noise exposure are temporary hearing loss, stress, annoyance, difficulty in verbal communication and safety hazards [2]. The main long-term effect on employee's health from noise exposure is noise-induced hearing loss (NIHL) which cannot be remedied by medical treatment [3]. Noise-induced hearing loss is one of the most common occupational injuries, resulting in health problems for many workers and a significant social and economic problem. This includes lost jobs, higher absenteeism, lower employee performance, lost opportunities for promotion, and disrupted social relationships. In case there is a hearing loss, it can be the cause for an accident at the workplace [4].

Usually, the noise in the industry is caused by the machines and equipment used in the production process. This means that not only the employee who is operating on a specific machine is under noise exposure but also the employees operating in the same area or within the plant. The various types of equipment used by the manufacturing sector results in different noise levels due to the usage of plant equipment, and the operating speed of the machines. A large percentage of the labour force employed in a production plant is exposed to noise and according to literature research, a huge part of the production plants create noise that exceeds the permitted limits, and on average ranges between 70-118 dB.

Noise exposure in the workplace vary in the level, duration, and frequency. These parameters can be continuous, impulsive, or intermittent. The frequencies are rated as high or low frequencies. The goal in all industrial plants is to reduce the noise levels and eliminate the risk of noise-induced hearing damage.

Noise exposure is a complex combination of the sound levels to which an employee has been exposed and the duration of each of those noise levels. The focus is on the two variables: sound levels

and duration. Equivalent sound level, $L_{eq, t}$ in dBA is the first of these. The simplest way to understand is as follows: In real life, sound levels constantly vary over time. They rise when the employee uses a power tool and shrink between operations, this means is constantly changing. $L_{eq, t}$ is a kind of "average" sound level for the entire period of exposure (working hours), which includes all "quiet" and "noisy" periods. It is defined as a constant sound level noise value that contains the same total A -long-term equivalent sound pressure level, expressed in decibels. While the real noise has a varying sound level, the equivalent has a constant level.

The negative effects caused by noise depend on the level of noise during the working hours. This means, as louder the noise becomes, it can cause damage for a short time. A 3 dB (A) increase of the noise level will produce twice as much energy and cause the same damage in half of the time compared to the noise level before this increase. For example, two minutes working in a noise level of 115 dB (a) can cause the same damage as eight hours working in a noise level of 90 dB. Long periods without exposure to noise in the workplace lead to a reduced risk of developing hearing impairment. As noise levels increase, the risk becomes greater. For example, exposure to a noise level of 90 dB (A) to 95 dB (A) represents a significantly risk of developing hearing damage.

Effective noise management in the industry is possible if the responsible team is focused on the following steps:

- regular risk assessment,
- corrective and protective measures and
- monitoring on the results of these measures.

The monitoring of the control measures is a necessary step to determine whether the measures are effectively implemented and provide adequate results for the employees. When the measures are implemented effectively, then the effects on the employees, such as unpleasant feeling, reduced concentration, injuries, and personal performance, will be eliminated or mitigate.

The following measures can be taken to improve the working conditions in relation to high noise exposure:

- application of equipment whit noise emission reduced to a minimum,
- adequate reconstruction of the workspace and installation of materials that enable better acoustics,
- regular maintenance of the machines and equipment,
- job rotation,
- provide personal protective equipment to the exposed employees.

While purchasing new equipment the industry should take in consideration the effect of the noise caused by the equipment as one of the sourcing criteria. This research is focuses on the analysis of personal noise exposure at different work positions in an auto part manufacturing plant and the effects on employee performance and productivity.

2. Aim and scope of the research

The purpose of the research is to determinate the levels of personal noise exposure from machines and equipment in all organizational units in a production plant, to identify the area in which the employees are most exposed to noise. In the organizational unit with the highest potential of noise exposure, the measurements will be performed to a higher number of employees. The personal noise exposure will be determined with the help of special instruments - dosimeters, which the employees should keep positioned closest to the ear during the day. The recorded personal exposure levels will then be processed using the software tool - Noise Safe.

Personal exposure to noise during a working day could have an impact on the employee performance. During the research, the type and degree of correlation between these two variables will be determined using correlation analysis. The analyses will show whether the exposure to noise in the production plant can be the reason for the drop of the employee concentration and a cause for injuries on the workplace. All this affects the productivity or performance of the company. The success of the company depends on the working conditions and the productivity of the employee.

3. Research methods

The research includes 75 employees working on 25 measurement points in a production plant, representatives from different organizational units: production, warehouse and maintenance. The criterion for selecting the employees is that they must be at their workplace for 8 hours and employed for longer than six months. The purpose of this study was shared with the participants and all of them voluntarily accepted to participate in conducting measurements of personal noise exposure, while the purpose of the study was first shared with them.

3.1. Measurement equipment – Dosimeters

Dosimeters are small devices that contain a microphone to capture personnel exposure to noise. The dosimeters used for the purpose of this research, CASELLA Dbadge2, satisfy the requirements according to IEC 61252 and in accordance with the requirements of IEC 61762-1: 2002 instrument class 1. The participants in this research will place the dosimeters on top of the shoulder without covering the microphone with clothing or other equipment. The procedure will be carried out in two different shifts, 6 hours per measurement, and repeated in at least three series per measurement point.

Before the dosimeters are distributed, the pilot group will receive instructions on how to use them. It is recommended to place them closer to the ear to capture the actual personal exposure levels. Before we put these instruments into use, we need to make sure that the battery is full and will last during the testing, as well as that they are placed in a suitable position without hindering the performance of the daily tasks of the employees. The software Noise Safe will be used to manage and collect the data from the dosimeters.

The Noise dosimeter which measures the noise level for several hours, calculates the cumulative noise level expressed as the application of a noise dose for a certain time in percentage [5].

3.2. Questionnaire

All the participants in the research filled a questionnaire for concentration check just after the end of the working hours. The results of the questionnaire will be used to determine the impacts of noise exposure on the employee performance. The questionnaire for each of the employees will be marked with an appropriate code, and the time required to answer is 2 minutes.

The results are manually collected and processed with statistical analysis. When the results of the questionnaire will be summarized, we can move on with statistical analysis and

determining the dependence of the employee concentration and the levels of personal noise exposure.

3.3. Statistical analysis

As final step in the research a correlation analysis will be used for determining the dependence between two variables. Correlation Analysis is statistical method that is used to discover if there is a relationship between two variables/datasets, and how strong that relationship may be. A relationship between two variables, X and Y, exists if an increase of the first one is followed by an increase or decrease of the second variable. Depending on the direction, the relationship between two variables can be: positive or negative. A positive correlation result means that both variables increase in relation to each other, while a negative correlation means that as one variable decreases, the other increases. The relationship between the variables differs not only in direction, but also in strength (intensity).

Scatter diagrams are used to investigate the relationship between two variables which may be: quality parameter and factor affecting it, two quality characteristic, and two factors related to one quality characteristic. The procedure for creating these diagrams is carried out through several steps. The first step is monitoring and collecting pairs of data (x,y) for the dependence we want to investigate and calculation of the maximum and minimum values for x and y. For further explanation it is necessary to enter data such as: time intervals of the measurements, number of pairs of data, units of measurement used and the team performing the measurements. Results presented in a scatter diagram may show a different dependence.

To understand the relationship between the variables, the correlation coefficient needs to be calculated. This coefficient requires a table of data which displays the raw data, it's ranks, and the difference between the two ranks. The constraint that this coefficient works under is $-1 \leq r \leq +1$, where a result of 0 would mean that there is no relation between the data. According to the obtained results for the degree of correlation, we can determine whether there is a correlation, positive or negative, and how strong the correlation is between the variables. The results at the end will be displayed graphically. This is the most widely used correlation analysis formula, which measures the strength of the 'linear' relationships between the raw data from both variables, rather than their ranks.

Having the data set of the personal noise exposure levels and the results of the questionnaire performed during the measurements the correlation coefficient will be calculated. The results will present the intensity of the relationship between these two variables and will give a direction for future actions.

Using a scatter graph is the easiest way of identifying any anomalies that may have occurred and running the correlation analysis twice (with and without anomalies) is a great way to assess the strength of the influence of the anomalies on the analysis. The regression equation representing how much y changes with any given change of x can be used to construct a regression line on a scatter diagram, and in the simplest case this is assumed to be a straight line. The direction in which the line slopes depend on whether the correlation is positive or negative.

The regression equation enables us to predict y from x and gives us a better summary of the relationship between the two variables. The regression equation can be used to find out what one variable is likely to be when we know the other.

4. Results

The measured levels of noise exposure in auto parts manufacturing plant have been obtained according to the ISO 9612-2009: Acoustics - Determination of occupational noise exposure method and have been normalized to 8 hours working day and the daily noise exposure level, LEX,8h, using the following formula: $LEX, 8h = LA_{eq, Te} + 10 \log_{10} Te/T0 \text{ dB (A)}$, where:

- $A_{eq, Te}$ - measured equivalent noise level in dB (A) during T_e ,
- T_e - daily duration of the employee's exposure,
- $T0$ - 8 hours reference time.

In Table 1 are presented the results of the personal noise exposure levels at 25 measurement points across 5 departments in the auto parts manufacturing plant. Due to the higher number of employees operating in Production 2 department, total 20 measurements were performed in this area.

Table 1. Personal noise exposure levels in an auto parts manufacturing plant

MP	Department	LEX, 8h dB
1	Maintenance	60.7
2	Maintenance	67.9
3	Maintenance	68.6
4	Warehouse	61.9
5	Warehouse	66.6
6	Production 1	67.0
7	Production 1	70.1
8	Production 1	70.3
9	Production 1	66.8
10	Production 2	76.4
11	Production 2	73.9
12	Production 2	71.0
13	Production 2	72.3
14	Production 2	71.1
15	Production 2	72.6
16	Production 2	76.2
17	Production 2	76.8
18	Production 2	74.2
19	Production 2	74.2
20	Production 2	71.8
21	Production 2	75.0
22	Production 2	79.6
23	Production 2	63.2
24	Production 2	64.2
25	Production 2	64.0

The results obtained from the monitoring of personal noise exposure vary depending on the work position in the plant. Considering the measured levels between 75-80 dB(A) regular control monitoring is required at the plant. From the previous research, we can expect that there is a correlation between the performance of the employees and the exposure to noise. For this purpose, a correlation analysis was performed using the results from the questionnaire (maximum score of 3; minimum score 0) and exposure levels in Table 1.

According to the correlation coefficient formula the dependence between the noise exposure levels and questionnaire score was calculated. Table 2 presents the parameters calculated based on the obtained results from the monitoring and the questionnaire. The correlation coefficient, $r=-0.5$, indicates moderate negative correlation between the two variables. When the

noise exposure level increase than the concentration of the employees decreases.

Table 2. Correlation analysis parameters

parameter	noise exposure level	questionnaire score
average	69.8	1.24
min	50.1	0
max	79.6	3
R	29.5	3
r (correlation coefficient)	-0.5	

The relationship between the variables can be represented by a simple equation called the regression equation. In this context regression means that the average value of y is a function of x and it changes with x. The regression equation for the variables, noise exposure level and questionnaire score, is the following: $y=5.35-0.06x$

Two points are enough to define the line, three are better as a check. Having put them on a scatter diagram, we simply draw the line through them. Regression line show how the variable questionnaire score changes on average with the noise exposure level. This equation is very useful as we can identify what will be the expected questionnaire score when only the noise level is known.

5. Discussion

The results of this study indicate a moderate negative impact of the noise exposure levels on the employee's performance in automotive industry. In the available studies there is much debate as how the length of time an occupant is working under a single background noise condition can impact their performance and perception [6]. Prolonged exposure to noise at high intensity is associated with damage to the sensory hearing cells of the inner ear and development of permanent hearing threshold shift, as well as poor speech in noise intelligibility [7].

The noise in an automotive industry plant is generated from the production process. Machinery, equipment, and work practices are typically the sources of excessive noise in the workplace [8]. The implementation of noise control and other aspects of noise regulations place a financial and compliance burdens on employers. However, this should not discourage employers from implementing feasible engineering noise controls [9]. The employers should implement regular noise measurements and adopt adequate action plan to maintain health and safety workplace and high product quality.

Pedro and Miguel [10] worked on research with a total of 434 industrial workers exposed to a noise level higher than 85dB (A). With the help of a questionnaire, the employees' perception of the exposure to high noise levels and the use of protective equipment was assessed. The analysis of the data with several variables showed that general risk recognition and personal efficiency have a significant role for employee's behaviour regarding the use of personal noise protection equipment. Furthermore, these results suggest that risk recognition should be considered as an essential issue in the design and implementation of Hearing Protection Programs.

To maintain a pleasant working environment, apart from noise, several factors have an impact and usually all of them are investigated individually. It is necessary to conduct further research for consolidating the impact of different factors to employee performance and propose preventive and corrective measure for risk mitigation or elimination.

6. Conclusion

According to the research work done in the field of personal noise exposure often the high exposure levels to noise cause negative effects to the employee health and productivity. This leads to a risk factor for hearing loss and reducing the quality and quantity of the products.

The results of this study performed in the automotive industry indicate that the levels of personal noise exposure vary depending on the work position in the plant. In general, the exposure levels are high and require regular control to avoid exceeding the industry limit levels and negative effects. The correlation between the exposure level and the employee performance is negative and indicates that there is a risk of lower performance while the noise exposure levels increase.

Therefore, the recommendations are to control the noise levels in the production facilities and keep them at the lowest possible level to enable a comfortable workplace and efficient production of quality products. Only with detailed measurements and risk assessment on the personal noise exposure level the companies can decide if there is need of additional protective measures.

7. References

- [1] B. Das, and A. Sengupta, "Industrial workstation design: a systematic ergonomic approach", *Applied Ergonomics*, 27(3), pp. 157–163, 1996, doi: 10.1016/0003-6870(96)00008-7.
- [2] M.J. Crocker, "General introduction to noise and vibration effects on people and hearing conservation", *Handbook of Noise and Vibration Control*, M.J. Crocker, John Wiley & Sons, New York, 2007, doi:10.1002/9780470209707.
- [3] J.M. John, "Occupational hearing loss", *American Journal of Industrial Medicine*, vol. 37, 112–120, 2000, doi:10.1002/1097-0274(200001)37.
- [4] K.C. Parsons, "Environmental ergonomics: a review of principles, methods and models", *Applied Ergonomics*, 31, pp. 581-594, 2000.
- [5] L.Trendova, M. Hadzi-Nikolova, D. Mirakovski, R.Timovski "Personal noise exposure on industry workers" *Natural resurces and techonologies* Vol 16, No. 1, pp. 83 - 87 2022, doi: 10.46763/NRT22161083.
- [6] J. Errett, E.E.Bowden, M.Choiniere, and L.M. Wang, "Effects of noise on productivity: does performance decrease over time?", *Architectural Engineering - Faculty Publications*. 13. 2006, doi: 10.1061/40798(190)18.
- [7] M. Hadzi-Nikolova, D. Mirakovski, N. Doneva, N. Bakreska, "Environmental and occupational noise management process in cement industry" *Safety Engineering*, pp. 7-12, 2019, doi:10.7562/SE2019.9.01.02.
- [8] P. Alagapan, M.Z. Hassan, M.H. Ibrahim, M.Y. Daud, N.A. Bani, and R. M. Kutty, "Measurement of hazardous personal noise exposure in spice manufacturing industry" *IOP Conf. Series: Journal of Physics, Conf. Ser.* 1150 012021, 2019, doi:10.1088/1742-6596/1150/1/012021.
- [9] O. Rikhotso, J. L. Harmse and J. C. Engelbrecht, "Noise Sources and Control, and Exposure Groups in Chemical Manufacturing Plants" *Applied Science*, pp. 1-27, 2019, doi: 10.3390/app9173523.
- [10] P. M. Arezes, A. S. Miguel, "Does risk recognition affect workers' hearing protection utilization rate?" *International Journal of Industrial Ergonomics*, Vol.36, pp. 1037–1043. 2006, doi: 10.1016/j.ergon.2006.09.005.

State and characteristics of the vehicle fleet of Montenegro with special reference to fuel consumption and electric vehicles

Marko Lučić

Faculty of Mechanical Engineering, University of Montenegro, Podgorica, Montenegro

E-mail: markol@ucg.ac.me

Abstract: It is very important to know the trends related to the structure and condition of the vehicle fleet, to be able to predict the structure of the vehicle fleet in the future. In Montenegro, it is noticed that there is a constant increase in the number of battery electric vehicles (BEVs). The share of BEVs in the vehicle fleet of Montenegro is too small to have any significant impact on CO₂ emissions as well as the power system. The pandemic COVID-19 virus had a great impact on the number of registered as well as the number of newly registered vehicles. Practically, in 2020, the year of the pandemic, only an increase in the number of BEVs was recorded. It is very worrying that the number of vehicles using diesel fuel is increasing, which can be a complicating factor in efforts to reduce the negative impact of road traffic on the environment.

Keywords: VEHICLE, IC ENGINES, FUEL CONSUMPTION, ROAD TRAFFIC

1. Introduction

Transport is a basic prerequisite for the development of society and the improvement of people's lives. Around the world, governments have played an important role in improving fuel consumption. In some developed countries, governments have implemented fuel economy standards and regulations and economic incentives, as well as disincentive policies such as fuel taxes to promote the introduction of alternative fuel vehicles into the market [1]. Diesel fuel is the most used fuel for buses and other urban transport vehicles in Europe. Air protection is one of the areas in which the EU is very active due to the need to provide cleaner air. Air pollution can significantly harm human health and the environment. Annually up to 400 thousand premature deaths in the EU are caused by poor air quality. Various actions are undertaken at the EU and national level, as well as through active cooperation at the level of international conventions. The goal is to improve air quality by controlling pollutant emissions into the atmosphere, improving fuel quality, and integrating environmental protection requirements into other sectors as well [2]. Today in the EU there are a large number of road transport companies that are struggling to stay in the big market with more or less problems. The supply in this area significantly exceeds the demand for transport services. The quality of the services provided is influenced by the characteristics of individual vehicles, which form a significant whole that affects the work of individual carriers. Such features include e.g. age of the vehicle, equipment, technical condition, etc. Indirect benefits include optimal intensity and structure of vehicles on the road infrastructure [3]. In this paper, an analysis of the structure of the vehicle fleet of Montenegro was performed, with a special focus on fuel consumption and electric vehicles that are increasingly used in this country. The number of transported passengers in road traffic is constantly increasing, as presented in the research [4]. In addition to road traffic, a constant increase in transported passengers is also present in rail and air traffic. In Montenegro, there has been a steady increase in transported cargo in road traffic over the last few years [5]. In other types of traffic, oscillations were recorded in the transportation of cargo in road traffic in Montenegro. Road traffic safety in Montenegro was investigated in the paper [6], and it was concluded that safety is not at an enviable level. The state of traffic safety is significantly different from other EU countries. Although relatively large efforts are being made to improve traffic safety in Montenegro, traffic safety is deteriorating from year to year. Although great efforts are being made to improve the infrastructure, the criteria for the technical inspection of vehicles are being tightened, various investigations are being carried out and a large number of investigations are being carried out, and the number of traffic accidents is constantly increasing.

2. Vehicle fleet of Montenegro

The structure of the vehicle fleet of Montenegro for the period from 2018 to 2022 by type of vehicle is shown in Figure 1 [7]. In

this paper, the vehicle fleet of Montenegro is divided into three groups:

- passenger vehicles
- trucks, tractors, and buses
- other vehicles (motorcycles, off-road vehicles, special vehicles, work vehicles, trailers, agricultural tractors).

It is noted that the total number of vehicles has an increasing trend in the observed period, although in 2020 there was a decrease in the total number of registered vehicles. The decrease in the total number of registered vehicles in 2020 was achieved mainly due to the pandemic of the COVID-19 virus. When it comes to passenger vehicles in 2019, there was an increase of about 5.5% compared to the previous year, 2018. In 2020, a year marked by the pandemic of the COVID-19 virus, there was a decrease in the number of registered passenger vehicles of about 3.6% compared to 2019. Then in 2021, there was an increase in the number of registered passenger vehicles of about 5.4% compared to 2020. The record in the number of registered passenger vehicles in Montenegro was recorded in 2022. In 2022, an increase in the number of registered passenger vehicles of about 2.8% was recorded.

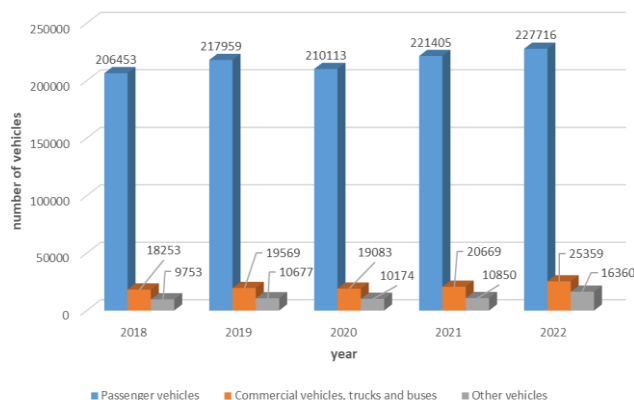


Fig. 1 Total number of registered vehicles in Montenegro [7]

When it comes to the group "trucks, tractors, and buses" in 2019, an increase in the number of registered vehicles of about 7.2% was recorded. The pandemic of COVID-19 virus also had an impact on the number of registered vehicles in this category, when a decrease in the number of registered vehicles of about 2.5% was recorded. In 2021, there was an increase of about 8.3% compared to 2020, while in 2022 there was an increase of about 22.7%. In the group of other vehicles in 2019, there was an increase of about 9.4% compared to 2018. In the group of other vehicles, the impact of the COVID-19 pandemic on the number of registered vehicles in 2020 was unavoidable, when a decrease in the number of registered vehicles of about 4.7% was recorded. In the group of other vehicles, an increase in the number of registered vehicles of about 6.6% compared to 2020 was recorded in 2021. An incredible 50%

increase in the number of registered vehicles in the group of other vehicles was achieved in 2022 compared to 2021. The number of newly registered vehicles in Montenegro is shown in Figure 2 [7]. It is noted that in 2019 there was a decrease of about 7.3% in newly registered passenger vehicles compared to 2018. The pandemic of the COVID-19 virus also had a great impact on the number of newly registered passenger vehicles in 2020, when there was a decrease of about 67.3% compared to 2019. After 2020, a slight recovery of the passenger vehicle sales market began, so in 2021, a growth of about 7.2% compared to 2020 was recorded. An increase in the number of newly registered passenger vehicles of about 22.4% was achieved in 2022 compared to 2021. In 2019, the number of NGO-registered vehicles in the group "trucks, tractors and buses" recorded a decrease of about 8.2%. In this group of vehicles, a decrease of about 25.6% was recorded in 2020 compared to 2019, which was largely influenced by the pandemic of the COVID-19 virus. In 2021, an increase in the number of newly registered vehicles of the mentioned group was recorded by 5.8%. Also, in 2022, an increase of about 3.5% was recorded compared to 2021. An increase in the number of newly registered other vehicles was recorded in 2019 compared to 2018 by about 22.5%. In 2020, the year of the COVID-19 virus pandemic, there was a decrease in the number of newly registered other vehicles compared to 2019 by about 14.6%. The number of newly registered other vehicles decreased in 2021 by about 5% compared to the previous year, 2020. It is interesting to note that when it comes to newly registered other vehicles in 2022, a growth of about 80.8% was recorded compared to 2021.

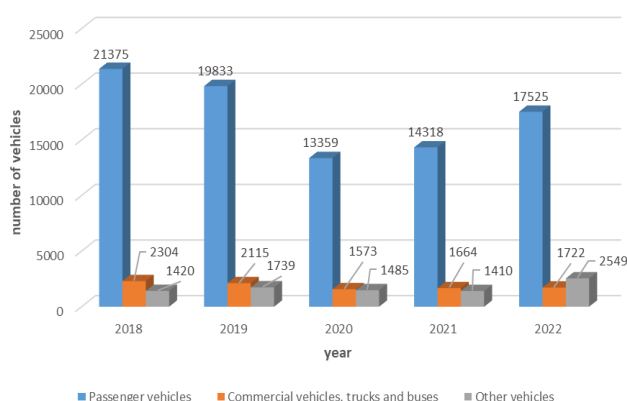


Fig. 2 Total number of newly-registered vehicles in Montenegro [7]

To better understand the structure of the vehicle fleet of Montenegro, it is very important to show the structure of the vehicle fleet according to the type of driving energy. Figure 3 shows the total number of vehicles in Montenegro for the period from 2018 to 2022 by type of fuel [7]. It is noticed that the number of vehicles that use diesel as fuel is a constantly growing trend. In 2019, there was an increase in vehicles with diesel fuel of about 7.6%. The decrease in the number of vehicles using diesel fuel in 2020 is lower by about 0.75% compared to 2019. In the following year, in 2021, there was an increase in the number of vehicles that use diesel fuel by about 7% compared to 2020, so in 2022 this increase amounts to about 6.1% compared to 2021. When it comes to the number of vehicles that use gasoline as fuel, in 2019 there was an increase in the number of vehicles that use gasoline by about 1.6% compared to 2018. In 2020, the number of vehicles using gasoline decreased by about 12% compared to 2019. In 2021, there was an increase in the number of vehicles using gasoline by about 2.3% compared to 2020. Also in 2022, there was an increase in vehicles that use gasoline by about 1.4% compared to 2021. The number of vehicles that use LPG as a fuel is constantly decreasing from year to year, in the observed period from 2018 to 2020. For example, in 2019, the number of vehicles using LPG decreased by about 1.5% compared to 2018. Then in 2020, the number of vehicles using LPG decreased by about 9%. In 2021, there was a decrease in the number of vehicles using LPG by about 5.7% compared to 2020, and in 2022,

the decrease in the number of these vehicles compared to 2021 would amount to about 8.3%.

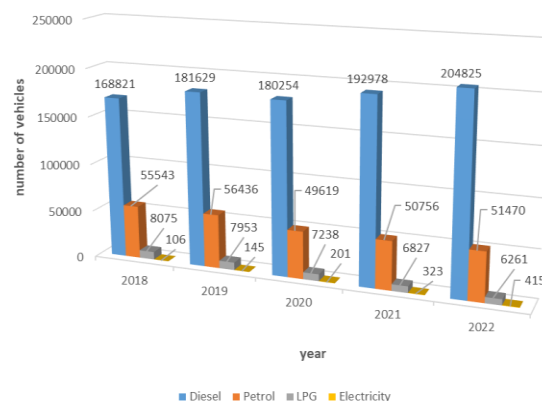


Fig. 3 Total number of vehicles by fuel [7]

3. Fuel consumption and electric vehicles in Montenegro

When analyzing the structure of the vehicle fleet, it is very important to show fuel consumption in the road transport sector. Figure 4 shows the total consumption of oil products in Montenegro. The largest share of consumption of oil products is accounted for by road traffic, while a significantly smaller consumption of oil products is realized in air traffic and transport. Data on the consumption of oil products for the year 2022 are still not available, so Figure 4 shows only the data for the period from 2018 to 2021 [7]. Road traffic in each year of the observed period has a share of more than 90% in the consumption of oil products. The share of road traffic in the total consumption of oil products for 2018, 2019, 2020, and 2021 is 91.5%, 91.5%, 97.8%, and 95.9% respectively. The consumption of oil products in road traffic in 2019 increased by about 4.4% compared to 2018. In 2020, the consumption of oil products in road traffic decreased by about 14.7% compared to 2019. This decrease was mostly caused by the impact of the COVID-19 virus pandemic. In 2021, the highest consumption of oil products in road traffic was achieved in the observed period from 2018 to 2021. In 2021, the consumption of oil products in road traffic increased by about 30% compared to 2020, by about 11.1% compared to 2019, and by about 16.1% compared to 2018. It can be noted that the consumption of oil products in road traffic is a growing trend. Of course, in 2020, a large reduction in the consumption of oil products in road traffic was recorded, which was caused for the most part by a drastic reduction in mobility in this sector due to the pandemic of COVID-19 virus. Although it is not the subject of this research, it can be noted that the drastic drop in fuel consumption in 2020 compared to 2019 of an incredible 80% is also present in air traffic and transport.

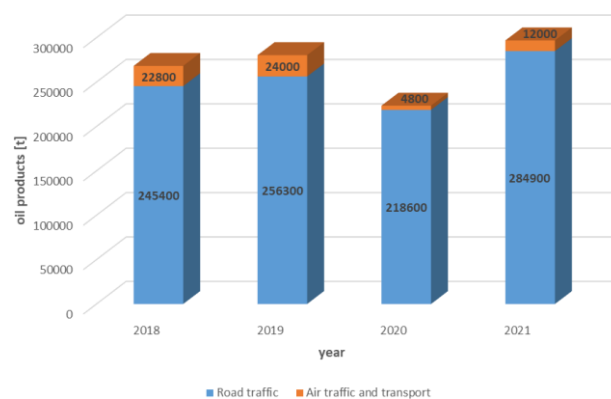


Fig. 4 Total consumption of oil products in Montenegro [7]

To make Figure 3 clearer and to better understand the number of BEVs in Montenegro, Figure 5 shows only the number of these vehicles in the period from 2018 to 2022 [7]. When it comes to the number of BEVs in the period from 2018 to 2022, an increasing trend was recorded. In 2019, an increase in BEVs of about 36.8% compared to 2018 was recorded. It can be noted that in 2020, despite the pandemic COVID-19 virus, an increase in the number of BEVs of about 38.6% was recorded compared to 2019. Also in 2021, an increase in the number of BEVs of about 60.7% compared to 2020 was recorded. An increase was also recorded in 2022 compared to 2021 of about 28.5%. It is characteristic of the number of BEVs in Montenegro that it increases from year to year in the observed period from 2018 to 2022.

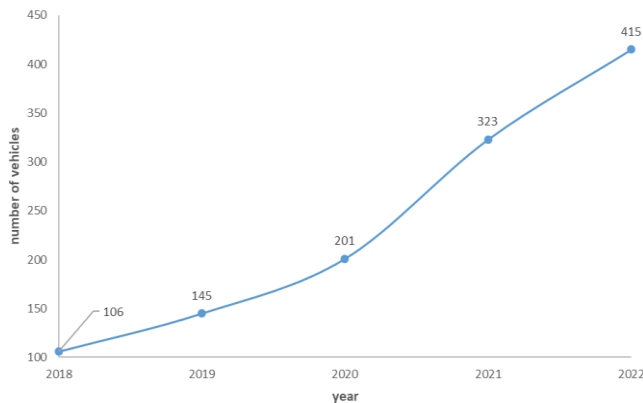


Fig. 5 Total number of BEVs in Montenegro [7]

To better understand the relatively small share of BEVs in the vehicle fleet of Montenegro, Figure 6 is given, which shows the share of vehicles by type of propulsion energy in each year of the period from 2018 to 2022 [7]. From Figure 6, it can be observed that the share of vehicles using gasoline and LPG has a decreasing trend, while the share of vehicles using diesel fuel has an increasing trend. It is not possible to comment on the share of vehicles that use electricity as driving energy from Figure 6, because the share of these vehicles is very small.

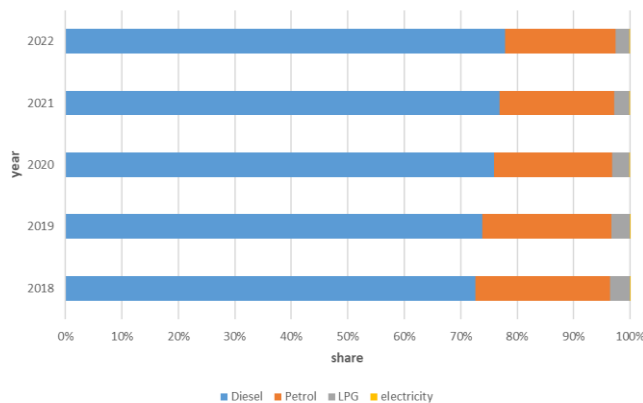


Fig. 6 Share of vehicles by type of fuel [7]

Figure 7 shows the share of BEVs in the total number of vehicles in Montenegro for the period from 2018 to 2022 [7]. The share of BEVs is very small, but it is noticeable that it is increasing year by year. Let's say in 2019, the share of BEVs increased by about 28.3% compared to 2018. Also in 2020, an increase in the share of BEVs of about 44% compared to 2019 was recorded. An increase in the share of BEVs was also recorded in 2021 compared to 2020 by about 51.2%. In 2022, an increase in the share of BEVs compared to 2021 was recorded by about 22.5%.

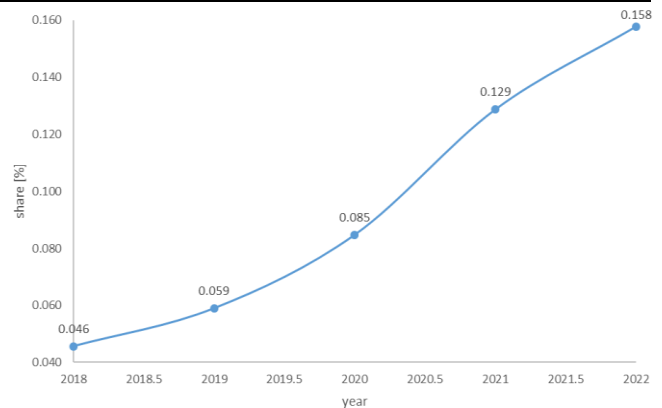


Figure 7 Share of BEVs in Montenegro [7]

4. Conclusion

In Montenegro, it is observed that the number of registered passenger vehicles has an increasing trend from 2018 to 2022. There is also an increasing trend in the number of registered commercial vehicles, trucks, and buses as well as other vehicles in the observed period from 2018 to 2022. In all the mentioned groups of vehicles, there was a decrease in the number of registered vehicles in 2020 compared to 2019, which was most likely caused by the crisis caused by the COVID-19 virus pandemic. It is important to note that the share of vehicles using diesel fuel has an increasing trend, while the share of vehicles using gasoline or LPG has a decreasing trend. Also, only the number of BEVs is increasing from year to year, and their share is also increasing from year to year, which is still very negligible. The vehicle fleet of Montenegro is dominated by passenger vehicles, which also show a constant growing trend. When it comes to the type of fuel, the traffic is dominated by vehicles that use diesel fuel. If you look at the current state and structure of the vehicle fleet in Montenegro, you can see that BEVs have a very small share, while the number of vehicles using diesel fuel is increasing. It can be concluded that if the structure of the vehicle fleet in Montenegro does not change significantly, it will be very difficult to reduce CO₂ emissions in the road transport sector.

5. References

1. K. He *et al.*, "Oil consumption and CO₂ emissions in China's road transport: Current status, future trends, and policy implications," *Energy Policy*, vol. 33, no. 12, pp. 1499–1507, 2005, doi: 10.1016/j.enpol.2004.01.007.
2. J. Gnap and T. Figlus, "Environmental Sustainability of the Vehicle Fleet," 2020.
3. J. Kubaňová, I. Kubašáková, and M. Dočkalík, "Analysis of the vehicle fleet in the EU with regard to emissions standards," *Transp. Res. Procedia*, vol. 53, no. 2019, pp. 180–187, 2021, doi: 10.1016/j.trpro.2021.02.024.
4. M. Lučić, "Status and characteristics of passenger transport in Montenegro," *TRANS & MOTAUTO WORLD*, vol. 145, no. 4, pp. 142–145, 2021.
5. M. Lučić, "Status and characteristics of freight traffic with special reference to road traffic in Montenegro and comparison with the EU," *TRANS & MOTAUTO WORLD*, vol. 95, no. 91, pp. 92–95, 2021.
6. M. Lučić, "Characteristics and state of road traffic safety in Montenegro," *TRANS & MOTAUTO WORLD*, vol. 53, no. 2, pp. 51–53, 2021.
7. MONSTAT, "Statistical Office of Montenegro," [www.monstat.org](http://monstat.org), 2020, Accessed: Sep. 04, 2023. [Online]. Available: <http://monstat.org/eng/index.php>

Trend Analysis of Using of Green Energies in Georgia until 2040

Raul Turmanidze¹, Giorgi Popkhadze²

Georgian Technical University (GTU), Faculty of Transportation and Mechanical Engineering, 0171 Tbilisi – Georgia^{1,2}
inform@gtu.ge¹, popxadzegiorgi@gmail.com²

Abstract: The main sources of green energy (GE) as the cleanest form of energy or types of renewable energy sources (RES) are: wind, water, sun and earth. While the world, especially in the most developed countries of the world, has advanced far in the application of various forms of green energy (GE), in Georgia this field is in its infancy and it is not possible to predict when the first major positive developments in this field will be made. The paper presents the forecast and trend analysis of the use of green energy (GE) in Georgia until 2040. According to the data on the plans of the state authorities of Georgia for the development and use of various forms of green energy (GE), the highest forecast growth of the development of these types of energy is expected in the field of wind energy (WE) until 2025 with a value of CAGR of 154.82 [%].

Keywords: Energy, Green energy (GE), Sustainable energy (SE), Clean energy (CE), Renewable energy (RE), Renewable energy sources (RES), Wind energy (WE), Trend analysis, Continuous annual growth rate (CAGR).

1. Introduction

Energy represents the ability of a body or system to do some work. There are many forms of energy, such as: Kinetic energy, Potential energy, Thermal energy (heat), Internal energy, Electrical energy, Chemical energy, Elastic potential energy and others.

One of the most commonly used forms of energy is electricity, which is a basic part of nature. The global tendency is for electricity production to increasingly shift to renewable energy sources (RES) for environmental reasons.

The consumption of energy in the world, from year to year, is growing (which is in direct correlation with the daily increase of the human population), and therefore the need for its production is also increasing. The vast majority of that energy is from non-renewable sources (currently more than 80%), which is already causing undesirable consequences for the environment. One of the solutions, in accordance with the principles of sustainable development, lies in reducing the share of fossil fuels in the total production and consumption of energy. So, the share of renewable energy sources (RES) should be significantly increased in the future, because there are fewer and fewer non-renewable energy sources and their reserves are running out, and also their harmful influence has become more pronounced in the last few years.

Currently, of the annual energy consumption, at the world level, appr. 50 [%] spend on industry, appr. 25 [%] is used for transport, and the remaining 25 [%] is consumed by households and the commercial sector.

China and India have the highest growth in consumption of all types of energy, at the world level, and of the developed countries, the highest growth in energy consumption is recorded in the USA, while the EU records a decrease in energy consumption from appr. 2 [%].

All these facts show that the best solution from this situation is in the increasing use of renewable energy sources (RES) and green energy (GE) [1, 4-6, 12-13, 15-16, 20]. The state and perspectives of the development and application of different types of green energy (GE) in different countries of the world are presented in works [3, 17-18, 24-26, 28, 31].

Currently, in the world, especially in the most developed countries, the application of various forms of green energy (GE) has advanced far, in Georgia this field is in its infancy and it cannot be predicted when the first major positive developments in this field

will be made. So that the state authorities in Georgia have foreseen in the following period until 2040 a greater application of these forms of energy, which is the goal of this paper with the trend analysis.

2. Classification of Natural Energy Sources

Considering the time possibility of exhaustion, natural or primary sources (forms) of energy can be divided into (Fig. 1) [8, 11, 19, 21-22, 29-30]:

1. Non-renewable energy sources (NRES):
 - Fossil fuels (coal, oil, natural gas, oil shale);
 - Nuclear fuels;
2. renewable energy sources (RES):
 - Water power (energy of water currents, sea currents and waves, tides);
 - Biomass and biogas, including wood and waste;
 - Solar radiation energy;
 - Wind energy;
 - Earth's internal heat (geothermal energy);
 - Tidal energy;
 - Wave energy.

Renewable energy (RE) is that form of energy that is renewable (naturally replenished) and produced from sources that are constantly renewed, meaning that this form of energy is created from natural sources (sun, wind, rain, waves, geothermal heat and similarly).

There are different types and categories of renewable energy sources (RES) (Fig. 1). According to the time of creation, renewable energy sources (RES) are divided into two main categories:

- traditional renewable energy sources such as biomass and energy from large hydroelectric plants and
- "new renewable energy sources" such as solar energy, wind energy, geothermal energy and the like.

In addition to renewable energy (RE), the following terms are often used in the literature: green energy (GE), sustainable energy (SE) and clean energy (CE). The question arises whether there is a difference between: GE, SE, CE and RE energy and what is the difference.

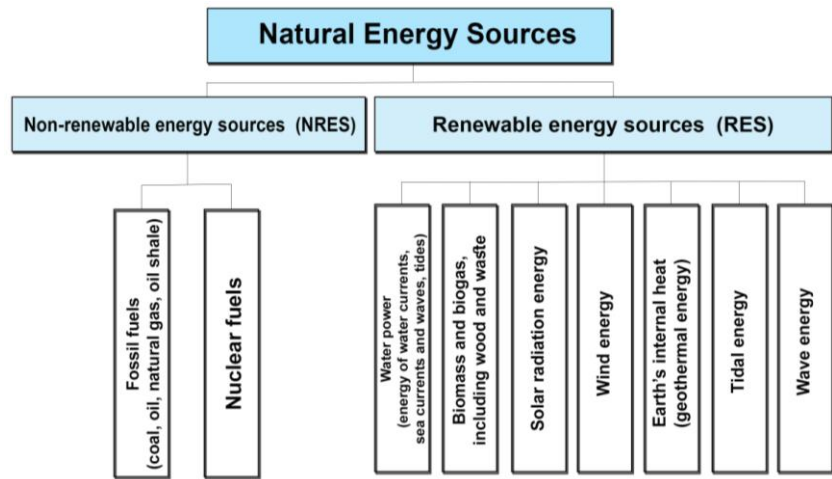


Fig. 1. Division of natural or of primary sources (forms) of energy, considering the time possibility of depletion

3. Trend Analysis of Using of Green Energies (GE) in Georgia until 2040

Georgia is country from 3.7 million people, nestled between Russia, Turkey, Armenia and Azerbaijan. About 70 [%] of the electricity in the country comes from hydropower. The 20 [%] is garnered from coal and natural gas, and the rest is covered by imports from Russia [14, 23]. Which means that the use of renewable energy sources (RES) and green energies (GE) in Georgia is insignificant, but the construction of new wind parks and photovoltaic devices is planned [14, 23].

For trend analysis of using of green energies (GE) in Georgia until 2040, data that exist in state bodies and the public were used to predict the use of different forms of green energies (GE) for Georgia for the following period: today, 2025, 2030 and 2040 (Table 1). In Table 1, for each form of green energy (GE), the CAGR (Compound Annual Growth Rate) is determined and the time period is determined, based on which the trend and forecast of the use of these forms of energy in Georgia until 2040 can be observed.

Based on the data from Table 1, the values of different forms of green energy (GE) for Georgia until 2040 (Figure 2) and the values of the CAGR index (Figure 3) are shown.

Based on Table 1 and Figures 2 and 3, it can be seen that the largest growth in the use of green energy (GE) in Georgia until

2040 will be wind energy (WE), with an increase from the current 77 [MW] to 2000 [MW] in 2040, with a CAGR index of 21.12 [%] for that period, followed by solar energy (SE), increasing from the current 70 [MW] to 1320 [MW] in 2040, with a CAGR index of 18.86 [%] for that period.

4. Examples of Effective Use of Wind Energy

Wind energy (WE) is a form of energy derived from the power of the wind. It represents a conventional renewable energy source (RES), which has been used for centuries to obtain mechanical, and more recently, electrical energy [2, 10, 26-27].

Wind energy (WE) belongs to the group of renewable energy sources (RES) and green energy (GE) and can help reduce dependence on fossil fuels. Wind is an indirect form of solar energy and is caused by the differential heating of the earth's surface by the sun. It is estimated that around 10 million [MW] of energy is continuously available from the wind [2, 10, 26-27].

Wind energy (WE) is converted into a useful form of energy, electricity, by means of wind farms. In classic windmills, wind energy (WE) is converted into mechanical energy and is directly used for grinding grain or pumping water. In the last few tens of years, wind farms have also been built for the production of electricity. Figure 4 shows a practical example of wind power plants and their use for obtaining wind energy (WE).

Table 1. Data on the use of different forms of green energy (GE) in Georgia until 2040

Energy Year	Wind		Solar		Hydro with water reservoir		Hydro running water		Installed capacity	
	Value [MW]	CAGR [%]	Value [MW]	CAGR [%]	Value [MW]	CAGR [%]	Value [MW]	CAGR [%]	Value [MW]	CAGR [%]
Today	77	-	70	-	150	-	-	-	4500	-
2025	500	154.82	250	88.98	430	69.31	230	-	6500	20.19
2030	1230	19.73	800	26.19	430	0.00	230	0.00	6500	0.00
2040	2000	10.21	1320	10.53	740	11.47	-	-	7900	3.98

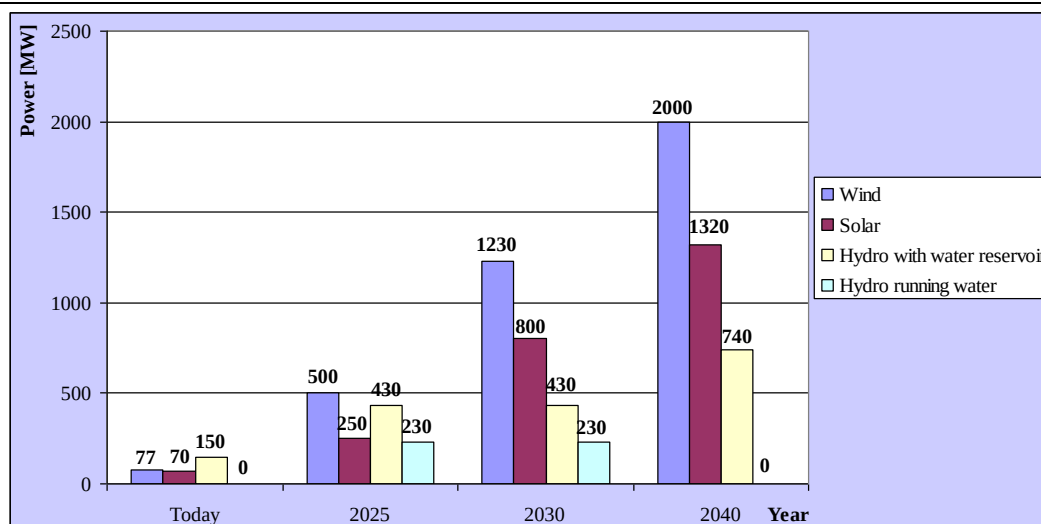


Fig. 2. Graphic representation of the value of use of different forms of green energy (GE) in [MW] in Georgia until 2040

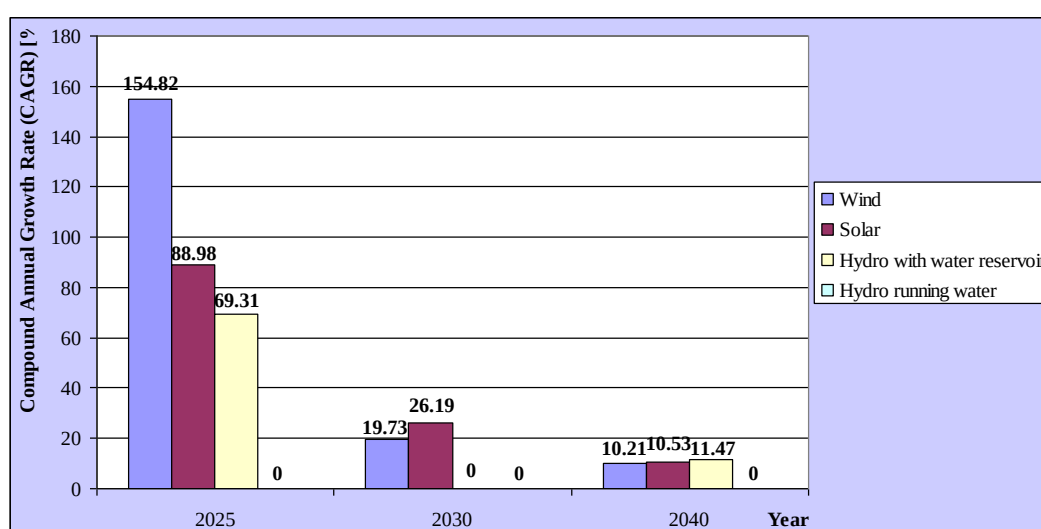


Fig. 3. Graphical representation of the value of the CAGR [%] on the use of different forms of green energy (GE) in Georgia until 2040



Fig. 4 Primer vetroelektrana i njihovog korišćenja za dobijanje energije vetra (WE)

At the end of 2010, the installed capacity of wind farms in the world was appr. 100 [GW], which in percentage is only 1 [%] of the world's electricity needs. In Denmark, this value is 19%, in Spain and Portugal 9%, in Germany and Ireland 6% etc. (data for 2010).

Figure 5 shows the graph of wind energy (WE) (includes both onshore and offshore wind sources) generation in [TWh] by region for the period 1965-2022 [31].

Wind is a good, renewable, easily available and clean source of energy. The lack of wind rarely causes insurmountable problems when it participates in a small share in the supply of electricity, but with greater reliance on wind it leads to greater losses.

5. Conclusion

Fossil fuels such as: coal, oil or gas are a group of non-renewable energy sources that are decreasing in number (slowly disappearing) and also cause undesirable consequences for the environment, and their harmful influence has become more and more pronounced in the last few years. Whereas, renewable energy sources (RES) and green energy (GE) will not disappear because they are naturally renewable and at the same time do not have a harmful impact on the environment. Renewable energy sources (RES) and green energy (GE) are predicted to become economically competitive with conventional energy sources in due course.

The largest growth in the use of green energy (GE) in Georgia by 2040 will be from wind energy (WE), increasing from the current 77 to 2000 [MW] in 2040, with a CAGR=21.12 [%] for that period (or app. 26 times more than today's value), followed by solar energy (SE), increasing from the current 70 to 1320 [MW] in 2040, with a CAGR=18.86 [%] for that period (or app 18.85 times more than today's value).

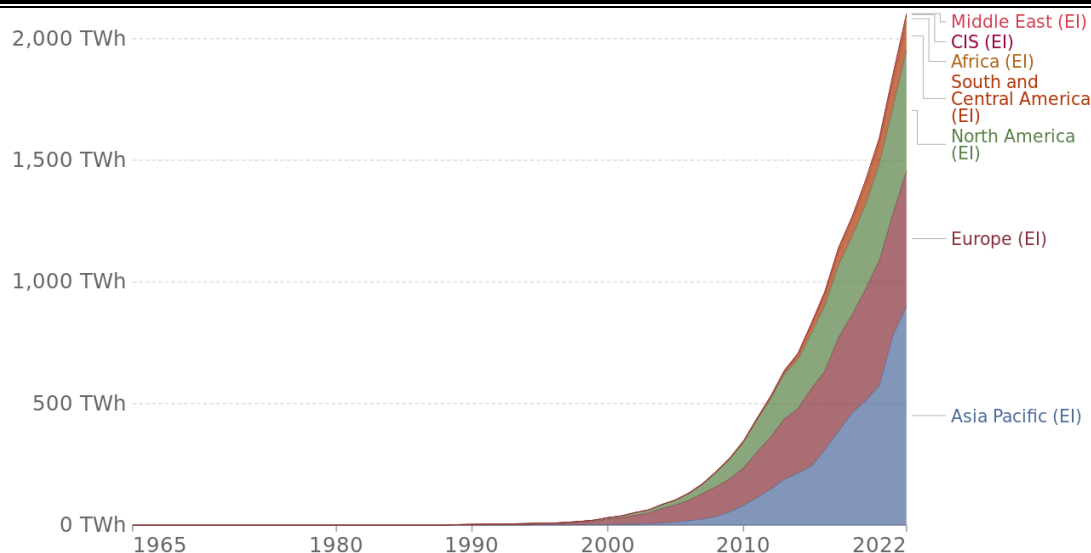


Fig. 5. Wind energy (WE) generation by region for the period 1965–2022 [31]

References

- [1] Abrell, J.; Rausch, S. & Streitberger, C.: The economic and climate value of flexibility in green energy markets. *Environmental and Resource Economics*, Vol. 83, Issue 2 (October 2022), pp. 289–312. ISSN 0924-6460. doi: [10.1007/s10640-021-00605-6](https://doi.org/10.1007/s10640-021-00605-6).
- [2] Ackermann, T. & Söder, L.: Wind energy technology and current status: A review. *Renewable and Sustainable Energy Reviews*, Vol. 4, Issue 4 (December 2000), pp. 315–374. ISSN 1364-0321. doi: [10.1016/S1364-0321\(00\)00004-6](https://doi.org/10.1016/S1364-0321(00)00004-6).
- [3] Balat, M.: The use of renewable energy sources for energy in Turkey and potential trends. *Energy Exploration & Exploitation*, Vol. 22, Issue 4 (August 2004), pp. 241–257. ISSN 0144-5987. doi: [10.1260/0144598042886317](https://doi.org/10.1260/0144598042886317).
- [4] Bogachkova, L.Yu.; Guryanova, L.S., Usacheva, N.Yu., Usacheva, I.V.: Conditions and trends of green energy development in the largest economies of the post-soviet space. *Lecture Notes in Networks and Systems (LNNS)*, Vol. 155 (2021), pp. 152–163. ISSN 2367-3370 and ISBN 978-3-030-59125-0. doi: [10.1007/978-3-030-59126-7_18](https://doi.org/10.1007/978-3-030-59126-7_18).
- [5] Conroy, G.: Data are key to proving green-energy benefits. *Nature*, Vol. 609, Issue 7926 (September 2022), pp. S2–S4. ISSN 0028-0836. doi: [10.1038/d41586-022-02831-4](https://doi.org/10.1038/d41586-022-02831-4).
- [6] Dašić, P.: *Scientific and technological trends: Selected scientific-professional papers* (in Serbian). Vrnjačka Banja: SaTCIP Publisher Ltd., 2020. – 305 str. ISBN 978-86-6075-072-5.
- [7] Fadaeenejad, M.; Radzi, M.A.M.; Fadaeenejad, M.; Zarif, M. & Gandomi, Z.: Optimization and comparison analysis for application of PV panels in three villages. *Energy Science & Engineering*, Vol. 3, Issue 2 (March 2015), pp. 145–152. ISSN 2050-0505. doi: [10.1002/ese3.52](https://doi.org/10.1002/ese3.52).
- [8] Filippov, S.; Mikova, N. & Sokolova, A.: Green energy prospects: Trends and challenges. *International Journal of Social Ecology and Sustainable Development*, Vol. 6, Issue 3 (July 2015), pp. 1–20. ISSN 1947-8402. doi: [10.4018/IJSESD.2015070101](https://doi.org/10.4018/IJSESD.2015070101).
- [9] Goswami, D.Y.; Vijayaraghavan, S.; Lu, S. & Tamm, G.: New and emerging developments in solar energy. *Solar Energy*, Vol. 76, Issue 1-3 (January-March 2004), pp. 33–43. ISSN 0038-092X. doi: [10.1016/S0038-092X\(03\)00103-8](https://doi.org/10.1016/S0038-092X(03)00103-8).
- [10] Herbert, G.M.J.; Iniyan, S.; Sreevalsan, E. & Rajapandian, S.: A review of wind energy technologies. *Renewable and Sustainable Energy Reviews*, Vol. 11, Issue 6 (August 2007), pp. 1117–1145. ISSN 1364-0321. doi: [10.1016/j.rser.2005.08.004](https://doi.org/10.1016/j.rser.2005.08.004).
- [11] Hoogwijk, M.M.: *On the global and regional potential of renewable energy sources*. Ph.D. Thesis. Utrecht (Netherlands): Utrecht University, Faculty of Chemistry, 2004. – 256 pp. ISBN 978-90-393-3640-3.
- [12] Huan, Y.; Sun, Z.-J.; Ali, M.; Yan, R. & Ur Rahman, Z.: Green finance, green energy and green revolution: An impulse response function of food security in developing economies. *Frontiers in Environmental Science*, Vol. 10 (October 2022), Article no. 982785: pp. 1–13. ISSN 2296-665X. doi: [10.3389/fenvs.2022.982785](https://doi.org/10.3389/fenvs.2022.982785).
- [13] Husain, S.; Sohag, K. & Wu, Y.-R.: The response of green energy and technology investment to climate policy uncertainty: An application of twin transitions strategy. *Technology in Society*, Vol. 71 (November 2022), Article no. 102132. ISSN 0160-791X. doi: [10.1016/j.techsoc.2022.102132](https://doi.org/10.1016/j.techsoc.2022.102132).
- [14] *Industrial production of wind power plants to begin in Georgia following signing of memorandum*. Tbilisi (Georgia): Agenda.ge, 23 March 2022. Available on the Web page: <https://agenda.ge/en/news/2022/849>.
- [15] Kaur, R.; Sandhu, V.; Bhabra, K. & Kaur, H.: A multivariate analysis of factors influencing green energy. *IOP Conference Series: Earth and Environmental Science*, Vol. 795 (2021), Article no. 012004: pp. 1–6. ISSN 1755-1307. doi: [10.1088/1755-1315/795/1/012004](https://doi.org/10.1088/1755-1315/795/1/012004).
- [16] Kovtun, D.; Tovmasyan, N. & Nazarov, A.: Trends and conditions for the development of green energy in the Russian Federation. *E3S Web of Conferences*, Vol. 270 (2021), Article no. 01040: pp. 1–5. eISSN 25550403. doi: [10.1051/e3sconf/202127001040](https://doi.org/10.1051/e3sconf/202127001040).
- [17] Kuzior, A.; Lobanova, A. & Kalashnikova, L.: Green energy in Ukraine: State, public demands, and trends. *Energies*, Vol. 14, Issue 22 (November 2021), Article no. 7745: pp. 1–114. eISSN 1996-1073. doi: [10.3390/en14227745](https://doi.org/10.3390/en14227745).
- [18] Li, J.; Dong, K.-Y. & Dong, X.-C.: Green energy as a new determinant of green growth in China: The role of green technological innovation. *Energy Economics*, Vol. 114 (October 2022), Article no. 106260: pp. 1–13. ISSN 0140-9883. doi: [10.1016/j.eneco.2022.106260](https://doi.org/10.1016/j.eneco.2022.106260).
- [19] Nguyen, Q.H.; Hoai Ta, Q.T. & Tran, N.: Review on the transformation of biomechanical energy to green energy using triboelectric and piezoelectric based smart materials. *Journal of Cleaner Production*, Vol. 371 (October 2022), Article no. 133702. ISSN 0959-6526. doi: [10.1016/j.jclepro.2022.133702](https://doi.org/10.1016/j.jclepro.2022.133702).
- [20] Palmer, L.: Green energy financing. *Nature Sustainability*, Vol. 5, Issue 11 (November 2022), pp. 910–911. eISSN 2398-9629. doi: [10.1038/s41893-022-00972-y](https://doi.org/10.1038/s41893-022-00972-y).
- [21] Panwar, N.; Kaushik, S. & Kothari, S.: Role of renewable energy sources in environmental protection: A review.

- Renewable and Sustainable Energy Reviews*, Vol. 15, Issue 3 (April 2011), pp. 1513–1524. ISSN 1364-0321. doi: [10.1016/j.rser.2010.11.037](https://doi.org/10.1016/j.rser.2010.11.037).
- [22] Pavlović, T.; Milosavljević, D. & Mirjanić, D.: *Renewable energy sources* (in Serbian). Banja Luka (Bosnia and Herzegovina): Academy of Sciences and Arts of the Republic of Srpska (ANURS), 2013. – 365 pp. ISBN 978-99976-42-41-0.
- [23] Ristau, O.: *Georgia: A source of green energy for Europe?* DW.com, 25 June 2023. Available on the Web page: <https://www.dw.com/en/georgia-a-source-of-green-energy-for-europe/a-66010720>.
- [24] Rybak, A. & Rybak, A.: Analysis of the strategy for the energy policy of Poland until 2030 implementation effects in the aspect of environmental protection taking into account the energy security of Poland. *IOP Conference Series: Earth and Environmental Science*, Vol. 261 (April 2019), Article no. 012044: pp. 1–12. ISSN 1755-1307. doi: [10.1088/1755-1315/261/1/012044](https://doi.org/10.1088/1755-1315/261/1/012044).
- [25] Rybak, A. & Włodarczyk, E.: Energy policy until 2040 and the future of hard coal in Poland. *IOP Conference Series: Earth and Environmental Science*, Vol. 609 (December 2020), Article no. 012009: pp. 1–9. ISSN 1755-1307. doi: [10.1088/1755-1315/609/1/012009](https://doi.org/10.1088/1755-1315/609/1/012009).
- [26] Sahu, B.K.: Wind energy developments and policies in China: A short review. *Renewable and Sustainable Energy Reviews*, Vol. 81 (January 2018), pp. 1393–1405. ISSN 1364-0321. doi: [10.1016/j.rser.2017.05.183](https://doi.org/10.1016/j.rser.2017.05.183).
- [27] Saidur, R.; Islam, M.R.; Rahim, N.A. & Solangi, K.H.: A review on global wind energy policy. *Renewable and Sustainable Energy Reviews*, Vol. 14 (2010), pp. 1744–1762. ISSN 1364-0321. doi: [10.1016/j.rser.2010.03.007](https://doi.org/10.1016/j.rser.2010.03.007).
- [28] Topçu, Y.I. & Ulengin, F.: Energy for the future: An integrated decision aid for the case of Turkey. *Energy*, Vol. 29, Issue 1 (January 2004), pp. 137–54. ISSN 0360-5442. doi: [10.1016/S0360-5442\(03\)00160-9](https://doi.org/10.1016/S0360-5442(03)00160-9).
- [29] Turmanidze, R. & Popkhadze, G.: Classification of green energies and possibilities of their effective use. *Industry 4.0*, Vol. 7, Issue 6 (2022), pp. 254–258. ISSN 2534-8582.
- [30] What is green energy? (Definition, types and examples). Available on the Web site: <https://www.twi-global.com/technical-knowledge/faqs/what-is-green-energy>.
- [31] *Wind energy generation by region*. Our World in Data & Energy Institute Statistical Review of World Energy, 2023. Available on the Web site: <https://ourworldindata.org/grapher/wind-energy-consumption-by-region>.
- [32] Xie, C.Y. & Zhou, J.: Assessment of provincial total factor green energy efficiency in China: Based on super-SBM model. *IOP Conference Series: Earth and Environmental Science*, Vol. 495 (2020), Article no. 012017: pp. 1–7. ISSN 1755-1307. doi: [10.1088/1755-1315/495/1/012017](https://doi.org/10.1088/1755-1315/495/1/012017).
- [33] Zainol Abidin, M.A.; Mahyuddin, M.N. & Mohd Zainuri, M.A.A.: Solar photovoltaic architecture and agronomic management in agrivoltaic system: A review. *Sustainability*, Vol. 13, Issue 14 (July 2021), Article no. 7846: pp. 1–27. eISSN 2071-1050. doi: [10.3390/su13147846](https://doi.org/10.3390/su13147846).
- [34] Zeng, S.-H.; Tanveer, A.; Fu, X.-L.; Gu, Y.-X. & Irfan, M.: Modeling the influence of critical factors on the adoption of green energy technologies. *Renewable and Sustainable Energy Reviews*, Vol. 168 (October 2022), Article no. 112817: pp. 1–14. ISSN 1364-0321. doi: [10.1016/j.rser.2022.112817](https://doi.org/10.1016/j.rser.2022.112817).