DOI: 10.2507/34th.daaam.proceedings.034

METROLOGICAL ASPECTS IN MAINTENANCE OF ENERGY-SAVING AUTOMATED SYSTEMS FOR CONTROL OF PUMP UNITS IN PUMPING STATIONS

Svitlana Artiukh, Miroslav Kokalarov, Viktoria Kniazieva,
Ivan Georgiev, Anastasiia Artiukh & Mihail Milchev

This Publication has to be referred as: Artiukh, S[vitlana]; Kokalarov, M[iroslav]; Kniazieva, V[iktoria]; Georgiev, I[van]; Artiukh, A[nastasiia] & Milchev, M[ihail] (2023). Metrological Aspects in Maintenance of Energy-Saving Automated Systems for Control of Pump Units in Pumping Stations, Proceedings of the 34th DAAAM International Symposium, pp.0268-0273, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-41-9, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/34th.daaam.proceedings.034

Abstract

In the specialized realm of hydrocarbon transport engineering, this article presents a focused exploration into refining the current regulatory paradigms, with a cardinal objective: to enhance the operational efficacy of pumping units within oil pumping stations throughout their standard functional modalities. Historically, there exists a significant lacuna concerning comprehensive solutions capable of attenuating energy dissipation during oil conveyance and achieving benchmarked efficiency metrics intrinsic to oil pumping infrastructure. This pivotal matter, if addressed rigorously, stands to elevate both the technical and economic dimensions of primary oil conduits. The article's central aim, underpinning its entire analytical discourse, is to accentuate the energy efficiency of pumping units operational within oil transport hubs. To achieve this, the research introduces an avant-garde methodology primed for the calibration of pumps' dynamics and their associated network functionalities, optimizing their consumption paradigms in the process. Given the tangible fiscal constraints around the modernization of both primary and auxiliary equipment within oil pumping stations, there emerges an even more pressing impetus to amplify the paradigm of energy conservation. In a technologically progressive era where oil transport processes are rapidly automating, the development of automated energy-conservation-centric control systems is paramount. Such systems, by design, should ensure the reduction of energy losses, underscoring the article's overarching aim of bolstering energy efficiency within the hydrocarbon transportation sector.

Keywords: oil pumping station; efficiency; main pump; automated control system.

1. Introduction

The share of oil and gas in the energy balance of industrialized countries is about 80%. Oil transportation requires significant energy consumption to drive pumping units at oil pumping stations. In this regard, the urgent task is to reduce energy consumption by developing and implementing energy-saving automatic control systems (ACS) for oil pumping units, which are an integral part of integrated ACS for oil transportation and ensure maximum efficiency [1].

That is why improving the regulatory framework to increase the efficiency of pumping units at oil pumping stations remains an important scientific and technical task. Oil and gas continue to dominate the energy landscape of industrialized nations, accounting for approximately 80% of their energy mix. Such a substantial reliance underscores the magnitude of energy necessitated for oil transportation, particularly for driving the pumping units integral to oil pumping stations. Given this context, there is an exigent imperative to minimize energy usage. One salient approach to address this pressing concern is through the design, development, and deployment of energy-conservative ACS tailored for these pumping units. These systems not only form the backbone of integrated automated control platforms for oil transportation but are also pivotal in ensuring their peak operational efficiency, as referenced in [1].

Given this backdrop, refining the regulatory framework to amplify the performance efficiency of pumping units within these oil transport hubs emerges as both a crucial scientific endeavor and a technical imperative. This, in turn, further accentuates the significance of our research, aimed at revolutionizing the standards and practices in the oil transportation sector.

2. Discussion

Trunk pipelines are designed in such a way that their design capacity values are provided by pumping (for oil and oil products) or compressor (for gas) stations. At the same time, it is assumed that the pumping units of the stations operate at rated modes corresponding to the rated speed of their rotors and maximum efficiency. At the same time, the analysis of existing regulatory and technical documentation shows that today the regulatory and technical and regulatory and methodological documentation does not fully formulate the requirements for the creation and operation of control systems for main oil pipelines that would ensure maximum efficiency of pumping units and maintain their operation at an appropriate level.

The need to regulate the operation mode of the oil pumping stations - main oil pipeline system, is due to energy savings for pumping a unit volume (mass) of oil through the main oil pipeline. Methods of regulation of main oil pipelines can be divided into two classes: methods determined by the pressure balance and methods determined by the smoothness of regulation. Methods determined by the pressure balance are divided into methods related to changes in the parameters of the NPS and methods related to changes in the parameters of the main pipeline.

The main element that determines the efficiency of an individual pumping unit or an oil pumping station as a whole is the reference model of the control object and the energy-saving control program. The energy-saving control program is an algorithm for finding the required values of the regulated quantities at which the efficiency of the control object will be maximized while maintaining the required process parameters. For the tasks of energy-saving control of main oil pipelines, the program is actually a procedure for minimizing the function of total energy losses in the oil pipeline-oil pumping station system with the subsequent issuance of relevant information to the regulators or diagnostic information to the control panel (in case of changes in pump or network parameters and the impossibility of ensuring energy-efficient operation without personnel intervention, for example, necessary repairs, etc.). For an oil pumping station consisting of groups of pumps connected in series and parallel, a generalized functional diagram will look like the one shown in Figure 1 [2], [11].

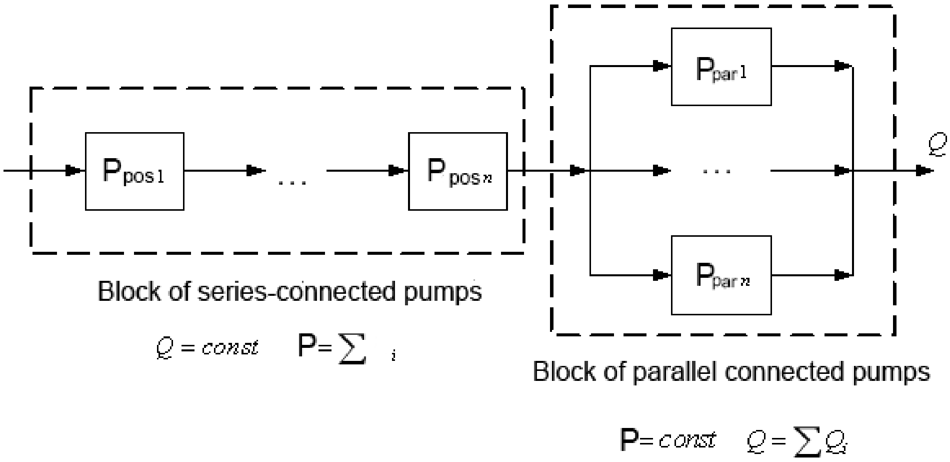

Fig. 1. Generalized functional diagram of an oil pumping station consisting of pumps connected in series and parallel

The use of a reference mathematical model of the oil pumping complex equipment, which can change its parameters in real time depending on specific conditions, allows for a more accurate and complete determination of the energy loss function at any time and identifies ways to reduce it without compromising the main technological indicators of the oil pumping equipment.

The positive effect of implementing the energy management system is as follows: power and energy losses at oil pumping stations are reduced, energy efficiency of oil pumping stations and the relevant section of the main oil pipeline is increased, and the cost of oil transportation through main oil pipelines is reduced [3]. Improving the measurement accuracy in determining the average oil flow rate in main oil pipelines is carried out through an integrated approach that includes the application and improvement of measurement methods and techniques, re-equipment of the technical park of measuring equipment, and the use of modern mathematical tools.

The measured parameter $X_{(t)}$, which passes through the measuring mechanism, has instability even when the adjustment of the regulatory bodies is unchanged. The presence of this instability causes errors in parameter measurements [4], [5], because if the phases of the moments of the beginning and end of the interval do not coincide, averaging over the periods of the parameter's pulsations, its average value X0, measured with any accuracy, will differ from the average over time X_{sr}, i.e., $X_{sr} - X_0 = \Delta_{nf}$. The nature of this phenomenon is illustrated in Fig. 2.

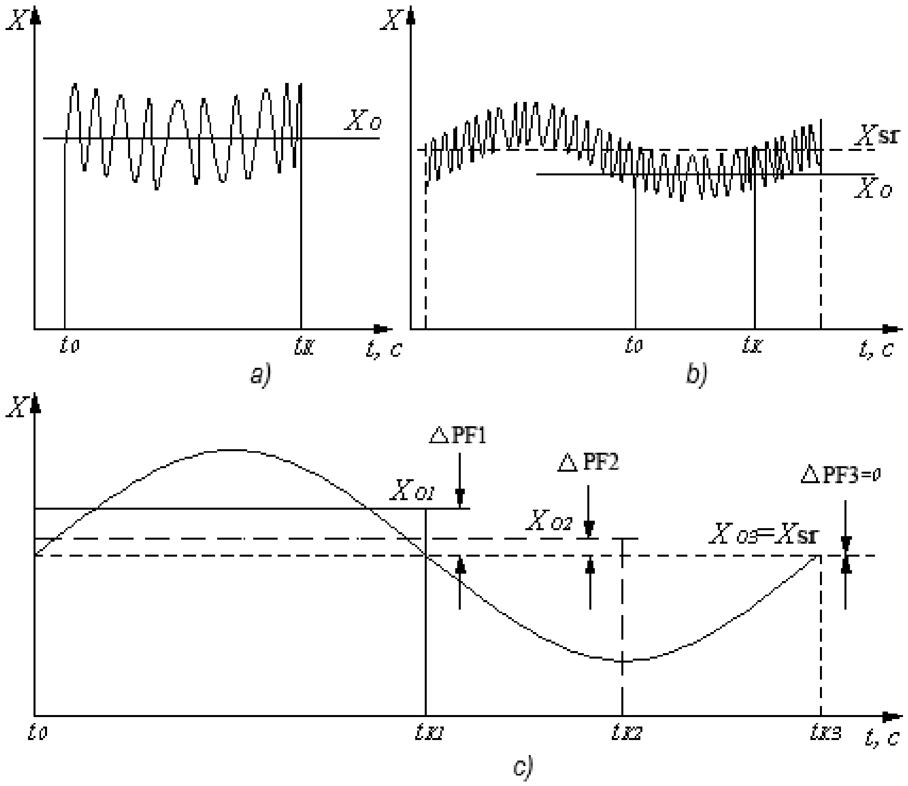

Fig. 2. Illustration of the nature of the out-of-phase error (a, b) and its dependence on the choice of the averaging (measurement) time interval T = t -t_0 (c)

The following model of the measured parameter was used to study the nature and estimate the out-of-phase error Δ_{nf}:

$$X(t) = X_0 + \tilde{X}, \tag{1}$$

X_0 and $\tilde{X}$ – is a constant and periodic variable of the constituent parameter, respectively.

A periodic process can be viewed as a superposition of harmonious components, i.e:

$$\tilde{X} = X_m sin(\omega t + \varphi) \tag{2}$$

$X_m, \omega\ and\ \varphi$ - are the amplitude, circular frequency, and initial phase of the parameter oscillations, respectively. The average value over the integration time T, taking into account (1) and (2), is represented as follows [6], [7], [8]:

$$X_{sr} = \frac{1}{T}\int_0^T X(t)\,dt = X_0 - \frac{X_m}{\omega T}[\cos(\omega T + \varphi)] \tag{3}$$

In this case, the relative error of the out-of-phase δnf of the measurement is determined:

$$\delta_{nf} = \frac{\Delta_{nf}}{\bar{X}_{sr}} = \frac{\bar{X}_{sr} - \bar{X}_0}{\bar{X}_{sr}} = \frac{\bar{X}_m}{\bar{X}_{sr}}\frac{\cos(\varphi) - \cos(\omega T + \varphi)}{\omega T} = AK \tag{4}$$

$A = \frac{\bar{X}_m}{\bar{X}_{sr}}$ – is the relative amplitude of the parameter oscillations;

$K = \frac{\cos\varphi - \cos\ (\omega T+\varphi)}{\omega T}$ - phase coefficient;

ω– is the circular frequency of the parameter oscillations, rad/s; φ– is the initial phase of the oscillations, rad.

It follows from (4) that the out-of-phase error depends not only on the initial phase of the parameter oscillations but also on the relative amplitude of the periodic component X_m/X_{sr}, the circular frequency ω, and the integration time T. The nature of the change in the phase coefficient K from the oscillation phase ωT at $0 < \varphi < \pi/2$ is shown in Fig. 3 - a). The initial phase of oscillations φ is a random variable, so to simplify calculations, we can set φ=0, while the family of curves K = f (ωT, φ) degenerates into the graph shown in Fig. 3 - b).

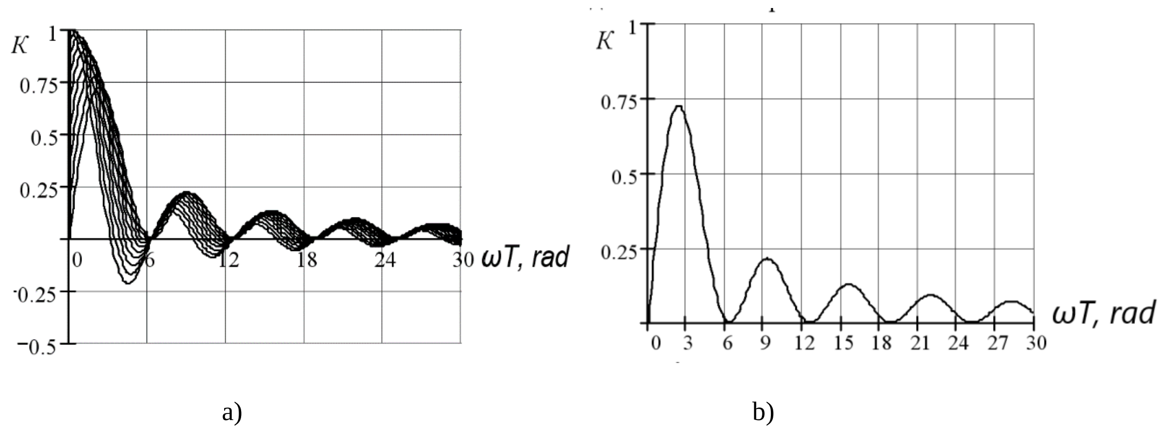

Fig. 3. Dependence of K on ω T at a) φ = random variables, b) φ = 0 rad

Measurements of hydraulic parameters (flow rate, head, pressure) are the basis for determining the characteristics of all pumps, which are the main consumers of auxiliary needs of main oil pipelines. The periodic processes occurring in the equipment of an oil pumping station are characterized by high inertia, which increases the out-of-phase error [9]. The criterion for the optimal operation of the energy-saving system of automated control of pumping units of the oil distribution system is the minimum total energy losses in the main oil pipeline while maintaining the required oil flow parameters at a given level determined by the technological process and reliability indicators. Based on the results of solving the problem of energy-saving control of pumping units of oil pumping stations, a mode map of adjustable parameters is constructed over the entire range of changes in oil flow (Fig. 4) [10].

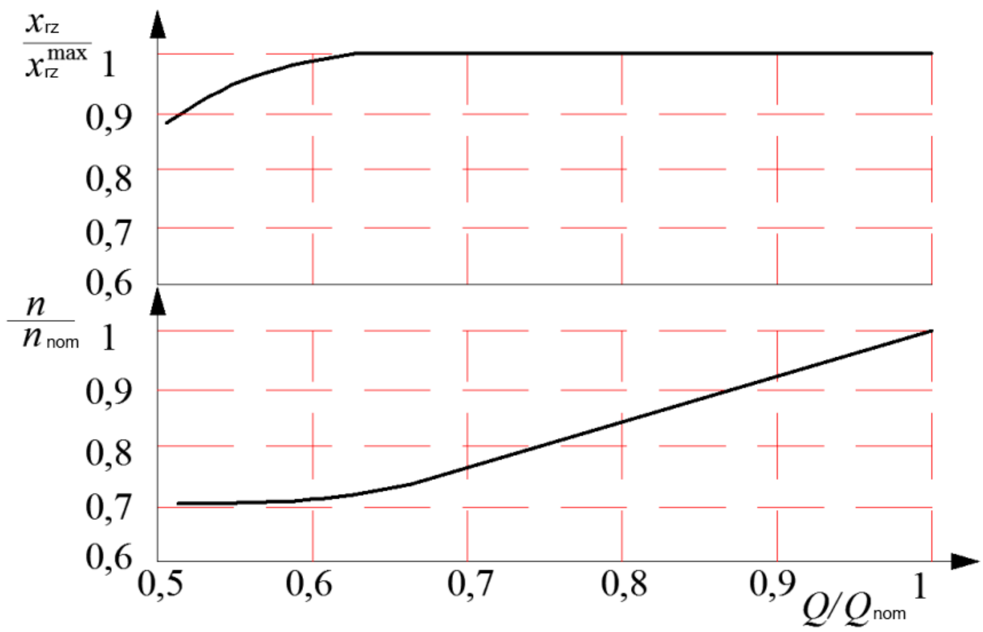

Fig. 4. Mode map of energy - efficient operation of an oil pumping station pump

Over the entire range of oil flow rates, the values of the positions of the control valves xrz and rotational speeds n are determined, at which the total energy losses in the main oil pipeline will be minimal. These dependencies should be used in the automated control devices of the pumping units of the Oil Pumping Station and periodically updated in real time. This will ensure minimal energy losses in the pumping unit and accurate maintenance of oil flow rates regardless of the technical condition of the pump and oil viscosity.

3. Conclusion

In light of the ever-increasing global emphasis on energy efficiency and conservation, this article introduces a meticulously crafted structural blueprint for the energy-saving automated control system for main oil pipeline pumping stations. Anchored in cutting-edge scientific methods tailored for energy-saving control, our research not only puts forth a pioneering methodology to bolster the energy efficiency of pumping unit controls but also foregrounds a strategic approach to minimize energy wastage during the intricate process of oil transportation. The novel analytical models proposed herein - which elucidate the intricate dependencies between energy losses in pumps and their respective input parameters - serve as a foundational cornerstone for the evolution of control systems. Such systems, underpinned by our core principle of minimizing energy losses, are instrumental in pushing the boundaries of contemporary practices.

Moreover, the tangible benefits of these innovations extend well beyond mere technical enhancements. By integrating our findings, oil industry enterprises stand to gain significantly, from ensuring consistent and disruption-free oil transportation to realizing substantial economic efficiencies. Furthermore, our approach champions a paradigm shift towards a more environmentally conscious oil industry. By advocating for the predominant use of oil pipelines, we underscore their pivotal role in mitigating environmental hazards, notably by diminishing the traditional reliance on rail and maritime oil transportation avenues. In essence, our research not only paves the way for operational advancements within the oil sector but also underscores the intertwined narrative of technological innovation, economic prudence, and environmental stewardship.

Future Research Recommendations: Technological Innovations Analysis: While the article introduces advanced methods of automation and control, future research could delve deeper into the latest technological innovations specific to oil transport systems, evaluating their efficiency, and feasibility.

- Environmental Footprint Assessment: Beyond energy efficiency, studies could be conducted on the environmental footprint of the introduced technologies and methods, examining emissions, waste, and other ecological impacts.
- Economic Implications: A detailed economic study focusing on the Return on Investment (ROI) for the new technologies and methods proposed in the article would be invaluable for stakeholders in the industry.
- Cross-industry Comparison: Analyze methods and technologies utilized in parallel industries to discern potential insights or technologies that could be integrated into the oil transportation sector.
- System Sustainability and Reliability: Future studies can focus on the long-term resilience and reliability of the proposed systems, especially under changing climatic conditions or other extreme circumstances.
- Education and Training: Create educational and training programs for personnel handling the new technologies, ensuring their effective and safe operation.
- Artificial intelligence, big data, neural networks and fuzzy logic [12]: Investigate the potential of integrating artificial intelligence and big data analytics for optimizing operations at oil transport stations.
- Internet of Things (IoT) Application: Research opportunities to integrate IoT devices for real-time monitoring and control of various parameters within pumping stations.

These suggestions for future research stem from the content and emphasis of the provided article and are aimed at a more profound understanding and development of practical solutions for the industry. Complex analysis and evaluation of hazardous environment in case of oil man-made disaster [13]. Research and prediction of the need for individual anti-chemical protection in case of technological accidents with oil pipelines [14].

4. Acknowledgments

The publication of this study is supported by Project BG05M2OP001-1.001-0004 UNITe, funded by the Operational Programme “Science and Education for Smart Growth”, co-funded by the European Union trough the European Structural and Investment Funds.

5. References:

[1]. Kniazeva, V. N.; Kaniuk, H. Y.; Mezeria, A. Iu. & Andreev, A. V. (2019). Analyz normatyvnikh dokumentov po obespechenyiu effektyvnoi rabotoi nasosnikh ustanovok mahystralnыkh nefteprovodov (Analysis of normative documents providing the effective work of the pumping stations on main oil supply pipelines). Visnyk Natsionalnoho tekhnichnoho universytetu (Newspaper of the National technical university) «KhPI». Seria: Novi rishennia v suchasnykh tekhnolohiiakh (Series: New decisions in modern technologies). Vol.5 (1330). p. 27-34;

[2]. Topliceanu, L.; Gabriel, P. & Furdu, I. (2016). Functional problems and maintenance operations of hydraulic turbines. TEM Journal Vol. 5, No. 1, (February 2016), p. 32-37, DOI: 10.18421/TEM51-05;

[3]. Cherniuk, A. M. & Kniazieva, V. M. (2016). Povishenye urovnia enerhosberezhenyia pry upravlenyy nasosnымy ustanovkamy nefteperekachyvaiushchykh stantsyi (Increasing the level of energy saving in management of pumping installations of oil pumping stations). Proceedings of «Informatyka, Matematyka, Avtomatyka» naukovo-tekhnichnoi konferentsii («Informatics, Mathematics, Automation» technical science conference). Sumy.Ukraine;

[4]. Stoev, I. I.; Zaharieva, S. L. & Mutkov, V. A. (2019). Evaluation of gross errors in measured temperature with an electronic system for management of residential energy systems. Proceedings of 27th telecommunications forum (TELFOR), pp. 1-4, doi: 10.1109/TELFOR48224.2019.8971309, Belgrade, Serbia;

[5]. Zaharieva, S.; Stoev, I.; Borodzhieva, A. & Petrova, T. (2023). Assessment of gross errors and uniformity of readings of sensors for relative humidity measurement in indoor premises. Proceedings of 22nd international symposium INFOTEH-JAHORINA (INFOTEH), pp. 1-5, doi: 10.1109/INFOTEH57020.2023.10094132, East Sarajevo, Bosnia and Herzegovina;

[6]. Dichev, D.; Diakov, D.; Zhelezarov, Y.; Nikolova, H.; Kupriyanov, O. & Dicheva, R. (2022). Accuracy evaluation of flat surfaces measurements in conditions of external influences. Proceedings of 2022 XXXII international scientific symposium “Metrology and Metrology assurance” (MMA), (September 2022), pp. 1-7. DOI: 10.1109/MMA55579.2022.9992334, Sozopol, Bulgaria;

[7]. Dichev, D.; Zhelezarov, I. & Madzharov, N. (2019). System for measuring the attitude of moving objects, using a Kalman filter and MEMS sensors. Comptes rendus de l’academie bulgare des sciences, Vol.72, No. 11, pp. 1527-1536. DOI: 10.7546/CRABS.2019.11.10. Sofia, Bulgaria;

[8]. Dichev, D.; Kogia, F.; Koev, H. & Diakov, D. (2016). Method of analysis and correction of the error from nonlinearity of the measurement instruments. Journal of engineering science & technology review, Vol.9, No. 6, pp. 116 – 121. DOI: 10.25103/jestr.096.17. Sofia, Bulgaria;

[9]. Andreev, A. V.; Cherniuk, A. M. & Kniazeva, V. N. (2017). Effektivnost upravlenyia nasosnimy ahrehatamy nefteperekachyvaiushchykh stantsyi. Udoskonalennia turboustanovok metodamy matematychnoho i fizychnoho modeliuvannia (Effectiveness of management of pumping aggregates of oil pumping stations. Improvement of pipeline stations by methods of mathematical and physical modeling). Proceedings of VI Mizhnar. nauk.-tekhn. konf. (VI-th international technical science conference), NAN Ukraine, International problem mashynobuduvannia imeni A. N. Pidhirnoho NAN Ukraine, Turboatom, Enerhoprohres, Ukraine;

[10]. Pulov, D.; & Karadzhov, Ts. (2021). Optoelectronic device for measuring the power of laser radiation, Proceedings of the 13th International scientific and practical conference “Environment. Technology. Resources.”. Vol. 3, p. 286-290, Online ISSN 2256-070X, DOI: 10.17770/etr2021vol3.6590, Rezekne, Latvia;

[11]. Kaniuk, H. Y.; Mezeria, A. Iu. & Laptynov, Y. P. (2014). Model enerhosberehaiushcheho upravlenyia nahnetatelnimy ustanovkamy teplovikh elektrostantsyi (A model of energy saving management of pressurizing devices in thermal power stations). Visnyk NTU “KhPI”: Enerhetychni ta teplotekhnichni protsesy y ustatkuvannia (Newspaper: Power and thermal technical processes and equipment). Vol. 12 No 1055, p. 90-97. National Technical University, Kharkiv, Ukraine.

[12]. Veselov, O.; Veselov, A. & Svetushenko, S. (2019). The use of fuzzy logic in automatic control systems, Proceedings of the 30th DAAAM international symposium, pp.0897- 0903, B. Katalinic (Ed.), Published by DAAAM international, ISBN 978-3-902734-22-8, ISSN 1726-9679, Vienna, Austria DOI: 10.2507/30th.daaam.proceedings.125

[13]. Burdzhiev, S.; Stoychev, K.; Bratanov, D.; Dimitrov, D.; Panevski, V.; Damyanov, G. & Georgiev G. (2014) Comprehensive analysis and assessment of a hazardous environment. IN: fourth national conference with international participation metallurgy, hydro- and aerodynamics, national security '214, pp. 323-330, Bulgarian Academy of Sciences, IMCTCX-BAS, ISBN 1313-8308

[14]. Georgiev, G. & Burdzhiev, S. (2013) Individual anti-chemical and anti-radiation protection. In: Collection of materials from the third national conference with international participation "Metallurgy, hydro- and aerodynamics, national security, pp. 453-457, Sofia, ISBN 1313-8308