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THE RELATIONSHIP OF GLOBAL CLIMATE CHANGES AND THE OPERATION OF OPEN COOLING SYSTEMS OF ENERGY FACILITIES OF UKRAINE

ABSTRACT. *This study provides an assessment of the possible impact of climate change on increasing the temperature of water in the sources from which water is taken for open technical cooling systems. In recent years, there has been a decrease in the efficiency of nuclear reactors at Ukraine's nuclear power plants in the hot summer months of the year. Using the example of cooling ponds of operating nuclear power plants, an assessment of the mutual influence of air temperature indicators and the temperature of surface water for cooling was made. Based on the monitoring temperature data of the cooling reservoirs of the NPP of Ukraine in different months of 2020, as one of the hottest years of observations, the equations of the correlation dependences between the temperature indicators of the surface air and the temperature of the cooling water were obtained. In the OriginPro8 software environment, which is widely used as an industrial standard for data collection and visualization, a climatic forecast of the atmospheric air in the territory of Ukraine was made and a forecast dependence of the water rise in water bodies was established for the period until 2160. The obtained forecast values of the relative total efficiency of the NPP reactors of Ukraine for different periods until 2050, which indicates a gradual decrease in the output power in the nuclear power industry of Ukraine. This approach to the analysis of the operation of cooling ponds can be acceptable for evaluating the operation of thermal plants and other industrial facilities that have an open cooling pond and can serve as support for making management decisions in the context of global climate change and for preventing the risks of emergency situations on the object.*

Key words: *energy facilities, cooling water temperature, climate changes, reactor efficiency.*

ВЗАЄМОЗВ’ЯЗОК ГЛОБАЛЬНИХ КЛІМАТИЧНИХ ЗМІН ТА РОБОТИ ВІДКРИТИХ СИСТЕМ ОХОЛОДЖЕННЯ ЕНЕРГЕТИЧНИХ ОБ’ЄКТІВ УКРАЇНИ

АНОТАЦІЯ. *В данному дослідженні приводиться оцінка можливого впливу змін клімату на підвищення температурних показників води в джерелах, з яких здійснюється водозабір для відкритих технічних систем охолодження. Останніми роками спостерігається зниження ефективності роботи атомних реакторів на АЕС України в літні спекотні місяці року. На прикладі роботи ставків-охолоджувачів діючих АЕС зроблена оцінка взаємовпливу температурних показників повітря і температури поверхневих вод для охолодження. На основі моніторингових температурних даних водойм-охолоджувачів АЕС України в різні місяці 2020 року, як одного з найбільш спекотних років* *спостережень, були отримані рівняння кореляційних залежностей між температурними показниками приземного повітря та температурою води для охолодження. В програмному середовище OriginPro8, що широко використовується як промисловим стандартом для збору та візуалізації даних зроблено кліматичний прогноз атмосферного повітря на території України та встановлено прогнозну залежність підвищення води у водних об'єктах на період до 2160 р. Отримані прогнозні значення відносної сумарної ефективності роботи реакторів АЕС України різні періоди до 2050 року, що свідчить про поступове зниження вихідної потужності в атомній енергетиці України. Даний підхід до аналізу роботи ставків –охолоджувачів може бути прийнятним для оцінки роботи теплових станцій та інших промислових об'єктів, що мають відкритий ставок-охолоджувая та може слугувати підтримкою для прийняття управлінських рішень в умовах глобальної зміни клімату та для для запобігання ризиків виникнення надзвичайних ситуацій на об'єкті.*

Ключові слова: *енергетичні об'єкти, температура вод охолодження, зміни клімату, ефективність роботи реактора.*

1. INTRODUCTION. Many domestic and foreign authors dealt with the issue of the interrelationship of surface water quality, changes in the water regime of water bodies and water supply depending on global climate changes [1-3, etc.]. Thus, in work [3], the water balance method was used to assess possible changes in water resources of Ukraine based on the results of air temperature forecasting. A 25–50% decrease in water flow was predicted at the end of the current century in Ukraine across four regions of Ukraine according to the official regional division used by the Ukrainian Hydrometeorological Center [4]. Scientific studies [5-7] contain assessments of the probable vulnerability of one of the main water users - the energy industry, with recommendations on its adaptation to climate change. The abnormal heat of recent years affected not only the qualitative and quantitative characteristics of Ukraine's water resources, but also the overall efficiency of cooling systems. As an alternative, global research offers closed water circulation systems or dry cooling technologies. As for nuclear energy, it is increasingly possible to hear opinions about alternative options for cooling systems for the successful development of the industry, which are based not only on the general impact on the environment, but also on assessment and analysis consequences of climate change [8,9].

Global nuclear energy is currently developing against the background of a considerable list of unsolved dangerous environmental problems, and Russian aggression in Ukraine forces us to reconsider the sustainability of nuclear energy. On the territory of Ukraine, we have reactors of the VVER-1000 type, and decommissioning of the latter is planned by 2050. Even without extending their service life, research aimed at evaluating the efficiency of operating reactors depending on the water temperature of cooling reservoirs is relevant. The purpose of this work is aimed precisely at such studies.

2. OVERVIEW OF EXISTING SOLUTIONS. Existing models of the dependence of the use of water for cooling and the energy produced are based on the determination of the coefficient of consumption of fresh water in the system [6, 10]. Many studies, based on the results of studies on accident safety after the Fukushima accident, devote many works to the safety and reliability of the cooling management of the core and protective shell in reactors of various designs [11]. The heat load of the cooling system in work [7] is represented by the Senki diagram, which is based on balance studies, the balance ratio, and the coefficient of net electricity production is used to determine the efficiency of a nuclear power plant. The input heat flux in this approach consists of three output fluxes: net power generation, heat load and cooling systems, and heat loss. On the basis of this approach, it is possible to obtain the coefficient of consumption of fresh water in the systems, which makes this approach workable when drawing up the water balance in the technological system of reactors. A number of studies are devoted to hybrid cooling systems combining wet and dry cooling approaches.

But in the study [12] it is noted that despite the existence of many varieties of hybrid cooling, all of them are, in fact, a compromise between a wet tower and dry cooling. Works [13,14] describe detailed models of the processes of the most modern power plants for comparing various aspects of water use. A number of models presented in works [15,16] apply the assessment of the impact of carbon absorption on water use, but these models have a high level of detail in the assessment of water use and the potential consequences of the introduction of new technologies. The amount of water required for cooling a station with a VVER-1000 reactor can be found using the equations given in [17] and convenient to use.

3. MAIN PART. The following algorithm was used in the research: changes in water temperature indicators depending on air temperature were studied and correlation dependences between these indicators, which are usually linear functions, were constructed [10]; on the basis of the obtained correlation dependences, we find the coefficients of the Mohseni equation [18]. This equation allows for the estimation of the effect of the increase in water temperature and relates the waste heat at the plant to the demand for cooling water based on the efficiency data and the generated electricity, and for closed cooling systems the fraction of the waste heat released to the air is determined.

To determine the output power, equation (1) was used for open cooling systems, which is given in [10] with practical restrictions on the operation of the reactor, such as: the maximum permissible water intake, the maximum permissible temperature increase of the return water, and, finally, the overall efficiency of the installation.

$$KW_{max} = \frac{A \cdot S_{max} \cdot c \cdot \nu \cdot Q^{F}_{max}}{h \cdot 3.6 \cdot \left(\frac{1-\eta_{total}}{\eta_{electrical}}\right) \cdot (1-\alpha)}, \tag{1}$$

Where: KWmax – the maximum installed power in (kW); $\boldsymbol{Q^F}$ мах - the need for cooling water (m3); h – working hours in (hours); 3.6 is the coefficient for converting kWh into megajoules; $\boldsymbol{\eta_{total}}$ — total efficiency in (%); $\boldsymbol{\eta_{electrical}}$ - electrical efficiency in (%); $\boldsymbol{\alpha}$ - share of spent heat not removed by cooling water in (%); $\boldsymbol{\nu}$ - density of water in (t/m3); c – specific isobaric heat capacity of water in (MJ/t K); ASмах – is the maximum permissible increase in the temperature of the cooling water in (K).

To study the cooling tanks of nuclear power plants in Ukraine, we used the OriginPro8 software environment, and to construct the correlation dependences for the cooling reservoirs of the Khmelnytsky NPP, the Rivne NPP and the South Ukrainian NPP between the water temperature and the air temperature of one of the hottest years in the last decade - 2020. The data of the correlation dependences, based on which the coefficients in equations (1) and the Mohnesi equation can be identified, are given in Table 1. The values of the parameters for calculating the need for cooling water are presented in Table 2.

Table 1 - Forecast and estimation parameters according to equation (2)

Object	Tashlitsky Reservoir (PNPP)	Netishyn Reservoir (KHNPP)	Styr River (PNPP)
Нахил (м)	1,6249	1,1801	1 . 2337
$\boldsymbol{\gamma}$ = (**4** ×m / $\boldsymbol{\alpha - \mu}$)	0,382	0,2247	0 . 2234
$\boldsymbol{\beta}$ – (°C).	8	7.5	1 2
$\boldsymbol{\alpha}$ - (°C)	33	24	25
$\boldsymbol{\mu}$ – (°C)	14	3	3

Table 2. Values of parameters for calculating the need for cooling water

Parameters	
$\boldsymbol{\alpha}$ = 0.01	AS = 10 K
h = 24*30 = 720	EZ = 3
$\boldsymbol{\eta_{total}}$ = 0,75-0,85	$\boldsymbol{\omega}$ = 0.975
$\boldsymbol{\eta_{electrical}}$ = 0.33	(**1** − $\boldsymbol{\beta}$)= 0.013696

The analysis of changes in temperature indicators on the territory of Ukraine during the period 1881-2020 is presented in Fig. 1. and Fig. 2.

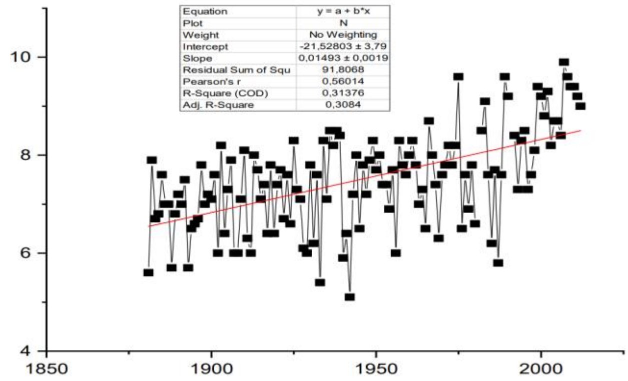


Fig. 1 Correlation dependence of average annual temperature changes of the atmospheric surface air on the territory of Ukraine in the period 1881-2020.

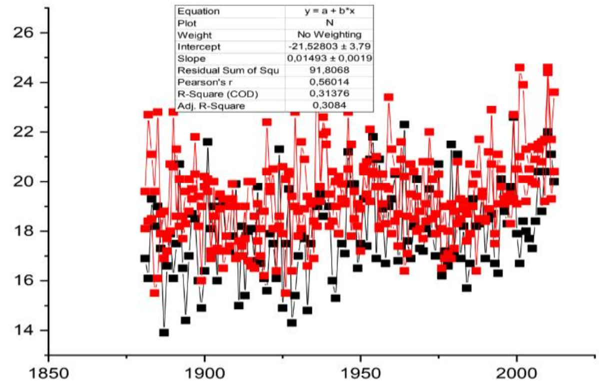


Fig. 2. Correlation dependence of average monthly temperature changes of atmospheric surface air in the summer months on the territory of Ukraine in the section 1881-2020.

Modeling of the forecast data of the average annual temperature of atmospheric air for the period until 2160 is presented, respectively, in the graphs of Fig. 3 and Fig. 4.

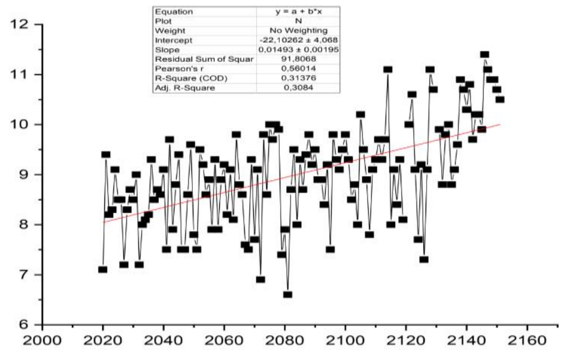


Fig. 3. Modeling of forecast data of the average annual atmospheric temperature for the period up to 2160

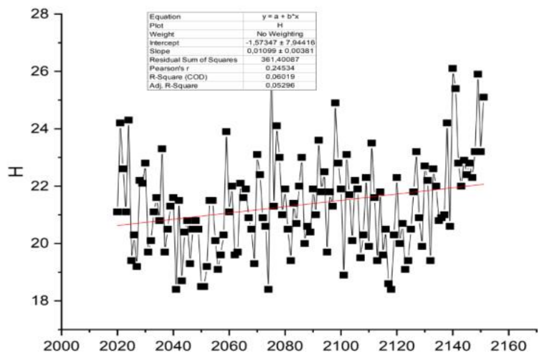
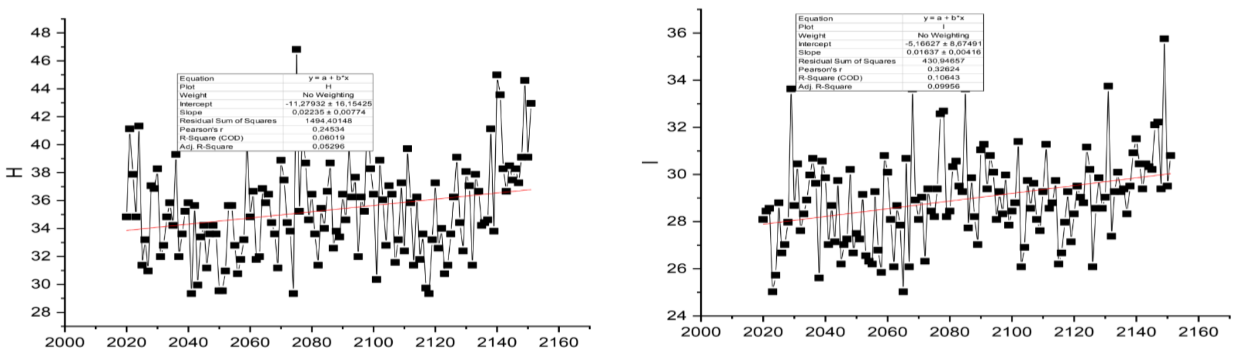
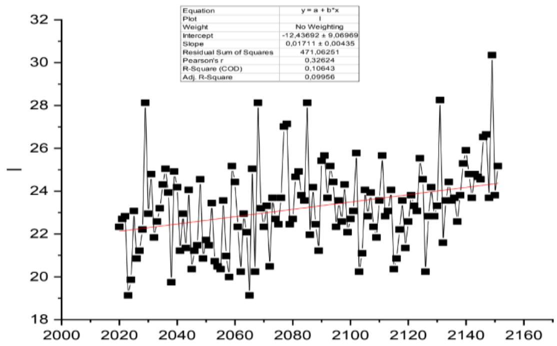


Fig. 4. Modeling forecast data of the average monthly air temperature in July for the period until 2160

Modeling of forecast water temperatures of cooling reservoirs is presented in the graph of Fig. 5.

a) b)





c)

Fig. 5. Modeling of forecast water temperatures of cooling reservoirs of the NPP of Ukraine: a) - Tashlitsky Reservoir, в) - Netishyn reservoir, c) - Styr River

The equation of the relationship between the temperature of the surface layer of the air and the cooling water is linear with the corresponding correlation coefficients: Tashlitsky Reservoir - 0.8278, Netishyn Reservoir - 0.9408 and cooling water of the Rivne NPP (Styr River) - 0.8759.

When calculating the efficiency of the reactors according to equation (1), practical restrictions are imposed, such as: the maximum permissible water intake, the maximum permissible temperature increase of the return water, etc.

Taking into account the terms of decommissioning of reactors at the nuclear power plants of Ukraine, it is sufficient, in our opinion, to make a forecast of the efficiency of their work for the period until 2050. Calculation data showed that in the period 2023-2030, if the current trend of increasing climatic indicators is maintained, the value of the coefficient of the total power of nuclear reactors in the summer months is 0.40; in the period of 2031-2040 - is 0.38 and in the period of 2041-2050 it may reach 0.35 and below.

4. CONCLUSIONS. One of the main negative factors affecting the reduction of energy efficiency of NPPs in Ukraine is open cooling systems, when higher efficiency in the technological process can be achieved if the temperature of the suitable water is lower. Nuclear power plants of Ukraine require a fairly large amount of water for the process of cooling waste and removing heat. Analysis of the impact of global climate change on the presence of cooling through open cooling ponds showed that a gradual increase in the temperature of cooling water in the coming decades will lead to a decrease in the efficiency of reactors at nuclear power plants in Ukraine. In order to avoid the risks of emergency situations at the station and in the area of its influence, it is necessary to have a tool for predictive assessment of the efficiency of the cooling systems in conditions of a gradual increase in the temperature indicators of water resources that enter the technological process for making strategic decisions regarding the transition to "clean" energy. and new generations of reactors.

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