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Section: Environmental protection

The risks of global warming and cooling efficiency of circulating water in cooling towers of nuclear power plant

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Abstract

Given the known risks of global warming are discussed technical problems of increasing the efficiency of the cooling water in cooling towers at nuclear power plants. A new concept of building fill space and air windows in the cooling tower, based on the results of the analysis of the aerodynamics of the cooling towers. The results of hydrodynamic testing pieces of the proposed designs, the totality of which provides the required cooling performance of recycled water in extreme weather conditions with low wind load.

Keywords: cooling tower; the aerodynamic conditions; the speed of the air flow; flow resistance; fluid distribution.

Nomenclature

Z	the current coordinate (m)
h	the height of the window air (m)
k	coefficient of non-uniformity of air distribution in fill
F_1	area inlet section (m^2)
F_2	irrigated area (m^2)
A	coefficient of influence the design features of fill to a depth of cooling recycled water in a cooling tower, (m^{-1})
H	the height of the fill (m)
Me	Merkel number, the criterion of similarity
m	the exponent describing the dependence of the speed change mass air flow from Me
ΔP	pressure loss in fill (Pa)
W_0	speed air flow
Greek symbols	
ξ	hydraulic resistance coefficient
λ	mass air flow related to the consumption of water

1. Introduction

According to an Intergovernmental Panel on climate change (IPCC) to the beginning of the 22ND century, the average surface temperature of the Earth may rise by an amount of 1.8 to 3.4 °C [1]. Responding to climate change involves the process of risk management, adaptation and mitigation of the effects of global warming. In the energy industry an important part of the strategy of adaptation is the research of the effects of climate change on the work of energy facilities and integrating changes in design standards. It is known that the work of most modern power plants is based on the conversion of the energy to heat, light and other forms of energy, which is transferred to the working environment, such as water or gaseous products of combustion.

The distinctive feature of the nuclear power plant from other types of power plants is to produce huge amounts of excess heat, which is not involved in the main type of electric or thermal energy. The excess heat is sent into the environment. To remove excess heat NUCLEAR POWER PLANTS, equipped with special cooling systems to maintain the required temperature range. Malfunctioning of the cooling systems of NUCLEAR POWER PLANTS operating temperature changes

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that could eventually lead to emergencies, the most dangerous of which are thermal deformation of materials of construction and demolition.

Of particular interest in this respect are the processes occurring in the cooling towers NUCLEAR POWER PLANTS, the reliability of which for reasons of environmental protection should be ensured in all weather conditions [2–4].

The concept of NUCLEAR POWER PLANTS is shown in Figure 1 The main zone of counter flow cooling towers is shown in Fig. 2).

Environmental aspects of the operation of the cooling towers are considered in [5, 6]. Below on the basis of the analysis of the aerodynamics of the cooling tower, present a new concept of building a layer of cooling tower fill. Proposed approaches to composition and relative position elements of fill in a cooling tower to provide the required cooling performance of circulating water in hot weather conditions with low wind load.

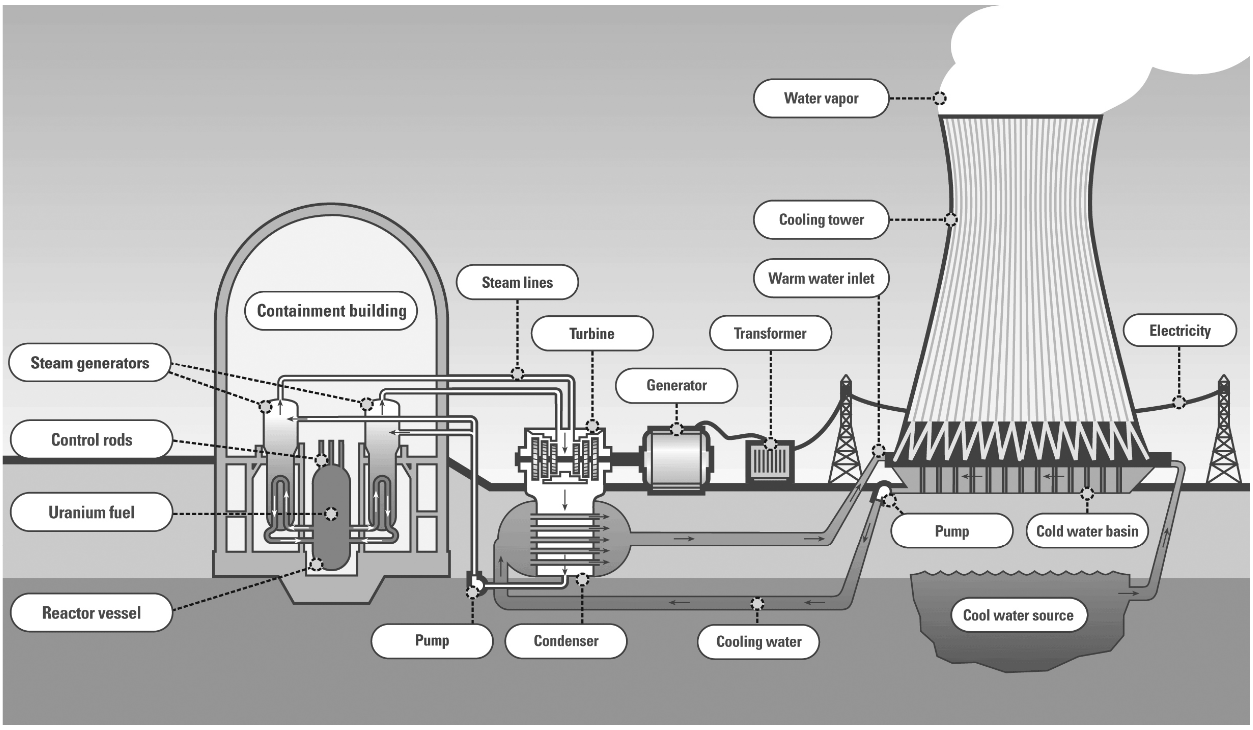

Fig. 1. Scheme of the nuclear power plant

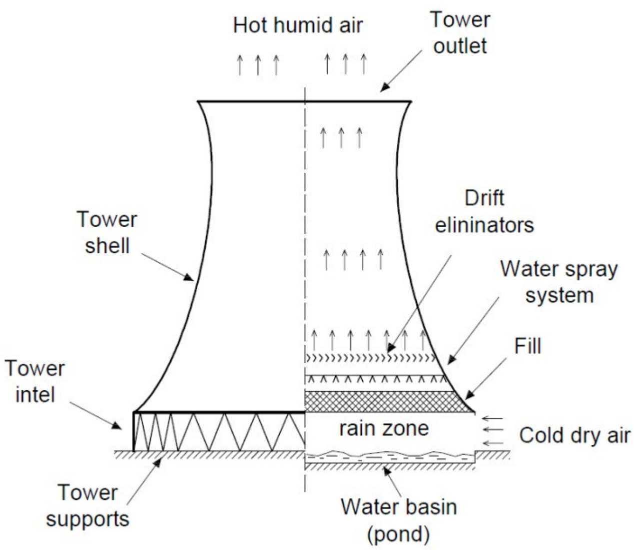

Fig. 2. Main zone of counter flow cooling tower

2. Concept block for of cooling tower fill

2.1. Aerodynamic conditions at the entrance of the air flow in the cooling tower

As it is known, for the efficient operation of cooling tower in the hottest period of the year is very important to the wind environment around cooling towers [7, 8].

Available meteorological data such as wind parameters for the seaside region of Lithuania, show that the average annual wind speed at 50 m from the surface of the Earth is 6.4 m/s [9]. At the same time, as can be seen from Table 1, as it approaches the surface of the Earth, the average wind speed is greatly reduced.

Table 1. The average annual wind speed at the meteorological stations of the seaside region of Lithuania at different distances from the Earth's surface, according to [9]

Meteorological observation	The average annual wind speed, m/s		
	The distance from the Earth's surface, m		
	10	25	50
Nida	5,75	6,94	8,0
Kaunas	3,77	4,71	5,58
Utena	2,94	3,74	4,5
Varena	2,5	3,23	3,93

From the diagram, Figure 3 shows that the highest wind speed of the autumn-winter period. In summer, the hottest period of the year, wind loading is greatly reduced, up to 5.4 m/s (see Fig. 3), which can be seen as a disadvantage for the effective operation of cooling tower [5–7].

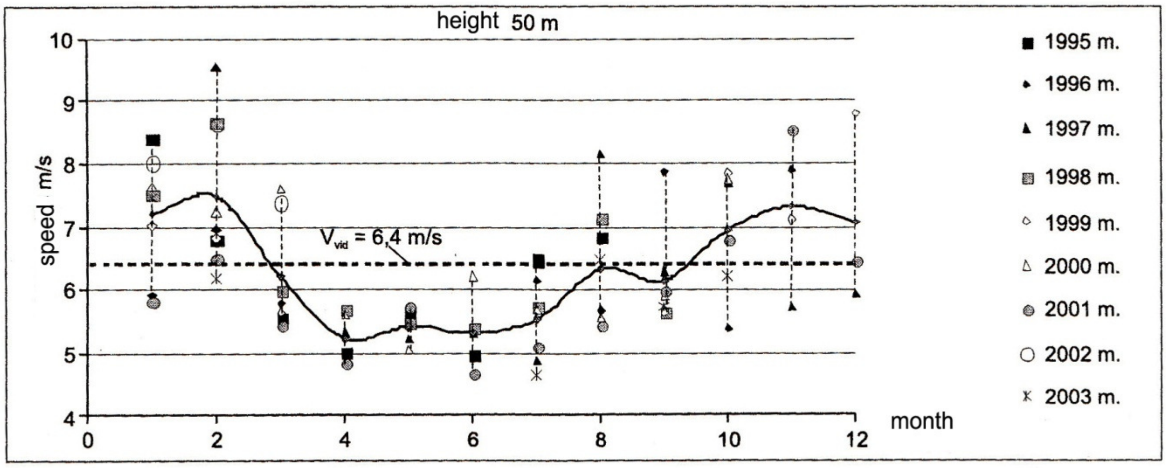

Fig. 3. The wind speed at 50 m from the surface of the Earth for the region Klaipeda according to meteorological observations in 1995–2003, broken down by month of the year

Made in [10] experiments on measurement of air flow velocity field in inlet section of cooling tower showed that air flow is the maximum speed in surface area when Z/h = 0.25. Here, h – is the height of the air window cooling towers, m; Z-the current coordinate, m. At Z = 0 and Z/h = 1 because of the conditions of adhesion of the air flow to hard surface wind speed equal to zero.

Experiments [10] have also shown that at the top of the inlet section of cooling tower, air speed is quite small, and the structure of currents of air in this region is unstable. Eddy currents return appear. While the air in rain zone the cooling tower is vortex.

According to work [10] the magnitude of these vortices is estimated to be the size of order 0, 2 h. In a strong wind, as shown by experiments on the visualization of air currents in the input windows and rain zone of cooling tower, the structure of the flow becomes much more uneven in height. As noted in [10], this also increases the speed and amplitude of reverse currents.

For the fill zone of the cooling towers, it is important that the vortical structures are formed between the water surface and the bottom edge of the window and the vertical wall of the pond. The work also indicates that the air flow in the upper part of the rain zone is reciprocating vortex, and the scale of vortex structures can reach 1 m [10]. Scheme of eddy currents near the inlet section is shown in Figure 4.

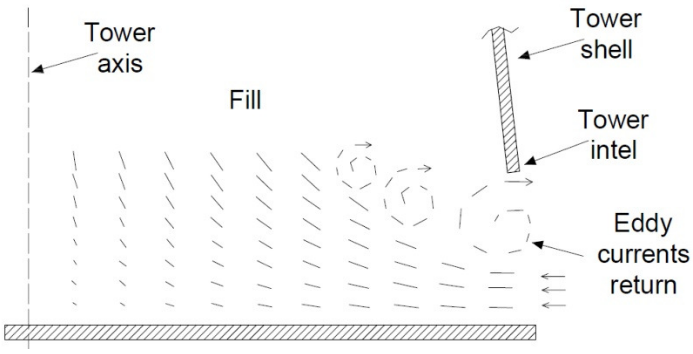

Fig. 4. Eddy currents in the rain zone space of cooling tower near inlet section

The aerodynamic features of the situation in the rain zone of cooling towers are not taken into account in the design of fill. Meanwhile, return flow, stagnant zones and generally uneven distribution in rain zone, as shown by the work carried out by VNIIG them. B.E. Vedeneeva considerably reduces the cooling capacity of cooling towers [11].

Figure 5 shows dependence of uneven air distribution in fill – k from ratio of cross sectional area of the inlet section to the cross sectional area of the fill – (F1/F2) with different values of resistance coefficient of rain (drops) – ξ_l. This relationship is built by us on the basis of empirical data [11].

As we can see from the charts on the Figure 6, if we increase ratio of the size of the inlet section area to the cross sectional area of the fill – (F1/F2) from 0.25 to 0.6 coefficient of uneven air distribution in the fill decreased on average from 0.4 to 0.2.

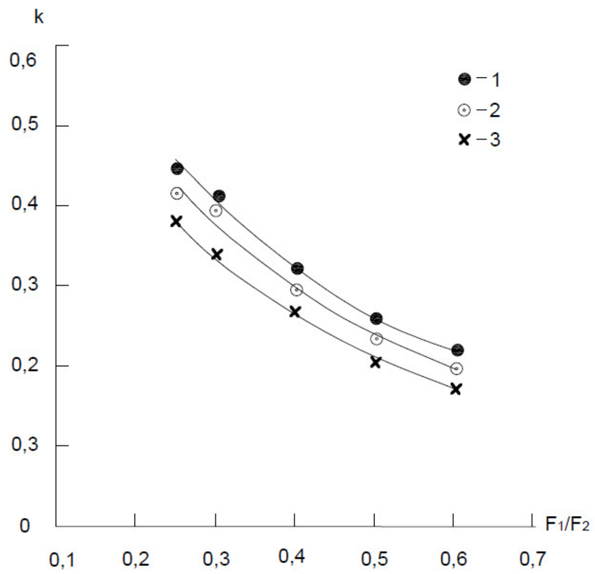

Fig. 5. The dependence of k = f (F1/F2) for different coefficient of resistance to rain ξ_l:
$\xi_l = 30$; 2 – $\xi_l = 25$; 3 – $\xi_l = 20$.

2.2. Methods to improve the efficiency of cooling recycled water

In the light of the above, a meteorological situation in the climatic characteristics of summer, taking into account the risks of global warming [12], as well as the above features of wind environment in inlet section and rain zone of cooling tower weu can formulate the following requirements to the optimal design of fill:

- even distribution of the air flow from the rain zone at the entrance to the main technology of the block fill;
- maximum effectiveness of evaporative cooling process of recycled water in the fill while ensuring the maximum possible energy and resource conservation;
- to ensure even distribution of the cooling water around the cross sectional area of the fill.

2.3. The theoretical part

Consider the evaporation cooling tower scheme (Fig. 2). The cooling towers can be the following specific areas:

- inlet section h_l– 5 m, $R_l \sim 40$ m;
- rain zone $h_l \sim 5 \div 10$ m, $R_l \sim 40$ m;

– fill zone of the cooling towers, including the blocks fill the $h_2 \sim 3 \div 5$ m, (depending on the type and efficiency of fill), $R_2 \sim 40$ m;
– water spay area, including the space between the nozzles and the top of the block of fill $h \sim 1 \div 2$ m, $R \sim 40$ m;
– area of free convective motion of the rising masses of vapor flow $h_3 \sim 100$ m, R_3– 25 m

Thus, the characteristic of the air-flow velocity of W_1, W_2, W_3, in different areas (zones) of cooling tower significantly differ, what to consider when we build a perspective model fill.

Equation witch relating the number of Merkel – Me and the ratio of mass flow cooling water and cooling air – λ is of the form [7]:

$$Me=A \cdot H \cdot \lambda^{m} \quad (1)$$

The analysis published in the famous literature of hydraulic and aerothermal tests various industry types and designs of fills shows that the most effective have fills drip-film and film type. The results of this analysis in the form of dependence A = f (ζ/H) are shown in Figure 8. Type drip fill, as can be seen from Figure 8 schedules, have significantly lower efficiency in comparison with fills drip-film and film type.

The scheme effectively fill the drip-film type proposed is presented in [13]. Use fills that type ensures fluid film-surface helicoids elements that make up the block. In addition fill construction made of plastic helicoids element allows to perfectly implement principles of short layer fill, whose idea is repeated using "end" effects [14, 15].

A set of shapes, helicoids architecture build in space can provide a significant increase in the efficiency of evaporation cooling of circulating water in a cooling tower.

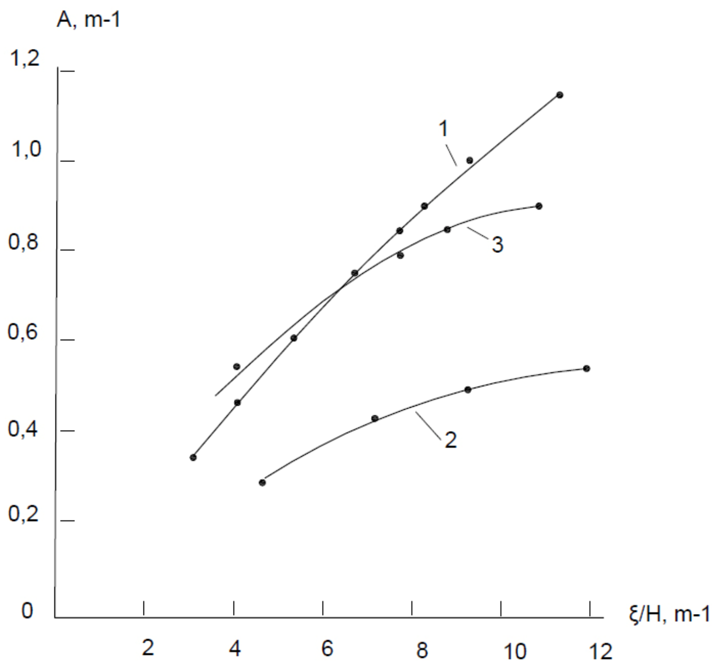

Fig. 6. The dependence of a = f (ξ/H) is of different types:
1 – film type fill; 2 – drip type fill; 3 – drip-film type fill

2.4. The combination of contact devices.

A detailed analysis of the various designs of fills, shows that construction requirements of prospective fill best serves combined contact device made out of 3 's component parts, each of which performs its technological features.

Schema options combined contact devices are presented on Figure 10. As can be seen from the information shown in Figure 7, and the physical model of the proposed contact device most of the construction is done in the form of fill drip-film or film type. As a drip-film fill is the most interesting designs from helicoids elements [13]. The fill should perform in the form of a system of shot layer fills [15].

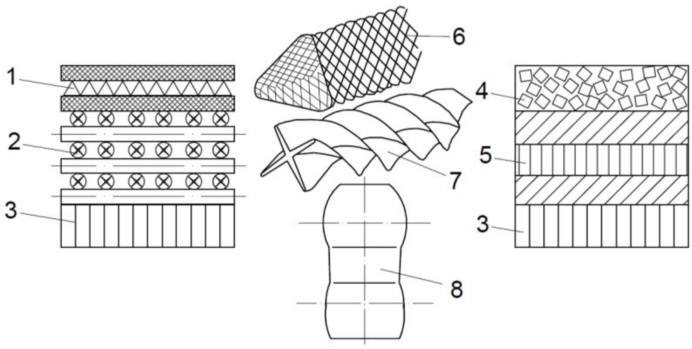

Fig. 7. The scheme of combined contact device: 1 – liquid distributor in the form of latticed structures 6; 2 – drip-film fill from helicoids elements 7; 3 – honejkomb in the form of a lattice of nozzle elements 8; 4 – layer bulk packings; 5 – fill type film type of corrugated plates

2.4.1. Liquid distributor

As a distributor of liquid in accordance with the requirements of the energy efficiency (Δp = min) it is advisable to use a layer of loose packings or latticed structure. The characteristics of these packings are shown in Figure 8.

Scheme of spreading a single Jet of fluid in a 3-d grid is shown in Figure 9. In the case of the construction of the main fill from helicoids elements as distributor liquid using a lattice structure. In the case of channel plates – bulk packing.

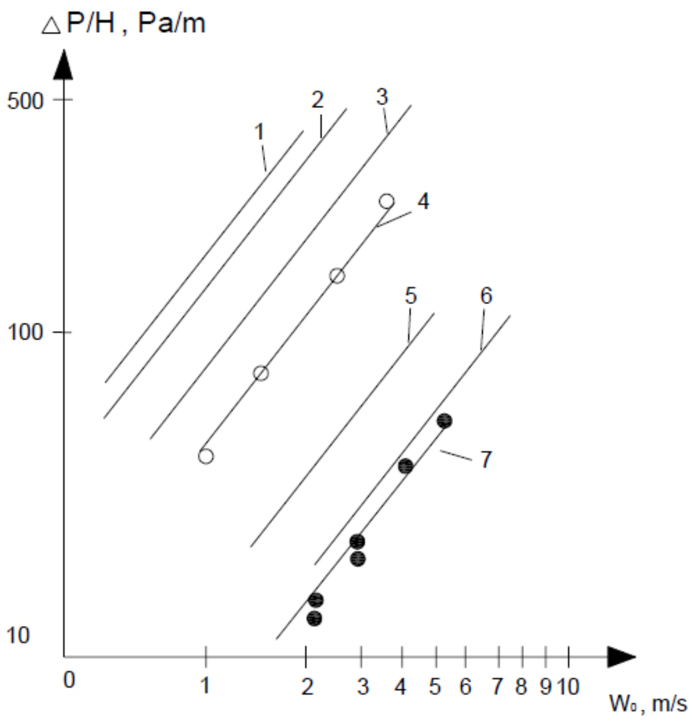

Fig. 8. Dependency (Δ P/H) = f (W_0) for different bulk and regular fills (packings): 1 ÷ 3-bulk packings; 4 ÷ 7 – regular fills; 1 – Ring Byalyatski 50×50 mm [16]; 2 – 50×50 mm Raschig Rings [16]; 3 – Pall ring 50×50 mm [16]; 4 – Regular fill from helicoids elements [13]; 5 – Vaky-Pak [17]; 6 – Zulcert [17]; 7 – Lattice structure

2.4.2. Inlet gas distribution device

To align the inlet velocity field drop zone fill device cooling towers can be used in construction of the honeykomb whose elements represent a vertically nozzle bodies of rotation. One of these elements is shown in Figure 13. The cross-sectional area of the channels formed by these elements is constantly changing in height of the honeykomb (see Fig. 9).

Honeykomb aerodynamics tests proposed designs have shown that this device provides even flow distribution, splits large eddies in the rain zone at the smaller ones, which quickly fade.

It may be noted that the input device in the form of konfuzer are used to align the gas flow at the entrance of the rod installation of the fuel elements in nuclear reactors [18].

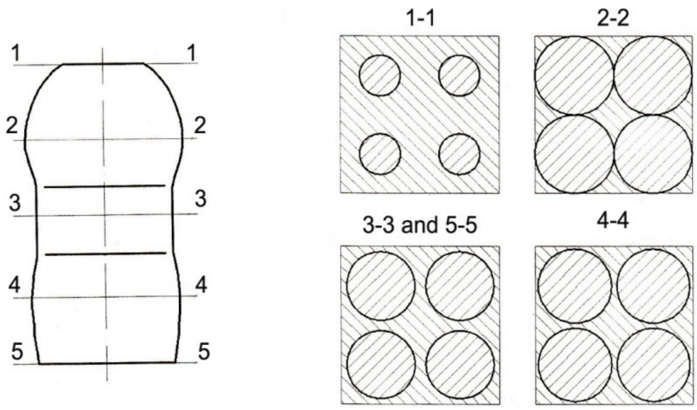

Fig. 9. General view of the element input device

Dependence of hydraulic resistance it device at the inlet to the unit fill Δ P/H of air velocity in the expectation of full cross section of an empty apparatus of Wa based on our experiences in the apparatus of a diameter of 200 mm are represented on Figure 10.

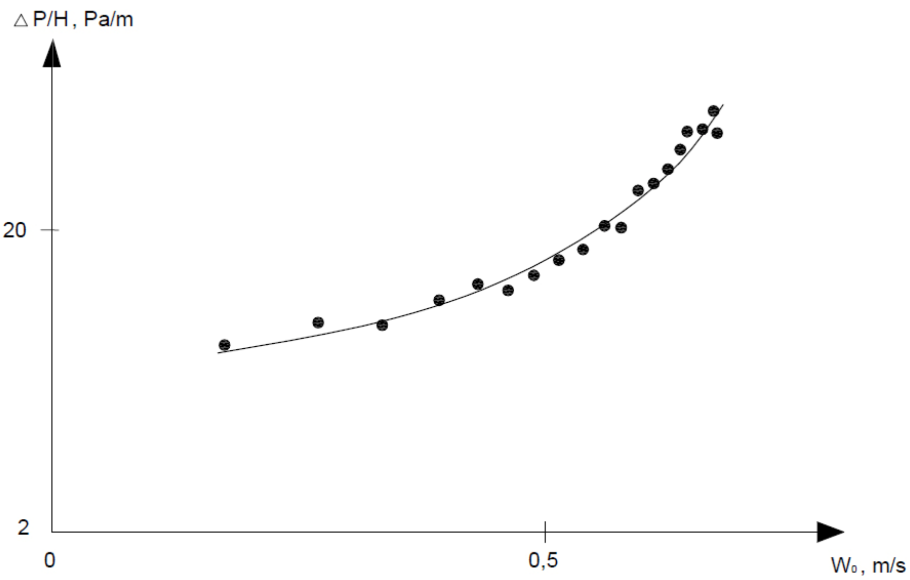

Fig. 10. The dependence of Δ P/H = f (W_0)-fragment of a timing device at the entrance of the block of fill

3. Conclusions

1. Addresses the risks of global climate change and the potential impact on the performance of cooling recycled water in extreme conditions the summer period.
2. Presents the concept of perspective construction of cooling tower fill with combined contact device, based on the results of the analysis of the aerodynamics of the cooling towers for nuclear power plants.
3. Presents the results of the test liquid distributor and fragments of the input device, it is forming with fill drip-film (or film) a perspective combination contact device.

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