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ANALYSIS OF CHANGES IN COOLANT PARAMETERS IN THE PRIMARY CIRCUITS OF COOLING SYSTEMS OF LINEAR ELECTRON ACCELERATORS

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For cooling and thermostatting of linear electron accelerators (LEAs), ordinary tap water from underground sources was used, which has a fairly significant salt content. During the operation of the LEA, as a rule, scale is deposited on the heating surfaces, in addition, process pipelines are clogged, which interferes with the efficient operation of the equipment, and in some cases leads to it's damage. A study of the quality of both tap water and water from cooling systems was carried out. Conductivity and pH measurements were used for continuous monitoring. Elemental analysis of salts present in waters was performed by emission spectral analysis with inductively coupled plasma on the ICPE-9000 Shimazu spectrometer and mass spectrometric method. It is recommended to flush cooling systems with dilute nitric acid to stop the decrease in conductivity.

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INTRODUCTION

A systematic study of accelerator cooling systems was carried out for eight months. The first cooling and thermostatting circuits of LEA-10 and LEA-40 consist of storage tanks, pipelines, heater blocks, heat exchangers and cooling elements of accelerators. The cooling system is filled from the water supply and was periodically replenished (on average by 80 l per 100 h of operation of the accelerator). Cooled elements of linear accelerators are acceleration sections, solenoids, gun housings, collimators, vacuum pumps, high-frequency loading, etc. The total volume of the cooling system of LEA-10 is 3500 l, and LEA-40 is 450 l. The operating time of thermostatting systems with a beam was 970 and 190 h, respectively, and the total time was 1250 and 260 h. From the experience of accelerator operation, it is known that deposits primarily accumulate on the surface of heaters and in the coil of the pulse transformer block. To predict the rate of growth of the thickness of the sediment layer, water was analyzed weekly for some parameters – pH, conductivity, and sometimes the content of metal ions. Irradiation affects the oxidizing capacity of water and, as a result, increases the corrosion of equipment, as evidenced by the presence of a noticeable concentration of chromium in the return water. In turn, corrosion products together with carbonates and sulfates of alkaline earth metals pass into sediments. As water circulates, the conductivity decreases and the pH increases, indicating that the number of ions in the water has decreased, the bicarbonates have decomposed, the carbon dioxide that acidified the water has been released into the atmosphere, and the layer of sediments has grown.

1. USUAL COMPOSITION OF GROUNDWATER USED FOR WATER SUPPLY

There is always a significant amount of bicarbonates in groundwater, which causes temporary hardness. When water is heated to a temperature slightly less than the boiling point, alkaline earth metal and iron bicarbonates decompose, and insoluble carbonates and calcium and strontium sulfates settle on the heating surfaces and precipitate. In the case of iron and magnesium, these are hydroxides.

Table 1

Groundwater composition of Europe (mg/l)

Element	1	2	3	4	5	6	7	8	9	10	11
HCO_3	577	360	360	236	390	238	1816	360	1300	243	17
Ca	125	50	–	70	147	180	348	80	190	125	5
Mg	44	20	–	7	3.4	52	108	26	85	13	2
SO_4	24		–	–	33	459	38.3	12.6	40	–	–
Na	17	75	5	76	9	57	118	6.5	150	16	–
Cl	15	–	8	111	22	57	39.7	6.8	40	81	5
K	5	8	2.8	5.2	0.6	2.8	10.8	1	10	3.7	1
NO_3	–	–	0.5	–	18	2.2	5.1	3.7	–	0.5	2
F	–	–	–	0.17	0.12	0.6	0.21	–	1	0.2	–
SiO_2	–	–	–	–	–	7.5	40.2	15	–	–	7
Sr	–	–	–	–	–	3.2	2.9	–	–	–	–
Dry. Res.	–	–	–	–	–	–	–	–	–	567	38

Notes: 1 – Gerolstein (Germany); 2 – Zhashkiv; 3 – Sifresbron (Neth.); 4 – Cora Brunnen (Germany); 5 – Perrier (Fr.); 6 – San Pelegrino (It.); 7 – Gerolsteiner (Germany); 8 – Evian (Fr.); 9 – Badoit (Fr.); 10 – Rheinfurst(Bel.); 11 – Reine(Bel.).

The typical composition of groundwater is almost the same for many regions of the world. Some data on the composition of groundwater are given in Table 1.

Table 2

Chemical composition of tap water in mg/l

№	Ca	Cr	Fe	Mg	Mn	Ni	S	Si	Sr
1	3.13	0.001	0.06	3.11	0.01	0.002	–	6.58	–
2	38	–	0.01	1.8	0.001	–	5.2	0.33	1.3
3	38	0.004	0.01	–	–	0.007	5.2	–	–
4	3.13	0.001	0.06	–	–	0.002	–	–	–
5	4.5	–	–	0.36	0.001	–	1.2	0.13	0.35

Notes: data №1, 4 were obtained by the mass spectrometric method, data № 2, 3, 5 were obtained by the emission spectral method with inductively coupled plasma on the ICPE-9000 Shimadzu spectrometer.

Based on the data in Table 1, it can be assumed that the average composition of groundwater in mg/l is as follows: HCO_3^- – 360, Ca^{2+} – 70, Mg^{2+}– 20, SO_4^{2-} – 20, Na^+ – 45, Cl^- – 15. Some analyses have been performed for our tap water, mg/l: Ca^{2+}– 38, Mg^{2+}– 1,9, Sr^{2+}– 1,4, S – 5, For more details, see Table 2. In our opinion, the tap water that comes to the accelerators is similar to 8-Evian groundwater.

In Table 2, there is a significant discrepancy in the data, which is understandable, since the measurements were carried out without standards. The content of sodium was from 6 to 18 mg/l, potassium from 0.2 to 1.4 mg/l, copper was determined only in sample No. 1 at the level of 0.003 mg/l. In the neighboring region of the Kharkiv region, the calcium content in groundwater reaches 150 mg/l [1], which is significantly higher than the data for our water and this requires explanation Table 1. In many test results, there is no data on the content of strontium, which is always present in water at the level of several mg/l. Strontium carbonate and sulfate are less soluble than calcium compounds and primarily settle on heating surfaces. Some water has a significant content of nitrates (5-Perrier), which indicates contamination by surface waters, but this would not prevent them from being used for circulating water supply, usually deep-lying groundwater does not have nitrates. The groundwater dry residue has a variety of values starting from 38 mg/l. For our tap water we have 400 mg/l, which leads to noticeable scale formation.

2. COOLING WATER QUALITY CONTROL

Under the influence of temperature changes and ionization radiation, the parameters of water changed. The specific salt content and pH were measured once a week using the Multi-350i device. The salt content was estimated by electrical conductivity, equating 1 μs to 1 mg/l of salts, that is, the conversion factor was equal to one. For a particular water, it is desirable to clarify the conversion factor when using the value of the dry residue. Changes in conductivity and pH values from observation time are shown in Figs. 1 and 2. From the above data, it can be seen that the water in the cooling circuits is more alkaline than tap water, which can be explained by the blowing off of carbon dioxide, which is formed during the decomposition of bicarbonates. Over the same period, the concentration of salts in the water of each cooling circuit decreased by about 100 mg/l over 230 days of observation. The composition of tap water and water in the two cooling circuits is shown in Table 3.

Table 3

Composition of tap and cooling water, mg/l

Element	Tap.	LEA-10	LEA-40
Ca	4.5	0.17	0.003
K	0.18	0.031	0.29
Mg	0.36	0.14	0.39
Mn	0.001	0.001	0.015
Ni	–	0.004	–
S	1.2	0.048	0.001
Si	0.13	0.021	0.09
Sr	0.35	0.002	0.26
Zn	0.006	0.003	0.005

There is some variation in the values of the concentrations of elements in the Table 3 can also be explained by a measurement without standards on the Shimadzu spectrometer. The decrease in the salt content in the cooled water is confirmed by a decrease in the mass of the dry residue from 0.4 to 0.24 g.

Thus, the mass of deposits (M) on the surfaces of heaters and second systems of the primary circuit of accelerators washed by the coolant is approximately equal to M = 100 mg/(l·V), where V is the volume in l. Based on this assumption, we have that for LEA-10 the mass of deposits will be 350 g, and for LEA-40 about 45 g. Papers [2, 3] show that deposits on the surfaces of water heat exchangers usually consist of calcium carbonate and magnesium hydroxide, in addition, iron is present in the form of magnetite and oxide ($CaCO_3$, $Mg(OH)_2$, Fe_3O_4, Fe_2O_3). X-ray fluorescent analysis on an electron microscope was used to assess the composition of sediments [3]: C 25%, O 57%, Mg 2.4%, S 0.14%, Ca 16%, Fe 0.4%, as well as some elements whose presence is doubtful, in particular Ta. The data are semi-quantitative, since those authors also measured without standards. In our case, based on the data of Table 2, as well as the processes of water ionization, the formation of radicals and peroxide compounds due to this, increased corrosion of surfaces, it can be assumed that the deposits consist of the above substances with an admixture of oxides of chromium, nickel, copper, which react with the formation of spinels such as $CuFe_2O_4$, $NiCr_2O_4$, etc. With an average sediment density of 2.6 g/sm^3 (since the bulk of the sediments are calcite ($CaCO_3$) [4], it would be possible to calculate the volume of the sediments, assuming that all insoluble compounds are deposited on surfaces, which is doubtful.

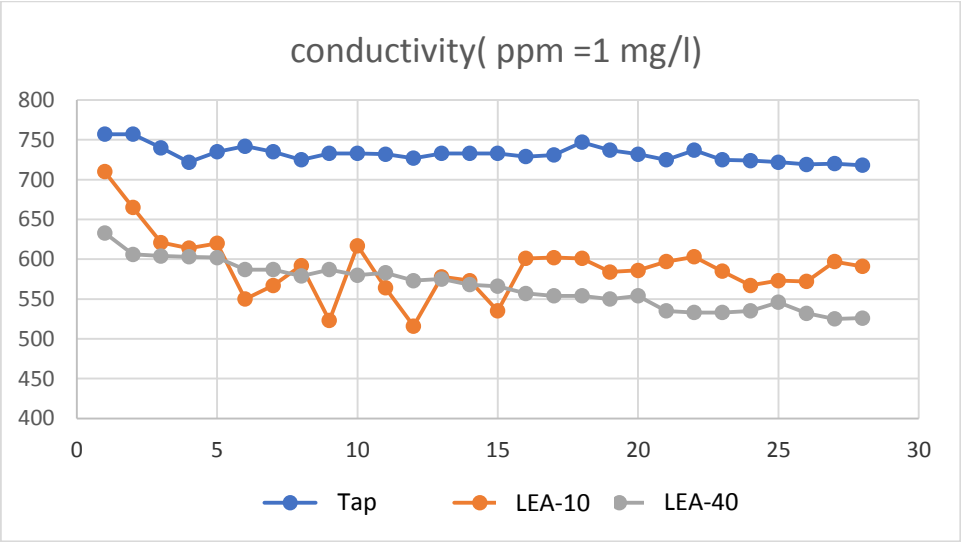

Fig. 1. Dependence of water conductivity on the time of observations

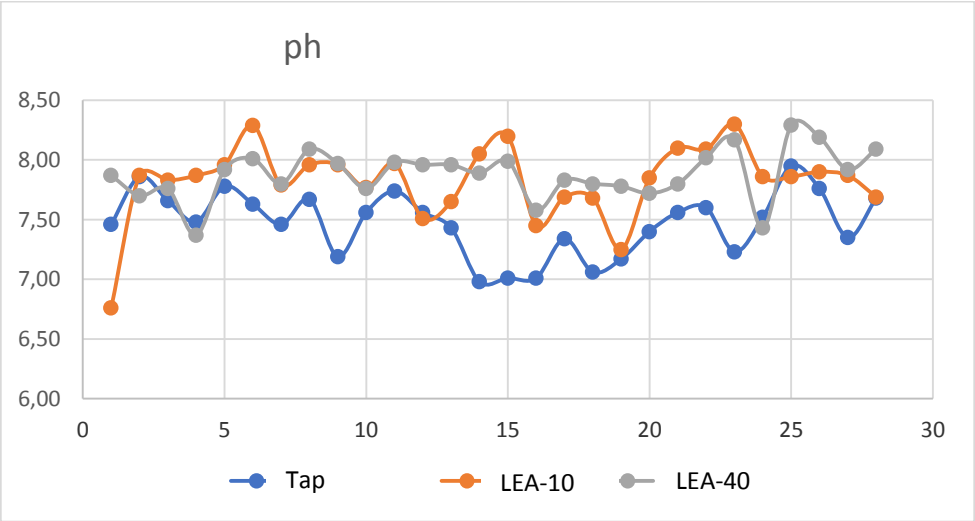

Fig. 2. Dependence of the pH of water on the time of observations

3. LIMESCALE BUILD-UP AND REMOVAL OF HEATING SURFACES

An approximate scale composition is given in section 2. To this can be added what researchers did not pay attention to before, that is, groundwater contains a significant amount of strontium and silicic acids, and all this is deposited on the inner surfaces of heat exchangers, in pipelines, in the coil of the pulse transformer block, and precipitates in storage tanks. The appearance of the heaters removed from the accelerator is shown in Fig. 3. As can be seen in Fig. 3, the sediment layer leads to overheating and rupture of the heater shell. For washing heat exchangers, pipelines and other equipment, i.e. removing deposits, it is recommended to use hydrochloric acid with the simultaneous use of corrosion inhibitors [2]. In our opinion, this is not very convenient, since as a result we get hazardous waste, in addition, hydrochloric acid has the greatest corrosiveness among acids. In the work [5], nitric acid up to 50% concentration was recognized as the best reagent among hydrochloric up to 36%, sulfuric up to 50%, acetic, phosphoric, sodium and potassium hydroxides, ammonia, Ca, Mg, Fe, Cu, Zn, Cr were determined in the solution after removing deposits. It is not permissible to use high-concentration acids for descaling, which leads to corrosion of the metal. We have previously successfully used nitric acid of 5% concentration, which has no corrosive activity, confirmation of this can be found in [3] where we are talking about 5…10% concentration of nitric acid. We descaled the loop heat exchanger and found that the concentration of strontium in the wash solution was as high as that of calcium, although the initial concentration of strontium in tap water did not exceed a few mg per liter, an order of magnitude less than calcium. Thus, strontium passes from the cooling water to the sediments in the first place, rather than calcium. The use of dilute nitric acid does not require corrosion inhibitors. Wash water can be used as a nitrogen fertilizer. Looking closely at Fig. 1, where the data on the dependence of conductivity on the time of observations are given, it can be seen that after a while the decrease in conductivity stopped. In our opinion, at the same time, the layer of sediments has grown to the maximum and it is time for acid washing.

Fig. 3. Appearance of heaters removed from the accelerator

CONCLUSIONS

All elements, with the exception of potassium, which are listed in Table 3 and are part of the waters, can produce scale and deposits. These are mainly carbonates, sulfates, oxides. The latter, when interacting with each other, can give spinels. Elemental analysis of sediments revealed that more than 50% of the weight is oxygen [3, 5]. There is very little calcium detected in our water, which does not correspond to the value of the dry residue, which reaches 400 mg/l, but all this is due to the fact that the analysis is semi-quantitative. The data on the decrease in the concentrations of sulfur and silicon in the cooling water are very indicative, most of the mass of these elements passes into deposits in the form of strontium and calcium sulfates and silicon dioxide. It should be noted as an achievement that, on the basis of the data in Table 3, the behavior of silicon in waters was predicted, although there is almost no data on this topic in the literature. Disparate data for silicon are shown in Table 1. There is not much data on strontium, although a significant part of the scale consists of its compounds. It is known that $SrSO_4$ and SiO_2 are insoluble in acids, but why is scale so easily soluble in dilute nitric acid. The fact is that the particles of these compounds are distributed in the mass of $CaCO_3$ and $Mg(OH)_2$, which are easily soluble in acids, while insoluble particles precipitate into the sludge. Not all insoluble compounds released from water give scale, some of them fall into the sludge, which accumulates in the tanks and therefore it is impossible to calculate the thickness of the sediment layer based on water analysis data. This study does not discuss sodium assay data because they are highly questionable. It should be noted that the analysis for sodium is a difficult thing, since it is present everywhere – in reagents and in distilled water, in further studies we will pay personal attention to this.

REFERENCES

1. Л.Ф. Голдовская-Перистая, В.А. Перистый, А.А. Шапошников. Гигиеническая оценка качества питьевой воды централизованной системы водоснабжения Белгородской области по некоторым химическим показателям // *Научные ведомости БГУ*. 2008, №3 (43), с. 140-146.
2. I.B. Obot, Abdelkader Meroufel, Ikenna B. Onyeacu, et al. Corrosion inhibitors for acid cleaning of desalination heat exchangers: Progress, challenges and future perspectives // *Journal of Molecular Liquids*. 2019, v. 296, 111760, p. 1-14; https://doi.org/10.1016/j.molliq.2019.111760
3. К. Кусаинов, С.Е. Сакипова, З.К. Айтпаева и др. Особенности структуры накипных отложений на поверхностях теплообменных аппаратов // *Вестник Карагандинского университета. Сер. "Физика"*. 2010, №1(57), с. 30-35.
4. В.И. Перельман. *Краткий справочник химика*. М.: ГХИ, 1963, 621 с.
5. А.М. Зимняков, Р.В. Наумов. Анализ химических отложений теплового оборудования и способы их очистки // *Известия ПГПУ им. В.Г. Белинского*. 2010, №17(21), с.104-108.

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АНАЛІЗ ЗМІН ПАРАМЕТРІВ ТЕПЛОНОСІЯ У ПЕРШИХ КОНТУРАХ СИСТЕМ ОХОЛОДЖЕННЯ ЛІНІЙНИХ ПРИСКОРЮВАЧІВ ЕЛЕКТРОНІВ

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Для охолодження і термостатування лінійних прискорювачів електронів (ЛПЕ) використана звичайна водопровідна вода з підземних джерел, яка має доволі значний вміст солей. При роботі ЛПЕ, як правило на поверхнях нагріву висаджується накип, окрім того забиваються технологічні трубопроводи, що заважає ефективній роботі обладнання, а в деяких випадках призводить до його пошкодження. Проведено дослідження якості як водопровідної води, так і вод з систем охолодження. Для постійного контролю використали вимірювання провідності і pH. Елементний аналіз присутніх у водах солей виконано емісійним спектральним аналізом з індуктивно-пов'язаною плазмою на спектрометрі ICPE-9000 Шимадзу і мас-спектрометричним методом. Рекомендовано проводити промивання систем охолодження розведеною азотною кислотою з метою запобігти зниженню провідності.