

# Characteristics of hydrogen rich water at different stages of electrolysis

*Dmitry Petrov<sup>1</sup>, Elena Panina<sup>2,\*</sup>*

<sup>1</sup>Scientific Center of Biomedical Technologies of the Federal Medical and Biological Agency of Russia, 143442, Svetlye Gory settlement, Krasnogorsk district, Moscow region, Russian Federation

<sup>2</sup>Federal State Budgetary Educational Institution of Higher Education Russian State Agrarian University-Moscow Timiryazev Agricultural Academy, 127434, Timiryazevskay St. 49, Moscow Russian Federation

**Abstract.** The article presents data on the enrichment of molecular hydrogen by the electrolysis of water using different types of water at different time periods using different types of water of different types (bottled drinking, distilled and tap). During the electrolysis process, which consisted of seven stages, it was found that the concentration of molecular hydrogen increases until the second stage and subsequently does not change. In general, electrolysis of all types of water except distilled water slightly increases the pH. In redox processes, sharp changes occur towards reduction reactions. During the electrolysis process, the temperature increases at all stages. The concentration of hydrogen molecules remains at the maximum level for half an hour after electrolysis. It is also permissible to use this water from an hour to an hour and a half after electrolysis as a dietary supplement.

## 1 Introduction

Global economic growth, increased growth rates of agricultural industrialization and increased production intensity lead to the emergence of negative factors affecting the welfare of animals, which reduce the adaptive capabilities of the animal body, thereby reducing the quality of the resulting products. Therefore, there are prerequisites for creating innovative approaches to keeping and breeding farm animals through the use of biologically active additives (BAS) [1]. Such biologically active additives also include natural inhibitors of free radical oxidation - antioxidants. Many authors consider the use of molecular hydrogen as an effective antioxidant to be one of the promising areas [2-6]. Molecular hydrogen is produced by electrolysis of water. Water enrich with molecular hydrogen (hydrogen rich water – HRW) thanks to scientific research, they have successfully learned to use both in the field of medicine and animal husbandry. Numerous foreign studies have proven the positive therapeutic effect of HRW in the treatment of various diseases of the human cardiovascular and nervous systems [7-10]. It is known that molecular hydrogen has positive physicochemical properties for the body, is capable of normalizing excess amounts of reactive oxygen species formed during lipid peroxidation, and is classified as an antioxidant.

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\* Corresponding author: [epanina@rgau-msha.ru](mailto:epanina@rgau-msha.ru)

Since molecular hydrogen has the lowest molecular weight, it easily diffuses into the bilipid layer of cell membranes and the karyolemma of the nucleus. At the same time, it does not disrupt the physiological processes occurring both in the cytoplasm of the cell and in the body as a whole [11-14]. In addition, the introduction of water enriched with molecular hydrogen into the diet helps reduce anxiety and depression [15]. It is also noted that HRW increases the proportion of active behavior in animals and helps improve their productive qualities [16-17]. Due to its low molecular weight, hydrogen easily diffuses through cell membranes into the cytoplasm without affecting changes in homeostasis. Molecular hydrogen has antioxidant properties, which allows it to participate in the inactivation of excess free radicals that arise in the body under the influence of various external and internal factors that cause oxidative stress.

Molecular hydrogen can be administered through inhalation, drinking HRW, or taking molecular hydrogen baths; using eye drops with molecular hydrogen [18, 19]. Excess molecular hydrogen is quickly eliminated from the body through the lungs [20].

Due to the fact that in the scientific literature there is a lack of information on the nature of the concentration and duration of the content of molecular hydrogen in water, the purpose of our research was to study water enriched with molecular hydrogen using different types at different time ranges of electrolysis.

## 2 Materials and methods

The material for the study was four types of drinking water: "Holy Spring" (1), "Chernogolovka" (2), "Kubai" (3), "Lipetsk pump room" (4), as well as distilled (5) and tap water (6). In the first experiment, three samples of each type underwent electrolysis in the Lourdes apparatus HS -81" for 70 minutes. Before electrolysis and every 10 minutes during its continuation, total mineralization (impurity content) was measured using a TDS meter (TDS), hydrogen concentration ( $H_2$ ), oxidation-reduction potential (ORP), pH value, temperature ( $t^\circ$ ). In the second experiment, electrolysis was carried out for 30 minutes. Then the same indicators were measured 30, 60, 90, 120, 150 and 180 minutes after electrolysis. The data obtained were processed statistically.

## 3 Results and its discussion

Before using different types of water (bottled drinking, distilled and tap) to obtain a hydrogen antioxidant, we initially analyzed the indicators of the objects under study. It was found that the largest amount of impurities (total mineralization) was contained in sample 2, and the smallest in distilled water. The redox potential varied in the range from +225 to +297 mV, pH – 6.6-7.7, temperature – 21-23 °C. The concentration of molecular hydrogen was 0 mg/L (Table 1).

**Table 1.** Indicators of water of different types before electrolysis (volume 1.5 l, n = 3)

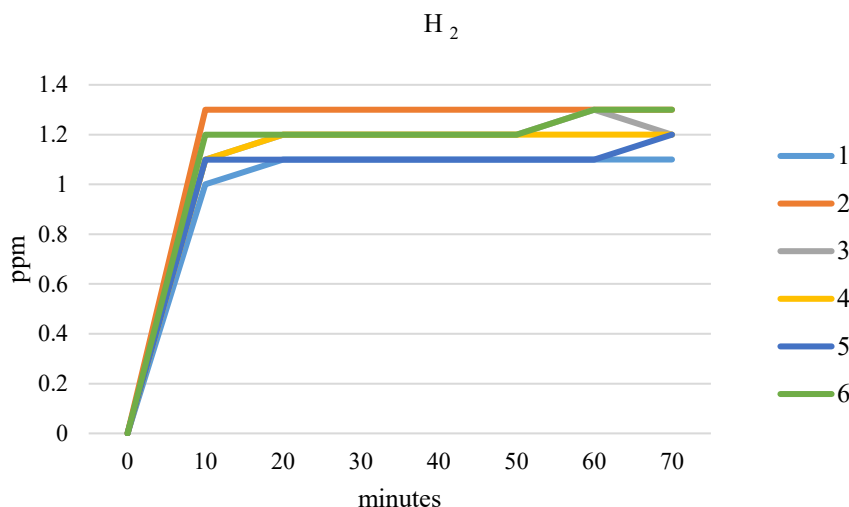
Type water	Drinking				Distilled	Tap	
Sample	1	2	3	4	5	6	
Index	TDS	104±1.5	187±1.3	74±1.1	120±0.6	2±0.3	168±10.1
	H	0	0	0	0	0	0
	ORP	297 ± 9.2	225±16.8	254±22.8	247±14.6	288±7.7	264±39.3
	pH	6.8±0.07	7.7±0.03	7.2±0.04	7.1±0.04	6.6±0.121	7.3±0.06
	$t^\circ$	23.4 ± 0.66	23.0 ±0.40	23.1 ± 0.42	23.3 ±0.24	23.2 ± 0.18	23.1 ±0.76

The amount of particles dissolved in water (total mineralization) in intact samples was different. The highest value of this indicator was recorded in sample 2, the lowest in distilled water.

After 10 minutes of electrolysis, we found that in samples 1 and 3 total mineralization (TM) increased by 5%, in sample 2 it increased by 2%. In distilled water (sample 5), mineralization increased by 50%, and in tap water (sample 4) – by 4%. After 20-minute electrolysis, TM compared to the first period (0-10 minutes) increased in samples 1, 2, 6 (3%, 2% and 1%, respectively), and in samples 3 and 4 TM decreased by 1 and 2%. In sample 5 OM did not change. After 30-minute electrolysis, when compared with the second period (10-20 minutes), TM increased by 1% in samples 1 and 2, and decreased in samples 2 and 4 (by 3 and 2%, respectively). In sample 5 TM did not change. After 40-minute electrolysis, when compared with the third period (20-30 minutes), TM increased in samples 1, 2,3,4 (by 2,1,4,2%), and in samples 5 and 6 the concentration of impurities did not change. After 50-minute electrolysis, when compared with the fourth period (30-40 minutes), TM increased in samples 1.3 by 1%, in sample 4 by 3%, and in sample 6 TM decreased by 1%. In samples 2 and 5, the concentration of impurities did not change. After 60-minute electrolysis, when compared with the fifth period (40-50 minutes), TM decreased in samples 1,2,4 and 6 (by 1,3,2,1%, respectively), in sample 4 by 3%, and in sample 6 TM decreased by 1%. In samples 3 and 5, the concentration of impurities did not change. After 70-minute electrolysis, when compared with the sixth period (50-60 minutes), TM increased in samples 1 and 6 by 4% and 1%, in samples 2 and 3 decreased by 2 and 1%, and did not change in samples 4 and 5. As a result, over all periods of electrolysis, when compared with intact water in samples 1, 3 and 6, TM increased (by 15, 9 and 2%), and in samples 2 and 4 TM decreased by 4 and 3%. In distilled water, TM did not change.

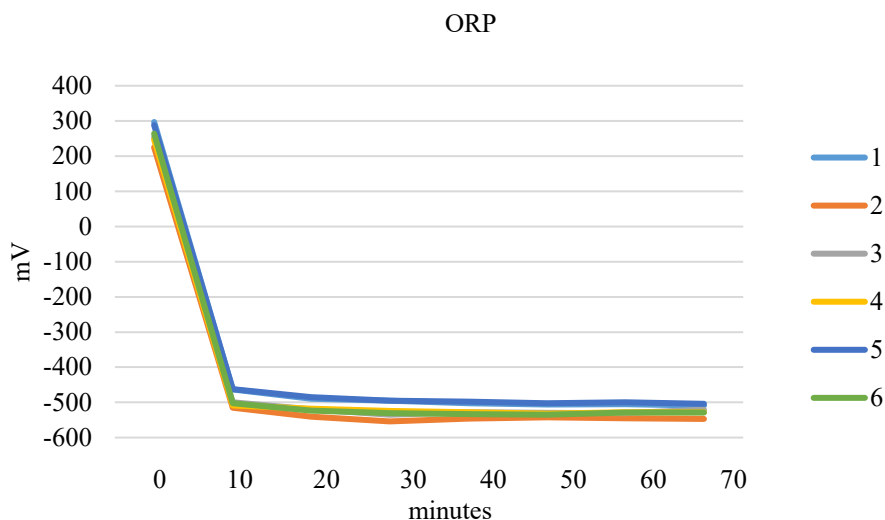
Before starting electrolysis, when analyzing all types of water, the concentration of molecular hydrogen (CMH) was at a value of 0. After 10 minutes of electrolysis and checking water indicators, we found that the concentration of molecular hydrogen in all samples sharply increases to 1-1.3 ppm. The highest concentration of hydrogen molecules was recorded in sample 2 and amounted to 1200% of the original, the lowest - in the first sample (900%). In the remaining samples, the concentration of hydrogen molecules was at the level of 1.0-1.1 ppm.

After 20-minute electrolysis, the CMH, compared with the first period (0-10 minutes), increased in samples 1,2,3 (10%, 9% and 9%, respectively), and in samples 4,5,6, the CMH did not change and amounted to on average 1.1-1.3 ppm. After 30, 40, 50 minutes of electrolysis, when compared with the second, third and fourth periods, the CMH did not change. After 60 minutes of electrolysis, an increase in the CMH was noted in the third and sixth samples (by 8%), in the remaining samples the concentration of hydrogen molecules did not change. After 70-minute electrolysis, the CMH increased only in sample 5 by 9%, in sample 3 this indicator decreased by 8%, and in the remaining samples there were no changes (Figure 1).



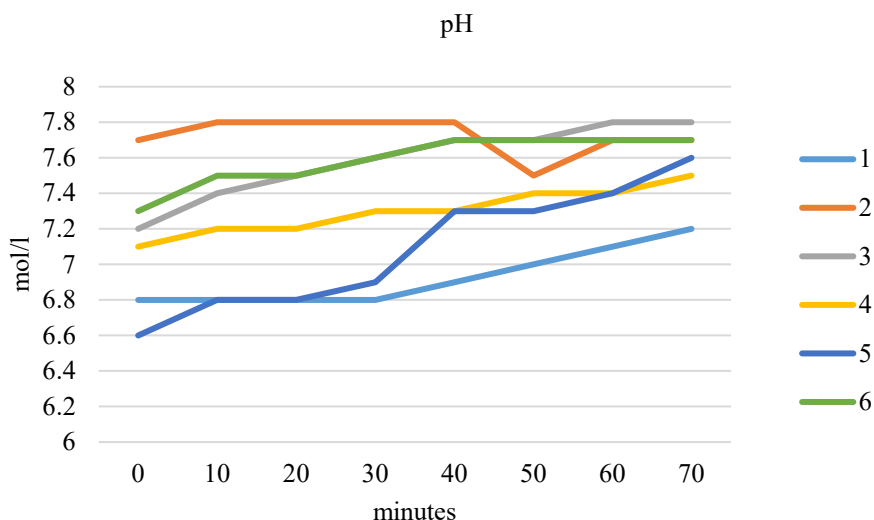
**Fig. 1.** Dynamics of changes in the concentration of molecular hydrogen during different periods of electrolysis

When analyzing the oxidation-reduction potential (ORP), we discovered that during the electrolysis process, water in all studied samples undergoes a transition from the oxidation process to the reduction process. When measuring intact water before electrolysis began, the samples showed that they had oxidized properties. Thus, the highest oxidation rates were found in sample 1 (+297 mV), 5 (+288 mV). Average values are in samples 3 (+254 mV) and 6 (+264 mV). The lowest values were found in the second (+225 mV) and fourth samples (+247 mV). After 10 minutes of electrolysis, we found that the ORP acquired reducing properties in all water samples. Thus, samples 1 and 5 showed the highest recovery rate (-463, -462 mV, respectively), and the lowest - sample 2 (-515 mV). Average values in samples 3, 4, 6 (-500, -509, -502mV). After 20-minute electrolysis, the ORP increased in sample 1 by 6% compared to the first period, in the second and fifth by 5%, in 3 and 6 by 4%, and in sample 4 only by 2%. After 30-minute electrolysis, when compared with the second period, the ORP in samples 1 and 4 increased by 1%, in samples 2,5,6 - by 2%, in sample 3 - by 3%. After 40-minute electrolysis, when compared with the third period (20-30 minutes), the redox potential in samples 1, 4, 5 increased by 1%, in sample 6 it did not change, and in samples 2 and 3 the reduction potential decreased by 1%. After 50-minute electrolysis, when compared with the fourth period (30-40 minutes), the redox potential increased in samples 1,4,5 by 1%, in sample 2 it decreased by 1%, and in samples 3 and 6 the potential did not change. After 60-minute electrolysis, when compared with the fifth period (40-50 minutes), the ORP decreased in samples 4 and 6 by 1%, in sample No. 2 it increased by 1%. In samples 3 and 5, the ORP did not change. After 70-minute electrolysis, when compared with the sixth period (50-60 minutes), the ORP increased in samples 1 and 5 by 1%, in sample No. 3 it decreased by 2%, and in samples 2,4,6 did not change (Figure 2).



**Fig. 2.** Dynamics of changes in the redox potential during different periods of electrolysis

When analyzing the pH value of the studied water samples, we obtained the following results: the lowest pH was observed in samples 1 and 5 (6.8 and 6.6 mol/l), the average in samples 3, 4 and 6 (7.2; 7.1 and 7.3, respectively), high – in sample 2 (7.7 mol/l). After 10 minutes of electrolysis and checking the water parameters, we found that the pH in samples 3, 5 and 6 increased by 3%, in sample 2 it increased by 1%, and in sample 1 did not change. After 20 minutes of electrolysis, the pH increased by 1% in sample 3 compared to the first period, but did not change in the remaining samples. After 30-minute electrolysis, when compared with the second period, the pH increased by 1% in samples 3, 4, 5, 6, and did not change in samples 1 and 2. After 40-minute electrolysis, when compared with the third period, the highest increase in pH was observed in sample 5 (6%), in samples 1, 3 and 6 - by 1%, and in samples 2 and 4 did not change. After 50-minute electrolysis, when compared with the fourth period, the pH in sample 2 decreased by 4%, in samples 1 and 4 it increased by 1%, and in samples 3, 5, 6 did not change. After 60-minute electrolysis, when compared with the fifth period, an increase in pH was noted in the second (by 3%) and by 1% in samples 1, 3 and 5, and in samples 4 and 6 the pH did not change. After 70-minute electrolysis, when compared with the sixth period, pH increased in sample No. 5 by 3%, an increase was also observed in samples 1 and 4 (1%), and in samples 2, 3, 6 there were no changes. In general, at the end of electrolysis, when comparing all the studied samples with intact water, we found that an increase in the hydrogen index was observed in almost all samples, only in sample 2 the hydrogen index did not change, the greatest changes occurred in sample 5 (by 15%), in sample 3 (8%), in samples 1 and 4 (6%) and in sample 6 (5%) (Figure 3).



**Fig. 3.** Dynamics of changes in pH value during different periods of electrolysis

The initial temperature ( $t^\circ$ ) of the studied samples varied in the range of 23.0-23.4 °C. After 10 minutes of electrolysis and checking water parameters, we found that in all samples there was an increase in temperature by 1-3%. In subsequent periods, the water temperature steadily increased by 1-5%. In general, at the end of electrolysis, when comparing all studied samples with intact water, we found that an increase in temperature was observed in almost all samples, the greatest changes occurred in samples 4 (by 15%) and 6 (by 14%), in samples 1 and 3 (by 13%) and in samples 2 and 5 (by 12%).

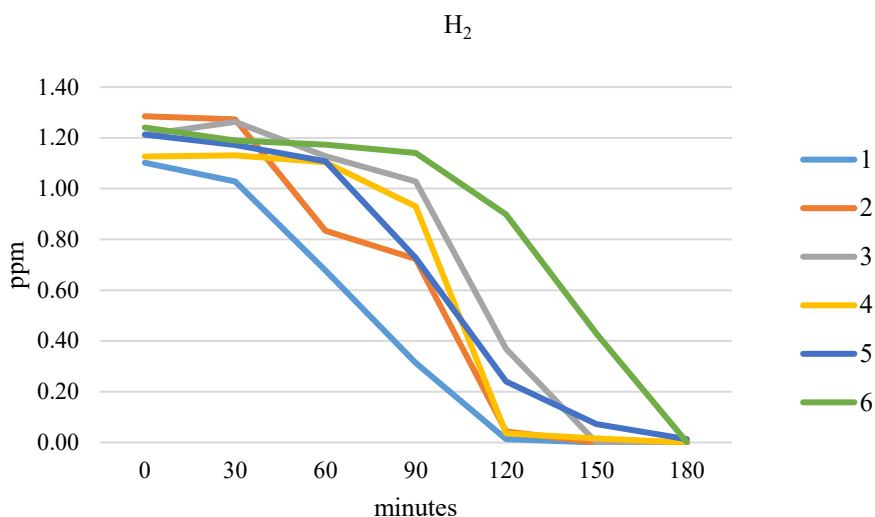
When studying the dynamics of changes in water indicators (TDS, ORP, H, pH,  $t^\circ$ ) in the temporal aspect (30, 60, 90, 120, 150, 180 minutes) as a result of a continuous 30-minute period, we obtained the data presented in Table 2.

**Table 2.** Indicators of different types of water after 30 minutes of electrolysis (volume 1.5 l, n = 3)

Type water	Drinking				Distilled	Tap	
Sample	1	2	3	4	5	6	
Index	TDS	113± 4.41	188± 3.93	78± 1.15	114± 1.33	4± 0.33	171± 6.84
	H	1.10± 0.03	1.29± 0.02	1.21± 0.03	1.13± 0.03	1.21± 0.12	1.24± 0.02
	ORP	-495± 13.2	-554± 7.7	-535± 6.4	-521± 6.0	-493± 5.6	-531± 7.7
	pH	6.83± 0.15	7.78± 0.02	7.57± 0.18	7.30± 0.02	7.58± 0.64	7.58± 0.25
	$t^\circ$	24.3± 0.69	24.8± 0.20	24± 0.42	24.7± 0.43	25.1± 0.46	24.9± 1.07

30 minutes later (I period) after electrolysis and checking the water indicators, we found out that the concentration of molecular hydrogen in all samples begins to decrease. Thus, in the first sample the decrease in  $H_2$  concentration was 7%, in the fifth and sixth samples – 3% and 4%, and in the second and third – 1%. In the fourth sample, the  $H_2$  concentration remained unchanged. After another 30 minutes (60 minutes after the first measurement, period II), the  $H_2$  concentration maintained a downward trend in all samples. Thus, in samples 1 and 2, the concentration decreased by 34% compared to period I and amounted to 0.68 – 0.83 ppm. In samples 3, 4, 5, 6 the decrease was insignificant (6, 2, 5, 1%). After another half hour (90 minutes, period III), the  $H_2$  concentration decreased most in the first sample (54%) compared

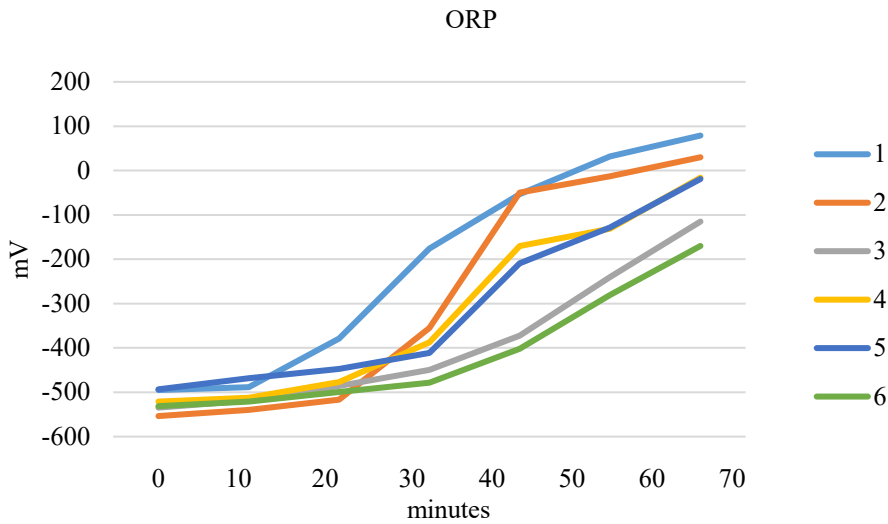
to period II and amounted to 0.31 ppm, in the remaining samples - by 13, 9, 16, 34, 3%. In period IV (120 minutes after electrolysis), when compared with the previous one in samples 1 and 4, a sharp decrease in the concentration of  $H_2$  was recorded by 96% (0.01, 0.04 ppm), in the second by 94% (0.04 ppm). In samples 3 and 5, the decrease in  $H_2$  concentration was 64% and 67% (0.37; 0.24 ppm). In the sixth sample, compared to the third period, the decrease was insignificant (21%, 0.43 ppm). In period V (150 minutes after electrolysis) no molecular hydrogen was detected in samples 1, 2, 3, but in samples 4, 5, 6 the  $H_2$  concentration decreased by 55%, 70%, 52% and amounted to 0.02; 0.07 and 0.43 ppm, respectively. In period VI (180 minutes after electrolysis), molecular hydrogen was not detected in almost all samples, only in sample 5 0.01 ppm was recorded (a decrease compared to period V was 82%) (Figure 4).



**Fig. 4.** Dynamics of changes in the  $H_2$  value of water of various types in time

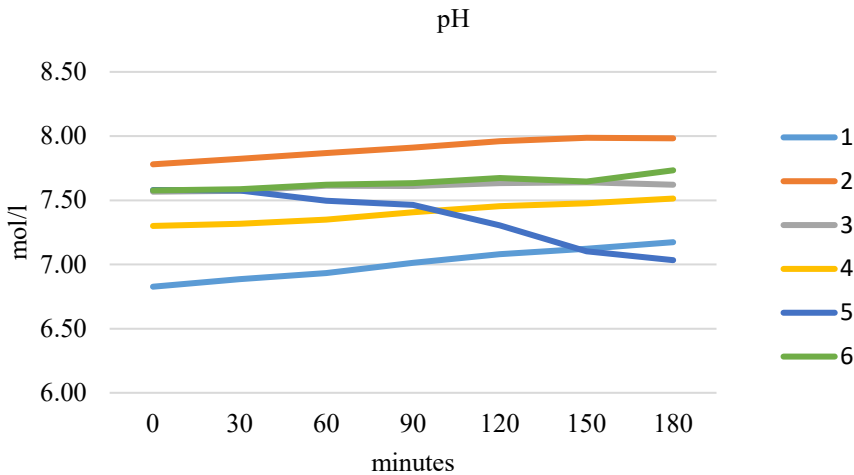
After electrolysis, 30 minutes later (period I), we found that the ORP begins to gradually increase in all samples by 1-5%. For example, the highest values (-489; -468 mV) were in samples 1 and 5, and the lowest (-540, -521; -519 mV) were in samples 2, 6, 3. After another 30 minutes (60 minutes after the first measurement, period II), the ORP charge continued to increase by an average of 4-7%, but in sample 1 the increase was 23% (-379 mV) compared to period I. 90 minutes (III period) after electrolysis ORP in samples 1 and 2 increased by 54 and 31% (-176; -355 mV) compared to period II, the average increase was in sample 4 (19%), and in samples 3, 5, 6 the increase was 4-8%. In period IV (120 minutes after electrolysis), when compared with the previous one, a sharp increase in charge is observed in samples 1, 2, 4, 5 (70, 86, 56, 49%, respectively), and in samples 3 and 6 the increase was insignificant (13, 16%). In period V (150 minutes after electrolysis) in sample 1, water went from the reduction process to the oxidation process with a value of +32 mV. In the remaining samples, the recovery reaction was preserved with absolute values of -13, -240, -131, -128, -281 mV (an increase of 74, 35, 23, 39, 30%, respectively, compared to period IV). When measuring the ORP indicator in period VI (180 minutes after electrolysis), we found that in the second sample water goes into an oxidative reaction with a value of +30 mV, just like in 1 sample (+79 mV). In samples 3 and 6, reduction reactions with values of (-115, -170 mV) are preserved; close to neutral reactions (-16, -19 mV) in samples 4 and 5 (Figure 5). In

general, over the entire period of time (180 minutes after electrolysis), water in all samples gradually passes from reduction processes to oxidation processes.



**Fig. 5.** Dynamics of changes in the redox potential of different types of water in time

When analyzing the pH value 30 minutes after electrolysis, we found that the pH practically did not change in samples 3, 4, 5, 6 (7.57; 7.32; 7.58; 7.59 mol/l), and in samples 1 and 2 increases slightly to 1% with absolute values of 6.89; 7.82 mol/l. In general, in other periods of electrolysis and after 180 minutes, changes are observed towards an increase in the pH value by 1-5% (7.17; 7.98; 7.62; 7.51; 7.73 mol/l). The highest rate was observed in the first sample (5%), the lowest in the third sample (1%). It is worth noting that in sample 5 pH with a value of 7.03 mol/l (-7% compared to water after electrolysis of 7.58 mol/l) tends to increase the number of hydrogen ions (Figure 6).



**Fig. 6.** Dynamics of changes in the pH value of water of various types in time

by 2-6% compared to intact water. Over time, the temperature decreases in each measurement range by 1-3°C. Thus, after 180 minutes, a decrease in water temperature is observed in all samples in the range of 5-8% (22.9-23.1°C).

## 4 Conclusion

As a result of our analysis, we found that at different stages of electrolysis of various types of water, the concentration of molecular hydrogen increases until the second stage (20 minutes) and amounts to 1.1-1.3 ppm, but subsequently this indicator does not change. In terms of hydrogen index, slight shifts occur towards an increase in the range of 1-3% at stage I; at subsequent stages, the increase is generally insignificant. But in distilled water, the hydrogen index at the end of electrolysis increases to 15% with a value of 7.6 mol/l when compared with the initial 6.6 mol/l. In general, electrolysis of all types of water, except distilled, did not affect the acid-base balance. In redox processes, sharp shifts occur towards reduction reactions in the range (-463; -515 mV). In stage II, the recovery potential increases from 4 to 6%; in the subsequent stage, an insignificant increase in reactions is observed. During electrolysis, the temperature increases at all stages within 1-5%, reaching 12-15% of the initial temperature at stage VII before starting electrolysis. When measuring total mineralization, changes due to electrolysis are negligible. Based on the available information, we recommend electrolysis of water for 20-30 minutes to obtain a hydrogen antioxidant, since subsequent steps do not increase the concentration of molecular hydrogen. When studying water after 30 minutes of electrolysis, we found that the stability of hydrogen molecules remained at a maximum level for 30 minutes after electrolysis - the best period of use during this period of time. It is also permissible to use this water in the period from 60 to 90 minutes after electrolysis as a dietary supplement to maintain the body's adaptive capabilities.

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