Fig. 6. (a) Chronoamperograms of gold electroreduction in the solution of 28.98 mg L^{-1} HAuCl$_4$ (pH = 1.5) at different temperatures with the addition of carbon adsorbent; (b) Gold adsorption capacity (mg g^{-1}) as a function of duration of the contact with activated carbon.

Table 2
Gold recovery at different temperatures.

T, K	288	298	308
The adsorption percentage, %	98.92	95.99	97.95
The adsorption capacity q, mg g^{-1}	143	139	142

solution. During electrosorption of gold, there is a decrease in the concentration of gold in the volume of the solution, which can be determined directly by measuring the limiting current. This determines the effectiveness of chronoamperometry in studying the kinetics of the gold sorption process.

Kinetic curves (I-t) of Au^{3+} adsorption were obtained at the constant potential +200 mV corresponding to the limiting current of Au^{3+} ion reduction on a platinum electrode with varying potential-determining ions concentration and temperature (Fig. 6a). The completeness of the gold electroreduction reaction on a platinum electrode during chronoamperometric measurements was ensured by applying a potential of +200 mV to the electrode and a disk electrode rotation rate of 1000 rpm. 1.5 g of sorbent was introduced into the electrolytic cell. As a result, the concentration of gold ions in the electrolyte decreased; there was a decrease in the limiting current of Au^{3+} reduction. The curve (I-t) had a falling form. The residual concentration of Au^{3+} ions in the solution was determined using a flame atomic absorption spectrometer Perkin Elmer AAnalyst 200 (Fig. 6b). As a result, the adsorbent obtained from RH has a sorption degree of 95–98%, a sorption capacity of 139–143 mg g^{-1} at a temperature in the range of 288–308 K (Table 2).

Activated carbon from RH was wrapped with filter paper and then immersed in a thermostatically controlled electrochemical cell with a constant convection. Convection in the cell was provided by a rotating disk electrode. Fig. 6a shows that the limiting diffusion currents of the electroreduction of gold ions decrease with time, which indicates a decrease in the concentration of gold ions into the depth of the solution afterwards by its electrosorption by the adsorbent. This trend persists at temperatures from 288 to 308 K. The exception is the chronoamperogram at temperatures of 308 K with a steep slope. It is also clear that the limiting currents at the initial point are directly proportional to temperature, which once again emphasizes the diffusion nature of the process. It can be seen from Fig. 6a that the slope angles linearly depend weakly on temperature with the exception at 308 K. The linearity of the dependence of current on time at all temperatures is explained by a constant convection rate, in other words, mass transfer of gold

ions. In this case, the supply of the potential of the determining ion to the surface of activated carbon is limited with the convective flow rate (angular velocity of rotation of the disk electrode).

At the end of the experiment, it was revealed that the electrosorption of gold ions occurred only on the surface layer of the wrapped sorbent in filter paper. Free immersion of the sorbent would provide a strong difference in the concentration of gold ions in the electrolyte, which can be recorded by the method of chronoamperometry, however, the contact of the sorbent with the indicator electrode creates noise of the recorded signal (limiting diffusion current). Therefore, the use of a chronoamperogram for free immersion of the sorbent is difficult, and it requires special organization of the experiment to study the kinetics of sorption.

In addition to chronoamperometric measurements, an atomic absorption analysis of the concentration of gold ions after their adsorption was performed. In this case, the sorbent was immersed in the solution in the form of powder and the solution was stirred with a magnetic stirrer at a constant rate of 200 rpm. The adsorption curves representing the concentration of gold ions plotted versus time are shown in Fig. 6b. From the Fig. 6b it can be seen that the change in the concentration of gold decreases exponentially with time (up to 40 min). Further adsorption of gold ions proceeds with a limiting velocity by a characteristic linear dependence. The form of the curve representing the concentration plotted as a function of time weakly depends on time. This once again confirms the statement made earlier about the diffusion nature of this process, since the diffusion coefficient depends only slightly on temperature than the charge transfer rate constant (or the constant of the electrochemical reaction). From this we can conclude that the reaction (1) is reversible.

The SEM and optical images clearly demonstrate that a gold chloride is reduced to metallic gold and deposited on the surface of activated carbon. The smallest gold nanoparticles that could be revealed were 70–200 nm in diameter on the surface of activated RH (Fig. 7a–d). The morphology of activated RH examined using SEM and BET analysis revealed that, the adsorbent represented by carbonized and activated RH is highly porous.

In total, the outstanding characteristics of the resulting activated carbon such as an BET specific surface area equal to 2818 m^2 g^{-1} and the total pore volume of 1.59 cm^3 g^{-1}, along with a high adsorption degree of gold ions equal to 95–98% and sorption capacity of 139–143 mg g^{-1}, allow to declare this material as an effective adsorbent applicable for extraction of noble metals.