Anodic process: $CRH-Red - 3 \rightarrow CRH-Ox$ (2)

where Red and Ox –R-COOH; R-Ph; R-OH; R-NH$_2$ and oxidized forms of carbon groups of the sorbent.

Pesic and Storhok [19] investigated the kinetics of gold (III) bromide complex adsorption and observed that gold is accumulated in its original ionic form on the surface of activated carbon. This phenomenon is different from the gold (III) chloride complex behavior, where adsorption process is accompanied by the reduction of the ions [20].

In recent years, many works have been published on gold adsorption using various biosorbents [21]. However, the literature is still insufficient to cover this research area, and more work and studies are needed in this field to develop other locally available and economical adsorbents. In this research, results showing the possibility of activated carbon application in electroreduction of gold from aqueous solution are presented. The studies were performed with synthesized activated carbon based on RH. The influence of amount of activated carbon used, initial concentration of gold (III) chloride complex ions, temperature was investigated.

2. Experimental details

2.1. Synthesis of the porous carbon and their characterization

The cleaned and dried RH was collected from local farms of Almaty region, Kazakhstan, and subjected for carbonization at 773 K in an argon atmosphere. Carbonized RH was mixed with potassium hydroxide by use the weight proportion of 1:5 (precursor to KOH) and activated at 1123 K under argon atmosphere. The resulting mixture was subjected to washing by distilled water until the neutral pH.

The obtained adsorbents composed of amorphous silica and carbon. Specific surface of carbonized and activated RH was determined by BET method (Brunauer-Emmett-Teller); it was 2818 m^2 g^{-1}, pore specific volume was 1.59 cm^3 g^{-1} and average pore size was within $1.0 \div 2.0$ nm. Measurements were carried out using SORBTOMETR-M device.

The characterization of the sorbents has been carried out by means of the methods such as Raman spectroscopy (NTEGRA Spectra Raman, laser wavelength is 473.0 nm, signal with an area diameter of 80 nm), scanning electron microscopy (SEM, Quanta 3D 200i Dual System, FEI) and the transmission electron microscopy (TEM, JEM-2100) with high stability of high voltage and beam current along with an excellent electro-optical system).

2.2. Electrochemical measurements and atomic absorption spectroscopy

All electrochemical measurements were carried out in a three-electrode cell using an Autolab PGSTAT 302 N galvanostat/potentiostat (Metrohm, the Netherlands). A working electrode with surface area of 0.071 cm^2 was represented by the platinum rotating disk Autolab RDE 80725. A platinum plate was used as an auxiliary electrode, and the silver-chloride electrode (Ag/AgCl) was used as a reference electrode. 0.1 mol L^{-1} potassium chloride solution containing HAuCl$_4$ with a pH of 1.5 was served as an electrolyte. The gold chloride solutions (HAuCl$_4$) with a gold concentration of 7.65; 23.13; 45.34 and 80.79 mg L^{-1} were prepared by dissolution of metallic gold in aqua regia.

In order to study the kinetics of gold (III) chloride complex adsorption the change in concentration of Au^{3+} was analyzed using the atomic absorption spectroscopy (Perkin Elmer AAnalyst 200, USA). Determination of the content of Au^{3+} in the solutions was conducted using a lamp with a wavelength of 242.8 nm.

3. Result and discussion

In order to identify the surface morphological features of synthesized samples, the SEM has been used. Samples have a complex structure. They exhibit a characteristic macrostructure with diameter of 4–22 μm (Fig. 1a). Next, the TEM image of graphene obtained from activated RH is shown in Fig. 1b. Samples have few-layer graphene with defects and inclusions of an amorphous carbon component, but there are sections of layers without defects with a homogeneous surface structure.
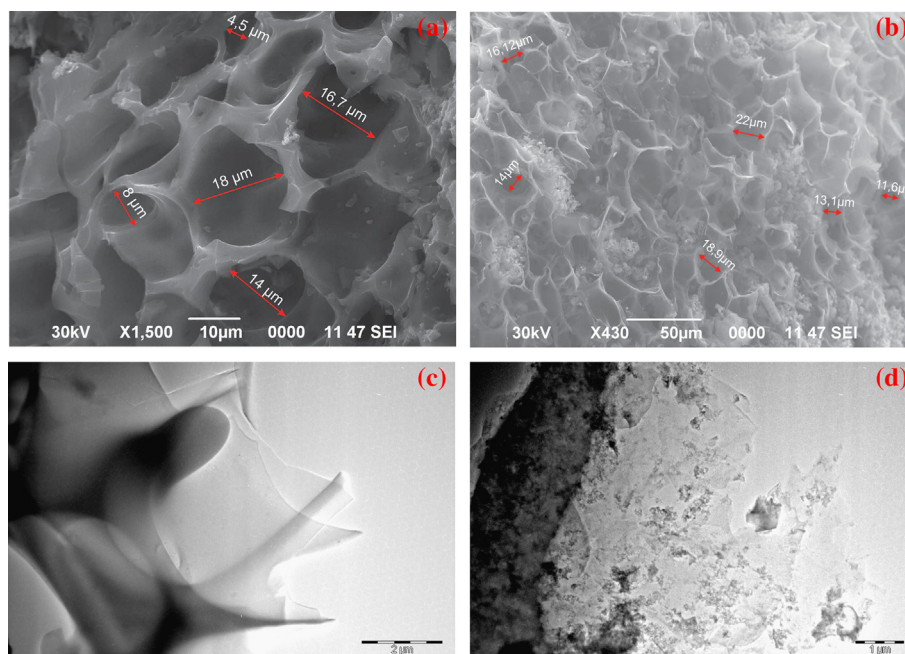

Fig. 1. (a, b) SEM images of carbon from the rice husk; (c, d) TEM images of the graphene layers.