

## Quaternary Alkylammonium and Alkylphosphonium Pertechnetates: Application to Pertechnetate Ion-Selective Electrodes

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Pertechnetate ion-selective PVC membrane electrodes based on quaternary alkylammonium and phosphonium salts (bromides and pertechnetates) were examined. The most favorable ionophore was tetradecyltrimethylammonium bromide. The response function was linear within the concentration range  $10^{-2}$ – $10^{-6}$  mol/L and the slope was 52 mV/pTcO<sub>4</sub>. The detection limit remained at  $5 \cdot 10^{-7}$  mol/L. The selectivity and response time of the electrodes was studied and it was found that the electrodes exhibited high selectivity to TcO<sub>4</sub><sup>-</sup> anion against the main inorganic components of radioactive waste solutions and environmental waters (nitrate, sulfate, chloride and others). The electrodes response was stable over a wide pH range.

### 1. Introduction

Quaternary alkylammonium and phosphonium salts are widely used for preparation of the membranes giving a response to different ions. The selectivity of ion determination depends on hydration energy of ion and on the nature of membrane solvent.<sup>1</sup> With this approach to a creation of new ion-sensitive sensors some electrode membranes for different anions and acidocomplexes determination have been developed.<sup>2-5</sup> But only one pertechnetate selective electrode was described earlier.<sup>6</sup> However, this liquid membrane electrode has not enough high selectivity and contains concentrated radioactive solution ( $10^{-1}$  M KTcO<sub>4</sub>). Thus, it can not be widely used in the analysis of the pertechnetate solutions.

The object of present work is a development and an investigation of new ion-selective electrodes for TcO<sub>4</sub><sup>-</sup> determination.

### 2. Experimental

Tetradecyltrimethylammonium pertechnetate [CH<sub>3</sub>(CH<sub>2</sub>)<sub>13</sub>N(CH<sub>3</sub>)<sub>3</sub>]TcO<sub>4</sub>, tetradecylphosphonium pertechnetate [(C<sub>10</sub>H<sub>21</sub>)<sub>4</sub>P]TcO<sub>4</sub>, and ethyldiphenyldodecylphosphonium pertechnetate [(C<sub>2</sub>H<sub>5</sub>)P(Ph)<sub>2</sub>(C<sub>12</sub>H<sub>25</sub>)]TcO<sub>4</sub> were synthesized by liquid-liquid extraction of Tc-99 from 0.1 mol/L aqueous solution of NaTcO<sub>4</sub> into solution of quaternary ammonium/phosphonium bromide in CH<sub>2</sub>Cl<sub>2</sub>. Properties of these compounds were studied by DTA, IR, Raman spectroscopy and X-ray diffraction.

**Membranes preparation.** The ionophore {[CH<sub>3</sub>(CH<sub>2</sub>)<sub>13</sub>N(CH<sub>3</sub>)<sub>3</sub>]Br (I), [CH<sub>3</sub>(CH<sub>2</sub>)<sub>13</sub>N(CH<sub>3</sub>)<sub>3</sub>]TcO<sub>4</sub> (II), [(C<sub>2</sub>H<sub>5</sub>)P(Ph)<sub>2</sub>(C<sub>12</sub>H<sub>25</sub>)]Br (III), [(C<sub>10</sub>H<sub>21</sub>)<sub>4</sub>P]TcO<sub>4</sub> (IV) or [(C<sub>10</sub>H<sub>21</sub>)<sub>4</sub>P]Br (V)}, plasticizer (o-nitrophenyloctyl ether, Fluka) and high molecular weight polyvinylchloride (Aldrich) were dissolved in the appropriate volume of cyclohexanone and mechanically stirred. All membrane cocktails were cast in glass rings placed on glass plates. Solvent from PVC membrane was allowed to evaporate for a week at room temperature. The thickness of the resulting membranes was about 0.2–0.3 mm.

The electrochemical properties of the electrodes were investigated in the conventional configuration. Small disks were punched from the cast membranes and mounted in electrode

bodies. Electrode structure is shown in Figure 1. Table 1 summarizes the compositions of the membranes and the internal solutions of the pertechnetate-selective electrodes employed in this study.

The external reference electrode was a double-junction Ag/AgCl reference electrode OP-8020 P (Radelkis). The electrochemical potential was measured using pH/ion analyzer OP-300 (Radelkis, Hungary) and Ionix-Alpha ionometric combine.

Potassium pertechnetate solutions in 1 mol/L Li<sub>2</sub>SO<sub>4</sub> were used for the electrode response function determination. The selectivity coefficients were determined by the separate solution method (SSM) using 0.01 mol/L potassium or sodium salts

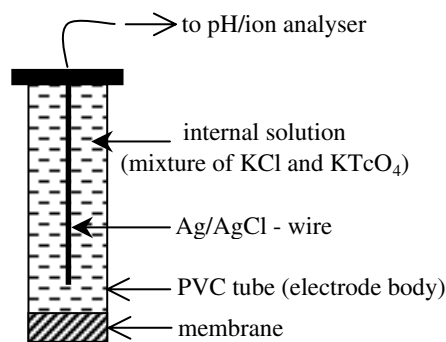


Figure 1. Electrode structure.

TABLE 1: ISEs Composition

No of electrode	Active component (ionophore)	Internal solution composition	
		KCL, M	KTcO <sub>4</sub> , M
1	I	$10^{-5}$	$10^{-6}$
2	I	$10^{-4}$	$10^{-5}$
3	I	$10^{-3}$	$10^{-4}$
4	I	$10^{-2}$	$10^{-3}$
5	III	$10^{-3}$	$10^{-5}$
6	IV	$10^{-3}$	$10^{-3}$
7	IV	$10^{-3}$	$10^{-5}$
8	V	$10^{-3}$	$10^{-3}$
9	V	$10^{-3}$	$10^{-5}$

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of the anions in accordance with the equation

$$\lg K_{\text{TcO}_4^-/\text{anion}}^{\text{pot}} = (E_A - E_{\text{TcO}_4^-})/S + (1 - Z_A/Z_{\text{TcO}_4^-}) \cdot \lg[A] \quad [7],$$

where  $K_{\text{TcO}_4^-/\text{anion}}^{\text{pot}}$  is the selectivity coefficient,  $E_{\text{TcO}_4^-}$  is the potential measured in 0.01 mol/L solution of  $\text{KTcO}_4$ ,  $E_A$  is the potential measured in 0.01 mol/L solution of the interfering anion,  $S$  is the slope of the response function,  $Z_{\text{TcO}_4^-}$  and  $Z_A$  are the charges of the pertechnetate anion and the interfering anion respectively,  $[A]$  is the concentration of the interfering anion.

The influence of pH on the electrode response was examined by adjusting the pH of the measured solution with 1 mol/L sodium hydroxide and hydrochloric acid. Potassium chloride aqueous solution (1 mol/L) was used as a background electrolyte.

### 3. Results and Discussion

The only pertechnetate selective electrode was described earlier.<sup>7</sup> It is the liquid membrane electrode based on **IV**. However, this electrode has not enough high selectivity and contains concentrated radioactive solution ( $10^{-1}$  M  $\text{KTcO}_4$ ). Therefore, it can not be widely used in the analysis of the pertechnetate solutions.

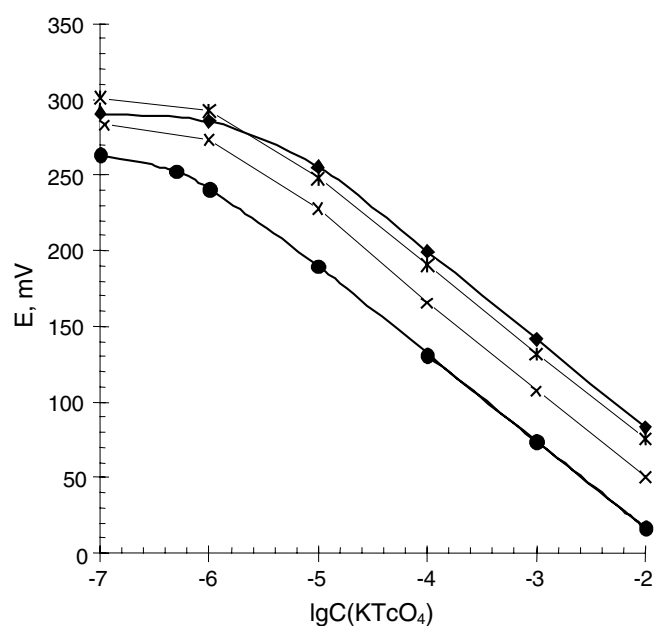
We have developed new  $\text{TcO}_4^-$  ISEs based on quaternary ammonia and phosphonia ionites with low radioactive internal solution. The response functions for electrodes based on **I** with different solution composition are shown in Figure 2. For all these electrodes response function is linear in the range  $10^{-6}$ – $10^{-2}$  mol/L  $\text{KTcO}_4$  with the slope equal to  $59 \pm 2$  mV/pTc at 25 °C. The concentration of  $\text{KTcO}_4$  in the internal solution has no marked influence on response function as well as on selectivity [Figure 2 (electrodes No 1–4); Figure 3 (electrodes No 1, 2)] but addition of pertechnetate into the internal solution is necessary in order that  $\text{TcO}_4^-$ -ISEs work stable. Thus, low radioactive diluted pertechnetate solutions ( $10^{-5}$ – $10^{-6}$  mol/L) can be used in the  $\text{TcO}_4^-$  ISEs.

The electrodes **1–4** are workable in the wide range of pH – from 0.5 to 13 (see Figure 4). The electrodes response time is 3–5 min for diluted pertechnetate solutions and less than 1 min for concentrated solutions. Almost the same results have been obtained with tetradecyltrimethylammonium pertechnetate (**II**) and, therefore, it is possible to apply non-radioactive membranes in the  $\text{TcO}_4^-$ -ISEs.

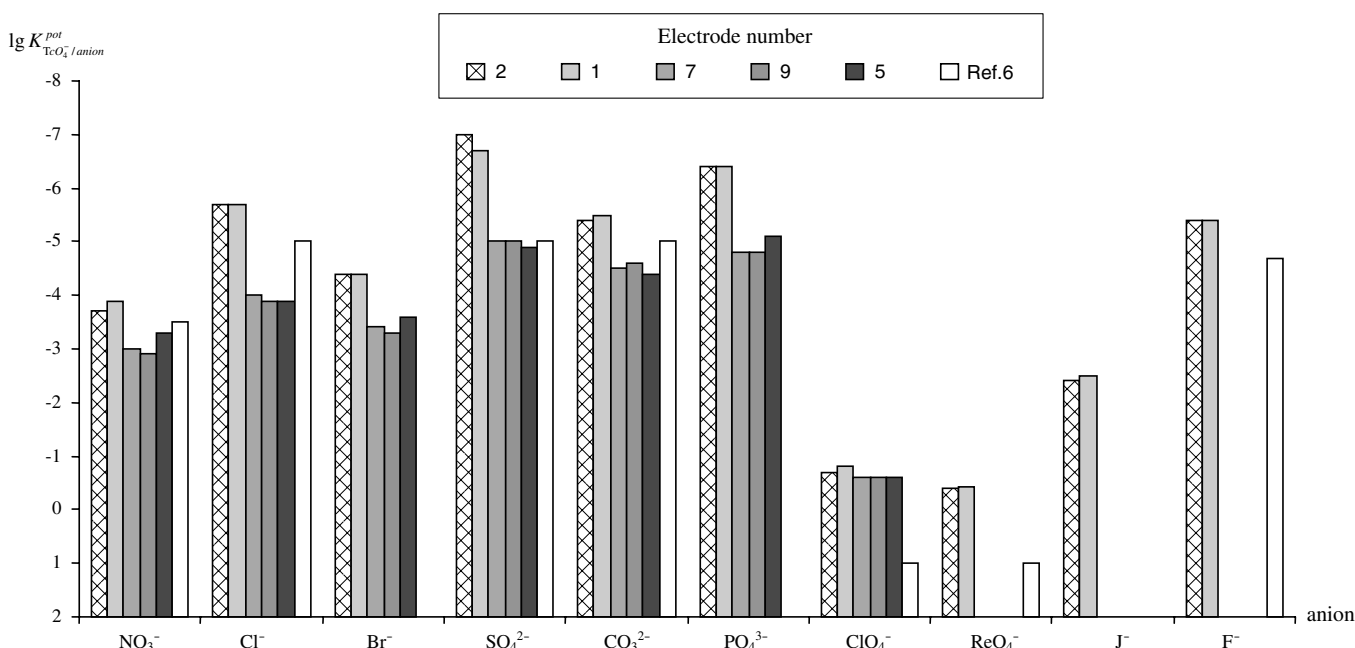
The response function for the electrodes based on quater-

nary alkylphosphonium salts is also linear in the range  $10^{-6}$ – $10^{-2}$  mol/L  $\text{KTcO}_4^-$ , with the slope equal to  $63 \pm 2$  mV/pTc at 25 °C (Figure 5). Electrodes electroanalytical characteristics remain stable in the range of pH from 1 to 13 (Figure 6). The electrodes response time is almost the same as for alkylammonium based ISEs.

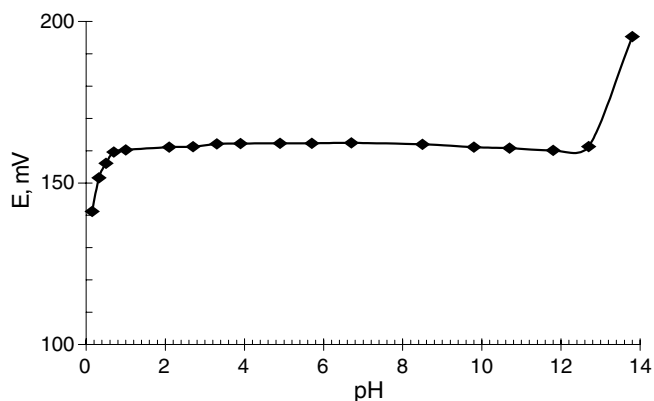
High potentiometric selectivity to  $\text{TcO}_4^-$  of the new ISEs against several important anions was found for all the ISEs developed (selectivity coefficients are in the range  $10^{-4}$ – $10^{-7}$  (see Figure 3). It means that  $\text{TcO}_4^-$  can be determined in the presence of interfering anions with the concentrations of  $10^4$ – $10^7$  times higher than one of  $\text{TcO}_4^-$ ). The ISEs have the highest selectivity of Tc-determination in the phosphates, sulfates and chlorides solutions. These results are of importance: phosphates are the main component of solutions proposed to Tc-stripping from anion-exchange resins used in REPA process. Sulfates are the salt base of Tc-electrodeposition solutions for Tc-electroplating. And large amount of chlorides is contained in the radioactive wastes of pyrochemical reprocessing of spent



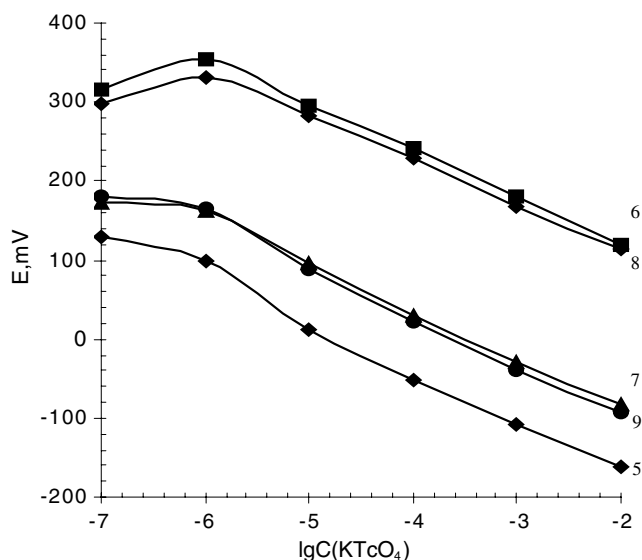
**Figure 2.** Electrode response function for ISEs **1–4**. ●–**1**; ×–**2**; ♦–**3**; ◆–**4**. The numbers of electrodes follow the corresponding numbers in table 1.



**Figure 3.** Potentiometric selectivity coefficients for some of  $\text{TcO}_4^-$ -ISEs developed to compare with the electrode described in [7].



**Figure 4.** Influence of pH on the electrode response function (ISE No 1). ( $10^{-4}$  mol/L  $\text{KTcO}_4$  in  $\text{HCl/KCl/KOH}$  solutions, background electrolyte – 1 mol/L  $\text{KCl}$ ).



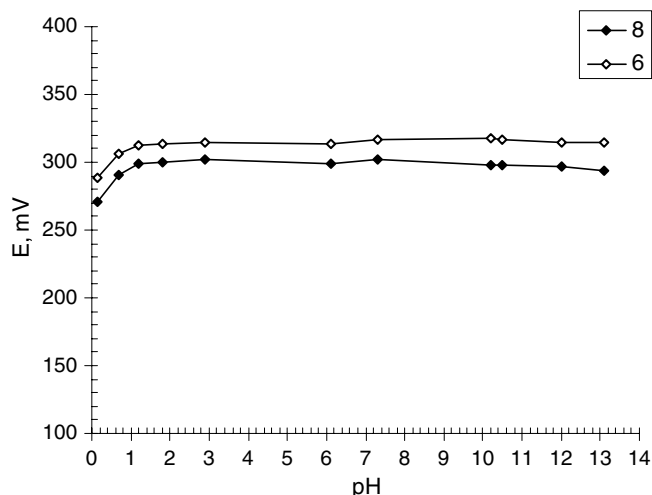
**Figure 5.** Electrode response function for ISEs 5–9.

nuclear fuel. The ISEs selectivity against  $\text{NO}_3^-$  anions is lower but with the electrodes 1 and 2 it is possible to determine Tc in some back extraction and wasting nitric acid solutions of improved PUREX.

The selectivity of alkylammonium ISEs is slightly better than those of alkylphosphonium but all the new Tc-ISEs have better characteristics compared to earlier proposed ISE with liquid membrane<sup>6</sup> (see Figure 3). Studies of some new Tc-ISE are in progress.

#### 4. Conclusion

The electrodes proposed do not contain high radioactive solutions and possess high selectivity to  $\text{TcO}_4^-$  against to the



**Figure 6.** Influence of pH on the electrode response function (ISE No 6, 8). ( $10^{-4}$  mol/L  $\text{KTcO}_4$  in  $\text{HCl/KCl/KOH}$  solutions, background electrolyte – 1 mol/L  $\text{KCl}$ ).

main inorganic components of radioactive waste solutions and environmental waters (nitrate, sulfate, chloride and others) and, therefore, they can be applied to the analyses of Tc in some kinds of technological solutions formed in the reprocessing of the spent nuclear fuel.

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