

CARBON ELECTRODES FOR THE ELECTROREDUCTION OF AIR OXYGEN

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Electrochemical properties of thin electrodes, based on the combination silver-active carbon-teflon, were studied. Attention was paid to the influence of the teflon and silver contents in the active layer, to the thickness of the active layer, and to the pressure and temperature employed in preparing the electrodes. A special attention was directed to the alkaline electrolyte concentration and to the structure of the teflon gas layer. The experimental data obtained were employed to formulate a model conception describing the function of an electrode, operating without overpressure or forced air stream (air-breathing electrode). By this model, the particles of teflon form a gas feeding system, the particles of active carbon play the role of a catalyst support and electrolyte carrier.

The research and development of high performance oxygen electrodes has, in recent years, centered upon solving the problem of light-weight electrodes which would be prepared by a relatively simple technology and which would be capable of long-lived operation with a minimum of auxiliary equipment (external heaters, pumps, manostats, etc.). This is also the reason why the technology of sintering metal powders has in many instances lost ground to the procedure of simply sandwiching the powdered catalyst between a current collector and an electrolyte carrier¹. Another promising type are electrodes operating on air oxygen without overpressure or forced air stream²⁻⁵. In this region, the research of electrodes consisting of catalyst powders⁶ or catalyst carrying supports, bonded with thermoplastic resins, seems to be the most advanced. Especially the latter type of electrodes is most suitable for the economy in the catalyst loading. Another advantage of the catalyst-teflon type electrodes is that they easily withstand acid media which was a further incentive for research in this direction.

Electrodes bonded with thermoplastic materials are in principle of the semi-wetted type, their performance being controlled by the difference in the contact angles of the catalyst and its support (highly hydrophilic materials) on the one hand, and the wetproofing agent (highly hydrophobic material) on the other hand. On the basis of the results available so far, these electrodes may be classified into two groups: a) elec-

trodes with a time stable position of the three-phase boundary (fixed-zone)⁷; b) electrodes with an advancing three-phase boundary.

Electrodes which will be the subject of the present paper are part of the first group, electrodes belonging to the second group have already been discussed⁸⁻¹⁰.

EXPERIMENTAL

The carbon electrode consists of two layers: one, the gas layer, faces the gas space of the electrode holder, the other, the active layer, is in contact with the electrolyte where it also carries a current collector. The *active layer* is a mixture of a silver catalyst on a carbon support and of teflon. The catalyst support is a finely ground active carbon. The mode of depositing the catalyst has already been described¹¹. The *gas layer* is formed by a thin teflon foil. The electrodes were prepared by pressing and sintering in an inert atmosphere. The finished electrode is a disc of a diameter of 31 mm and of cca 1 mm thickness.

The electrochemical measurements were carried out mostly in a half-cell arrangement. The electrode was held in the test vessel with the aid of a lock nut and a gasket ring. The potential was measured against a Hg/HgO reference electrode in the same electrolyte.

The electrodes were tested at an overpressure of 15 cm H₂O and a forced oxygen or air stream (streaming overpressure electrodes, henceafter referred to as S.O.) or as "air-breathing" electrodes, *i.e.* they operated without overpressure or forced gas stream. (These electrodes will further be referred to as A.B. electrodes.)

The course of polarization curves was characterized by the so called differential specific polarization resistance (R_{dif}). This value is the slope of the linear portion of the appropriate polarization curve. The current density at which the increase in the cathodic load brings about an appreciable deviation from the linear course of the curve, is denoted by the limiting current density (i_L).

The measurements of the specific resistance of the active layer alone (without the current collector and the gas layer) were made in a special perspex glass device. The test compacts were made of 1 g of the active mixture and pressed under 0.5 t/cm². The compact was then placed into a cylindrical opening in the device where it was pressed against two opposite current contacts of the form of segments of a circle. After connecting the contacts to a $d-c$ source, a current whose magnitude could be regulated, was passing through the carbon layer. With the aid of two brass spring contacts the voltage drop was determined and the resistance was then calculated from the thickness of the compact, the passing current, and the voltage drop.

RESULTS AND DISCUSSION

Initially, all electrochemical measurements were made on S.O. electrodes, as they enable to control the amount of oxygen, pure or in air, led to the electrode; aside from that, the employed overpressure helps to prevent the possible penetration of the electrolyte to the gas side of the electrode. The S.O. electrodes may, therefore, be considered as test electrodes for determining the individual properties taking part in the resultant electrochemical activity of the electrodes and in their time stability. The term electrochemical activity of the electrode in the present paper stands for the time stable potential value of the electrode at a constant current load (mostly 25 to 30 mA/cm² at ambient temperature).

Later, the experiments were made mostly on A. B. electrodes and aimed at the following problems: 1. The influence of the teflon and silver contents in the active layer; 2. the influence of the concentration and composition of the alkaline electrolyte and the mode of its application (free electrolyte or held in a porous matrix); 3. the influence of the active layer thickness and the magnitude of the pressing pressure employed; 4. the influence of the sintering temperature; 5. the influence of the porous structure of the gas layer.

When starting experimenting with S. O. electrodes, it was not yet unanimously decided whether their classification as semihydrophobic fixed-zone electrodes was justified. For this reason the content of teflon in the active layer was held at a maximum, to ensure a time-stable electrochemical activity. The polarization curves obtained suggested a maximum quantity of teflon to be 40–45%. In the course of life tests of electrodes containing 20–45% of teflon in the active layer, the evidence of the time dependence of the electrochemical activity on the teflon content was however, not conclusive. It was, therefore, necessary to direct the attention to the structure of the electrodes in order to elucidate whether and to what extent the teflon in the active layer was functioning as a wetproofing and/or binding agent¹².

Structural measurements¹² imply that the particles of teflon in the active layer are mostly enclosed in the intergranular voids among carbon grains which means that the porosity of the individual carbon grains proper is not affected by the presence of a larger quantity of teflon. This, however, greatly limits the wetproofing role of these particles, leaving to them almost exclusively the role of a binder. The teflon

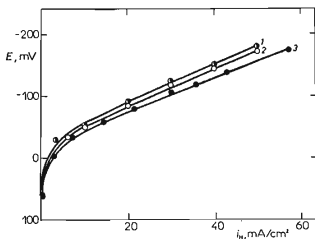


FIG. 1

Polarization Curves of A.B. Electrodes with an Increasing Amount of Teflon in the Active Layer

Teflon foil A, active carbon with 15% Ag, 7M-KOH. 1 35% PTFE; 2 25% PTFE; 3 15% PTFE.

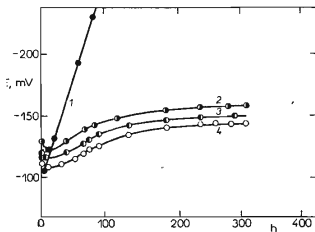


FIG. 2

Dependence Time-Potential of A.B. Electrodes with an Increasing Quantity of Teflon in the Active Layer at 30 mA/cm²

Teflon foil A, active carbon with 15% Ag, 7M-KOH. 1 15% PTFE; 2 25% PTFE; 3 30% PTFE; 4 35% PTFE.

content was, therefore, gradually decreased to find its optimum value. Galvanostatic measurements on S.O. electrodes showed an optimum behaviour of electrodes containing between 20–30% of teflon. Electrodes containing 15% of teflon had a considerably good initial activity (Fig. 1), but their life-time was low (Fig. 2). Electrodes with 35m of teflon exhibited already a higher polarization; this may be explained by the lower specific conductivity of the active layer and by the unfavourable ratio between the teflon particle voids and the pore volume in the active carbon grains, as will in detail be discussed later.

Another property, important for the performance of the electrode, is the content of silver in the active layer. It has previously been confirmed by electrochemical and specific resistance measurements that its presence was indispensable.

Due to the fact that the teflon particles are deposited in the voids among the active carbon grains, it may be expected that the number of contacts among carbon grains, determining the resistance of the active layer, will decrease after admixing teflon, and the resistance will rise. A further parameter influencing directly the contact resistance between individual grains and thus the resultant overall resistance is the chemical nature of the carbon grains. This assumption was confirmed by measuring the specific resistance of the active layer (Fig. 3).

It will be seen in Fig. 3 that the specific resistance of the layer may be greatly influenced by the sintering process on the one hand, and by the quantity of the silver deposited on the carbon surface on the other hand. The effect of the sintering process, especially at temperatures approaching the melting temperature of teflon (c. 320°C),

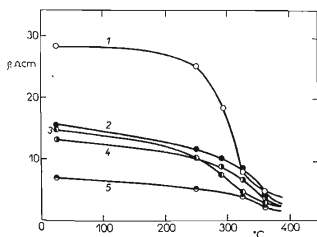


FIG. 3

Dependence of Specific Resistance of the Active Layer on the Sintering Temperature, Silver and Teflon Contents

1 40 % PTFE; 2 7% Ag + 40% PTFE; 3 7% Ag + 30% PTFE; 4 7% Ag + 25% PTFE; 5 15% Ag + 25% PTFE.

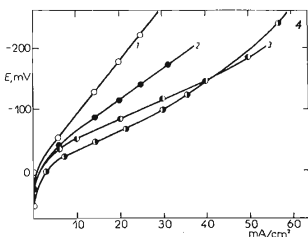


FIG. 4

Polarization Curves of A.B. Electrodes with an Increasing Quantity of Ag in the Active Layer

Teflon foil A, 25% teflon in the active layer, 7M-KOH. 1 0% Ag; 2 7% Ag; 3 15% Ag; 4 21% Ag.

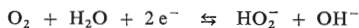
is due to the partial melting of some of the teflon grains which brings about an increase in the number of carbon contacts. A silver coating on carbon depresses, however, the contact resistance to such an extent that an increase in the number of contacting sites during the sintering process is no longer of primary importance.

This concept was confirmed by investigations of the influence of the sintering temperature, as will be discussed later. It should furthermore be noted that the teflon bonded active layers exhibit a specific resistance which is by an order of magnitude higher than that of carbon electrodes with an advancing three-phase boundary. For this reason a current collector proved to be requisite, aside from its being beneficial for the electrode strength.

The economy of the cell calls for a decrease in the silver catalyst loading in the active layer to a minimum value. This may be achieved either by decreasing the amount of silver deposited on the carbon surface or else by lowering the quantity of the active mixture in the electrode. Fig. 4 depicts the polarization curves of A.B. electrodes containing varying quantities of deposited silver, the quantity of the active substance being kept equal (70 mg/cm^2). As will be observed, an increase in the silver content above 15% (the weight of the mixture active carbon-silver equals 100%) does not lead to an appreciable improvement in the electrochemical performance, the activity being controlled by transport phenomena. Further experiments were, therefore, limited to electrodes containing approximately 7 mg of silver per cm^2 of the electrode surface.

A vital point which was clarified in the course of the initial tests made on the S.O. electrodes, was the problem of the effect of the alkaline electrolyte concentration. Life tests on S.O. electrodes were carried out in 7M and 12M-KOH at 25 mA/cm^2 current load. A typical time-potential curve of S.O. electrodes under these conditions will be found in Fig. 5. In the course of the life tests, air was fed to the electrodes instead of oxygen in regular time intervals, and the corresponding potential change was followed. This potential change may to a certain extent be taken as a reflection of the conditions under which air oxygen diffuses to, and inert nitrogen from, the reaction site the electrode.

Let us assume that the reduction of oxygen follows the scheme proposed by Berl¹³:



in that case the electrode potential is given by the equation:

$$E_{\text{O}_2/\text{HO}_2^-, \text{OH}^-} = -76 - 29.5 \log \frac{a_{\text{OH}^-} \cdot a_{\text{HO}_2^-}}{p_{\text{O}_2} \cdot a_{\text{H}_2\text{O}}}$$

The change in the potential, following a change of one decade of the pressure, should theoretically amount to 29.5 mV. In several cases this value was actually obtained¹⁴⁻¹⁷. An increase in the current load leads, however, to an increase in the potential difference^{18,19}; this is explained by the increased influence of the concentration polarization caused by the insufficient access of oxygen to the reaction sites.

During the initial periods of the life-tests on S.O. electrodes, a potential change, following the replacement of air by pure oxygen, amounted to c. 40 mV (the theoretical value was 20 mV). Later, the potential change increased, especially in 12M-KOH. This increase, however, was partly due to a drop in temperature (to c. 8°C) brought about by a failure of a thermostat within the 1100–1200 hours life period. Electrodes operating in 12M-KOH did not withstand this temperature drop and their potential drifted up to the potential of hydrogen evolution. The increase of the temperature to the previous level made the electrodes operating in 7M-KOH capable of further performance, their potential did, however, not fully recover.

As was later shown by experiments made on A.B. electrodes, the reason for these changes was the combined influence of the highly concentrated alkaline electrolyte and its low temperature. A blocking effect (in more detail described below), occurring in the pores of the electrode, was the cause of an inhibited transport of air oxygen,

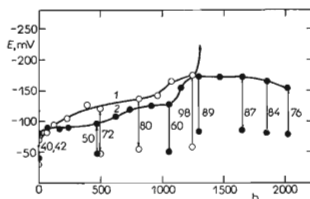


FIG. 5

Dependence Time-Potential of S.O. Electrodes at Varying Concentration of Alkaline Electrolyte $i_L = 25 \text{ mA/cm}^2$; teflon foil A, active carbon with 15% Ag + 25% teflon. 1 12M-KOH; 2 7M-KOH.

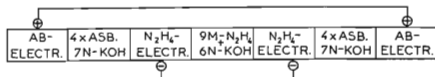


FIG. 6

Schematic Design of the Hydrazine Cell

although when fed with pure oxygen, the electrodes were operating up to 1100 hours without deterioration. If, however, the blocking effect surpassed a critical limit, the insufficient transport facilities were apparent even when feeding pure oxygen.

It was shown by tests made on S.O. electrodes that the transport phenomena were of a vital importance not only in the access of oxygen and removal of inert nitrogen in the gas space of the cathode, but also in the adjacent alkaline electrolyte and especially in the electrolyte anchored in the porous system of the active layer (henceafter referred to as catholyte).

In all types of alkaline power sources containing an air cathode, hydroxyl ions are formed in the catholyte at the expense of water molecules; aside from that the catholyte is in a permanent contact with carbon dioxide contained in the air. A disturbance in the concentration equilibrium of the catholyte may, therefore, easily occur as a consequence of an elevated current load, or an inhibited exchange of the hydroxyl ions and water molecules between the catholyte and the bulk electrolyte, caused by various membranes²⁰⁻²², immobilized electrolytes, unfavourable pore size distribution, or by a combination of these. A sensitive response to these effects may be expected from cathodes operating in a halfcell arrangement; the processes taking place at the anode are in this case a mirror reflection of the processes occurring at the cathode, and consequently no excess water is formed at the anode (as it is the case in complete O_2-H_2 cells). The increase in the alkalinity of the catholyte brings about a decrease in the solubility of oxygen, but it may eventually produce the formation of a solid hydroxide, and in the case of air cathodes of an alkaline carbonate. A direct consequence then is at first an inhibited access of oxygen to the reaction zone and later a complete blocking of the active sites. These phenomena may prove critical especially at temperatures below ambient.

In view of the aforementioned reasons, further experiments were made on A.B. electrodes in electrolytes containing a varying quantity of water. The following electrolytes were employed: 1. 7 - 13M-KOH; 2. KOH + K_2CO_3 ; 3. NaOH; 4. KOH + HCOOK; 5. KOH + asbestos.

Tests in 1. and 2. confirmed that A.B. electrodes could operate over long periods at temperatures above 20°C in potassium electrolytes containing more than 760 g H_2O per liter (the quantity of water necessary for preparing the electrolyte) at a current density of 30 mA/cm². This concentration corresponds to approximately 9.3M-KOH. It may be of interest that the same applies for electrolytes combining KOH + K_2CO_3 .

Less favourable is the situation when employing sodium hydroxide, where a steady state operation for at least 24 hours proved impossible, even when 4M-NaOH containing only 990 g H_2O /l was used. This fact also testifies to the inhibiting influence of the carbonate layer, caused by the low solubility of the sodium carbonate as compared to the potassium carbonate (110 g K_2CO_3 and 26.1 g $Na_2CO_3 \cdot H_2O$, respectively, in 100 ml H_2O at 20°C).

It will be of interest that a gradual recovery of the electrode potential, due to a probable dissolution of the blocking layer, was observed in electrodes tested in 1. and 2. if the test was interrupted before a steady potential shift toward the hydrogen evolution potential set in, and if at this point the electrolyte was diluted to contain above 760 g H₂O/l. Electrodes blocked to a greater extent were recovered only after a long-term treatment with distilled water.

The tests in 4. were made in a laboratory cell formate – air, designed to contain the A.B. electrode in the side wall. Electrodes of a 7 cm² surface were tested first in 6M-KOH + 6.5M-HCOOK²⁰ containing approximately 230 g H₂O/l. The content of water being far below the critical value quoted, the potential of the air cathode exhibited at 20 mA/cm² a steady shift towards the cathodic region already during the first hours of operation. After two hours the test was interrupted and the electrolyte exchanged for a new electrolyte composed of 5N-KOH + 2.8M-HCOOK, containing c. 770 g H₂O/l. At a 30 mA/cm² load the electrode performance was completely stationary.

To determine the influence of an asbestos membrane on the behaviour of the A.B. electrode, a laboratory "chemically rechargeable" hydrazine–air cell was designed (see Fig. 6). The cell operated on hydrazine and air and contained two A.B. electrodes mounted in the side walls of the vessel. At 30 mA/cm², a pronounced shift of the cathodic potential to more negative values appeared already after four hours of operation in the first cycle, indicating that the asbestos membrane promoted the formation of a blocking layer, even if 7M-KOH was employed. To determine the part the carbonate layer plays in the overall blocking effect, the gas layers of both A.B. electrodes were protected by a layer, c. 8 mm thick, of a mixture of NaOH + Ca(OH)₂. In this way the entering air was purged of CO₂, which resulted in a steady-state operation of the air electrodes which persisted over several working cycles of the cell. A mention should be made, however, that the potential of the A.B. electrodes was by approximately 150 mV more negative than that of electrodes operating in a free electrolyte. This shift may be due to a concentration gradient across the asbestos layer or possibly to the presence of a certain quantity of hydrazine in the catholyte²¹.

TABLE I

Composition of the Active Layer in the Three Groups of Electrodes

Electrode type	Quantity, mg/cm ²		
	active carbon	teflon	silver
"thin"	31.9	12.5	5.6
"medium"	63.8	25.0	11.2
"thick"	100.0	39.3	17.6

A very important property of A.B. electrodes is the thickness and consequently the quantity of the active substance. The quantity of the active substance is decisive for the consumption of the catalyst; the thickness of the active layer further influences the overall resistance of the layer and the transport phenomena in the catholyte. The influence of the thickness of the active layer was followed in three groups of electrodes whose active layers were of equal composition and were prepared by pressing with an equal pressure. The only difference was in the amount of the active substance. The composition of the substance is given in Table I.

Attention was focused on the R_{dif} value and its time stability, and on the i_L value. Immediately after loading, the effect of the thickness of the active layer on the R_{dif} was not large but it increased with time, as will be observed from the values of R_{dif} ($\Omega \text{ cm}^2$) quoted below: the former value stands for electrodes immediately after loading, the latter for electrodes after 190 hours of operation, both at 30 mA/cm^2 current load. "Thin" 0.34, 0.46; "medium" 0.37, 0.59; "thick" 0.39, 0.70.

The initial value of i_L of all the electrodes was c. 40 mA/cm^2 irrespective of the thickness of the active layer, probably as a consequence of the inhibiting effect of the gas layer. After 190 hours of operation at 30 mA/cm^2 , a differentiation however appeared from one group to the next (see Fig. 7). An increase in the thickness of the active layer brings about an increase in the ohmic polarization and the transport in the catholyte is more difficult. This results in a rise in the concentration of KOH and K_2CO_3 which again produces an inhibition of the transport of the air oxygen.

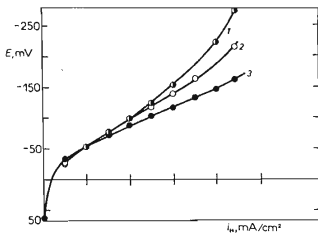


FIG. 7

Polarization Curves of A.B. Electrodes with Different Active Layer Thickness, after 180 Hours of Operation at 30 mA/cm^2

Teflon foil C, active carbon with 15% Ag + 25% teflon, 7M-KOH. Electrodes: 1 "thick"; 2 "medium"; 3 "thin"; current density readings from 10–50 mA/cm^2 .

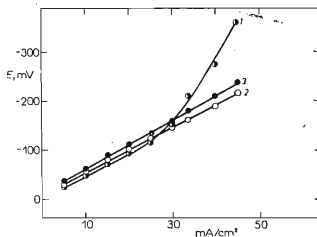


FIG. 8

Polarization Curves of A.B. Electrodes Pressed with Increasing Pressures, after 160 Hours of Operation at 30 mA/cm^2

Teflon foil C, active carbon with 15% Ag + 25% teflon, 7M-KOH. 1 0.85t/cm²; 2 0.55t/cm²; 3 0.3t/cm².

The same explanation applies to the potential time change of the described electrodes, found in the period 50–190 hours of operation at 30 mA/cm²: “thin” 71 μV/h; “medium” 79 μV/h; “thick” 179 μV/h.

To assess the effect of the pressing pressure employed in preparing the electrodes on the electrochemical properties, a series of electrodes was prepared using pressures 0.30, 0.55, and 0.85 t/cm². From the polarization curves obtained on these electrodes, the following values of R_{dif} were read off: 0.55, 0.45, and 0.41 Ω cm², respectively. It was apparent that a higher pressing pressure was favourable for the R_{dif} value, probably on account of a decrease in the specific resistance of the active layer. Polarization curves of electrodes pressed with 0.30 and 0.55 t/cm² show an i_L value of 40 mA/cm² which is typical for electrodes with a low porosity teflon foil (see below). Polarization curves of electrodes pressed with 0.85 t/cm² show an i_L c. 30 mA/cm²; the difference between these two values increased with time as will be seen from Fig. 8. The increase may be due to the fact that the porosity of the electrodes pressed with 0.85 t/cm² is so low that the transport of the catholyte is inhibited and the function of the electrode is thus electrolyte transport controlled, similarly as it is in the case of the asbestos membrane. On account of this, the transport phenomena in the gas layer are also affected. The time dependence of the potential of A.B. electrodes operating at constant current also testifies to the negative influence of the low porosity of the active layer (Fig. 9).

In the course of the A.B. electrode tests, the amount of the silver catalyst was eventually set down to 15%. To determine whether and to what extent the sintering

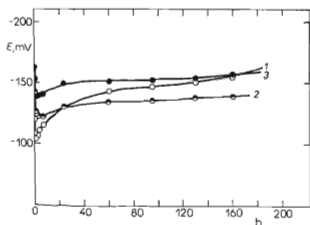


FIG. 9

Dependence Time-Potential of A.B. Electrodes Pressed with Increasing Pressures at 30 mA/cm²

Teflon foil C, active carbon with 15% Ag + 25% teflon, 7M-KOH. 1 0.85t/cm²; 2 0.55t/cm²; 3 0.3t/cm².

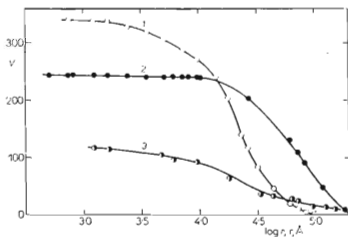


FIG. 10

Porosimetric Curves of Teflon Foils

1 Foil A; 2 B; 3 C. Volume readings ($v \cdot 10^{-3}$) in cm³/g.

process was still necessary, investigations were pursued in this direction. The results depicted in Fig. 3 imply that the effect of the sintering process on the specific resistance of the active layer containing 15% of silver is insignificant and it may, therefore, be expected that even electrodes which were not thermally treated, will stand current loads of about 30 mA/cm^2 without excessive ohmic polarization. Experiments made on unsintered electrodes confirmed our expectations. Definite answer will, however, be obtained only after long-term operation tests have been finished.

Aside from measurements made on unsintered electrodes, both A.B. and S.O. electrodes were investigated with respect to the influence of the sintering temperature exceeding that of the melting temperature of teflon ($380\text{--}390^\circ\text{C}$). The high sintering temperature lowered the porosity of the gas layer to such an extent that i_L of these electrodes was markedly below 30 mA/cm^2 ; electrodes fed with air were not capable of steady-state operation, when operated on pure oxygen, however, the current could be raised by severalfold without the electrodes showing the slightest sign of deterioration.

In electrodes with a fixed three-phase zone, a very definite pore structure, especially with respect to the size and quantity of the pores in the gas layer, is mandatory. From the point of view of reproducibility of preparation, the teflon foil seems to be most advantageous; its porous structure may namely be created independently of the rest of the electrode.

The influence of the porous structure of the gas layer on the electrochemical behaviour of the air electrode was studied on three different types of teflon foil. The characteristics of their porous structure will be found in Fig. 10. It will be seen from the porosimetric curves that the foil A possesses mostly pores of approximately 3μ diameter. Its total pore volume is of all the foils the highest one. In the foil B the maximum frequency pore size exhibits a pronounced shift toward bigger pores, the curve of the foil C raises monotonically without any maximum at all.

The requirement of unpermeability to the alkaline electrolyte in a complete electrode is best met in the foil A, to a certain extent in the foil C, but the foil B is already quite permeable. Comparing these facts with the porosimetric curves, we may conclude that the main cause is the rather high porosity of the foil B in the pore region above $r = 10 \mu$. The requirement of the optimum distribution of oxygen and removal of nitrogen is best met in the foil A and also in the foil B, whereas in the foil C i_L was observed in the proximity of 40 mA/cm^2 as has already been stated. These observations, too, are in agreement with the mutual position of the porosimetric curves, in this case with the total porosity value.

The same picture is furnished by measurements of i_L in dependence on different quantities of air entering into and streaming by the gas side of the electrode. Fig. 11 shows the curves of foils A and C. The figure also contains a theoretical relationship to enable comparing the results obtained with the theory. In harmony with i_L values obtained on A.B. electrodes prepared with the foil C, the corresponding curve

in Fig. 11 shows a shift of the measured from the theoretical curve at approximately 40 mA/cm^2 (280 mA).

The experimental data now at hand suggest the following model of the mechanism of function of electrodes based on the combination active carbon–teflon: The structural measurements imply that the active layer is an agglomerate of grains of active carbon coated with silver which are bound with particles of teflon. The outer surface of these grains is partly covered with the considerably smaller teflon particles (the size of teflon was $0.05\text{--}0.5 \mu$, the active carbon grains were mostly of $15\text{--}20 \mu$ size). The inner surface of the carbon grains, especially the surface of the micropores, is practically not affected by the teflon. The teflon particles may inhibit the access of the electrolyte into the micropores but they cannot prevent it. On the assumption that the teflon particles form in the active layer an interconnected network, extending the teflon porous gas layer, we may attribute to the teflon skeleton the role of the gas distributor. The grains of carbon on the other hand play the role of the catalyst support and the electrolyte carrier. The electrochemical reaction proper then takes place at the site of the contact between the teflon and the carbon particles.

Fig. 12 shows a schematic design of the above model. It allows one to conclude that these electrodes fully satisfy the requirements imposed on fixed-zone electrodes.

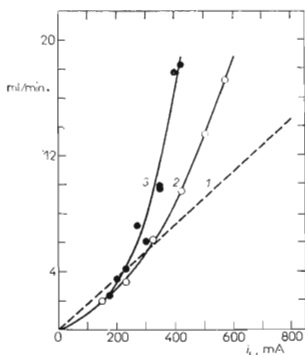


FIG. 11

Dependence of i_L on Quantity of Air Entering into the Gas Space of S.O. Electrode Holder

25% Teflon, 15% active carbon, 7M-KOH;
1 theory; 2 foil A; 3 foil C.

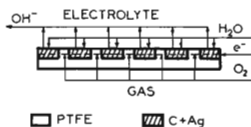


FIG. 12

Schematic Design of Function of Air Electrode

The main problem connected with these electrodes is then the question of an optimum access of the reactants, *i.e.* the air oxygen and water and of the removal of the air nitrogen and of the reaction products, *i.e.* the hydroxyl ions.

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