THE RESPONSE PATTERN OF POLAROGRAPHIC OXYGEN ELECTRODES AND ITS INFLUENCE ON LINEARITY AND HYSTERESIS*

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Abstract—Radiometer electrodes (E5044, E5046) with 20 μm polypropylene membranes were studied. The response time varied considerably from time to time, but some residual response was usually detectable after 10 min. Therefore in practice some incompleteness of response must be accepted. This incompleteness can be corrected mathematically. When this was done the fundamental linearity of the system was confirmed but without this correction there is marked hysteresis and apparent non-linearity. Response to blood samples at tensions on the steep part of the dissociation curve is faster than to samples of saturated blood or of water.

INTRODUCTION

A number of investigators have reported on the response times (BERKENBOSCH, 1967; BISHOP, 1960; MORAN, 1964; SILVER, 1963) and the linearity (HEITMANN, BUCKLES and LAVER, 1967; POLGAR and FORSTER, 1960; ROSEN and MAPLESON, 1965) of various oxygen electrodes. To help find out how to make the best use of commercially available systems we have made a detailed examination of response pattern and its influence on linearity and hysteresis in two types of Radiometer electrode: the E5044 and E5046. The designs of other commercially available electrodes differ from these in detail but not in principle, so that the general pattern of the results of the present investigation should be applicable to other electrodes although not, of course, the numerical values.

GENERAL PROCEDURE

The polarizing and measuring circuit used is shown in Fig. 1. The polarizing voltage was maintained nominally at 600 mV; it drifted by less than 1 per cent in any one experiment. For each experiment a series resistance was selected such that the maximum voltage drop across it was near to, but less than, 6 mV so that the polarizing voltage was reduced by less than 1 per cent at maximum oxygen tension. The digital voltmeter (Dynamco DM2020) read to the nearest 10 μV.

The membrane used in both electrodes was 20 μm polypropylene film as supplied by the manufacturers. This was applied in the recommended manner. Following application of the membrane it was found that the output current was high and that it drifted rapidly;

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we therefore left the electrode to 'settle' for at least 24 h before use. The integrity of the membrane was tested before each experiment by applying 15 V across it; if there was a perforation an appreciable fraction of the applied voltage appeared at the cathode giving a large alteration in output on the digital voltmeter. The membrane was changed whenever a perforation was detected.

The water jackets of the electrodes were supplied with a flow of water at 38 ± 0.1°C. The volume of the cuvette and inlet tube is 0.12 cm³ in the E5044 and 0.06 cm³ in the E5046. To make sure of flushing the cuvette and lead-in tube all injections were of 0.5 cm³ for the E5044 and 0.25 cm³ for the E5046. The outer wall of the cuvette is of stainless steel in the E5044 but in the E5046 it is of glass, permitting observation of the contents.

It has been suggested (Adams, Morgan-Hughes and Sykes, 1967; Heitmann, Buckles and LaVer, 1967) that bacterial contamination can lower the PO₂ of a liquid; to discourage bacterial growth we routinely left the cuvette filled with a 0.1 per cent solution of "Cetrimide" when not in use. From time to time algal contamination of the E5046 electrolyte was detected, presumably due to favourable conditions of light and warmth present behind the translucent cuvette. Occasional changing of the electrolyte and wiping over of the electrolyte chamber and electrode was sufficient to prevent significant contamination.

Most of the experiments were carried out with samples of water because this involves most of the difficulties encountered with blood samples, but avoids the complication of continuous oxygen consumption by the blood (Asmussen and Nielsen, 1961). Equilibration of blood or water with gas was performed in 250 cm³ bubble tonometers of the type used in the Medical Research Council Pneumoconiosis Research Unit. Cylinders of compressed gas were used as gas sources.

Sampling from the tonometers into glass syringes was effected by means of short plastic intravenous cannulae with Luer-fitting hubs. Before introduction into the cuvette, the first two or three drops of sample were rejected, and then a steady injection of the appropriate volume was made.

**DETERMINATION OF RESPONSE PATTERN**

*Experimental design*

Basically the technique employed was to observe the output of the electrode when the tension of the liquid in the cuvette was alternated between two different constant values, maintaining each tension for long enough for the output to reach a steady level. However, several factors can complicate the results and previous optimistic estimates of response time may be at least partly due to disregarding such complications. The present experiments were therefore designed to reveal and allow for these complicating factors.

In detail: a bubble-free sample of water, 5 cm³ for the E5044, 2.5 cm³ for the E5046, equilibrated with the selected lower tension (0% oxygen) was drawn into a 5 cm³ glass syringe which had previously been 'decontaminated' by being filled with water at this tension at least 5 min previously and by being emptied only immediately before the sample was drawn. Aliquots of 0.5 cm³ or 0.25 cm³ were injected at 1 min intervals for 10 min at the lower tension. During the last of these 1-min intervals the syringe was refilled with water at the same lower tension and injections continued for a further 10 min. Then a sample of water equilibrated with the higher tension (100% O₂) was drawn into a second syringe which had previously been 'decontaminated' and the 20-min procedure was repeated. The whole 40-min cycle was repeated until three full cycles had been completed. The experiment was concluded with ten injections at the lower tension. The output was recorded every 15 s throughout the experiment.

*Results and discussion*

The overall picture of a typical experiment is shown in Fig. 2 and enlarged details of various experiments in Figs. 3 and 5. Figure 3 reveals