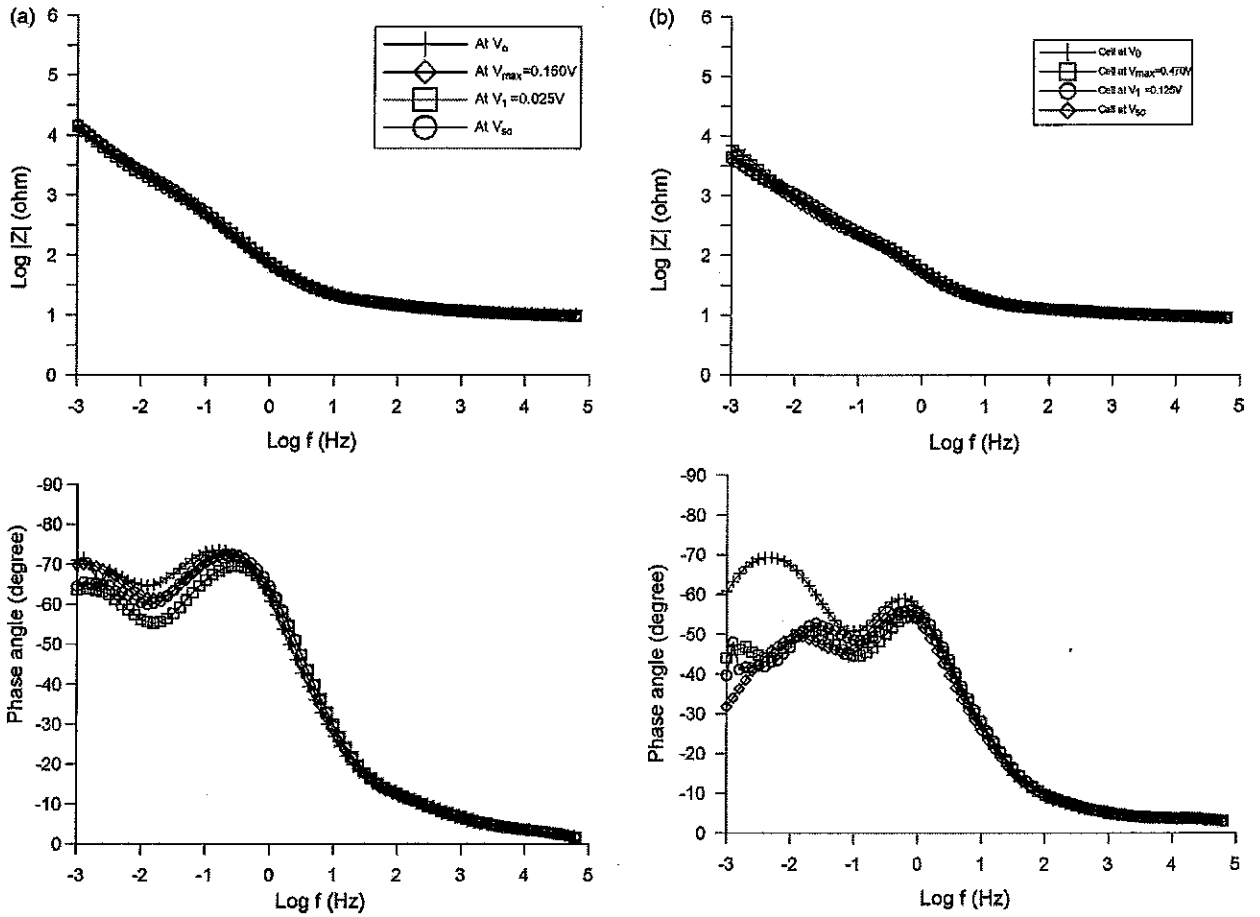

Fig. 5. Bode plots obtained at different cell voltages for the MFC with SS balls with (a) buffer and lactate as anolyte and (b) buffer, lactate and MR-1 as anolyte.

The impedance spectra of the anode, cathode (Fig. 4) and of the MFC measured at different applied cell voltages (Fig. 5a and b) were analyzed using the two-time constant model in the ANALEIS software [12,17,18]. The fit-parameters of the impedance spectra for the anode are listed in Table 3. For the MFC with SS balls in the anode compartment, R_p of the anode can be defined as $R_p^a = R_1 + R_2$. While R_1 decreased only slightly in the presence of MR-1, a very large decrease of R_2 was found (Table 3). R_1 was much smaller than R_2 in both anolytes. C_1 was smaller than C_2 and both parameters decreased when MR-1 was added to the anolyte.

The fit-parameters of the impedance spectra for the MFC measured at various cell voltages (Fig. 5) are shown in Fig. 6 for both anolytes. R_4 was much larger than R_3 and decreased significantly with cell voltage, while R_3 did not seem to depend on cell voltage (Fig. 6a). C_4 was larger than C_3 and both fit-parameters did not seem to change much with applied cell voltage (Fig. 6b). R_{int} was determined according to Eq. (1).

Table 3
Fit-parameters for the impedance spectra of the graphite/SS ball anode for anolytes A1 and A2

Fit-parameter	A1	A2
R_1 (Ω)	5.99×10^2	1.65×10^2
R_2 (Ω)	1.44×10^6	1.72×10^4
C_1 (F)	1.62×10^{-3}	6.45×10^{-3}
C_2 (F)	1.72×10^{-1}	7.5×10^{-2}
R_s (Ω)	9.2	8.2

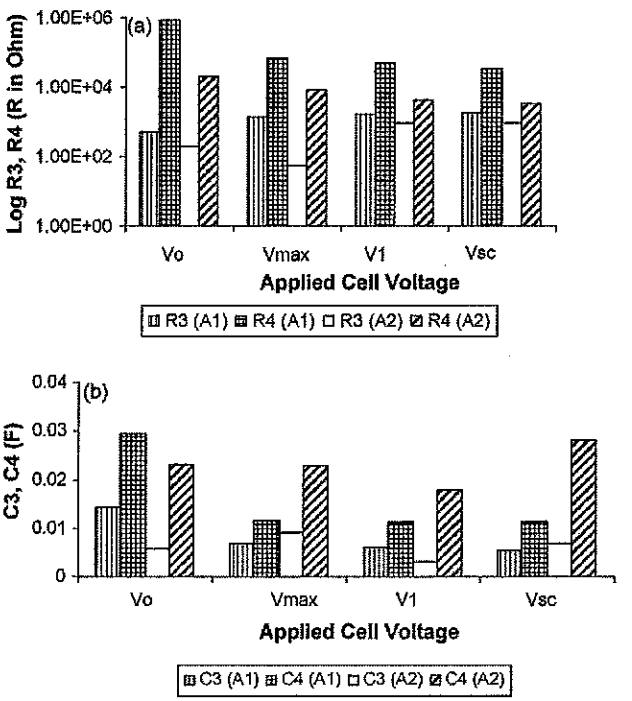

Fig. 6. (a) R_3 and R_4 and (b) C_3 and C_4 for MFC with SS balls at four different applied cell voltages with buffer and lactate (A1) and buffer, lactate and MR-1 (A2) as anolyte.

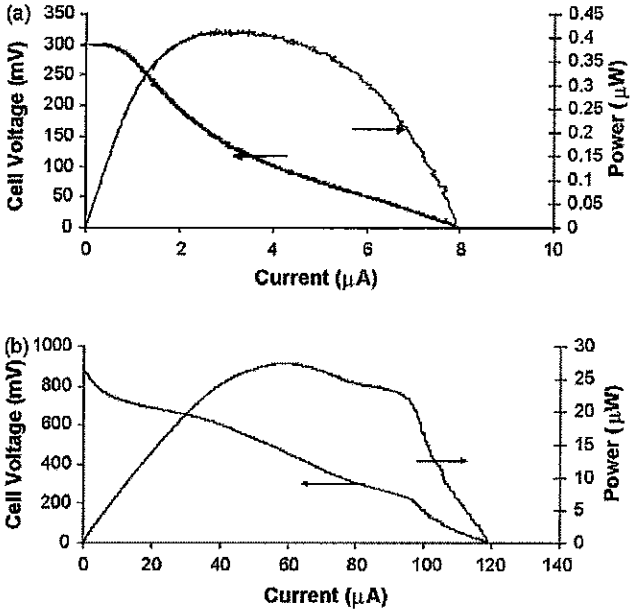

Fig. 7. *V–I* and *P–I* curves for the MFC with SS balls with (a) buffer and lactate and (b) buffer, lactate and MR-1 as the anolyte.

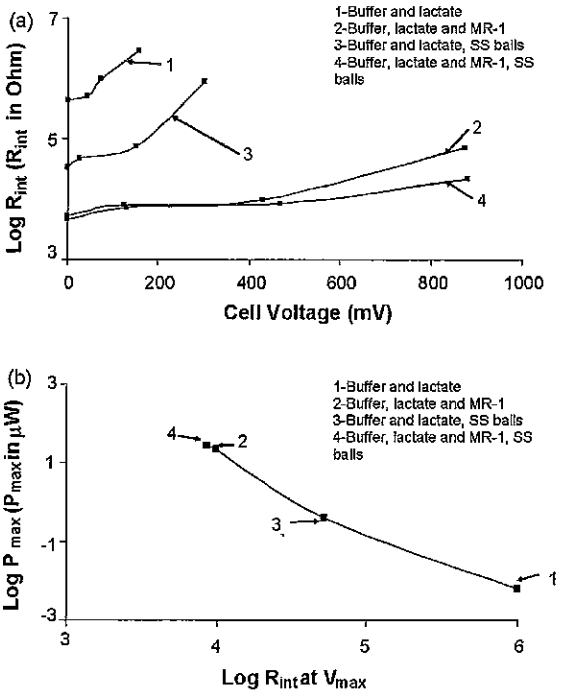

Fig. 8. Dependence of (a) R_{int} on cell voltage and (b) P_{max} on R_{int} for the four cases studied.

The *V–I* and *P–I* curves of the MFC with SS balls for the two anolytes are shown in Fig. 7a and b, respectively. With buffer and lactate as the anolyte, V_o was about 300 mV. I_{sc} of the cell with SS balls was found to be 8 μA (0.06 μA/cm^2) which is about 50 times larger than I_{sc} obtained for the MFC without SS balls (Fig. 3). P_{max} was about 0. 4 μW (0.003 μW/cm^2) at V_{max} = 150 mV as compared to 0.006 μW in the same anolyte without SS balls (Fig. 3a).

After the addition of MR-1 to the anode compartment, V_o increased to about 880 mV and I_{sc} increased to 120 μA (0.92 μA/cm^2) (Fig. 7b) which is much higher than the maximum current obtained without MR-1 (Fig. 7a). P_{max} = 26 μW (0.2 μW/cm^2) was obtained at V_{max} = 470 mV which is slightly higher than P_{max} obtained in the absence of the SS balls (Fig. 3b). The *V–I* and *P–I* curves in Fig. 7b seem to contain contributions from both the graphite and the SS ball electrodes.

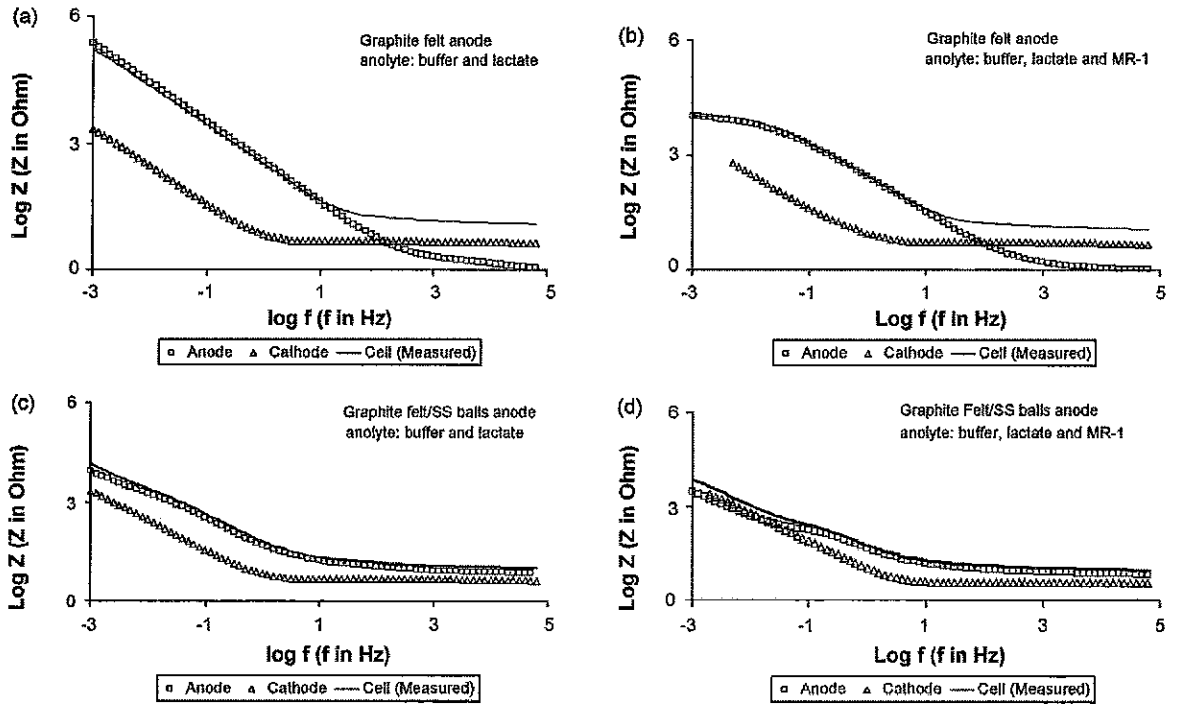

Fig. 9. Impedance spectra for the anode and the cathode at their OCP and the MFC at V_o for the four cases studied.