

# Electrocatalytic Efficiency of the Oxidation of Ethylene glycol, Glycerol, and Glucose under Oscillatory Regime

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There is an increasingly interest in the use of small organic molecules in the interconversion between chemical and electrical energies. Among the strategies to improve the processes of yielding electrical energy in fuel cells and the production of clear hydrogen in electrochemical reform is the use of kinetic instabilities to improve the conversion and selectivity. Herein we report on the electrocatalytic efficiency of the oxidation of ethylene glycol, glycerol, and glucose, under regular and oscillatory regimes, on polycrystalline platinum, in sulfuric acid aqueous solution, and at 25 °C. Despite the high overpotentials for the electro-oxidation of these molecules, the electrochemical activity along quasi-stationary potentio/gavanostatic experiments evidenced that, in all cases, relatively lower potential values, and thus higher activity, are reached during oscillations. Noticeably higher power densities for the electro-oxidation of ethylene glycol and glycerol under oscillatory regime in a hypothetical direct liquid fuel cell. The use of identical experimental conditions of that of our previous study[J. Phys. Chem. C 120 (2016) 22365] allowed at discussing some universal trends for seven small organic molecules. We compile the results in terms of the peak current, the maximum poisoning rate found along the oscillations, and the oscillation frequency. The three parameters were found to decrease in the order: formaldehyde > formic acid > methanol > ethanol > ethylene glycol > glycerol > glucose. In addition, we discussed the increase of the voltammetric current with the self-organized poisoning rate and reinforce the trend that high electrocatalytic activity implies high susceptibility to surface poisoning for this set of species. Finally, the analysis done for all species (formic acid, formaldehyde, methanol, ethylene glycol, ethanol, glycerol, and glucose) adds to the available thermodynamic data and is a benchmark against which the activities under oscillatory regime at 25 °C may be compared or assessed. This point of reference permits to explore further experimental conditions that are relevant for energy-related devices, including the conversion of chemical into electrical energy and the electrochemical reform to produce clean hydrogen in electrolyzers.

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**Keywords:** electrocatalysis, oscillations, efficiency, ethylene glycol, glycerol, glucose.

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## Introduction

The importance of storing and harvesting energy in chemical bonds is continuously growing as the world evolves towards a cleaner and sustainable future.<sup>1,2</sup> The electrochemical interconversion between chemical and electrical energies comprises for instance the direct use of some small organic molecules in fuel cells or their use to produce hydrogen in the so-called electrochemical reform.<sup>3-9</sup> The ultimate goal is to maximize the reaction rates, or current, and simultaneously minimize the deviation from the standard potential for a given reaction.

Table I shows the standard free energy,  $\Delta G^\circ$ , the number of electrons transferred,  $n$ , for the complete oxidation of hydrogen ( $H_2$ ), formic acid ( $HCOOH$ ), formaldehyde ( $CH_2O$ ), methanol ( $CH_3OH$ ), ethylene glycol ( $C_2H_6O_2$ ), ethanol ( $C_2H_5OH$ ), glycerol ( $C_3H_8O_3$ ), and glucose ( $C_6H_{12}O_6$ ), at 25 °C and 1 bar.  $U^\circ_{cell}$  and  $E^\circ_{anode}$  are the thermodynamic open circuit voltage for the complete fuel cell, and the theoretical standard potential for the anodic reaction, respectively. Thermodynamics shows the theoretical advantages of such systems, but kinetics hindrance severely limits the use of the energy available in those systems. The formation of strongly adsorbed species, such as  $CO_{ad}$ , and the partial oxidation, rather than the complete one to  $CO_2$ , severely limit the usage of the carbonaceous fuels given in Table I in the so-called Direct Liquid Fuel Cells (DLFC).

**Table I:** Thermodynamic data for the total electro-oxidation of hydrogen, formic acid, formaldehyde, methanol, ethylene glycol, ethanol, glycerol, and glucose at 25 °C and 1 bar.<sup>10-12</sup>

Theoretical cell reaction	$\Delta G^\circ$ (kJ mol <sup>-1</sup> )	$n$	$U^\circ_{cell}$ (V)	$E^\circ_{anode}$ (V)
$H_2 + 1/2 O_2 \rightarrow H_2O$	-237 <sup>(a)</sup>	2	1.23	0.00
$HCOOH + 1/2 O_2 \rightarrow CO_2 + H_2O$	-285 <sup>(a)</sup>	2	1.48	- 0.25
$CH_2O + O_2 \rightarrow CO_2 + H_2O$	-522 <sup>(a)</sup>	4	1.35	- 0.12
$CH_3OH + 1/2 O_2 \rightarrow CO_2 + 2H_2O$	-698 <sup>(a)</sup>	6	1.21	0.02
$C_2H_6O_2 + 5/2 O_2 \rightarrow 2CO_2 + 3H_2O$	-1,349	10	1.22	-0.01
$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$	-1,325	12	1.14	0.09
$C_3H_8O_3 + 7/2 O_2 \rightarrow 3CO_2 + 4H_2O$	-1,850	14	1.25	-0.02
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$	-3,012	24	1.29	-0.06

Those kinetic limitations are the subject of electrocatalysis,<sup>13</sup> or the heterogeneous catalysis of reactions that take place at the electrified solid/liquid interface. Research in this direction includes for instance tailoring the interface or the electrochemical properties of the electrode. Alternatively, or coupled to the improvement of the electrode materials, there is also the possibility of working with processes or operation modes, and exploring kinetic peculiarities of the system to improve the overall performance of electrochemical devices.

Many energy-related electrochemical reactions are associated to kinetic instabilities and thus to the presence of current and/or potential oscillations under some conditions.<sup>14–17</sup> Understanding the nonlinearities in these systems is important from the fundamental, but also for applied aspects, as it might imply improvement in the design of operation and processes.<sup>15</sup> In a paradigmatic example, Sundmacher and co-workers<sup>18</sup> studied the dynamics of the Direct Methanol Fuel Cell (DMFC) by means of experiments and model-based analysis, with different methanol feeding strategies. Importantly, the authors reported a significant increase in the cell voltage and a decrease in the methanol cross-over when the DMFC is operated with periodically pulsed methanol feeding.<sup>18</sup> As far as the autonomous, self-organized oscillations are concerned, there are reports of performance improvement in Polymer Electrolyte Membrane Fuel Cells (PEMFC) fed with H<sub>2</sub>/CO mixtures,<sup>19–23</sup> and, more recently, also in some DLFC operating with methanol,<sup>24–26</sup> formic acid,<sup>25,26</sup> and ethanol.<sup>26</sup> Finally, Nogueira *et al.*<sup>27</sup> have recently proved that self-organized potential oscillations not only imply an increase in the average activity but also prevent the dissolution of the catalyst. In short, they monitored on line the dissolution of platinum using a stationary probe located near a rotating disk electrode and an inductively coupled plasma mass spectrometer (ICP-MS).<sup>28</sup> The authors studied the electro-oxidation of formic acid and methanol and discussed the compromise between stability and activity in terms of the potentials applied or visited as the reaction proceeds. Hence, the self-cleaning process and the prevention the dissolution of platinum resulted from the emergence of potential oscillations under galvanostatic regime.<sup>27</sup>

Aside from these reports, it can be said that the study of the impact of nonlinear phenomena on electrocatalytic systems is still in its early days. The understanding of the mechanistic aspects underlying the nonlinearities in the electrochemistry of energy-related systems are imperative for benefiting from those features in applications such as fuel cells<sup>15</sup> and electrolyzers. We have recently reported<sup>10</sup> a systematic investigation of the oscillatory electro-

oxidation of some small organic molecules (SOM): formaldehyde, formic acid, methanol, and ethanol on platinum. The focused was on the comparison of the overall performances under conventional and oscillatory regimes, employing identical experimental conditions, namely (electrochemically annealed) polycrystalline platinum as working electrode; [SOM] = 0.5 mol L<sup>-1</sup> in a 0.5 mol L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub> aqueous solution; and T = 25 °C.

Herein we extend this previous study and investigate the electro-oxidation of ethylene glycol, glycerol, and glucose. The choice of these three molecules is based on their role in energy-conversion systems. Ethylene glycol is attractive because of its good reactivity and low toxicity, besides the high energy density.<sup>29,30</sup> Glycerol is a low volatile, biomass-related compound which has gained considerable attention due its relevance in green technologies, as an profuse by-product of biodiesel.<sup>29,31,32</sup> Glucose is a key compound in the context of bio fuel cells electrochemical sensors.<sup>33–36</sup> We take advantage of the identical conditions employed and discuss the obtained results in connection with the previously published data, and generate a comprehensive analysis of the electro-oxidation of the seven liquid fuels (formic acid, formaldehyde, methanol, ethylene glycol, ethanol, glycerol, and glucose) on polycrystalline platinum, and in aqueous acidic media and at 25 °C.

## Experimental

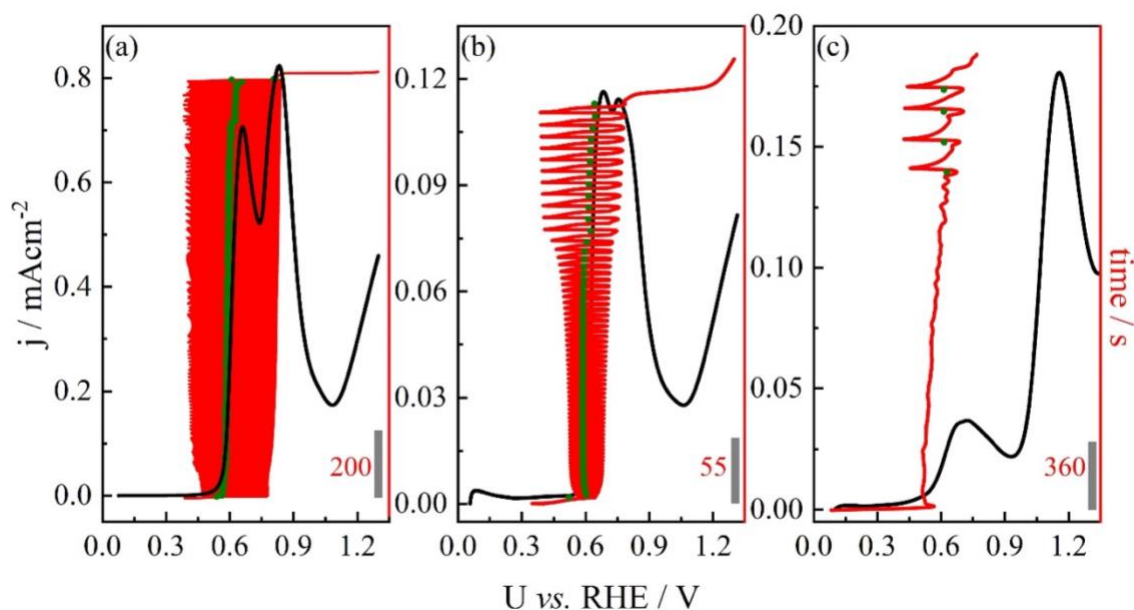
Experiments were conducted in a three-electrode glass cell, with working electrode (WE) consisting of a Pt flag and the counter electrode (CE) of a platinized Pt flag with high surface area. A reversible hydrogen electrode (RHE), prepared with a solution of identical concentration to that of the supporting electrolyte and connected to the supporting electrolyte through a Luggin capillary, served as a reference electrode. The electroactive area of the WE (1.7 cm<sup>2</sup>) was estimated by considering the value of 210 μC.cm<sup>-2</sup> as the charge density associated with the oxidation charge of HUPD region.<sup>37</sup> The supporting electrolyte was prepared with high purity water (Millipore, Milli-Q system, 18.2 MΩ cm) and H<sub>2</sub>SO<sub>4</sub> (Merck KGaA). Reaction temperature was kept at 25.0 ± 0.1 °C in all experiments.

Before the experiments, cyclic voltammogram with scan rate of 0.05 Vs<sup>-1</sup> from 0.05 to 1.50 V in an argon purged supporting electrolyte attested the cleanness of the systems (see Figure S1 in the supplementary material). Thereafter, ethylene glycol (J. T. Baker, 99.7%), glycerol (Fisher Chemical, 99.99%) or D-(+)-glucose (Sigma-Aldrich, 99.5%) was inserted

directly into the cell yielding a 0.5 mol L<sup>-1</sup> solution.

## Results and Discussion

The general conditions and cleanness of the system was confirmed by comparing the voltammetric profile recorded before the addition of the organic fuel, see Figure S1 in Supporting Information, with previously published data.<sup>38</sup> Figure 1 shows the slow potentiodynamic sweeps (black lines) for the electro-oxidation of ethylene glycol, glycerol, and glucose. Experiments were carried out from 0.05 to 1.30 V at 0.002 V s<sup>-1</sup>. Up to about 0.30 V, the activity remains very small and the reaction current about zero, because of the poisoning of the electrode surface by strongly adsorbed species.<sup>39–41</sup> Comparing the onset of detectable reaction currents in Figure 1 and the thermodynamic potentials in Table I, overpotentials of at least 0.60 V are observed. The potentiodynamic profiles are characterized by two current peaks at varying magnitude and potentials: at 0.66 V and 0.84 V for ethylene glycol, 0.68 V and 0.76 V for glycerol, and 0.72 (actually a shoulder with presumably more than one peak) and 1.16 V for glucose. At higher potentials, > 1.10 V, the oxidation occurs presumably on the oxidized surface.<sup>42,43</sup> For the electro-oxidation of formaldehyde, formic acid, methanol, and ethanol,<sup>10</sup> only one current peak, and a small shoulder prior to the main peak in some cases, were discernible. Although the definition of the current profile in those systems might depend on a number of experimental variables, the use of identical conditions discussed here suggests a, somehow predictable, more complex mechanism for the molecules studied here. In terms of the voltammetric activity, remarkably higher reaction currents are observed for the electro-oxidation of ethylene glycol, and comparable rates are observed for glycerol and glucose. Low activity for the electro-oxidation of the later on platinum and in acidic media have been reported.<sup>34,44–46</sup>



**Figure 1:** Slow potentiodynamic sweep (black lines, @0.002 V s<sup>-1</sup>) for the platinum electrode in 0.5 mol L<sup>-1</sup> of (a) ethylene glycol, (b) glycerol, and (c) glucose, in 0.5 mol L<sup>-1</sup> H<sub>2</sub>SO<sub>4</sub> aqueous solution at 0.002 V s<sup>-1</sup>; and galvanostatic curves (red lines) at: (a) 0.70 mAcm<sup>-2</sup>, (b) 0.10 mAcm<sup>-2</sup>, and (c) 0.01 mAcm<sup>-2</sup>. The mean potential at each cycle is presented by the green dots. T = 25 °C.

Potential oscillations under galvanostatic regime are illustrated in red, the mean potential in green, in Figure 1. In all three cases studied it became clear that, under galvanostatic regime, moderately lower potential values, and thus higher activity, are reached during oscillations. The choice of the applied current in each case was done according with the protocol described in reference <sup>47</sup>. Oscillations in the electro-oxidation of ethylene glycol have been reported,<sup>48</sup> and most of the literature available in this respect concerns studies in alkaline medium. Oscillating reaction rates have been also observed for glycerol,<sup>40,49</sup> and glucose.<sup>50,51</sup> Period-1 oscillations along the electro-oxidation of ethylene glycol, Figure 1(a), are observed between 0.38 and 0.84 V and have frequencies ( $\omega$ ) around 0.2 Hz. After some time, period-2 oscillations set in and then mixed-mode ones prevail before the abrupt potential increase at the end; in agreement with previously published data.<sup>52</sup> In terms of reaction mechanism, it has been proposed that CO (linearly and multiply adsorbed) and glycolate are the main adsorbates that poisoning the platinum surface,<sup>39</sup> and thus are very likely to play a role during oscillations.

Figure 1(b) compare the profiles under potentiostatic, already discussed, and galvanostatic control modes for glycerol. Potential oscillations set in at around 0.60 V with

smaller amplitudes compared to ethylene glycol. As the oscillations develop, the amplitude increases with the decrease/increase of the lower/upper potential limit to 0.38/0.78 V. Accordingly, the oscillation frequency decreases from 0.5 to 0.1 Hz. This system is particularly affected by the mass transportation of fresh reactants and partially oxidized species to and from the electrode, respectively. Oliveira *et al.*<sup>49</sup> showed that the duration of such oscillations depends on the concentration of glycerol, and an increase from 0.1 to 0.2 mol. L<sup>-1</sup>, resulted in time-series twice longer. Melle *et al.*<sup>40</sup> studied in depth the effect of mass transport in the electro-oxidation of glycerol and observed that enhancing the mass transport resulted in a new Faradaic process at  $U < 0.55$  V. The authors suggested that the removal of aldehydes near the surface might prevent the formation of strongly adsorbed poisoning species, and this would cause the stabilization of longer time-series.

Finally, oscillations in the electro-oxidation of glucose are given in Figure 1(c). Oscillations start after a rather long induction period (c.a. 1700 s) and are clearly less robust in this case. As for all oscillations' features, the induction period depends on parameters such as the applied current and the concentration of glucose, as well as on the nature and coverage of adsorbates.<sup>53</sup> Oscillations are in the range between 0.43 and 0.70 V, frequency of about 1 mHz, and only four cycles subsist. These results reflect the already mentioned low reaction rates observed for the electro-oxidation of glucose on platinum and in acidic media.

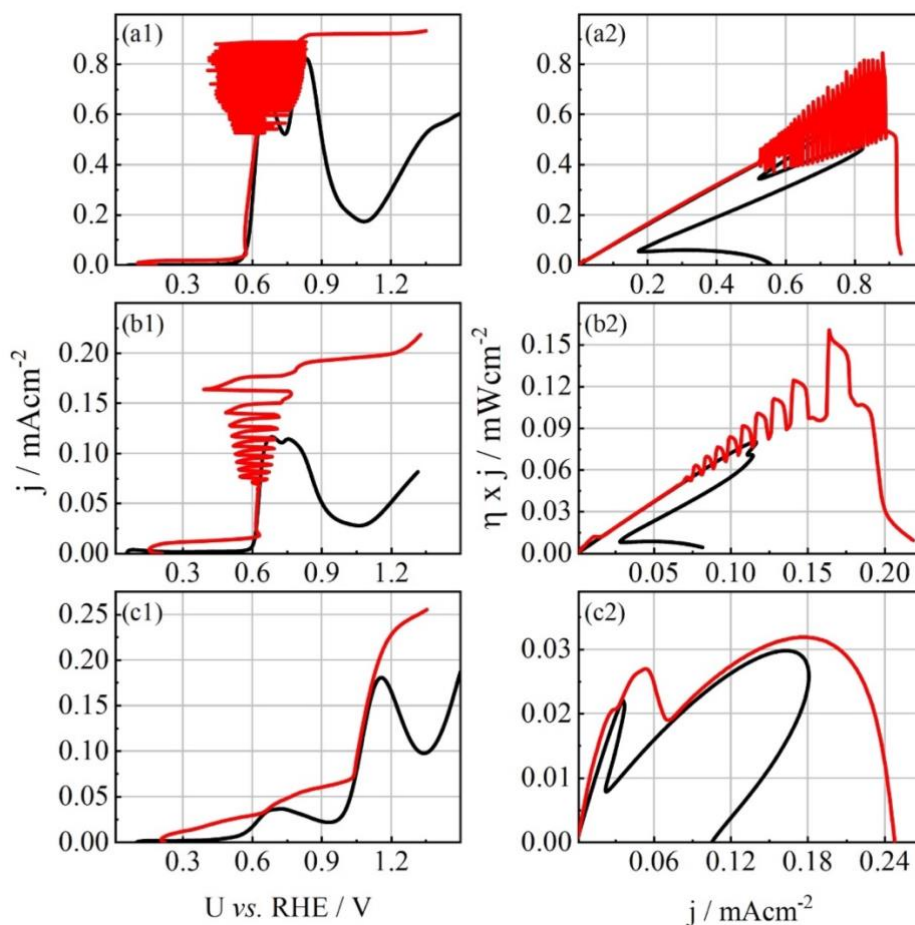
As already mentioned, lower potentials, and thus higher efficiency, are reached during the oscillations. We have discussed<sup>10</sup> the efficiency of an idealized fuel cell operating at a given current  $i$ ,  $\varepsilon_U(i)$ , terms of the potential at a certain current,  $U(i)$ ,

$$\varepsilon_U(i) = \frac{U_{cell}^o - [U(i) - E_{anode}^o]}{U_{cell}^o}$$

where  $U_{cell}^o$  and  $E_{anode}^o$  have been already defined as the thermodynamic open circuit voltage for the complete fuel cell, and the theoretical standard potential for the anodic reaction, respectively, c.f. Table I. As stated, the efficiency  $\varepsilon_U(i)$  is given for a hypothetical fuel cell with an ideal cathode, i.e., all limitations in the cell performance are attributed to the kinetic in the anodic reaction. Similar enhancement in the performance can be formulated in terms of the decrease in the energy consumption during electrochemical reform.<sup>4,7</sup>

Lower electrode potentials  $U(i)$ , reduces the difference  $[U(i) - E_{anode}^o]$ , and so increase the fuel cell efficiency. Figure 2 illustrates the responses for a slow linear sweep of potential (black) and current (red) for the electro-oxidation of (a1) ethylene glycol, (b1) glycerol, and

(c1) glucose. The resulting power density versus current density plots for (a2) ethylene glycol, (b2) glycerol, and (c2) glucose, under constant current (red) and potential (black) control. The decrease in the electrode potential presented in Figure 1 is also clearly seen in Figure 2(a1) and (b1). Consequently, noticeably higher power densities are observed for the electro-oxidation of ethylene glycol and glycerol under oscillatory regime, c.f. Figure 2(a2) and (b2). Furthermore, under galvanostatic control higher currents can be reached.



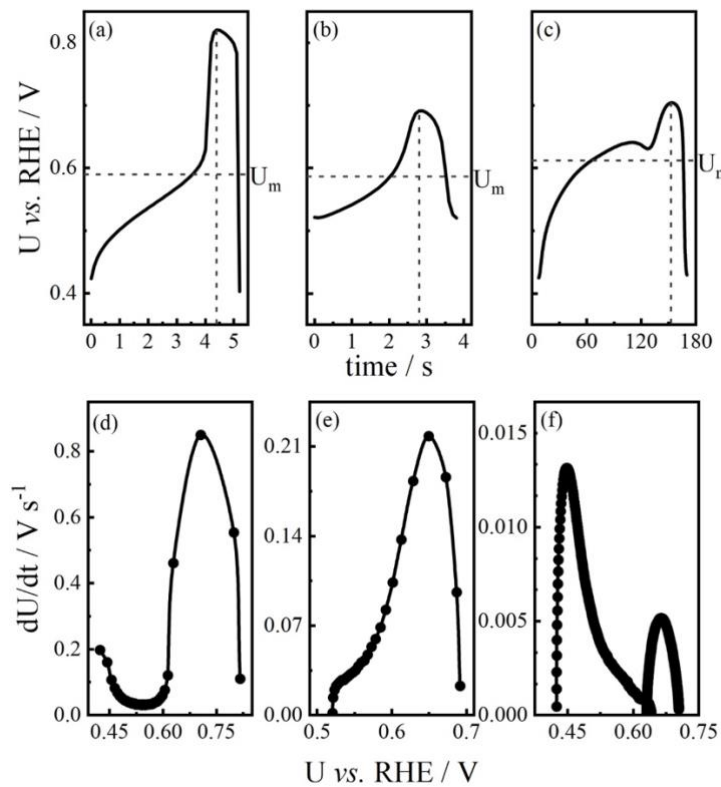
**Figure 2:** Linear sweep of potential (black lines, @0.002 V s<sup>-1</sup>) and current (red lines, @5  $\mu$ As<sup>-1</sup>) for the electro-oxidation of (a1) ethylene glycol, (b1) glycerol, and (c1) glucose. Corresponding power density versus current density curves for (a2) ethylene glycol, (b2) glycerol, and (c2) glucose, under galvanodynamic (red) and potentiodynamic (black) regimes. Remaining conditions as in Figure 1.

Under galvanodynamic conditions, no oscillations are observed for the case of glucose, Figure 2(c1). As discussed in Figure 1(c), oscillations are rather unstable for the electro-



oxidation of glucose on platinum and in acidic media. As a consequence, very similar power densities are reached in both control modes. Nevertheless, under galvanodynamic control, the system remains stable at higher applied currents.

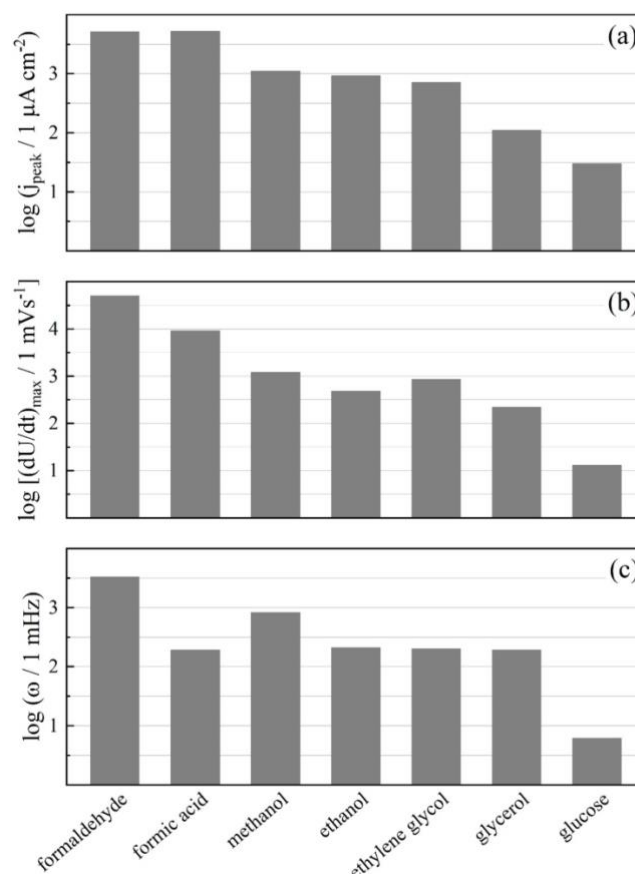
A detailed analysis of the potential oscillations might provide further insights. Figure 3 shows typical oscillatory cycles and the  $dU/dt$  rates for the electro-oxidation of the three organic fuels studied. The horizontal dashed lines  $U/t$  plots denote the mean potential<sup>10</sup> for each oscillatory cycle, the vertical ones designate the maximum  $U$  value for one cycle and thus the limit of the  $dU/dt$  range presented in Figure 3(d)-(f). Perini *et al.*<sup>54</sup> introduced the use of positive  $dU/dt$  rates as a measure of the poisoning processes that occur along the oscillations. This is an interesting parameter as, under those conditions, the adsorption of blocking species occurs in a self-organized manner.



**Figure 3:** (a)-(c):  $U$  vs.  $t$  and (d)-(f)  $dU/dt$  vs.  $U$  profiles for one oscillatory cycle. Data extracted from Figure 2 for (a) and (d) ethylene glycol, (b) and (e) glycerol, and (c) and (f) glucose.

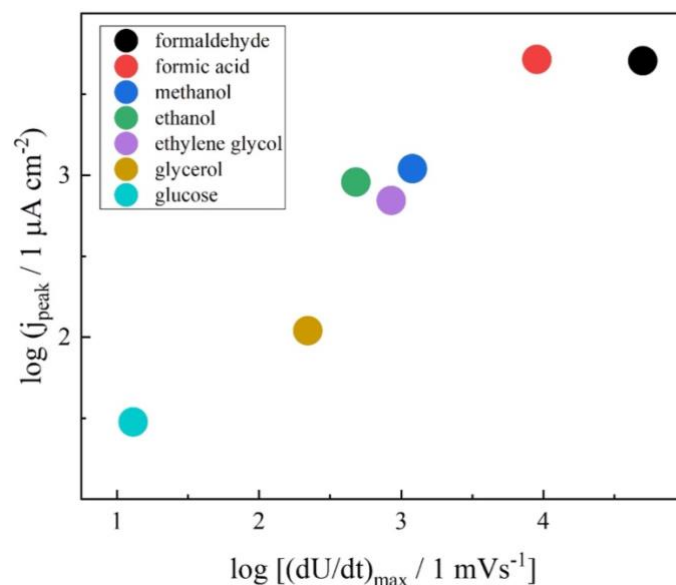
Despite the similarities in the voltammetric profiles illustrated in Figures 1 and 2, the self-organized evolution of  $U$  in Figure 3(a)-(c) shows intense differences in terms of amplitude, frequency and wave-form. These dissimilarities illustrates the importance of oscillations in mechanistic studies of electrocatalytic systems.<sup>55,56</sup> Quantitatively, it is seen for these typical cycles that the amplitude decreases in the sequence: ethylene glycol > glucose > glycerol, the frequency decrease as ethylene glycol  $\sim$  glycerol  $\gg$  glucose, and the gain caused by the decrease in  $U(t)$  is more pronounced for the electro-oxidation of ethylene glycol.

At this point it is illustrative to summarize the results obtained here in connection with the data published in our previous paper,<sup>10</sup> and discuss some universal trends in the seven molecules, studied under identical conditions. Figure 4 shows the results for the peak current, the maximum rate  $dU/dt$ ,  $(dU/dt)_{\max}$ , and the oscillation frequency for the electro-oxidation of formaldehyde, formic acid, methanol and ethanol,<sup>10</sup> and ethylene glycol, glycerol and glucose, recorded under identical experimental conditions. The electro-oxidation of formaldehyde reaches a maximum in the (voltammetric) activity, highest poisoning rate, and oscillation frequency. Aside from slight discrepancies, the three parameters were found to decrease in the order: formaldehyde > formic acid > methanol > ethanol > ethylene glycol > glycerol > glucose. The variations in the oscillatory frequency are less apparent and, excluding the extremes formaldehyde and glucose, the distribution for the five molecules can be described as plateau.



**Figure 4:** Plots (in log scale) of the (a) peak current recorded along a slow potential sweep (the first oxidation peak was used for glucose, see Figure 1), (b)  $(dU/dt)_{\text{max}}$ , and (c) oscillatory frequency (for typical oscillations), for the electro-oxidation of formaldehyde, formic acid, methanol and ethanol,<sup>10</sup> and ethylene glycol, glycerol and glucose.

Further correlation between the regular activity, estimated by the peak current in the slow potentiodynamic sweep, and the maximum  $(dU/dt)_{\text{max}}$  rate is evidenced in Figure 5 in a log-log plot, for the electro-oxidation of formaldehyde, formic acid, methanol and ethanol,<sup>10</sup> and ethylene glycol, glycerol and glucose. The increase of the voltammetric current with the poisoning rate  $dU/dt$  reflects the fact that high activity in these systems is compromised with the facility of poisoning formation.<sup>57,58</sup> Therefore, the trend that high electrocatalytic activity implies high susceptibility to poisoning is evidenced, for the first time, for a set of seven organic molecules with distinct characteristics. Importantly, the tendency evidenced in Figure 5 accounts for the self-organized poisoning process, recorded under oscillator regime.



**Figure 5:** bi-log plot of the peak current vs.  $(dU/dt)_{\max}$  for the electro-oxidation of formaldehyde, formic acid, methanol and ethanol,<sup>10</sup> and ethylene glycol, glycerol and glucose. See text for details.

Altogether, the presented results put in solid grounds the electrochemical activity for the electro-oxidation of formaldehyde, formic acid, methanol and ethanol,<sup>10</sup> and ethylene glycol, glycerol and glucose, on platinum, in acidic media, and at 25 °C, under regular and oscillatory regimes. All controllable experimental conditions, i.e., surface preparation, concentrations of all species, sweep rate, preconditioning, etc. were kept identical, so that the comparison is effective. In addition to the specific features discussed here and in our previous article,<sup>10</sup> it must be stressed that the compiled results represents a benchmark for comparison to the future studies with other systems under regular and oscillatory regimes. In particular, engineering electrochemical oscillations to optimize specific processes entails extending these studies for alkaline media<sup>59,60</sup> and using other materials and modified surfaces<sup>54,61,62</sup> are obvious targets. Furthermore, working closer to practical conditions also implies carrying out experiments at higher temperatures. The ultimate goal would be to map the gain in the electrochemical performance under oscillatory regime, and thus describe how to take advantage of kinetic instabilities to achieve higher rates and even control selectivity. The presented results provide a solid ground for such a comprehensive analysis.

## Conclusions

We have investigated the electrocatalytic efficiency of the oxidation of ethylene glycol ( $\text{C}_2\text{H}_6\text{O}_2$ ), glycerol ( $\text{C}_3\text{H}_8\text{O}_3$ ), and glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ), under regular and oscillatory regimes, on polycrystalline platinum, in sulfuric acid aqueous solution, and at 25 °C. Regular current/potential curves revealed overpotentials of at least 0.60 V for the electro-oxidation of these molecules, and considerably low activities were found for glycerol and glucose. Comparison of the electrochemical activity along quasi-stationary potentiogalvanostatic experiments evidenced that, in all cases, relatively lower potential values, and thus higher activity, are reached during oscillations. Analyzing the performance in a hypothetical fuel cell operated with idealized cathode, revealed noticeably higher power densities for the electro-oxidation of ethylene glycol and glycerol under oscillatory regime.

The use of identical experimental conditions of that of our previous study<sup>10</sup> allowed at discussing some universal trends for formic acid ( $\text{HCOOH}$ ), formaldehyde ( $\text{CH}_2\text{O}$ ), methanol ( $\text{CH}_3\text{OH}$ ), and ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ), in connection with the three species studied here. In particular, we compile the results in terms of the peak current, the maximum poisoning rate found along the oscillations,  $(dU/dt)_{\text{max}}$ , and the oscillation frequency. The electro-oxidation of formaldehyde reaches a maximum in the (voltammetric) activity, highest poisoning rate and oscillation frequency. Generally speaking, the three parameters were found to decrease in the order: formaldehyde > formic acid > methanol > ethanol > ethylene glycol > glycerol > glucose. We have also found an unambiguous increase of the voltammetric current with the self-organized poisoning rate and reinforce the trend that high electrocatalytic activity implies high susceptibility to surface poisoning, now for a set of seven organic molecules.

The full set of data for the seven molecules (formic acid, formaldehyde, methanol, ethylene glycol, ethanol, glycerol, and glucose) adds to the available thermodynamic data (see Table I) and is a benchmark against which the activities under oscillatory regime at 25 °C may be compared or assessed. This point of reference permits to explore further experimental conditions that are relevant for energy-related devices, including the conversion of chemical into electrical energy in direct liquid fuel cells, and the electrochemical reform to produce clean hydrogen in electrolyzers.

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