Estimation of Corrosion of Metal Wires in E-liquids

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Introduction & Objectives

- Based on the prevalence of metals found in heating elements of Electronic Nicotine Delivery Systems (ENDS), it has been suggested that metals may be present in the aerosol due to interactions of the e-liquid with the heating element.[1] One possible mechanism for availability of metals to transfer from the heating element to the liquid solution is by corrosion of the metallic heating element in e-liquids.
- The objective of this work was to develop a method of screening e-liquid compatibility with metallic heating elements via electrochemical corrosion measurements.
- Linear Polarization Resistance (LPR) was utilized to estimate corrosion rates in e-liquid formulations of varying pH.

Theory

$$R_p = \frac{\Delta E}{\Delta i_{\Delta E \to 0}}$$

$$i_{corr} = \frac{B}{R_p}$$

$$B = \frac{\beta_a \beta_c}{2.303(\beta_a + \beta_c)}$$

$$CR = K_1 \frac{i_{corr}}{\rho} EW$$

$\Delta E = \pm 20\ mV\ from\ E_{OC}\ (corrosion\ potential)$

$B = Stern - Geary\ constant$

$\beta_c = cathodic\ Tafel\ slope\ (\frac{V}{decade})$

$\beta_a = anodic\ Tafel\ slope\ (\frac{V}{decade})$

$R_p = polarization\ resistance\ (\frac{ohm}{cm^2})$

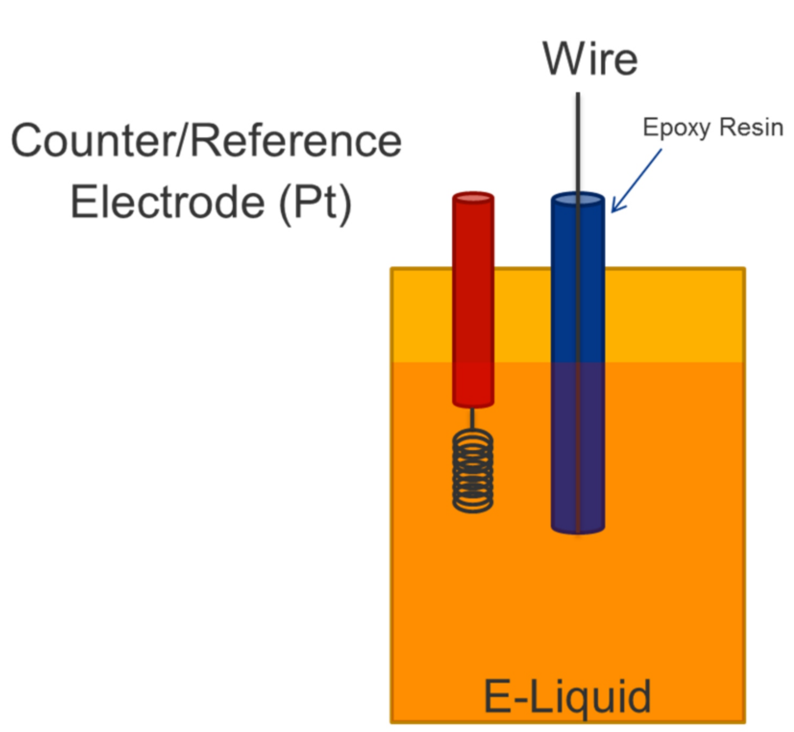
$CR = Corrosion\ Rate\ (\frac{mm}{yr})$

$K_1 = 3.27 \times 10^{-3}\ mm \frac{g}{\mu A} cm\ yr$

$EW = \frac{1}{\sum \frac{n_i f_i}{W_i}}$

f_i = mass fraction of the i^{th} element in the alloy
W_i = atomic weight of the i^{th} element in the alloy
n_i = valence of the i^{th} element in the alloy

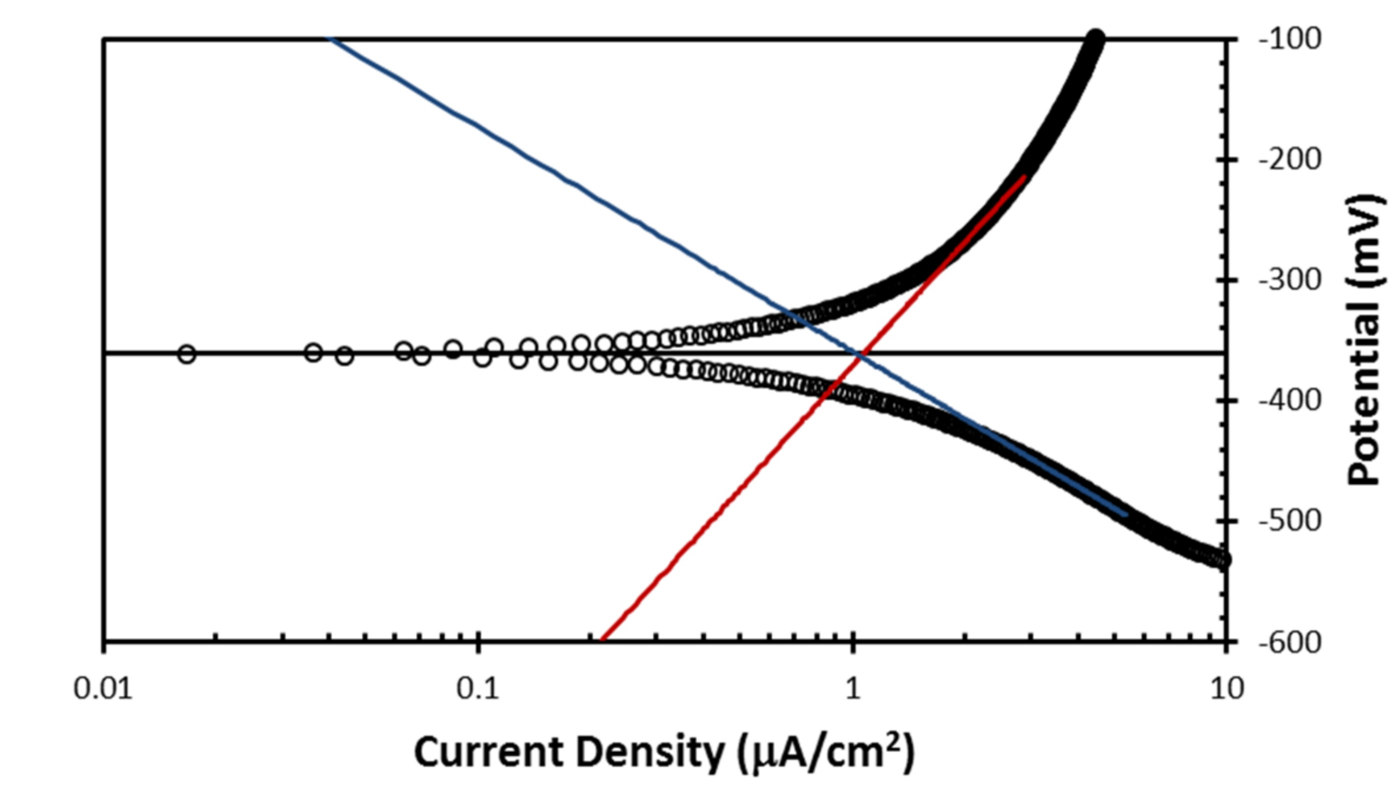
Experimental



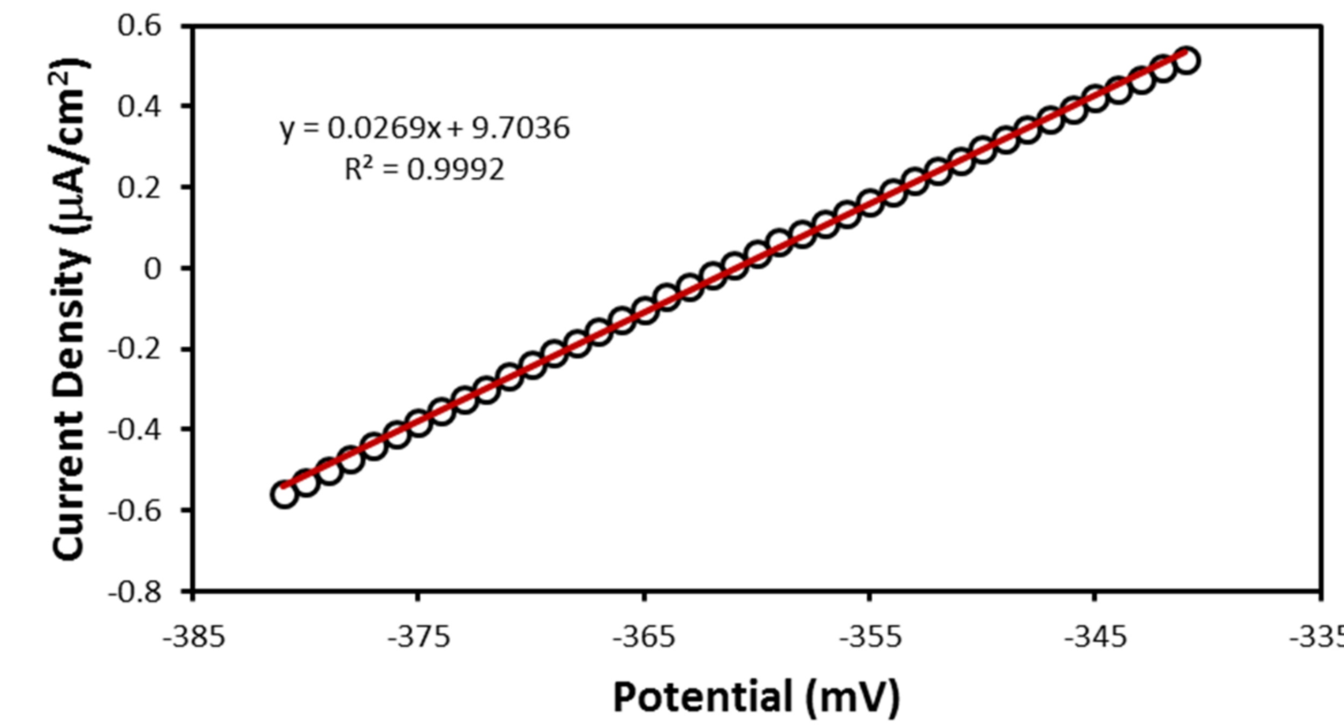
Schematic of the electrochemical cell set up with the working electrode (wire), and a combined counter and pseudo-reference.

- Electrodes were encapsulated in high temperature epoxy and polished to ~3 µm.
- A Pt electrode was used as both the counter and pseudo reference electrode.
- A BASi® Epsilon potentiostat was used to collect all the data presented in this poster.
- The system was allowed to equilibrate ~15 minutes or until the open circuit potential (OCP) drift was <0.5 mV/min. Once equilibrated, samples were swept ±250 mV from the OCP at a rate of 1mV/s.
- We used a commercially available e-liquid formulation consisting of (by weight): 15% water, 4% nicotine, 56% glycerol, 24% propylene glycol, and <1% flavors. The pH of the formulation was modified through the addition of organic acids.
- The experiments were conducted at laboratory ambient conditions, ~22-25 °C.
- Corrosion rates were calculated following ASTM G102-89.[2]

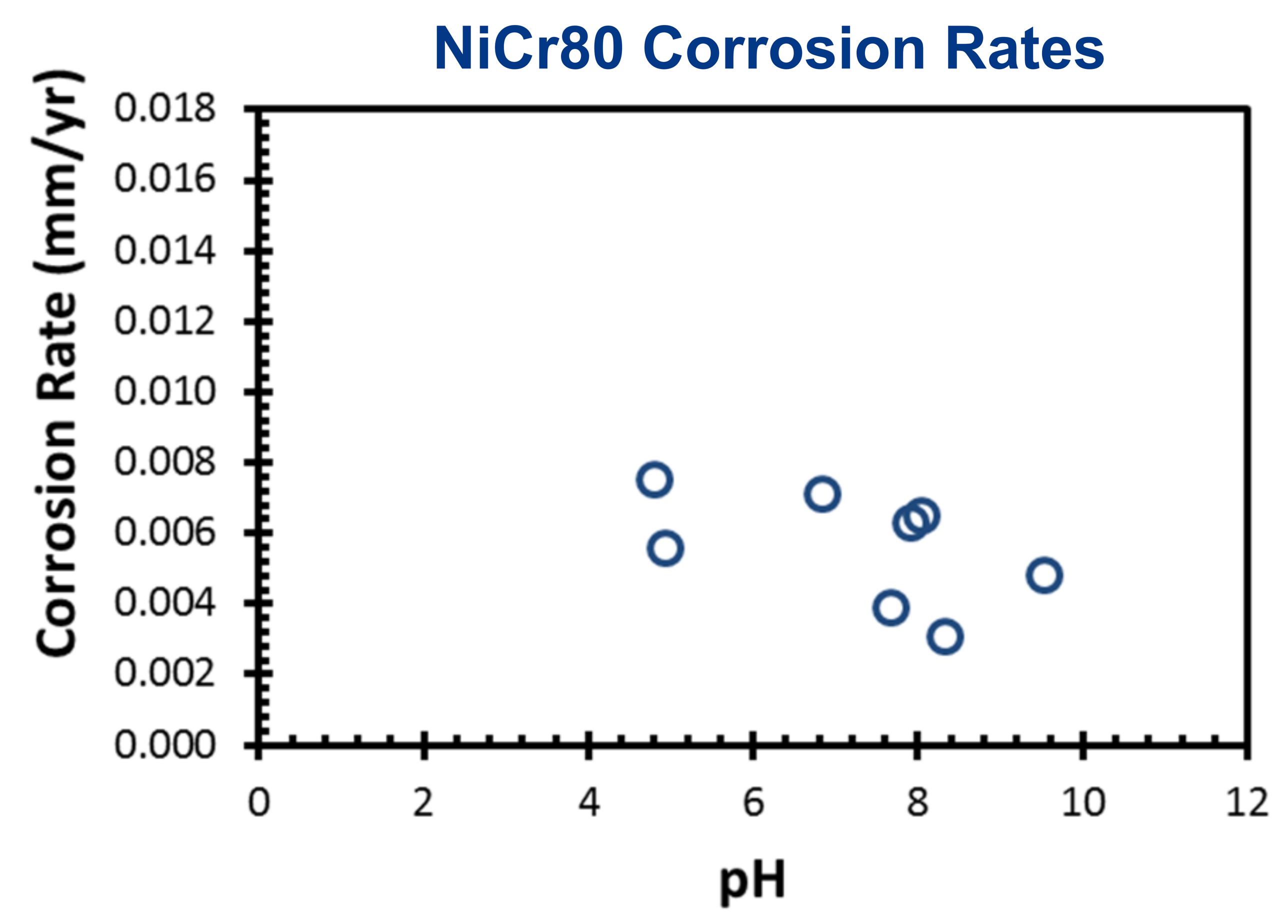
Results

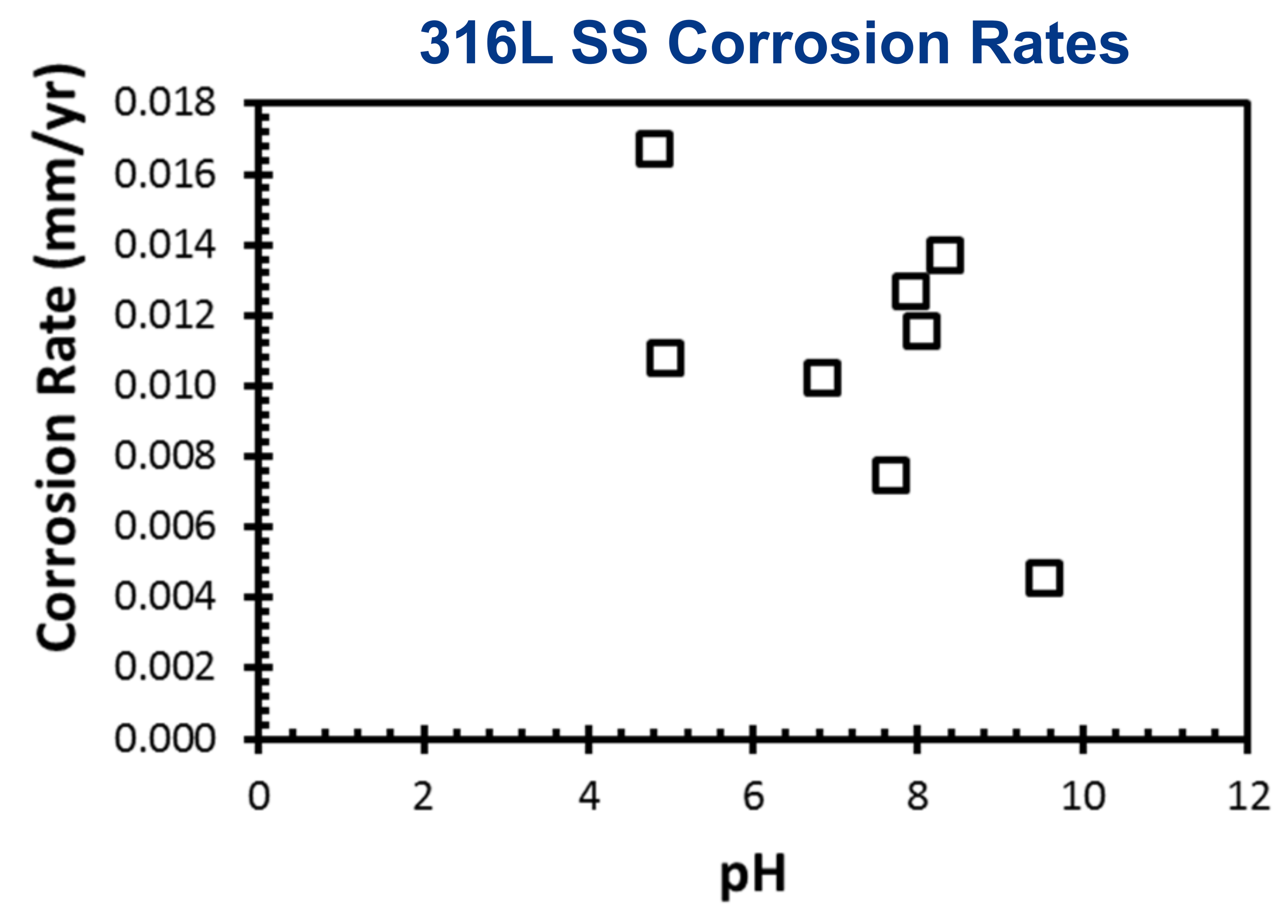


Representative polarization curve showing the equilibrium corrosion potential (E_{oc}) and Tafel regression



Current versus potential in the range of ±20 mV of E_{oc}. Polarization resistance (Rp) = slope.





Effect of solution pH on corrosion rates for nichrome 80 (NiCr80) and stainless steel (316L SS)

	NiCr80		316L Stainless Steel	
Solution pH	Average i_{corr} (µA/cm^2)	Corr Rate (µm/yr)	Average i_{corr} (µA/cm^2)	Corr Rate (µm/yr)
9.54	0.63 ± 0.04	5 ± 2	0.43 ± 0.12	5 ± 1
8.34	0.39 ± 0.13	3 ± 1	1.3 ± 0.01	14 ± 1
8.05	0.65 ± 0.15	7 ± 1	1.1 ± 0.3	12 ± 4
7.91	0.31 ± 0.06	6 ± 0.4	1.2 ± 0.2	13 ± 2
7.68	0.75 ± 0.06	4 ± 1	0.7± 0.4	7 ± 4
6.84	0.56 ± 0.16	7 ± 2	1.0 ± 0.2	10 ± 2
4.94	0.71 ± 0.25	6 ± 2	1.0 ± 0.3	11 ± 4
4.81	0.30 ± 0.08	8 ± 1	1.6 ± 0.2	17 ± 2

Average corrosion current and corrosion rate ± one standard deviation (n=3) for NiCr 80 and 316L SS in E-liquid (4.0% NBW) with varying pH.

Conclusions

- NiChrome and stainless steel are corrosion resistant metals, which makes traditional electrochemistry measurements challenging. The corrosion rates of carbon steel, for example, are several orders of magnitude higher under similar experimental conditions.
- This method can be used to qualitatively compare the potential for metal leaching into e-liquids. Further work is needed to derive accurate quantitative results.
- As pH decreases, the corrosion rate generally increases.
- Between NiCr80 and 316L stainless steel, NiCr80 has slightly lower corrosion rates likely arising from its higher Cr content.

References

1. Olmedo P, Goessler W, Tanda S, Grau-Perez M, Jarmul S, Aherrera A, et al.2018. Metal concentrations in e-cigarette liquid and aerosol samples: the contribution of metallic coils. Environ Health Perspect 126(2):027010, PMID: 29467105, doi:10.1289/EHP2175
2. ASTM G102-89. Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements. ASTM International: West Conshohocken, Nov. 2015. doi:10.1520/G0102-89R15E01

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