Anaerobic Digester Simulation

Pin Summary

A3 - MFC voltage 1
A4 - EC 2
A5 - PH 2
A6 - ORP 2
A7 - temp 1
A8 - Temp 2
A9 - MFC voltage 2

Claude Prompt:

"

Design me a python simulation. I have 3 inputs into a 1L anerobic digester. The 3 inputs are, fully fermented urine pure, iron oxide (roughly 10g/L) combined with spirulina in the powder form (10g/L) both in the same distilled water, and some concentration of molasses and red wine in distilled water.

Let's assume that there is instant mixing of the inputs on the states.

These three inputs are controlling 3 states. PH, EC, trace metals, iron oxide. Temperature is a disturbance that fluctuates by 5 degrees F from ambient.

I want the hydraulic retention rate (HRT Rate) to be set to 24 hours as a constant. This should change and go much lower when the PH goes below 6 or above 8 in order to correct the PH.

I want the pumps to dose the 1L reactor every 1 minute.

Run this simulation for 48 hours total. In the first few hours, dose with enough citric acid to make the PH 5. Once fully recovered, dose with enough lime to make the PH 9 in order to induce a stressor.

The outputs are MFC voltage and ORP. The baseline ORP should be around -220mV. THe baseline MFC voltage should be at 0.3V.

When printed, i wnat there to be an arduino style output every minute of how much of each input was used, what the states are, and what the outputs are.

At the end i want there to be a table of the final states next to the the target levels.

At the end I want there to be several graphs each graphing the ODEs of each of each of the states throughout the simulation and also the outputs throughout the simulation as well.

" End of claude prompt

States

1 PH

pH ODE Model for 1L CSTR

Core Equation:

$$\boxed{\frac{dpH}{dt} = \frac{1}{V} \cdot Q_{\text{total}} \cdot (pH_{\text{mix}} - pH) - 0.03 \cdot (T - 25) - 0.0167 \cdot (pH - pH_{\text{eq}})} \tag{1}$$

Where the mixed influent pH (buffer-weighted) is:

$$\boxed{pH_{\text{mix}} = \frac{\beta_u Q_u \cdot 9.1 + \beta_w Q_w \cdot 3.4 + \beta_s m_s \cdot 8.24 + \beta_m Q_m \cdot 5.5 + \beta_{fe} m_{fe} \cdot 7.0}{\beta_u Q_u + \beta_w Q_w + \beta_s m_s + \beta_m Q_m + \beta_{fe} m_{fe}}} \tag{2}$$

Parameters:

Symbol	Description	Value	Source
V	Reactor volume	1 L (1000 mL)	Given
Q_u	Fermented urine flow rate	mL/hr	Input
Q_w	Wine flow rate	mL/hr	Input
Q_m	Molasses flow rate	mL/hr	Input
m_s	Spirulina powder mass rate	g/hr	Input
m_{fe}	Iron oxide mass rate	g/hr	Input
β_u	Urine buffer capacity	490 meq/L	Larsen et al. (2021)
β_w	Wine buffer capacity	77 meq/L	Ribéreau-Gayon
β_m	Molasses buffer capacity	7 mEq/100g DM	Palmonari et al. (2020)
β_s	Spirulina buffer capacity	1.0 mEq/g	Ribeiro et al. (2012)
β_{fe}	Iron oxide buffer capacity	~0.5 mmol/(g·pH)	Jolsterå et al. (2012)
T	Temperature	°C	Disturbance
k_{decay}	Biological decay rate	0.0167 hr^{-1} (0.4/24)	Jonathan Castro
pH_{eq}	Equilibrium pH	~7	System dependent

Input pH Values:

Input	pH	Source
Fermented Urine	9.1	Larsen et al. (2021)

2 EC

Core EC Equation

$$\boxed{\frac{dEC}{dt} = \frac{1}{V} Q_{\text{total}} (EC_{\text{mix}} - EC) + 0.02 (T - 25) EC} \tag{3}$$

The 0.02 temperature coefficient is taken from your EC–temperature equation.

Mixed influent EC (flow-weighted)

$$EC_{\text{mix}} = \frac{Q_u\, EC_u + Q_w\, EC_w + Q_m\, EC_m + Q_s\, EC_s}{Q_u + Q_w + Q_m + Q_s} \tag{4}$$

pH–EC Coupling (piecewise, from your PDF)

This is the coupling block you can show under the EC section:

$$EC_{\text{eq}}(pH) = EC_{\text{base}} + \begin{cases} k_1(pH - 6), & pH < 6 \\ 0, & 6 \le pH < 8 \\ 0, & pH \ge 8 \end{cases} \tag{5}$$

(Your document labels this as the "Updated EC–pH Coupling Model.")
If you want it explicitly *applied* to the state, you can state:

$$EC \approx EC_{\text{eq}}(pH) \tag{6}$$

(algebraic coupling)

EC–Temperature Equation (reference form)

$$EC(T) = EC_{25}\left[1 + 0.02\,(T - 25)\right] \tag{7}$$

Legend / Parameters

Symbol	Description	Units
EC	Reactor electrical conductivity	mS cm^{-1}
V	Reactor volume	L
Q_u	Fermented urine inflow rate	mL hr^{-1}
Q_w	Wine inflow rate	mL hr^{-1}
Q_m	Molasses inflow rate	mL hr^{-1}
Q_s	Spirulina suspension inflow rate	mL hr^{-1}
Q_{total}	Total inflow rate $= Q_u + Q_w + Q_m + Q_s$	mL hr^{-1}
EC_u	EC of fully hydrolyzed urine	mS cm^{-1}
EC_w	EC of diluted wine	mS cm^{-1}
EC_m	EC of diluted molasses	mS cm^{-1}
EC_s	EC contribution of Spirulina	mS cm^{-1}
EC_{base}	Baseline EC at neutral pH	mS cm^{-1}
k_1	Acid-phase pH–EC coupling coefficient	mS cm^{-1} pH^{-1}
T	Reactor temperature	°C
EC_{25}	EC at 25°C	mS cm^{-1}

EC ODE with continuous pH coupling (with Spirulina)

$$\frac{dEC}{dt} = \frac{1}{V} Q_{\text{total}} \left(\frac{Q_u EC_u + Q_w EC_w + Q_m EC_m + Q_s EC_s}{Q_u + Q_w + Q_m + Q_s} - EC \right)$$
$$+ 0.02(T - 25)EC + k_1(pH - 6)\left[1 - \frac{1}{2}\left(1 + \tanh\left(\frac{pH - 6}{\varepsilon} \right) \right) \right] \tag{8}$$

Legend (with in-text citations)

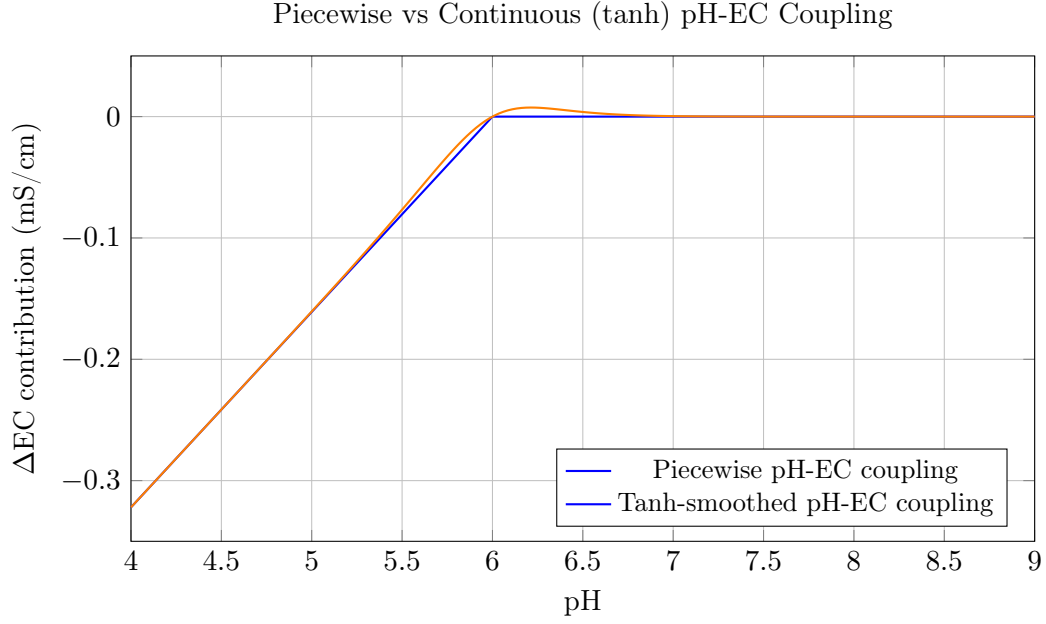| Symbol	Value / Definition	Units	In-text citation
EC	Reactor electrical conductivity (state)	mS cm^{-1}	—
t	Time	hr	—
V	Reactor volume	1 L	Given
Q_u	Fermented urine inflow rate	mL hr^{-1}	Model input
Q_w	Wine inflow rate	mL hr^{-1}	Model input
Q_m	Molasses inflow rate	mL hr^{-1}	Model input
Q_s	Spirulina suspension inflow rate	mL hr^{-1}	Model input
Q_{total}	$Q_u + Q_w + Q_m + Q_s$	mL hr^{-1}	Computed
EC_u	EC of fully hydrolyzed urine (20–25)	mS cm^{-1}	Udert et al., 2006
EC_w	EC of wine (~10% v/V)	1.5–2.5 mS cm^{-1}	Li et al., 2019
EC_m	EC of diluted molasses (~10%)	0.05–0.5 mS cm^{-1}	Darvishi et al., 2020
EC_s	EC contribution of Spirulina	0.3–0.5 mS cm^{-1}	MDPI 2023
T	Reactor temperature	°C	—
0.02	EC temperature coefficient	°C^{-1}	EC–T relation (PDF)
pH	Reactor pH	—	—
k_1	Acidic pH–EC coupling coefficient	mS cm^{-1} pH^{-1}	EC–pH model (PDF)
ε	Tanh smoothing width	0.1 pH	Hairer et al., 1993

Figure 1: Piecewise vs Continuous (tanh) pH-EC Coupling

3 Trace Metals

$$
\boxed{
\begin{aligned}
\frac{dC_{TM}}{dt} =& \frac{Q_U(t)}{V}\left(C_{TM,U}^{in}(t) - C_{TM}(t)\right) + \frac{Q_W(t)}{V}\left(C_{TM,W}^{in}(t) - C_{TM}(t)\right) \\
&+ \frac{Q_M(t)}{V}\left(C_{TM,M}^{in}(t) - C_{TM}(t)\right) + \frac{Q_S(t)}{V}\left(C_{TM,S}^{in}(t) - C_{TM}(t)\right)
\end{aligned}
}
\tag{9}
$$

Legend

Symbol	Definition	Units
$C_{TM}(t)$	Reactor **total trace-metal concentration** (aggregate)	mg L^{-1}
V	Reactor working volume (constant; inflow = outflow)	L
U	Fully fermented urine input stream	—
W	Winery wastewater / red wine input stream	—
M	Molasses input stream	—
S	Spirulina + iron-oxide slurry input stream	—
$Q_U(t), Q_W(t), Q_M(t), Q_S(t)$	Volumetric flow rates of each input stream	L time^{-1}
$C_{TM,U}^{in}(t)$	Total trace-metal concentration in the urine input	mg L^{-1}
$C_{TM,W}^{in}(t)$	Total trace-metal concentration in the wine input	mg L^{-1}
$C_{TM,M}^{in}(t)$	Total trace-metal concentration in the molasses input	mg L^{-1}
$C_{TM,S}^{in}(t)$	Total trace-metal concentration in the spirulina+FeOx input	mg L^{-1}

Iron Oxide (FeOx) ODE

$$\frac{dC_{FeOx}}{dt} = \frac{Q_{FeOx}(t)}{V}\left(C^{in}_{FeOx,FeOx}(t) - C_{FeOx}(t)\right) + \frac{Q_U(t)}{V}\left(C^{in}_{FeOx,U}(t) - C_{FeOx}(t)\right)$$
$$+ \frac{Q_S(t)}{V}\left(C^{in}_{FeOx,S}(t) - C_{FeOx}(t)\right) + \frac{Q_M(t)}{V}\left(C^{in}_{FeOx,M}(t) - C_{FeOx}(t)\right)$$
$$+ \frac{Q_W(t)}{V}\left(C^{in}_{FeOx,W}(t) - C_{FeOx}(t)\right)$$

(10)

Legend (Iron Oxide)

Symbol	Definition	Units
$C_{FeOx}(t)$	Reactor iron-oxide concentration (conservative species)	mg L^{-1}
V	Reactor working volume (constant; inflow = outflow)	L
FeOx	Iron-oxide nanoparticle input stream	—
U	Fully fermented urine input stream	—
S	Spirulina input stream	—
M	Molasses input stream	—
W	Wine / winery wastewater input stream	—
$Q_{FeOx}(t), Q_U(t), Q_S(t), Q_M(t), Q_W(t)$	Volumetric flow rates of each input stream	L time^{-1}
$C_{FeOx,FeOx}^{in}(t)$	FeOx concentration in the FeOx input stream	mg L^{-1}
$C_{FeOx,U}^{in}(t)$	Effective FeOx concentration in urine input	mg L^{-1}
$C_{FeOx,S}^{in}(t)$	Effective FeOx concentration in spirulina input	mg L^{-1}
$C_{FeOx,M}^{in}(t)$	Effective FeOx concentration in molasses input	mg L^{-1}
$C_{FeOx,W}^{in}(t)$	Effective FeOx concentration in wine input	mg L^{-1}

Assumptions: Well-mixed reactor; constant volume; $Q_{\text{out}} = Q_{FeOx} + Q_U + Q_S + Q_M + Q_W$; FeOx treated as conservative (no dissolution/aggregation/settling modeled).

Input Characterization Data

4   Fully fermented urine

Larsen, Riechmann, Udert (2021), State of the art of urine treatment technologies: A critical review, Water Research X. DOI: 10.1016/j.wroa.2021.100114

In Table 1 they give typical values for stored urine (i.e., after urea hydrolysis):

- pH = 9.1

- Alkalinity = 490 meq/L

Udert, Larsen, Gujer (2006)
Title: Fate of major compounds in source-separated urine
Journal: Water Science & Technology
DOI: 10.2166/wst.2006.921

This is the canonical urine chemistry paper used across wastewater, nutrient recovery, and urine treatment literature.

Reported values (stored / hydrolyzed urine):

- Electrical Conductivity (EC): 20–25 mS/cm

- pH: ≈ 9.1

- High ionic strength dominated by NH_4^+, HCO_3^-/CO_3^{2-}, K^+, Na^+, Cl^-

Udert, Larsen, Gujer (2006)
Title: Fate of major compounds in source-separated urine
Journal: Water Science & Technology
DOI: 10.2166/wst.2006.921

This paper is the foundation of modern urine chemistry modeling.
What it provides

- Explicit concentrations of major ions and trace metals

- Data refers to stored (fully hydrolyzed) urine

- Used extensively in nutrient recovery, electrochemical, and sanitation research

Reported trace metals (typical ranges, stored urine)

Values are typically reported in mg/L:

Metal	Concentration (mg/L)	Notes
Fe	0.3 − 1.5	Mostly complexed / particulate
Zn	0.2 − 0.6	Nutritional + corrosion sources
Cu	0.03 − 0.1	Low but measurable
Mn	0.02 − 0.1	Trace
Ni	0.01 − 0.05	Trace
Cr	<0.01	Often near detection limit
Cd	<0.001	Negligible
Pb	<0.005	Negligible

These values correspond to fully hydrolyzed urine, not fresh urine

Decay rate

0.4 / 24 hours estimated from Jonathan Castro

5   Spirulina Powder

Study Providing a Numerical Buffer Capacity Value for Spirulina Powder:

1. Primary Source (Direct Measurement):
Study Name: "Buffer Therapy for Cancer"
Authors: Maria de Lourdes C. Ribeiro, Ariosto S. Silva, Kate M. Bailey, et al.
Journal: Journal of Nutrition & Food Sciences, 2012. NIH-PA Author Manuscript (PMCID: PMC3872072).
Relevant Data: Table 1, under "Supplements."
Value: 1.0 mEq H$^+$ per gram of Spirulina powder.

Spirulina Powder pH Values

Source 1: MDPI Greece Study (2025)
Full Citation: Christodoulopoulou, M.A., Lazaridis, D.G., Simoni, M., et al. "Study of the Physicochemical and Phytochemical Parameters Together with Antibacterial Properties of Conventionally and Organically Cultivated Spirulina (*Arthrospira platensis*) in Greece." Life 2025, 15(11), 1761.
Link: https://www.mdpi.com/2075-1729/15/11/1761

Spirulina Form	Solvent	pH Value
Powder	Water	8.24 ± 0.01
Powder	Ethanol	7.77 ± 0.01

Spirulina Powder Trace Metals & Minerals - Study Summary

Source 1: Janda-Milczarek et al. (2023) - MDPI Applied Sciences

Citation: "Spirulina Supplements as a Source of Mineral Nutrients in the Daily Diet." Applied Sciences 2023, 13(2), 1011.

Link: https://www.mdpi.com/2076-3411/13/2/1011

Essential Minerals (mg/kg dry weight):

Mineral	Mean Value	Range/SD
Phosphorus (P)	15,149 mg/kg	± 13,024
Potassium (K)	14,274 mg/kg	± 3,628
Sodium (Na)	13,439 mg/kg	± 6,793
Calcium (Ca)	8,554 mg/kg	± 17,869
Magnesium (Mg)	3,726 mg/kg	± 1,283
Iron (Fe)	664 mg/kg	± 436
Strontium (Sr)	42 mg/kg	± 45
Selenium (Se)	0.31 mg/kg	± 0.91

Powder vs Tablet Form:

Mineral	Powder	Tablet
Iron (Fe)	673 mg/kg	Lower
Magnesium (Mg)	4,151 mg/kg	Lower
Potassium (K)	16,686 mg/kg	Lower
Sodium (Na)	9,868 mg/kg	Higher

Source 2: Al-Dhabi (2013) - Saudi Journal of Biological Sciences

Citation: Al-Dhabi, N.A. "Heavy metal analysis in commercial Spirulina products for human consumption." Saudi J Biol Sci. 2013;20(4):383-388.

Link: https://pmc.ncbi.nlm.nih.gov/articles/PMC3824145/

Heavy Metals/Trace Elements (mg/kg dry weight):

Metal	Range
Zinc (Zn)	0.533 – 6.225 mg/kg
Nickel (Ni)	0.211 – 4.672 mg/kg
Manganese (Mn)	0.005 – 2.248 mg/kg
Magnesium (Mg)	0.002 – 0.042 mg/kg*
Mercury (Hg)	0.002 – 0.028 mg/kg
Platinum (Pt)	0.001 – 0.012 mg/kg

*Note: The Mg value appears unusually low in this study; other studies report much higher values.

Source 3: Saharan & Jood (2017) - Indian Study

Citation: "Nutritional Composition of Spirulina platensis Powder and Its Acceptability in Food Products." Int. J. Adv. Res. 2017, 5(6), 2295-2300.

Link: https://www.researchgate.net/publication/318483740

Minerals (mg/100g dry weight):

Mineral	Value
Phosphorus (P)	790.42 mg/100g
Calcium (Ca)	620.80 mg/100g
Magnesium (Mg)	285.90 mg/100g
Iron (Fe)	49.50 mg/100g
Zinc (Zn)	3.95 mg/100g

6   Iron Oxide

Buffer capacity and pH of magnetite is negligible

Quantitative source: magnetite proton-exchange capacity is very small

What this paper does:

- Performs potentiometric titration of magnetite suspensions

- Quantifies surface protonation/deprotonation

- Reports site densities and titration curves

From their surface complexation modeling:

- Typical surface site density: $\sim$ 2–10 μmol H^+ per m^2

Even assuming high surface area magnetite ($\sim$100 m^2/g):

$$\beta_{\text{magnetite}} \sim 0.2\text{–}1 \text{ mmol } H^+ \, (g \cdot pH)^{-1} \tag{11}$$

This is the entire proton-exchange capacity of the solid.

7   Regular Red Wine

Ribéreau-Gayon, Glories, Maujean, Dubourdieu
Handbook of Enology, Volume 2: The Chemistry of Wine
Springer
ISBN: 978-0470010396
   Reported for regular red table wines

- Titratable acidity (TA): 5–7 g/L (as tartaric acid equivalents)

- Typical value often cited for red wine: ≈ 5.8 g/L

This value is measured by potentiometric titration and is explicitly used in enology as the wine's buffering capacity against added base.

✓ How you should state it (clean, review-proof)

"The buffering capacity of regular red wine is conventionally quantified by titratable acidity. Typical red table wines exhibit titratable acidity values of approximately 5–7 g L^{-1} (as tartaric acid equivalents)."
— Ribéreau-Gayon et al., Handbook of Enology, Vol. 2

Regular red wine — pH

Obreque-Slier et al. (2016)
Wine pH Prevails over Buffering Capacity of Human Saliva
Journal: Journal of Agricultural and Food Chemistry
DOI: 10.1021/acs.jafc.6b03013
   Reported:

- pH of commercial wines (including red): ~ 2.9–3.8

Trace metals in regular red wine (typical ranges)

Primary peer-reviewed source

Pohl, P. (2007)

Determination of metal content in wines by atomic absorption spectrometry

Journal: Food Chemistry

DOI: 10.1016/j.foodchem.2006.12.045

This paper reports measured trace metal concentrations in commercial wines (including red wines) using AAS.

Table: Trace metals in regular red wine

Metal	Typical concentration (mg/L)	Notes
Fe (Iron)	$1 - 10$	Highest trace metal
Zn (Zinc)	$0.2 - 5$	Yeast metabolism
Cu (Copper)	$0.05 - 1$	Fungicides, equipment
Mn (Manganese)	$0.5 - 2$	Naturally present
Ni (Nickel)	$0.01 - 0.1$	Trace contamination
Cr (Chromium)	<0.05	Usually very low
Pb (Lead)	<0.15	Regulated maximums
Cd (Cadmium)	<0.01	Near detection limit

Source: Pohl (2007), Food Chemistry, DOI: 10.1016/j.foodchem.2006.12.045

8 Molasses pH

Property	Value	Source
Molasses pH	5.5	Palmonari et al. (2020)
Molasses Buffer Capacity	7 mEq/100g DM	Palmonari et al. (2020)

Full Reference:

Palmonari, A., Cavallini, D., Sniffen, C.J., Fernandes, L., Holder, P., Fagioli, L., Fusaro, I., Biagi, G., Formigoni, A., & Mammi, L. (2020). Short communication: Characterization of molasses chemical composition. *Journal of Dairy Science*, 103(7), 6244-6249. DOI: 10.3168/jds.2019-17728

Molasses Trace Metals

Metal	Concentration (μg/g or mg/kg)	Source
Iron (Fe)	$1.61 - 287.03$	Altundag et al. (2016)
Copper (Cu)	$0.21 - 11.04$	Altundag et al. (2016)
Manganese (Mn)	$0.35 - 21.71$	Altundag et al. (2016)
Zinc (Zn)	$1.19 - 60.90$	Altundag et al. (2016)
Lead (Pb)	$0.82 - 3.06$	Altundag et al. (2016)
Nickel (Ni)	$0.04 - 1.96$	Altundag et al. (2016)
Aluminum (Al)	$0.62 - 120.52$	Altundag et al. (2016)

Full Reference:

Altundag, H., Bina, E., & Altıntig, E. (2016). The Levels of Trace Elements in Honey and Molasses Samples That Were Determined by ICP-OES After Microwave Digestion Method. *Biological Trace Element Research*, 170, 508-514. DOI: 10.1007/s12011-015-0468-3

9 Updated EC–pH Coupling Model

with specific in-text citation to the molasses MFC paper

$$EC(pH) = EC_{\text{raw}} + \begin{cases} 161(pH - 6), & \text{if } pH < 6 \\ 0, & \text{if } 6 \leq pH < 8 \\ 0, & \text{if } pH \geq 8 \end{cases} \tag{12}$$

Interpretation:

- $pH < 6$: Acidic EC–pH coupling due to MFC acid stress (Jin et al., 2022; Margaria et al., 2017)

- $6 \leq pH < 8$: Buffered/neutral range; negligible effect

- $pH \geq 8$: Alkaline regime; EC independent of pH in molasses-based MFCs (Rojas-Flores et al., 2022)

Full APA References

Jin, J., Amanze, C., Anaman, R., Zheng, X., Qiu, G., & Zeng, W. (2022). Electrochemical responses and microbial community shift of electroactive biofilm to acidity stress in microbial fuel cells. *Minerals*, 12, 1268.
https://doi.org/10.3390/min12101268

Margaria, V., Tommasi, T., Pentassuglia, S., Agostino, V., Sacco, A., Armato, C., ... Quaglio, M. (2017). Effects of pH variations on anodic marine consortia in a dual chamber microbial fuel cell. *International Journal of Hydrogen Energy*, 42(3), 1820–1829.
https://doi.org/10.1016/j.ijhydene.2016.07.250

Rojas-Flores, S., Pérez-Delgado, O., Nazario-Naveda, R., De La Cruz-Noriega, M., Benites, S. M., & Delfín-Narciso, D. (2022). Generation of bioelectricity using molasses as fuel in microbial fuel cells. *Environmental Research, Engineering and Management*, 78(2), 19–27.
https://doi.org/10.5755/j01.erem.78.2.30668

10   Temperature Equations

pH–Temperature Equation

$$pH(T) = pH_{25} - 0.03 \times (T - 25)$$
(13)

EC–Temperature Equation

$$EC(T) = EC_{25} \times [1 + 0.02 \times (T - 25)]$$
(14)

Both use **25°C** as the reference temperature.

Citations:

- **Hayashi, M. (2004).** "Temperature-electrical conductivity relation of water for environmental monitoring and geophysical data inversion." *Environmental Monitoring and Assessment*, 96(1-3), 119-128.

- **Bhuiyan, M.I.H., Mavinic, D.S., & Beckie, R.D. (2009).** "Determination of Temperature Dependence of Electrical Conductivity and Its Relationship with Ionic Strength of Anaerobic Digester Supernatant." *Journal of Environmental Engineering (ASCE)*, 135(11), 1221-1226.

11 Input EC Effect Summary

Input	Rate	EC Effect
Fermented Human Urine	104 mL/kg soil	0.28 → 2.35 mS/cm
Spirulina powder	1 g/L	∼0.3–0.5 mS/cm
Molasses (diluted)	100 mL/L (10% solution)	∼0.05–0.5 mS/cm
Iron Oxide NPs	50 mg/L	Negligible
Wine	100 mL/L (10% solution)	∼1.5–2.5 mS/cm

Input	Estimation Method	Source
Fermented Human Urine	Directly measured: soil EC baseline 0.28 mS/cm increased to 2.35 mS/cm at 104 mL/kg	Zhang, Y., et al. (2025). *Frontiers in Agronomy*, 7, 1610839.
Spirulina powder	Estimated from ion concentrations using standard EC-ion relationships	Microalgae biomass biofertilizer study. ResearchGate.
Molasses (diluted)	EC decreased from 0.5 to 0.05 S/m as sugar concentration increased	Darvishi, H., et al. (2020). *J. Food Sci. Technol.*, 57(4), 1362–1375.
Iron Oxide NPs	No significant EC/salinity stress at 20–100 mg/L	Hu, J., et al. (2017). *J. Nanobiotechnology*, 15(1), 51.
Wine	Wine EC typically 1.5–2.5 mS/cm; varies with pH	Li, C., et al. (2019). *Scientific Reports*, 9, 5765.

Claude is AI and can make mistakes. Please double-check cited sources.