Cal-Cu-lator: Copper Concentration Calculator for Industrial Wastewater Streams

Membrion Capstone Team
Asiran Chaing, Jacob Faulk, Trevor Gaffney, Kieran Heiberg, Alyssa Hicks
Department of Chemical Engineering, University of Washington

MEMBRION
CHEMICAL ENGINEERING
UNIVERSITY of WASHINGTON

Background

- $CuSO_4$ is a critical compound used in electroplating during the semiconductor manufacturing process
- Typical fab produces more than 1500 metric tons of $CuSO_4$ waste annually [1]
- Current lab-based methods to determine copper concentration in waste streams are time-intensive and expensive

pH	Cu Conc. (ppm)	Other metals	TDS (ppm)	Turbidity (NTU)
1–7.6	30–15k	Ni, Zn	1k–100k	0–300

Table 1. Typical electroplating effluent stream parameter ranges for semiconductor fab [2]

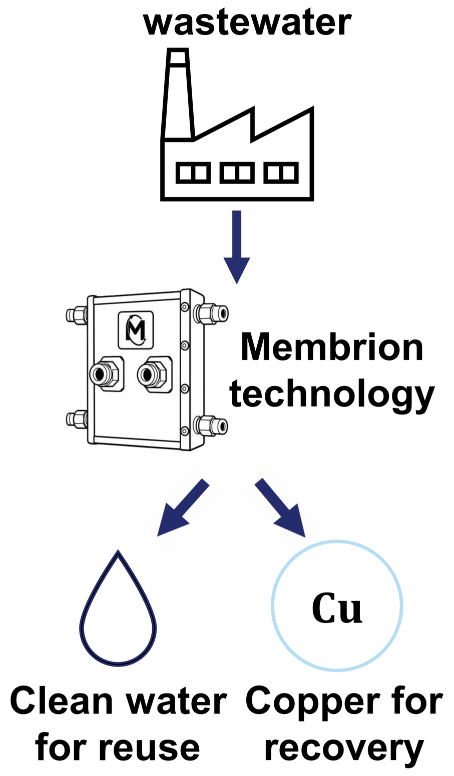

Fig 1. *Diagram of the separation of wastewater into water and copper*

Methods & Building Cu Calculator

1. Dissolve a known concentration of Cu^{2+} into a beaker
2. Adjust pH and temperature (ºC) to values shown in Table 2
3. Measure refractive index (RI) and conductivity (μS/cm)

pH	Temp. (ºC)	Cu Conc. (ppm)
2–4	15–35	0–250

Table 2. Experimental dataset parameter ranges

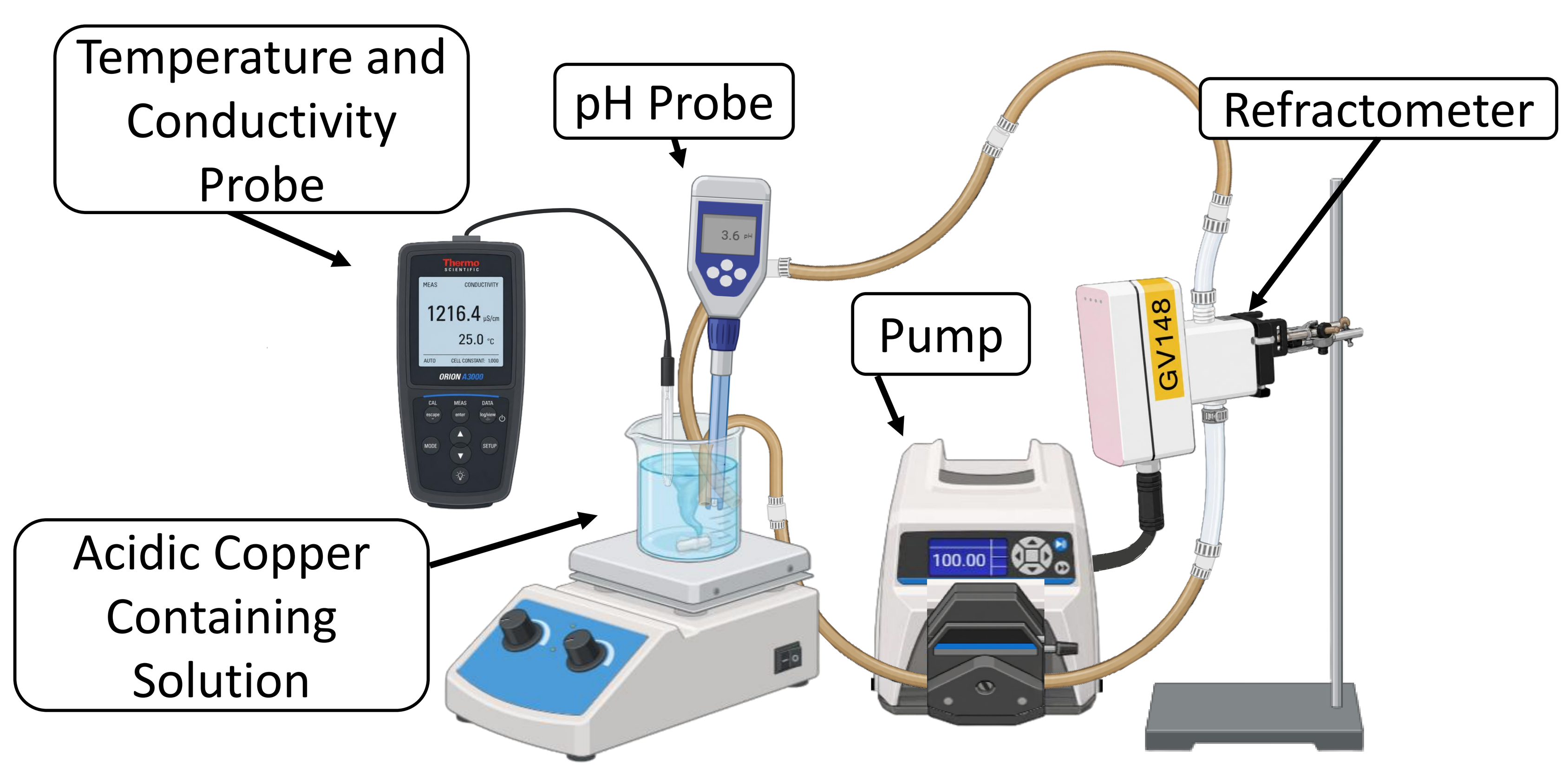

Fig 2. *Experimental setup including copper solution on a hot plate being tested for pH, temperature, and refractive index*

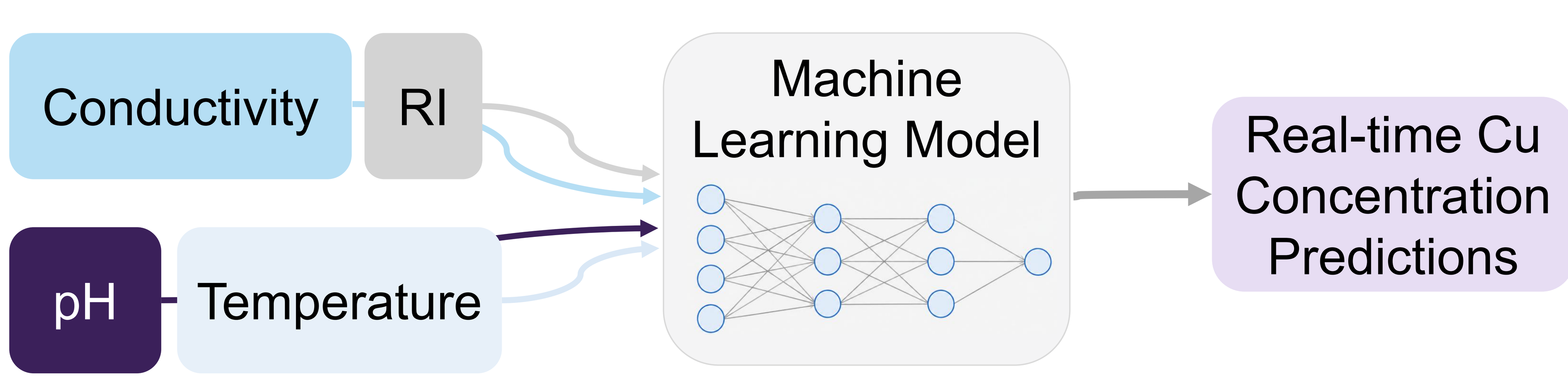

Fig 3. *Schematic of the machine learning framework used to make real-time copper concentration predictions based on conductivity, RI, pH, and temperature*

Results & Model Performance

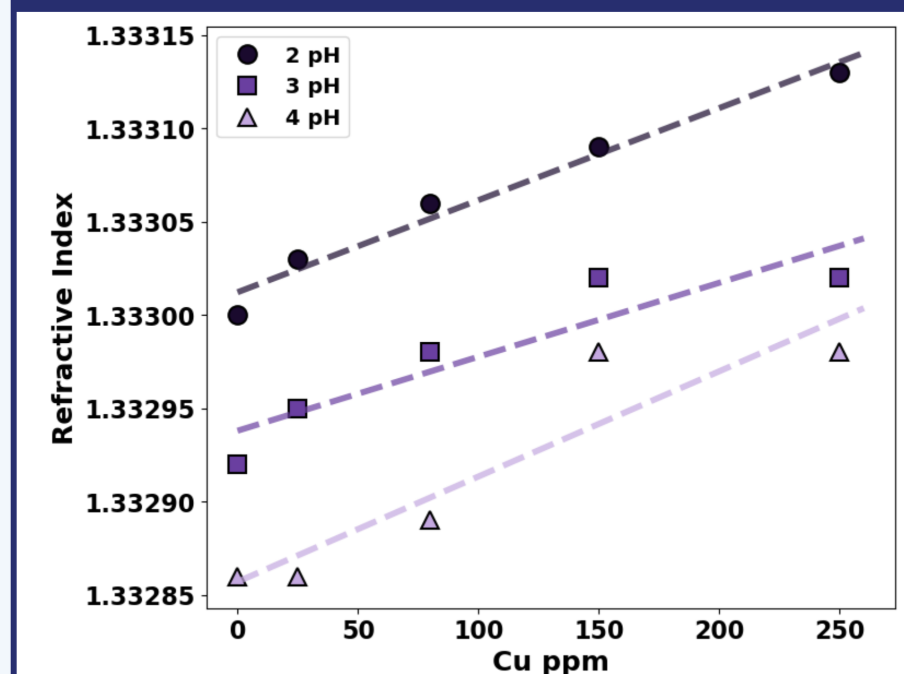

Fig. 4. *Refractive index vs. copper concentration at 22 °C. Dotted lines indicate the linear regression fit per pH*

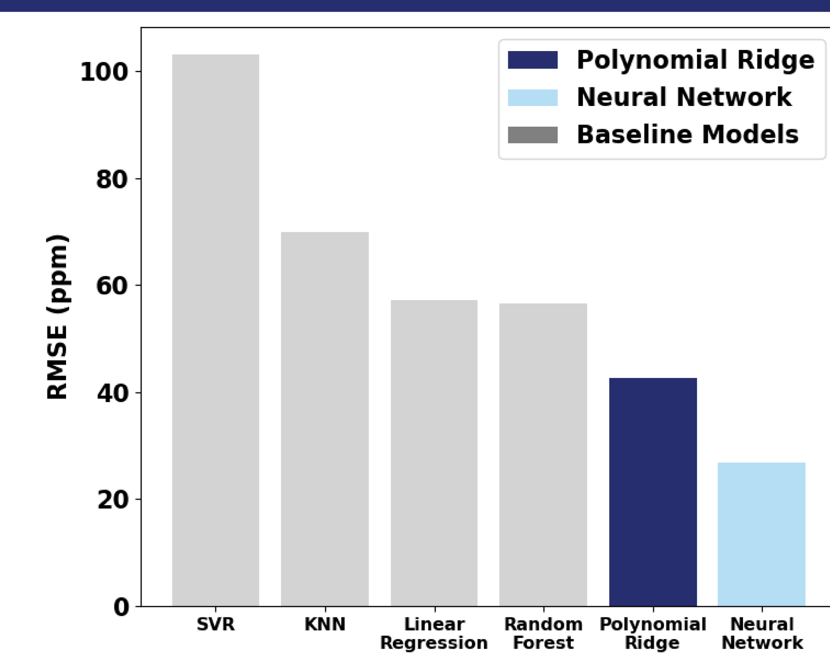

Fig. 6. *Root mean square error (RMSE) for various machine learning models based on the experimental dataset*

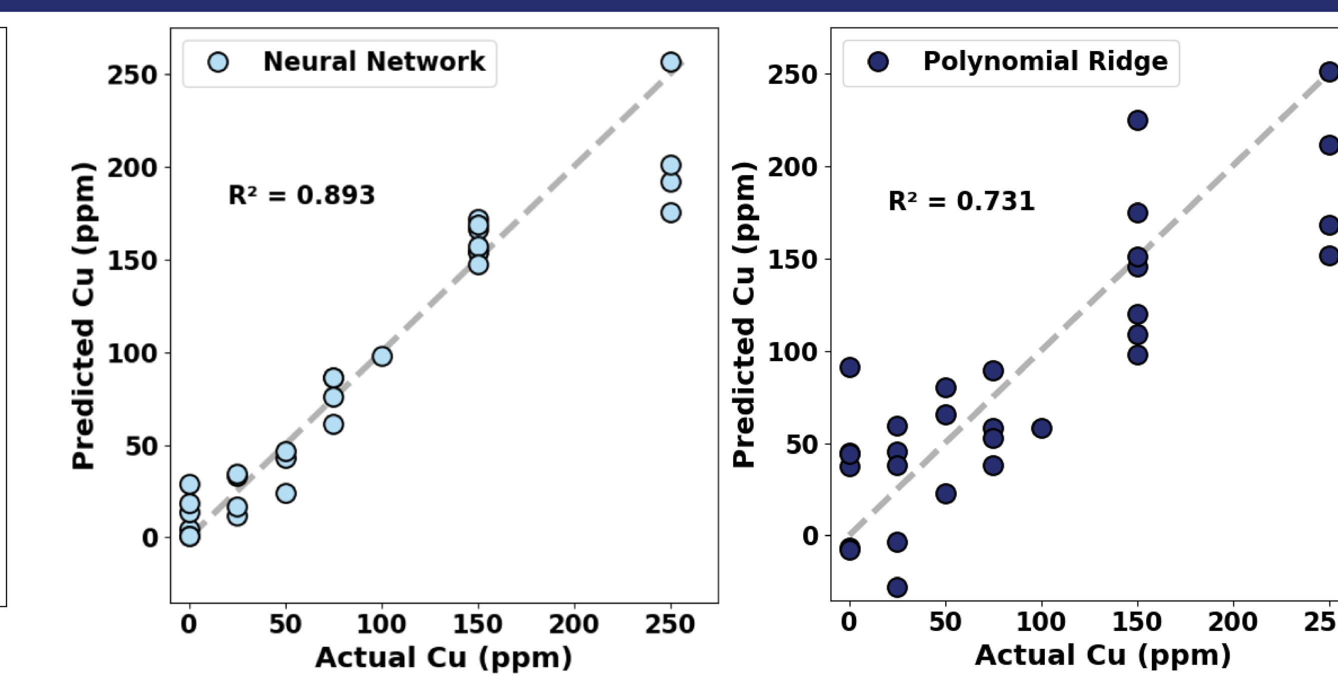

Fig. 8. *Parity plots of the actual copper ppm vs. model-predicted Cu ppm for both the NN and PR models. Parity is represented as the dotted line*

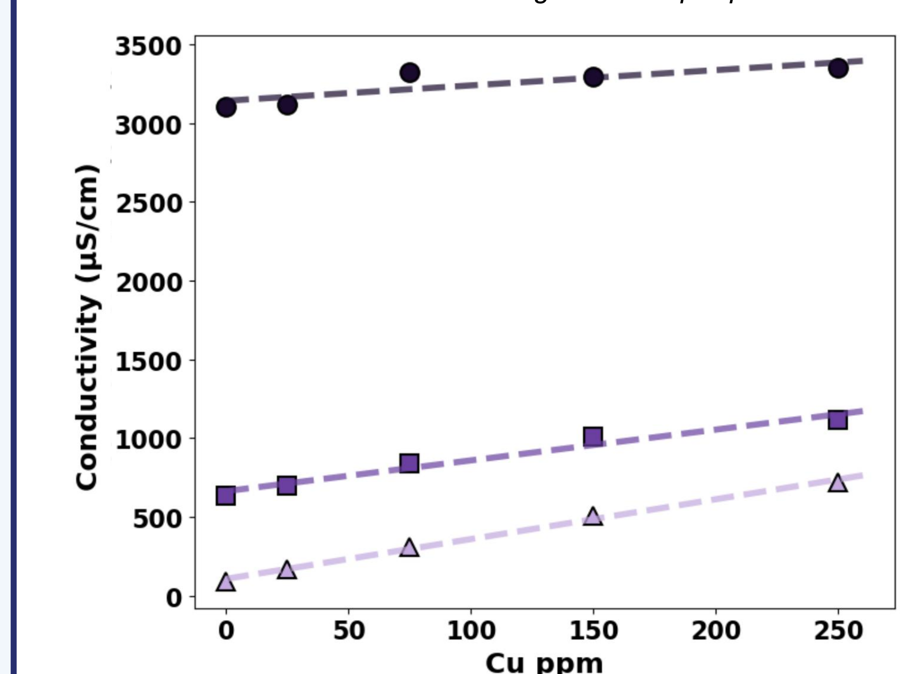

Fig. 5. *Conductivity vs. copper concentration at 22 °C. Dotted lines indicate the linear regression fit per pH*

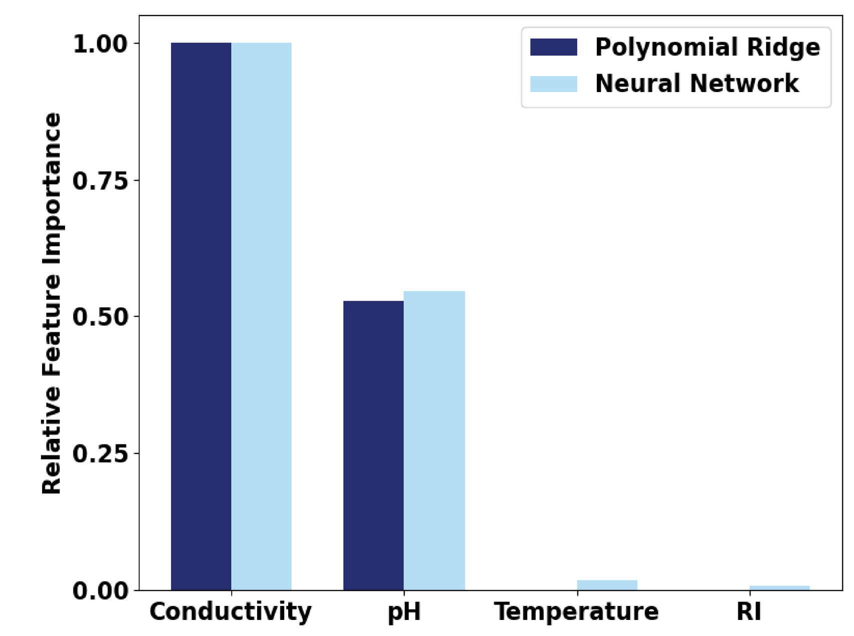

Fig. 7. *Relative feature importance of model parameters for the two best-performing ML models*

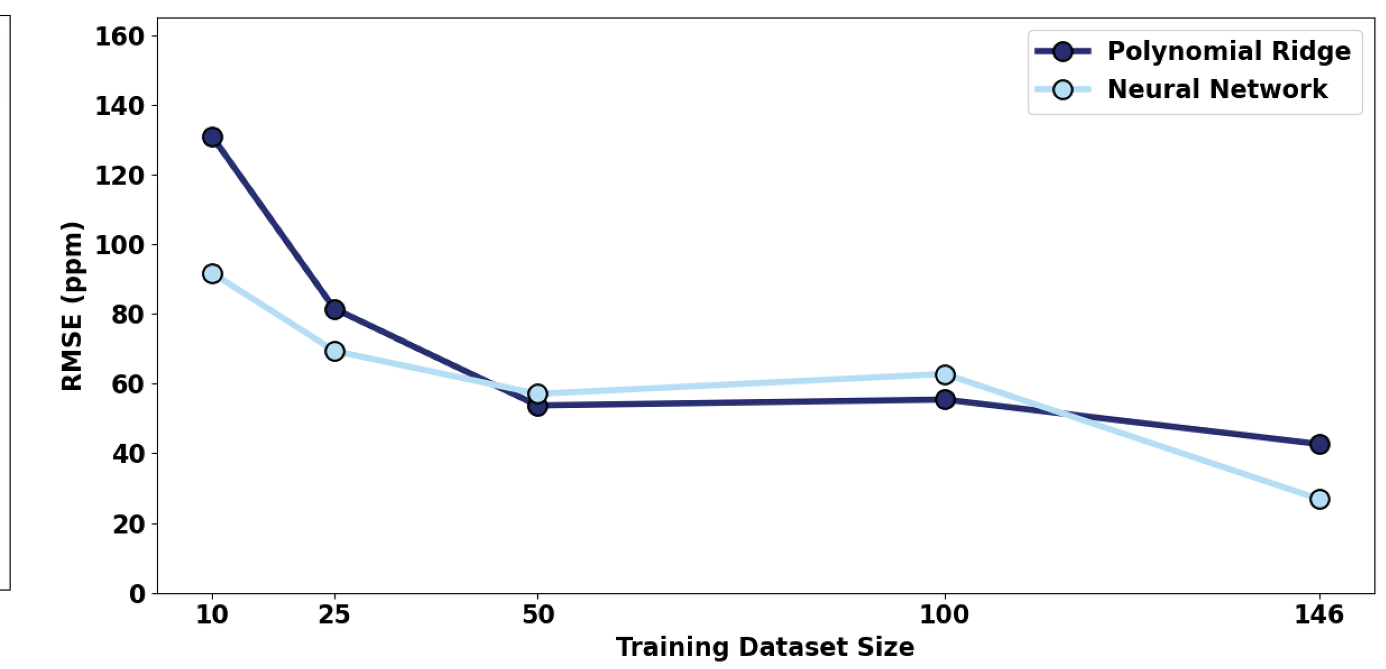

Fig. 9. *Model RMSE vs. training dataset size for the two best-performing models*

Cal-Cu-lator

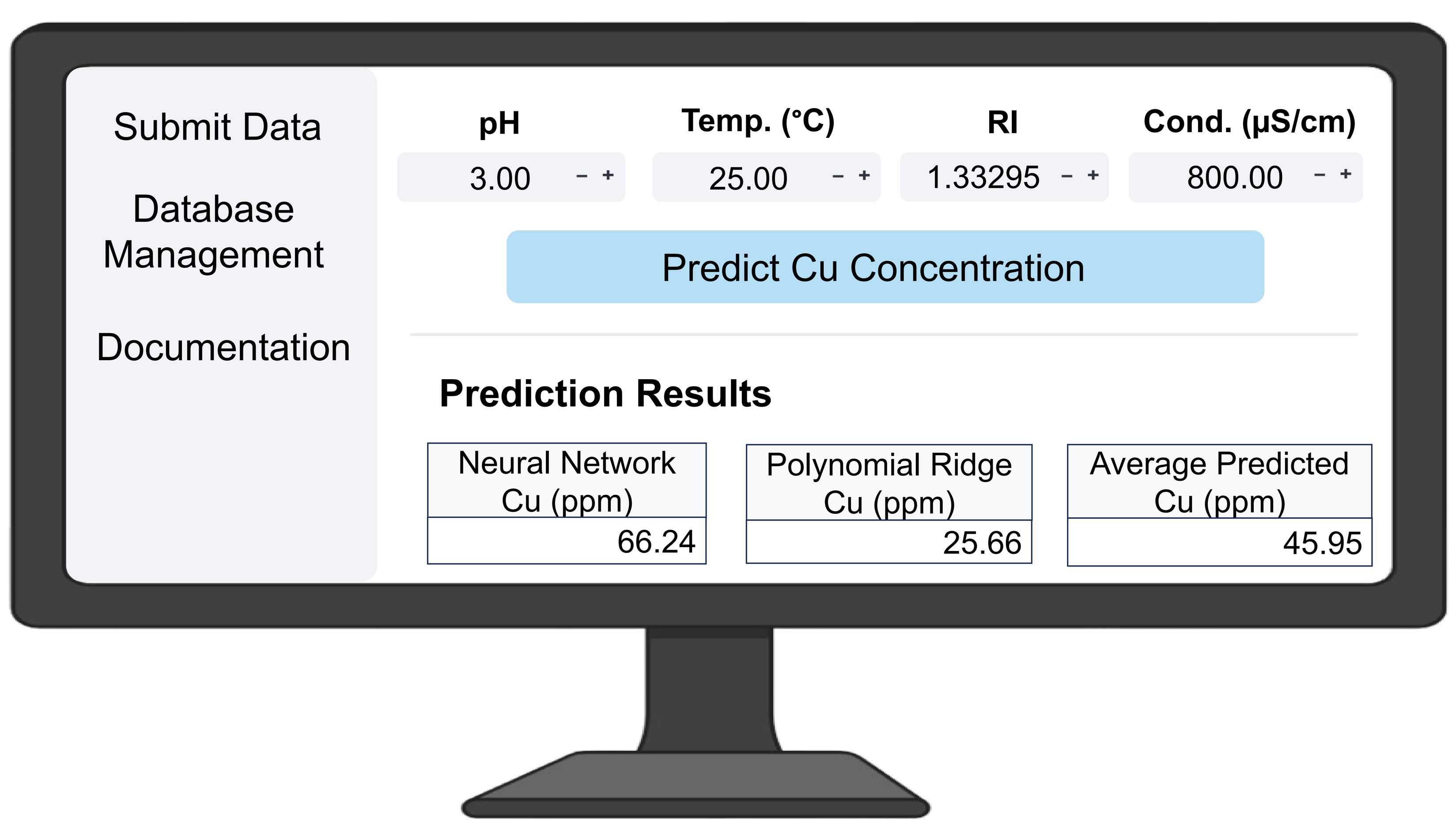

Fig 10. *Depiction of web-based copper concentration calculator, where user inputs of pH, temp, RI, and conductivity result in a neural network and polynomial ridge prediction of copper concentration*

- Users can submit new data to improve model accuracy, with user metadata integrated for active database management
- Multiple ML model predictions mitigate overfitting
- Data can be exported to and from Excel

Conclusions, Impact & Future Work

- A predictive ML model can estimate copper concentration with ~30 ppm accuracy, with conductivity and pH as the most influential variables
- Enhanced copper monitoring could support faster wastewater treatment, improved resource recovery, and more sustainable manufacturing
- Future work can include turbidity, other common metals, and expanded parameter ranges

Acknowledgments & References

Thank you to Ryan Flores and to the Membrion team for their continued support of UW Chemical Engineering. Thank you to Prof. Dave Beck for his mentorship.

[1] UMC, “Turning wastewater into gold - UMC recycles waste copper sulfate to produce copper pipes, contributing to the implementation of a circular economy,” *United Microelectronics Corporation*, 2023.
[2] M. A. Al-Shannag *et al.*, “Treatment of industrial electroplating wastewater for metals removal via electrocoagulation continuous flow reactors,” *Water Practice & Technology*, 2021.