Predicting Solution Color in Centrifugal Contactor Solvent Extraction

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Abstract

In the domain of nuclear non-proliferation, solvent extraction is instrumental. This research advances this domain by focusing on predicting solution color in centrifugal contactor solvent extraction using machine learning. Drawing from rich multi-modal sensor data from the Bonneville County Technology Center testbed—including parameters like pH, temperature, conductivity, and solution color—two distinct predictive models were curated. One harnessed the entirety of the sensor readings, while the other intentionally omitted conductivity to discern its impact on predictive precision. Extensive data preprocessing was paired with robust modeling techniques, revealing key predictors and their intricate interplay in determining solution color. The resultant models not only illuminate the nuances of solvent extraction but also set the stage for enhanced operational efficiency in the Beartooth Solvent Extraction Testbed. This work underscores the transformative potential of machine learning in refining and optimizing critical nuclear engineering processes.

Introduction & Objectives

Solvent extraction is critical in the nuclear industry…

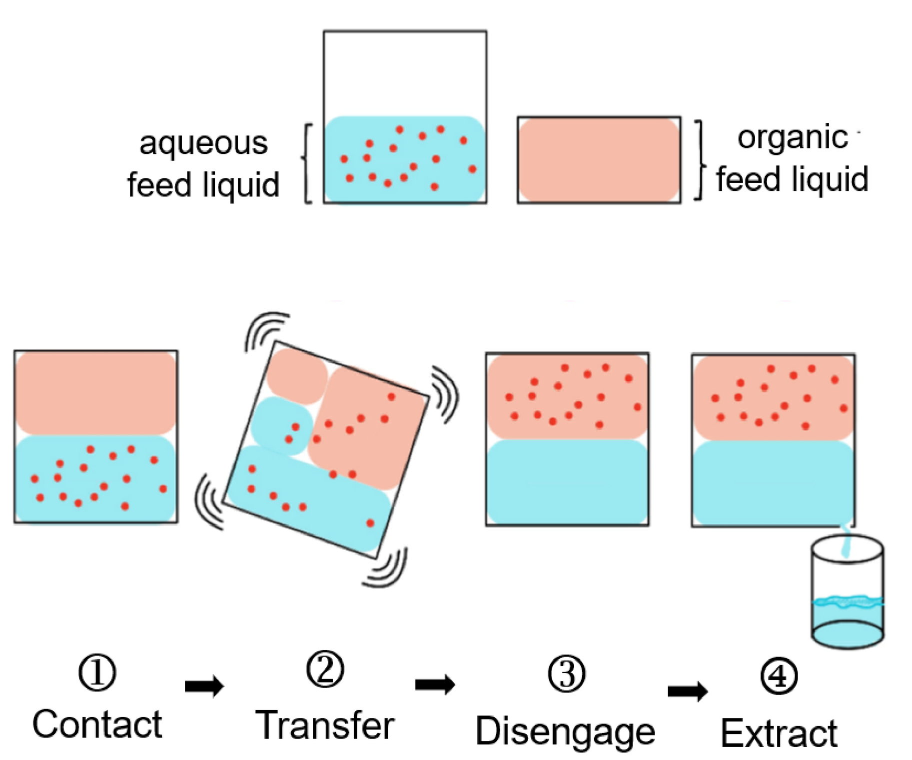


Fig 1. *Illustration of the four main steps in the general solvent extraction process: (1) Contact, (2) Transfer, (3) Disengagement, & (4) Recovery*

- Solvent extraction plays an indispensable role in the selective separation of different isotopes, a critical process in nuclear non-proliferation (NNP) efforts.

What challenges are faced in monitoring centrifugal contactor solvent extraction processes?

- Centrifugal contactors offer compactness, simultaneous mass transfer and phase separation, yet their intricate interactions make outcome prediction difficult.

How can machine learning and sensor measurements help?

- Our research employs machine learning and multi-sensor data to forecast solution color during solvent extraction.
- Real-time predictions can elevate process monitoring, control, and efficiency, minimizing waste.
- Our efforts bolster nuclear safety and NNP through refined predictive models and enhanced material usage understanding.
- The insights gained will directly inform the design of the Beartooth Testbed,

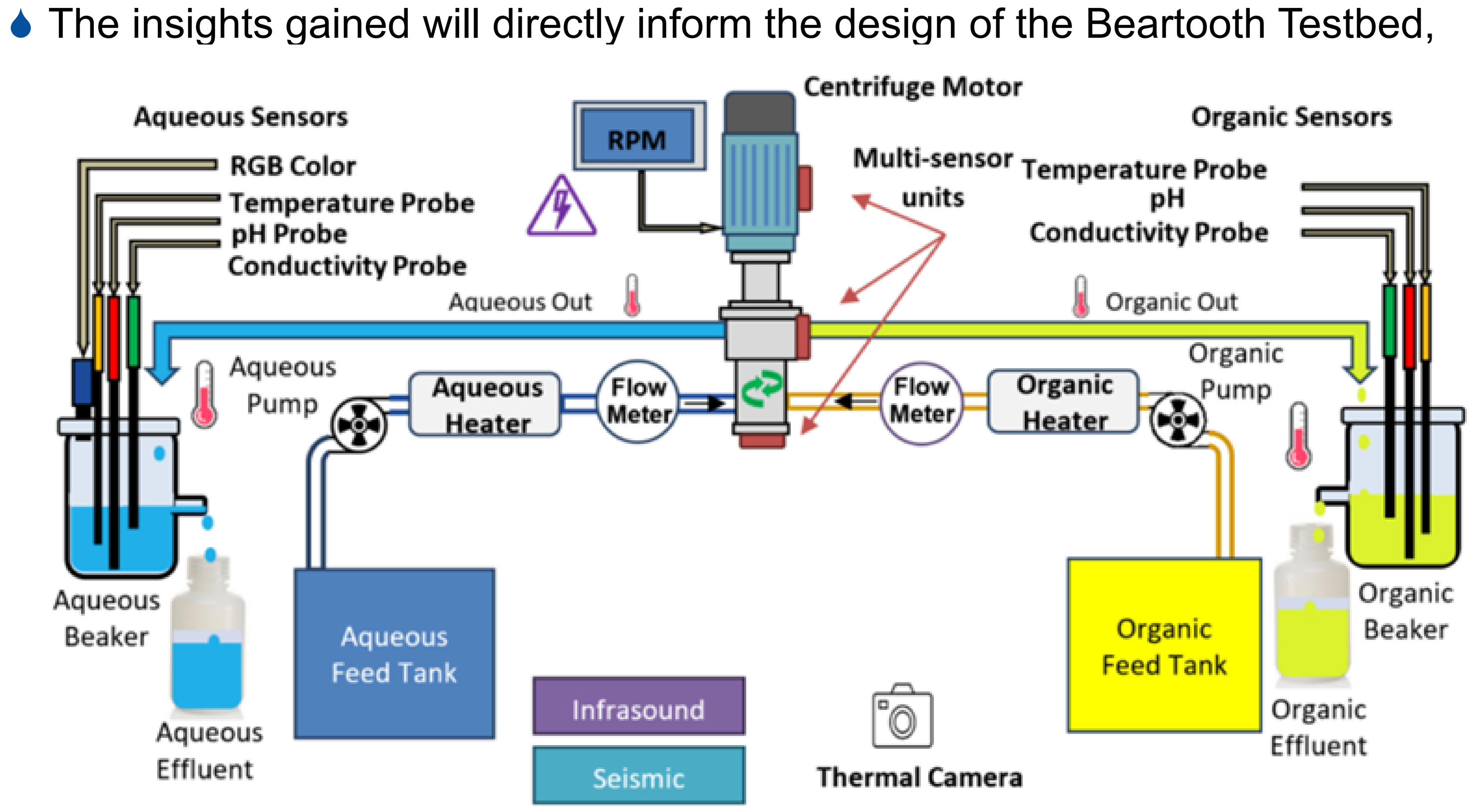
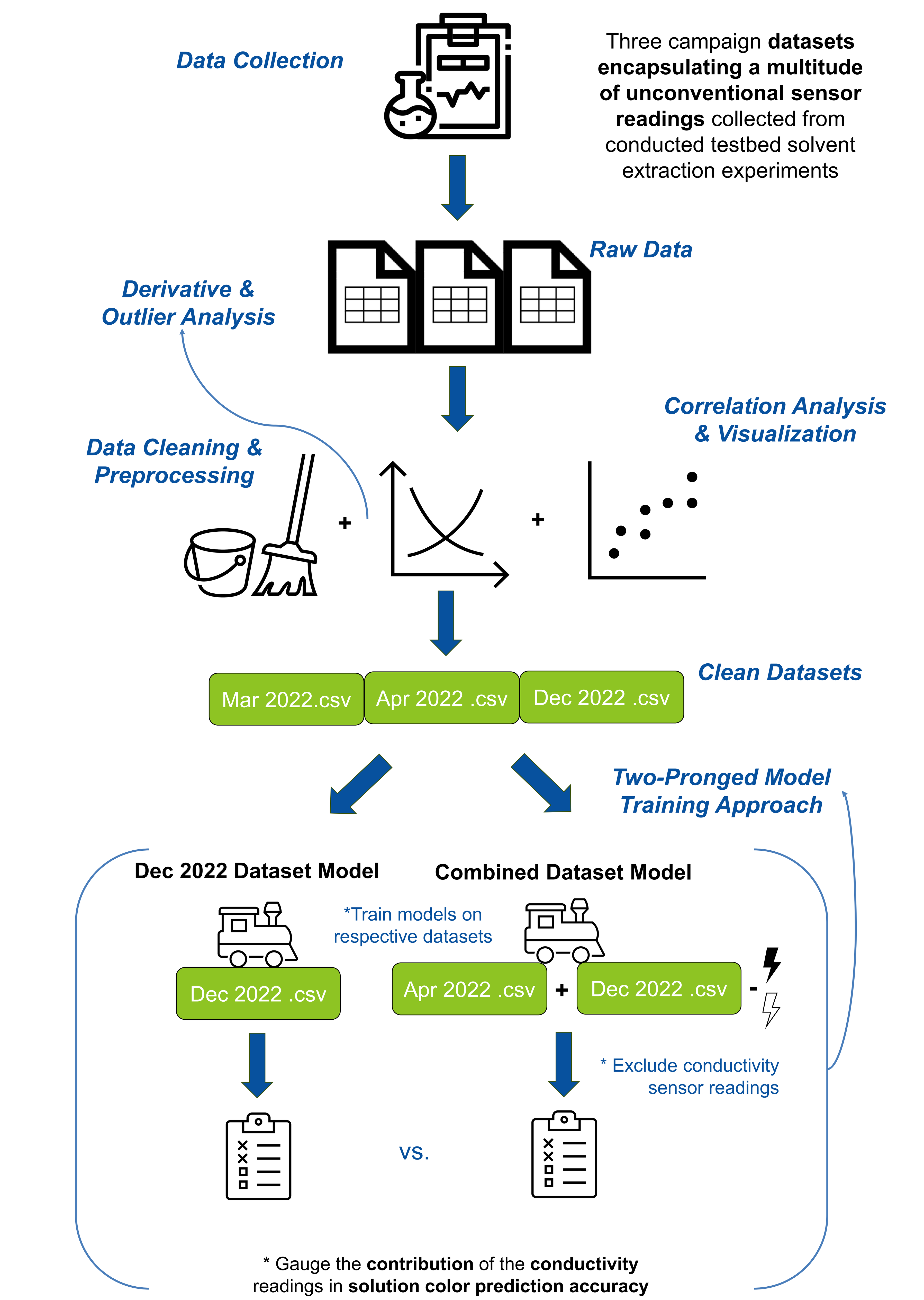


Fig 2. *Diagram of centrifugal contactor solvent extraction testbed experiment setup with sensors monitoring a single contactor. Non-traditional sensors have been installed around single and multiple contactors for testing.*

Materials and Methods



Acknowledgements

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Results

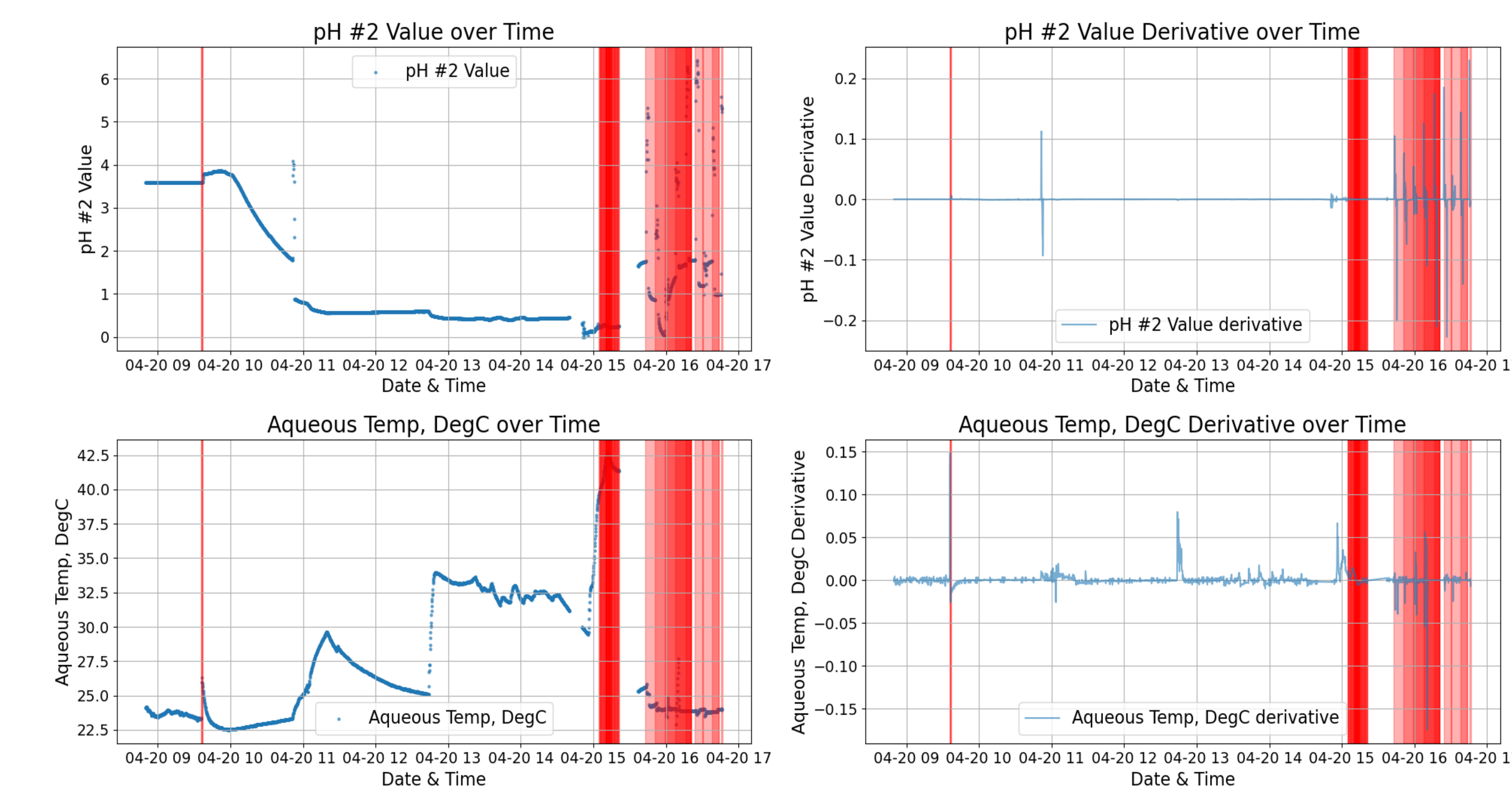

Fig 3. *This figure presents the final exclusion regions in our dataset after our comprehensive data cleaning process. The highlighted regions represent data points removed from our analysis, leaving behind a robust and reliable dataset for our ML model development.*

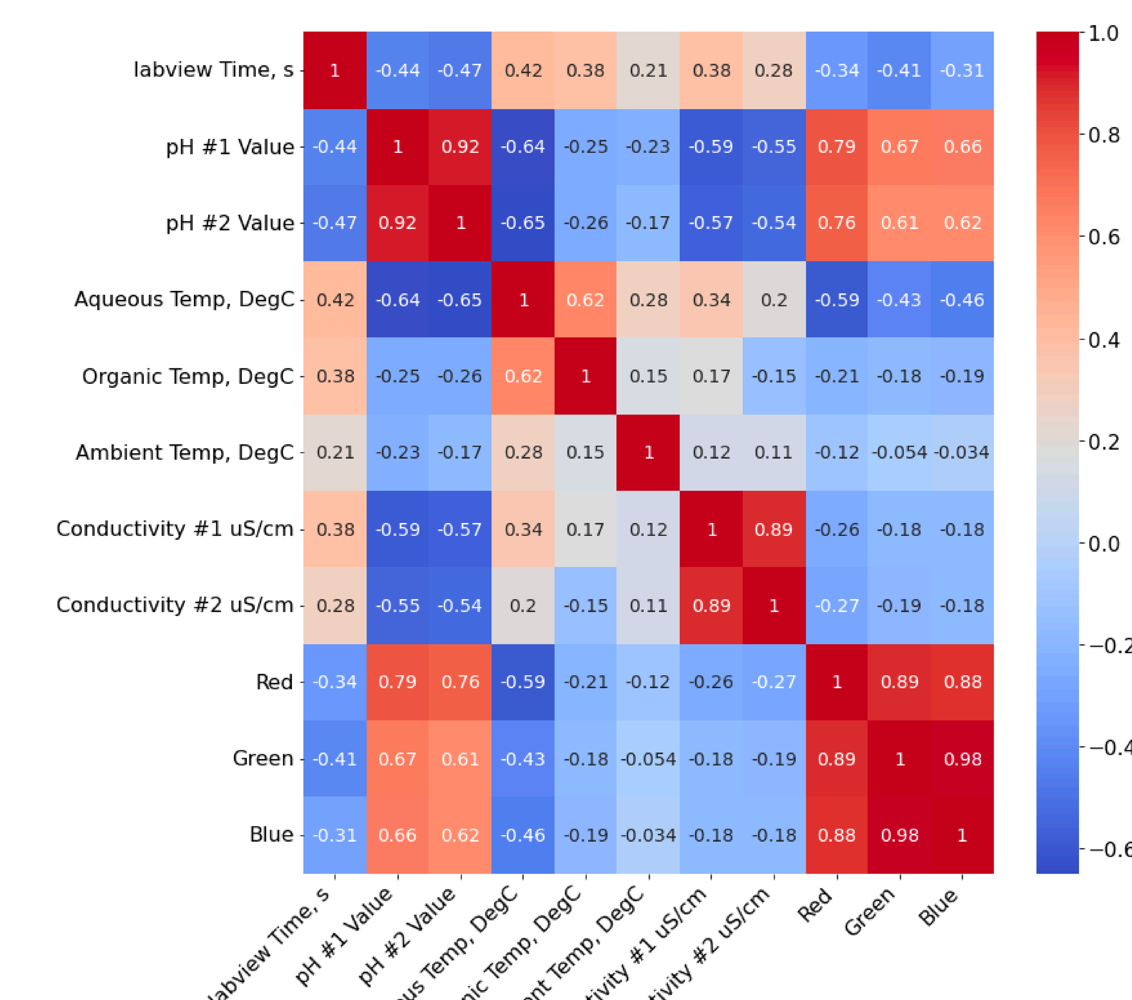

Fig 4. *This figure presents the final exclusion regions in our dataset after our comprehensive data cleaning process. The highlighted regions represent data points removed from our analysis, leaving behind a robust and reliable dataset for our ML model development.*

- Preliminary findings reveal significant correlations among sensor readings, with visualizations offering intuitive insight into these relationships.
- A rigorous data cleaning. methodology has produced a clean dataset, primed for ML model training.

Dec 2022 Model MAE	**~1.588**
Combined Model MAE	**~2.270**

Random December 2022 Prediction	Red	Green	Blue
True	229.0	250.0	241.0
Predicted	229.0	~249.999	~241.661

Optimal Model	Optimal Hyperparameters	Optimal Feature Combination
K-Nearest Neighbors (KNN) Regressor	• neighborhood size of 3 • Minkowski metric parameter (p) of 1 • weight function of 'distance'	all features available

Conclusion

Our research offers an innovative method for predicting solution color in solvent extraction using machine learning. Elevated mean absolute error in the combined dataset may arise from increased variability. KNN, and established optimal parameters, excels at deciphering non-linear relationships in compact datasets, its distance-weighting prioritizing proximate data points in high-dimensional contexts. Through MAE scoring, RFECV feature selection, and hyperparameter tuning, we identified the best models, accentuating pivotal features for enhanced accuracy. Comparative analysis across datasets illuminates the potential utility of our ML model in diverse operational studies.