

WHY THIS STUDY?

Se and Sr may coexist in mining, industrial, munition production and nuclear wastewaters, but their different aqueous chemistry makes simultaneous removal difficult.

Sono-EC combines in situ Fe/Al hydroxide formation with acoustic cavitation to improve mass transfer and limit electrode passivation.

OBJECTIVE: Evaluate simultaneous Se and Sr removal in a recirculating multi-stage reactor.

EXPERIMENTAL DESIGN

Matrix	Synthetic wastewater, 7 L; Se = Sr = 10 mg/L
Design	24-run D-optimal RSM
Current	5, 15, 25 A
Time	5, 15, 25 min per cycle
Ultrasound	150, 300, 450 W; 45 kHz
Electrodes	4 Fe or Al electrodes
pH regime	No adjustment or 2.5–3.5 / 9.5–10.5

MULTI-STAGE PROCESS

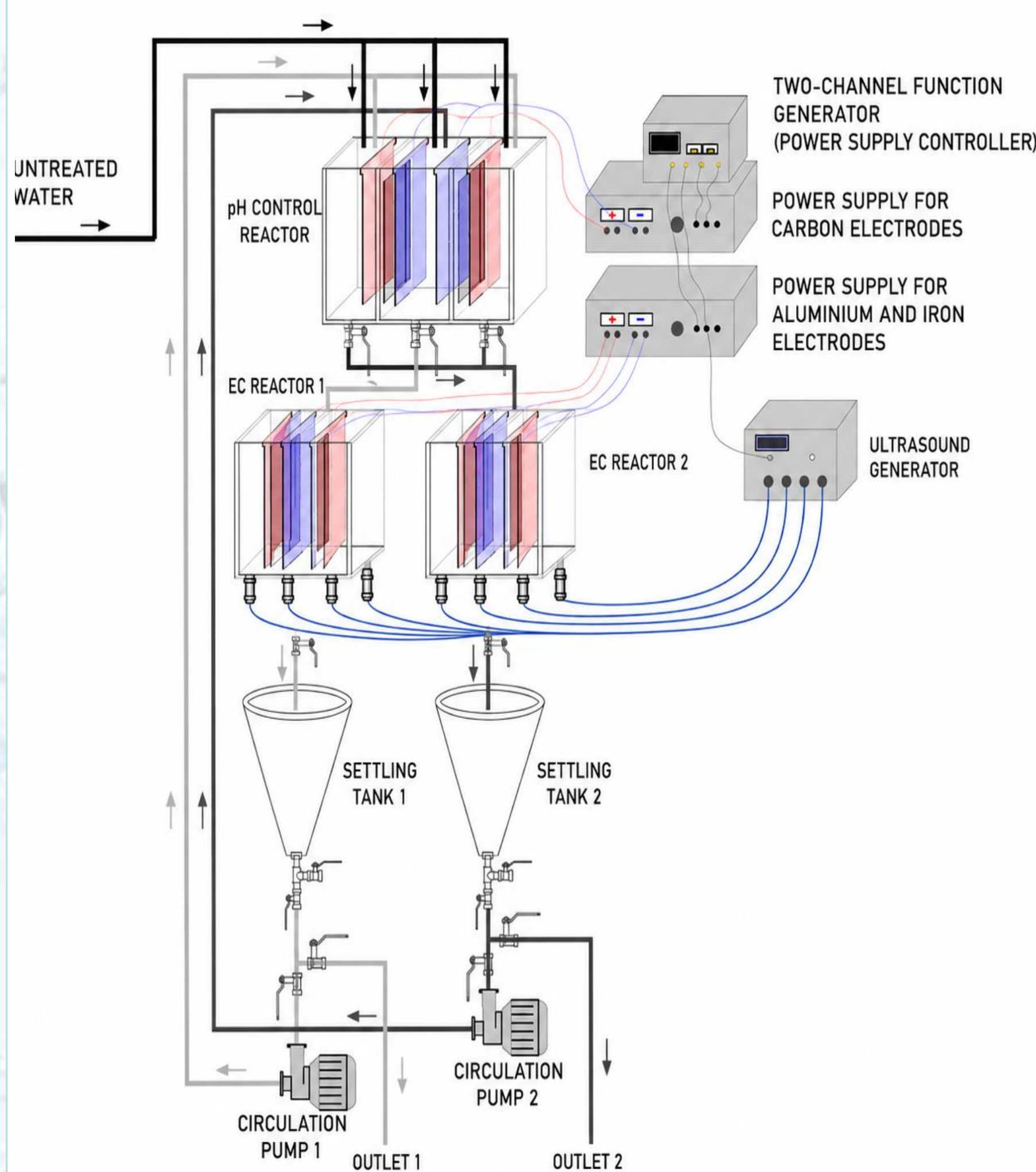


Fig. 1. Schematic overview of the process

Under the maximum pH regime, electrochemical pH modulation was performed for 15 min using graphite electrodes, producing acidic (pH 2.5–3.5) and alkaline (pH 9.5–10.5) streams. Each stream was treated separately in a sono-EC reactor equipped with 4 Fe or Al electrodes.

After first cycle of treatment, the suspensions were transferred to settling tanks and the clarified water was returned to the pH reactor for a second cycle, with the acidic and alkaline streams exchanged between compartments.

SONO-EC REACTOR

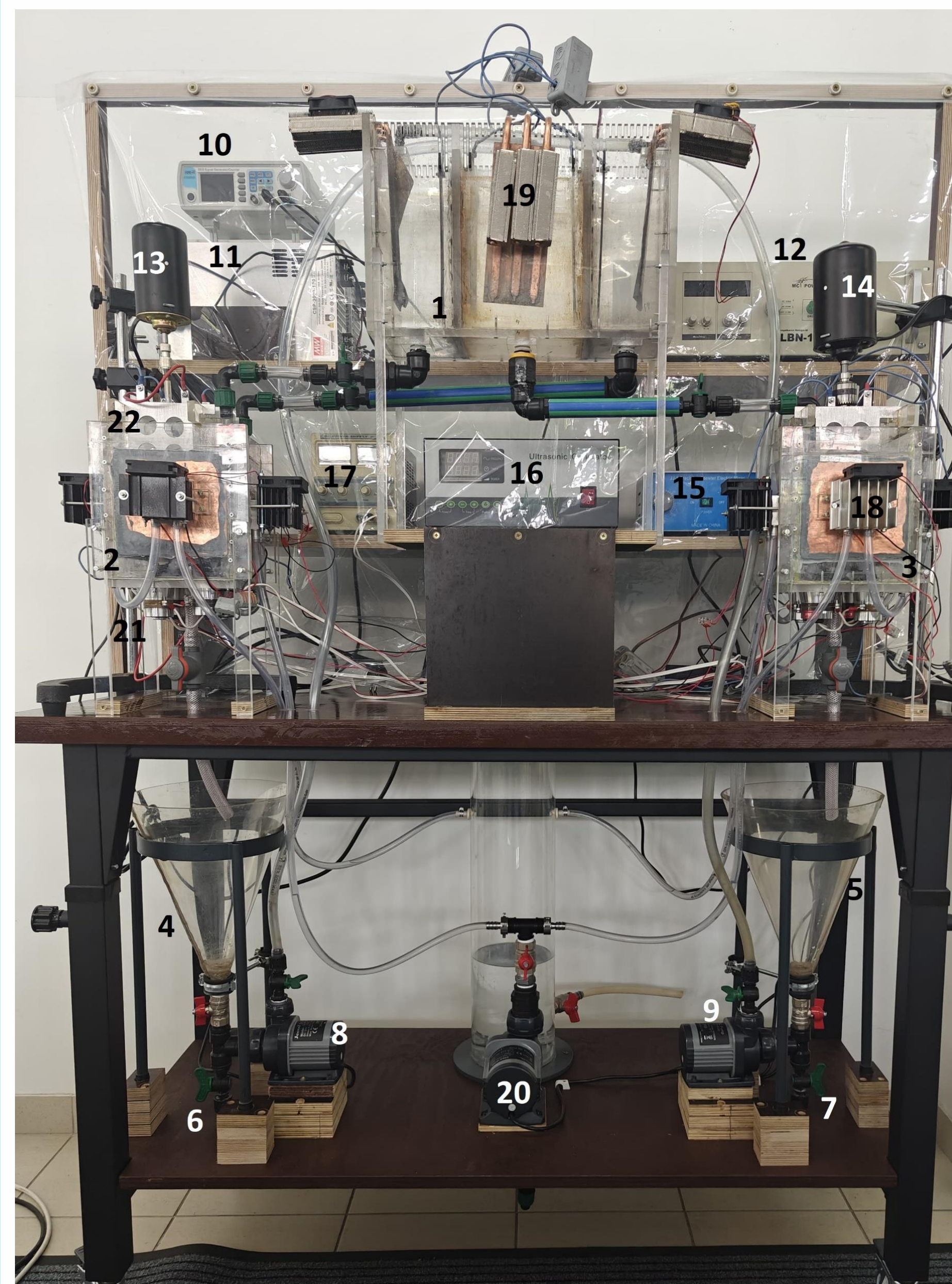


Fig. 2. Multi-stage reactor (Sono-EC system): 1 – pH reactor; 2 and 3 – sono-EC reactors; 4 and 5 – settling tanks; 6 and 7 – sludge outlets; 8 and 9 – circulation pumps; 10 – function generator; 11 – metal electrode power supply; 12 – graphite electrode power supply; 13 and 14 – stirrers; 15 – stirrer power supply; 16 – ultrasound generator; 17 – fan power supply; 18 – EC reactor cooling system (metal heat exchanger, fan and water-cooling unit); 19 – heat-exchange tubes for cooling the pH reactor; 20 – water-cooling system pump; 21 – ultrasonic transducers; 22 – electrodes.

SELENIUM REMOVAL

100.00%

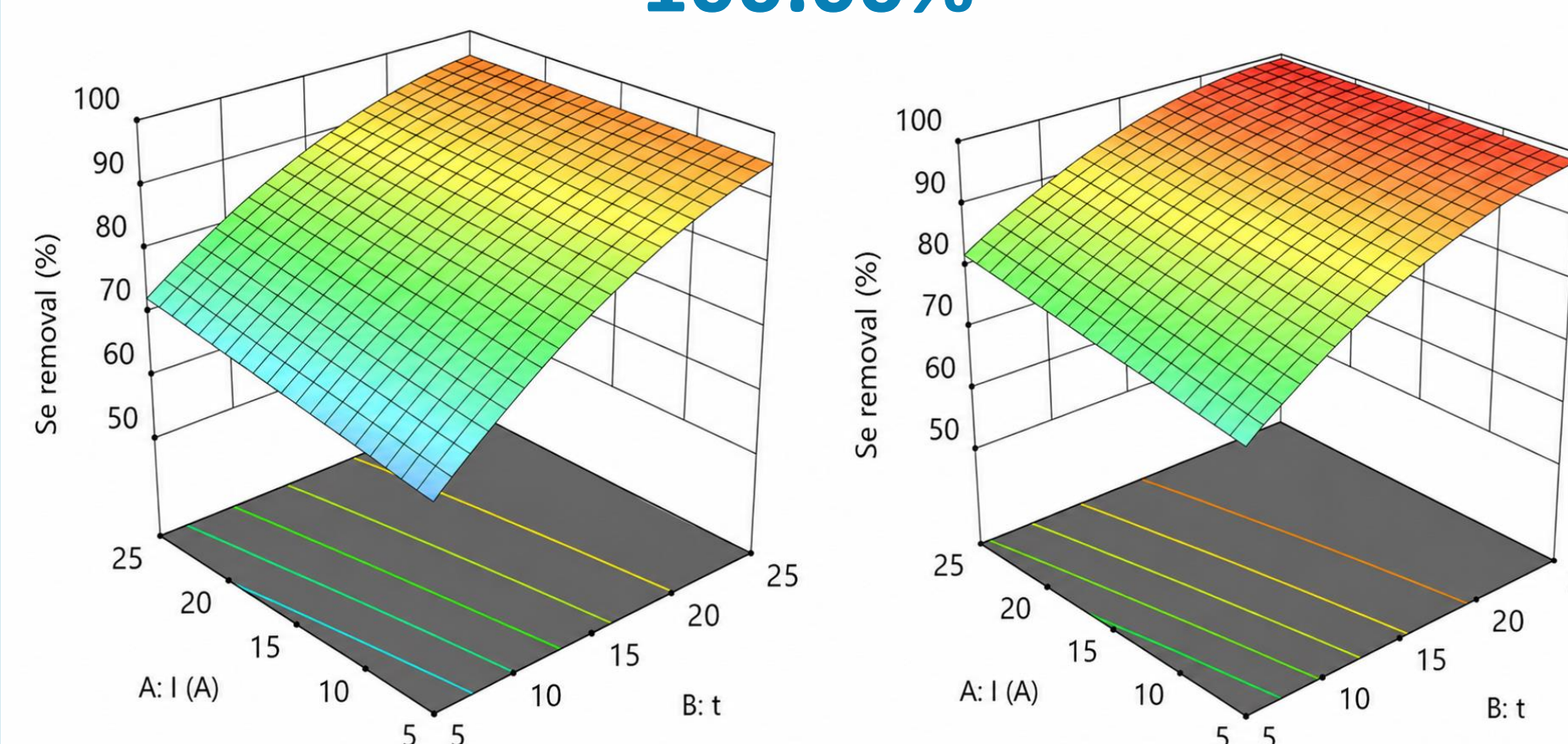


Fig. 3. Removal efficiency of Se as a function of the interaction between treatment time and current intensity, without pH control, at ultrasound powers of 150 W (left) and 450 W (right)

- Removal exceeded 95% under most tested conditions.
- Treatment time was the dominant factor; pH ranked second.
- US expanded the region of high Se removal, especially at shorter treatment times and lower current.
- Reduced quadratic model: $p < 0.001$; $R^2 \approx 0.98$.
- Mechanism: adsorption and co-precipitation with Fe/Al hydroxides; cathodic reduction to Se^0 may contribute.

STRONTIUM REMOVAL

94.68%

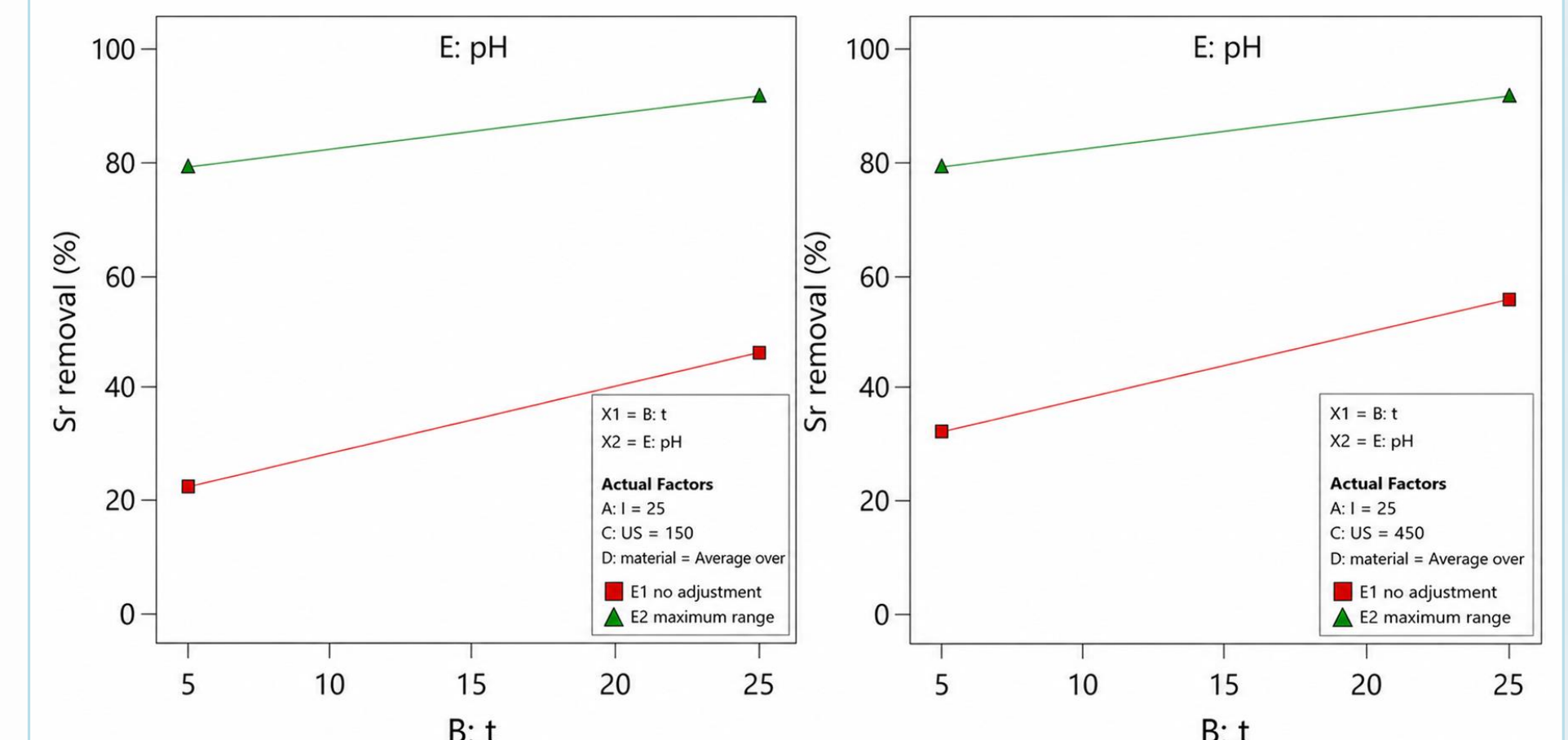


Fig. 4. Effect of treatment time and pH value on Sr removal efficiency at ultrasound powers of 150 W (left) and 450 W (right), at a maximum current intensity of 25 A

- Maximum experimental removal: 94.68% at 25 A, 25 min, 150 W, Fe and maximum pH range.
- pH dominated the response. Without pH adjustment, removal remained low (40–50%).
- Treatment time and current intensity had positive effects, while US provided only a secondary improvement.
- Reduced 2FI model: $p < 0.001$; $R^2 \approx 0.97$.
- Mechanism: alkaline precipitation of Sr-bearing carbonate/hydroxide phases plus co-precipitation with Fe/Al flocs.

MODEL VALIDATION

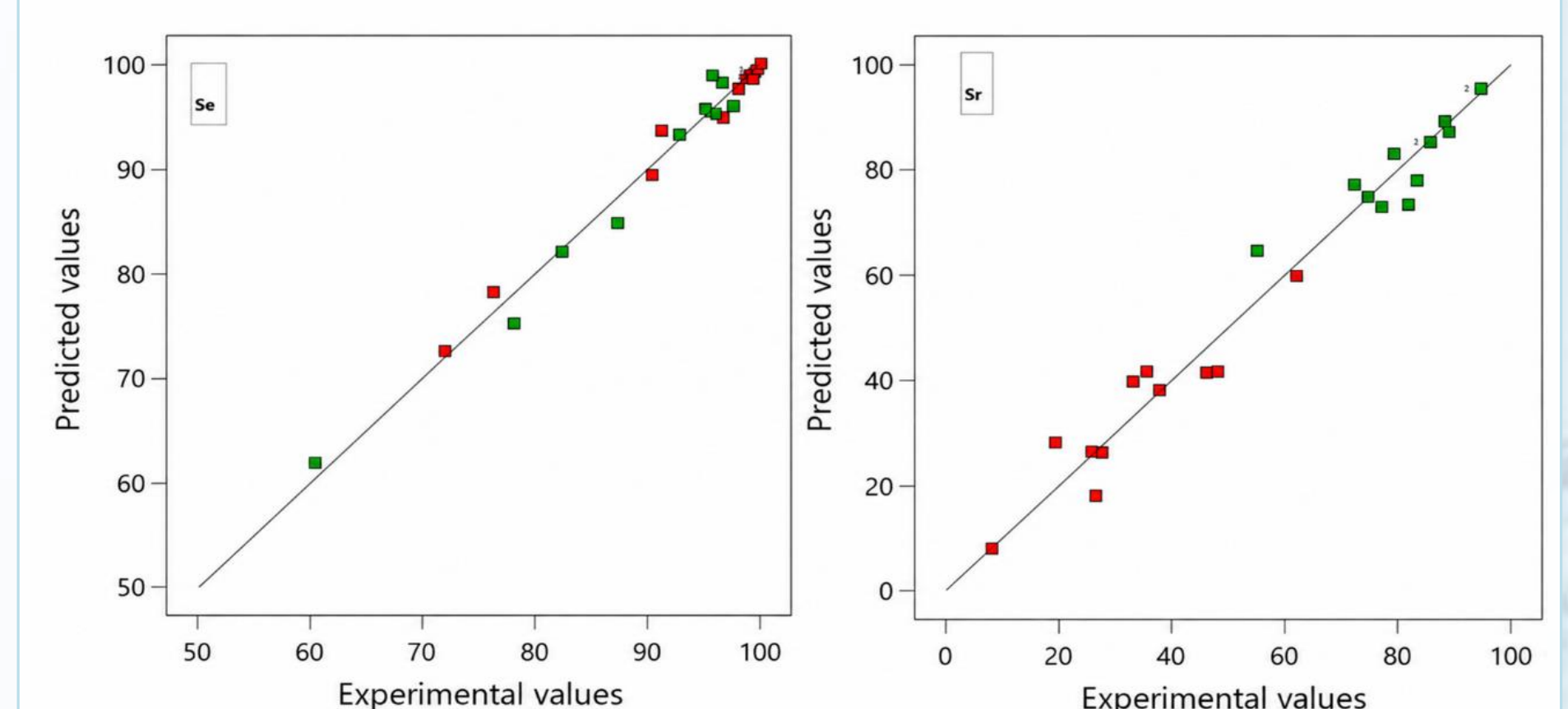


Fig. 5. Comparison of predicted and achieved removal efficiencies

The close fit, particularly for Se, confirms the reliability of the developed models for predicting Se and Sr removal within the investigated experimental range.

US CONTRIBUTION

150 / 300 / 450 W $\approx$ 750 / 1230 / 1520 CAVIN

Cavitation intensified mixing, mass transfer and partial electrode cleaning. It improved robustness, but it did not replace pH control for Sr.

CONCLUSION

Sono-EC removed chemically different trace elements in one integrated treatment train. Se removal remained robust, whereas Sr required electrochemical pH control.

Future work should focus on optimizing ultrasonic energy transfer and quantifying residual Fe/Al concentrations and sludge composition.