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Advancing produced water quality via integrated mechanical vapor recompression: Chemical and toxicological characterization, hazard identification and mitigation

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What's the Problem?

Produced water (PW) from oil and gas production is a highly saline, chemically complex wastewater containing salts, metals, radionuclides, and organic compounds that must be reduced to acceptable levels before the water can be safely reused. Researchers are studying advanced treatment technologies to remove these compounds; however, critical questions remain about which compounds persist in treated water and whether those compounds harm aquatic species.

How Was the Study Done?

Researchers studied PW at a Permian Basin pilot system at three stages: untreated (raw), after distillation (distillate), and after two post-treatment steps using granular activated carbon and zeolite (post-treated). Over 400 relevant analytes were measured, including ions, metals, organics, radionuclides, and per- and polyfluoroalkyl substances (PFAS), among others. Additionally, whole effluent toxicity (WET) tests were performed to determine whether the water was harmful to freshwater organisms, including bacteria, algae, water fleas, and zebrafish. Detailed developmental, genetic, and cardiac studies were performed on zebrafish embryos to detect sublethal effects that the WET tests might miss.

What Were the Results?

- Raw produced water was highly contaminated and lethal to all test organisms.
- Distillation removed 99% of salts, 89% of TOC, and 92% of petroleum hydrocarbons. Some organics and ammonia persisted or increased after distillation. Distillate remained toxic and caused developmental and cardiac effects in zebrafish embryos.
- GAC and zeolite post-treatment reduced contaminants below detection limits and eliminated toxicity. Post-treated water was indistinguishable from controls, with no significant changes in gene expression.

What's Next?

Future work should include large-scale, continuous pilot demonstrations to validate long-term performance and scalability, supported by non-targeted analysis (NTA), chronic toxicity and bioaccumulation studies, real-time monitoring, and more frequent water quality assessments to ensure safe and reliable water reuse.

Why Does this Matter?

This integrated chemical and biological assessment demonstrates that advanced multi-barrier treatment can effectively mitigate PW toxicity, supporting its potential reintegration into the hydrological cycle.

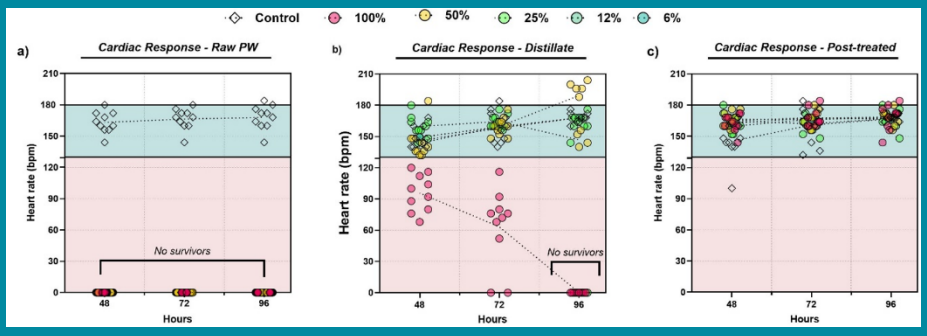

Figure 1. Cardiac responses of zebrafish embryos following exposure to (a) raw PW, (b) MVR distillate, and (c) post-treated water treated with GAC and zeolite; (d) representative microscopic observations after exposure. Heartbeat rates were measured in 10 randomly selected embryos per treatment at 48, 72, and 96 h of exposure.