A Multifunctional CombiSonoPlasma® Reactor for Simultaneous Treatment of Oil-Contaminated Hypersaline Produced Water and Hydrogen Production

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Highlights

- An effective produced water (PW) treatment via CombiSonoPlasma® is demonstrated at 0.1 L/min
- Actual PW became transparent within 24 h after the treatment due to post-treatment reactions
- The highest drop in the concentration of the organics of 43.3% in the treated PW occurred at 115 V
- The highest H_2 share in the cathodic gas (4.3 vol%) was at 115 V, with the rest of Ar sweep gas

1. Introduction

Despite the transition to the circular economy based on renewables, crude oil production will persist for decades, requiring mitigation of its environmental impacts. A major challenge is hypersaline produced water (PW), generated at >1 m³ per barrel of oil and containing toxic organic contaminants. Its high salinity and complex composition limit conventional treatment, demanding advanced solutions [1, 2]. Plasma-driven solution electrolysis (PDSE) degrades pollutants via highly reactive species formed near the discharge electrode while enabling H_2 generation through plasma–liquid interactions [3, 4]. This study presents the first lab-scale evaluation of ultrasound-assisted PDSE (CombiSonoPlasma®) representing the next stage in PDSE evolution, for treatment of actual PW originated from the oil extraction industry in Oman with simultaneous H_2 production.

2. Methods

Figure 1 shows the developed lab-scale CombiSonoPlasma® system for continuous PW treatment.

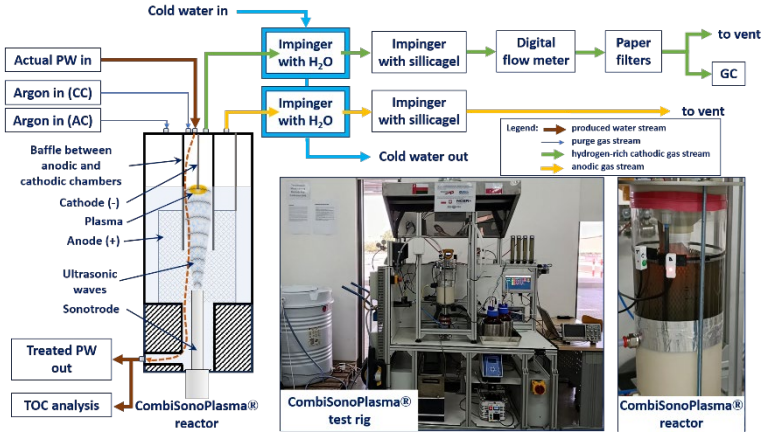


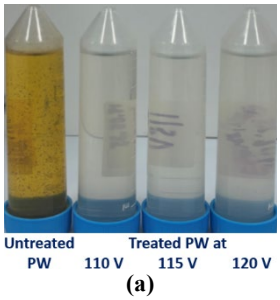
Figure 1. Scheme and photos of the experimental setup and CombiSonoPlasma® reactor

The reactor operated in single-pass mode with a 2 L volume and a PW flow rate of 0.1 L/min, with TOC monitoring. A coaxial electrode configuration consisting of a Pt-coated Ti mesh anode and a centrally positioned 2 mm tungsten cathode enabled high local current density and transition to the PDSE regime

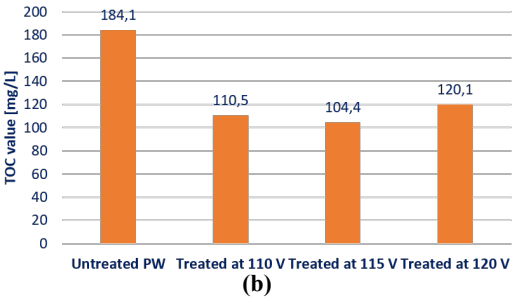
at elevated DC voltage under argon purge (368 sccm). Adjustable DC power was supplied. Cathodic plasma facilitated simultaneous water splitting and degradation of organics. Ultrasound (20 kHz), introduced through a bottom-mounted sonotrode, enhanced mass transfer, plasma–liquid interaction, and degassing. Key process parameters (voltage, current, pressure, temperature) were continuously monitored and centrally controlled. The cathodic gas stream was cooled, scrubbed, dried, filtered, and analyzed by GC-TCD, while the anodic gas underwent analogous treatment, but without GC analysis.

3. Results and discussion

All treated PW samples became transparent (**Figure 2a**), with discoloration occurring ~24 h after single-pass processing, indicating continued post-treatment oxidation. TOC removal was significant at all tested voltages (**Figure 2b**): 40.0% (100 V), 43.3% (115 V), and 34.8% (120 V). The highest drop at 115 V yielded a final TOC of 104.4 mg/L, identifying this voltage as the most effective for organics' degradation. H_2 evolution followed the same trend (**Figure 2c**), with a maximum share of 4.29 vol% (balance Ar) at 115 V, confirming enhanced plasma-assisted PW splitting. Traces of other gases (CO_2, CO, CH_4) were detected (not analyzed quantitively), evidencing the splitting of organic pollutants. Overall, 115 V provided the optimal balance between TOC removal and H_2 production, showing promising integration of PW treatment and energy recovery.



(a)



(b)

Voltage [V]	Chemical composition of the cathodic gas mixture [%vol]				
	H_2	N_2+O_2	CO	CO_2	CH_4
110	1.36	0.21	0.02	0,03	0.82
115	4.29	0.66	0	0.9	1.13
120	1.63	0.15	0	0,1	0.016

(c)

Figure 2. The study results: (a) the untreated and treated PW samples, (b) TOC of the untreated and treated PW samples, (c) the chemical composition of the cathodic gas mixture at different applied voltages.

4. Conclusions

The main conclusions are as follows: (i) all treated PW samples became transparent within 24 h, indicating continued post-treatment oxidation; (ii) TOC removal was achieved at all tested voltages, with the highest reduction (43.3%) at 115 V; (iii) the maximum H_2 concentration (4.29 vol%, balance Ar) was likewise obtained at 115 V; (iv) CO_2, CO, and CH_4 detection confirms organic pollutant decomposition. Thus, the obtained results are promising, and further process development, primarily focused on increasing the energy efficiency of PW treatment via CombiSonoPlasma®, is ongoing.

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Keywords

CombiSonoPlasma, produced water, total organic carbon reduction, hydrogen production.