ECP 2025 Conference

The 4th International Electronic Conference on Processes

20–22 October 2025 | Online

MDPI

Electrified Pressure Swing Distillation: A Systems-Based Sustainability Assessment

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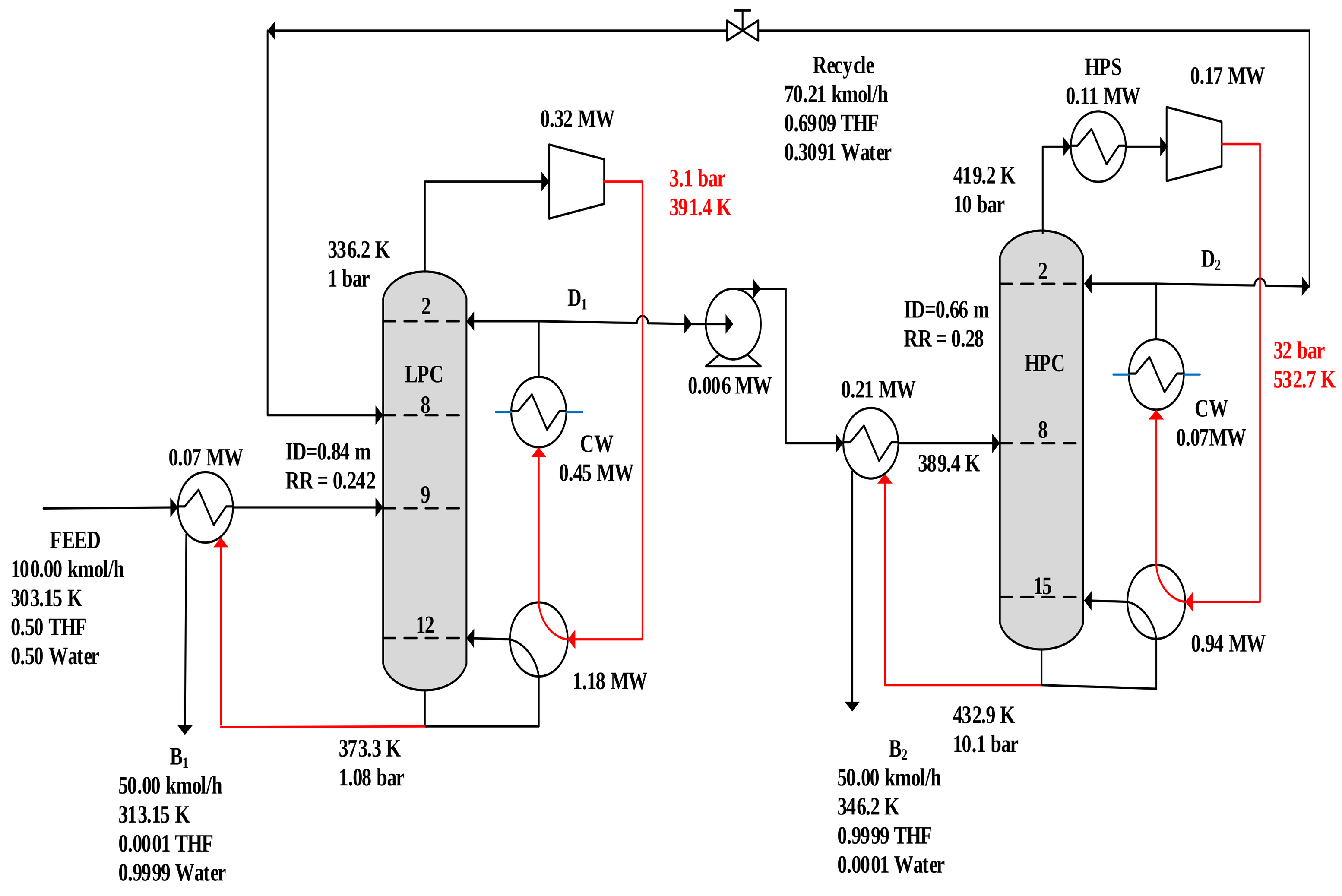
INTRODUCTION & AIM

- Pressure swing distillation (PSD) is widely applied for azeotropic separations but remains energy-intensive due to high steam and cooling demands [1].
- Decarbonization of PSD is essential for advancing sustainable chemical manufacturing [2].
- Heat pump-assisted PSD (HPAPSD) provides a promising electrification pathway by replacing steam-driven heating with vapour recompression, thus improving energy efficiency and reducing CO_2 emissions [3].

- **Aim:** To evaluate the technical, economic, environmental, and thermodynamic performance of HPAPSD for the tetrahydrofuran (THF)/water azeotrope.

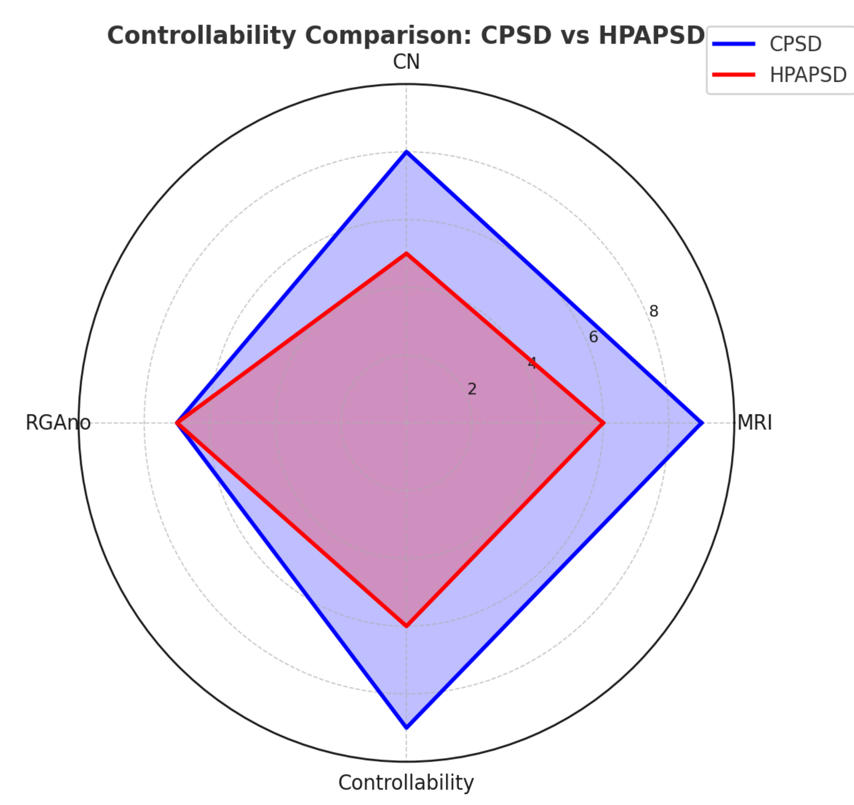
METHOD

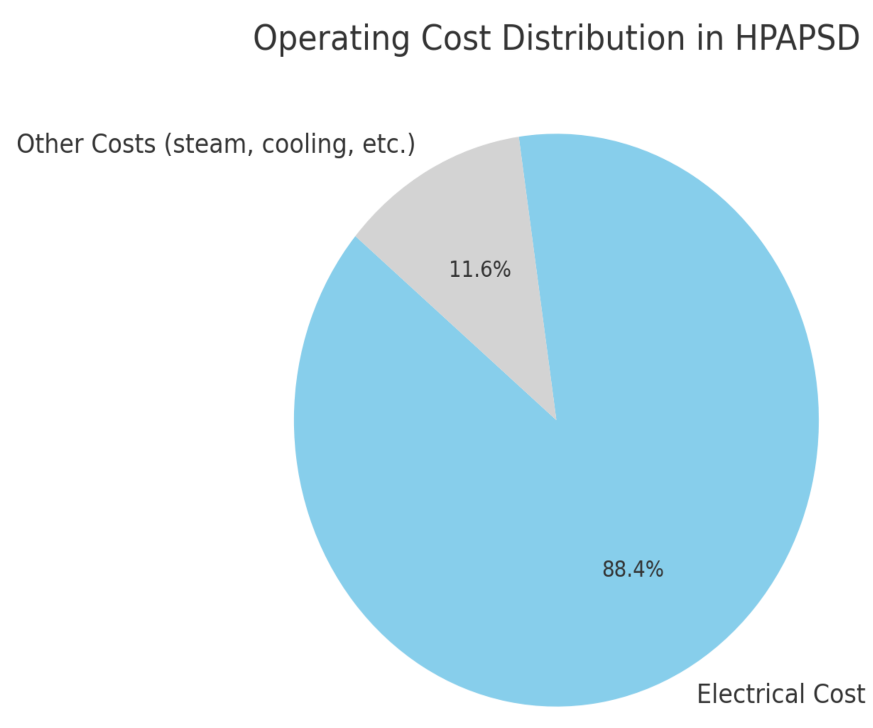
- **Case Study:** THF/water azeotrope separation. Feed: 100 Kmol/h equimolar mixture. Product Purity: 99.99 mol%.
- **Simulation Tools:** Aspen Plus, Aspen Plus Dynamics and Matlab with integrated energy and emissions models.
- **Configurations Compared:** Conventional PSD (CPSD) vs. HPAPSD.
- **Metrics:** Total annual cost (TAC), total energy consumption (TEC), CO_2 emissions, second-law efficiency and frequency-domain controllability.
- **Controllability Indices used:** Morari Resiliency Index (MRI), Relative Gain Array number (RGAno), Condition Number (CN)



RESULTS & DISCUSSION

- ✓ **Energy Performance:** TEC reduced by 59.6% in HPAPSD (vs. CPSD).
- ✓ **Economics:** 3-year TAC of HPAPSD higher by 36%, but 10-year TAC reduced by 32%, suggesting long-term economic viability.
- ✓ **Environmental Impact:** HPAPSD cut CO_2 emissions by 82.8%, demonstrating strong decarbonization potential.
- ✓ **Thermodynamics:** Exergy efficiency increased from 11.3% (CPSD) to 23.5% (HPAPSD), with lower exergy loss.
- ✓ **Operating Cost:** Electricity accounted for 88.4% of HPAPSD costs, emphasizing electrification reliance.
- ✓ **Controllability:** CPSD configuration showed highest MRI, acceptable CN and RGAno values.





CONCLUSION

- HPAPSD achieves substantial energy savings, CO_2 emission reductions, and improved exergy efficiency, offering strong long-term economic and environmental benefits despite higher initial capital investment.
- CPSD showed greater robustness and disturbance rejection capability compared to HPAPSD, highlighting a trade-off between energy efficiency and process controllability.

REFERENCES

1. Knapp, J. P.; Doherty, M. F. A New Pressure-Swing-Distillation Process for Separating Homogeneous Azeotropic Mixtures. *Ind. Eng. Chem. Res.* **1992**, *31* (1), 346–357.
2. Mtogo, J. W.; Mugo, G. W.; Mizsey, P. Enhancing Exergy Efficiency and Environmental Sustainability in Pressure Swing Azeotropic Distillation. *Clean. Energy Syst.* **2024**, *9*, 100134.
3. Yang, D.; Zhang, Q.; Zhang, Q.; Cui, C. Dynamics and Control of Electrified Pressure-Swing Distillation for Separating a Maximum-Boiling Azeotrope Featuring Small Pressure-Induced Shift. *Sep. Purif. Technol.* **2023**, *312*, 123360.