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Experimental Determination of Thermophysical Properties in Supercritical Heat Exchangers

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Extended Abstract

The study investigates the thermophysical properties of water in supercritical heat exchangers (HEXs) to enhance the efficiency of Supercritical Water Desalination (SCWD) systems. Given the global water crisis, SCWD presents a sustainable solution for high-yield water desalination with zero-liquid discharge (ZLD) [1]. However, designing efficient heat exchangers for supercritical conditions requires accurate experimental data to validate existing empirical models. This study explores the applicability of conventional dimensionless heat transfer correlations to supercritical processes.

An experimental system was developed using commercial off-the-shelf (COTS) components to construct and test a supercritical water heat exchanger. Two heat exchanger configurations (HEX1 and HEX2) were fabricated from 316 stainless steel and tested under varying temperature and pressure conditions [2]. Key thermophysical properties, including Reynolds number (Re), Prandtl number (Pr), Nusselt number (Nu), overall heat transfer coefficient (OHTC), and thermal resistance, were determined using MATLAB-based analysis and NIST-REFPROP data. Experimental validation involved steady-state and dynamic response studies. The system was tested at pressures ranging from 225 to 250 bar and temperatures up to 450°C. Brine concentration tests were conducted to evaluate heat exchanger corrosion and performance under 3.5%, 7.5%, and 14% NaCl solutions. The study confirmed that the conventional empirical correlations for heat transfer ($Nu = 3.66$, $Nu = 4.36$) were inadequate for supercritical water applications. The experimentally derived Nusselt numbers ranged between 74 and 130, significantly deviating from classical values. HEX1 exhibited higher thermal instability due to its thinner annular region, whereas HEX2 demonstrated improved heat transfer performance with increased cooling jacket volume. Brine concentration tests revealed signs of corrosion in HEX1 at higher salt concentrations, suggesting material degradation at prolonged exposure. Despite this, both HEX designs effectively facilitated laminar flow ($Re < 350$) under supercritical conditions, confirming theoretical predictions. The study also provided a new correlation for Nu, enabling future SCWD-ZLD heat exchanger designs. The derived correlations for Nusselt number, Reynolds number, and Prandtl number offer improved accuracy in designing high-pressure HEX systems.

References

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