INTISARI

Energi surya berpotensi besar dimanfaatkan melalui teknologi *Concentrated Solar Power* (CSP) yang terintegrasi dengan sistem penyimpanan energi termal (TES) berbasis molten salt sehingga mampu menyediakan daya yang lebih andal dan mendekati pembangkit beban dasar. Dalam konfigurasi tersebut, *Molten Salt Steam Generator* (MSSG) menjadi komponen kunci yang memindahkan panas *molten salt* ke air–uap melalui penukar kalor *shell and tube* yang mencakup *preheater*, *evaporator*, dan *superheater*. *Evaporator* memiliki peran sangat penting karena melibatkan proses perpindahan panas dua fase yang kompleks, sehingga memerlukan kondisi operasi dan rancangan yang tepat untuk mencegah penurunan kinerja dan kerusakan material. Untuk menjamin kinerja termal dan keandalan sistem, perancangan *evaporator shell and tube* umumnya mengikuti standar industri dengan metode Bell–Delaware yang mengoreksi koefisien perpindahan panas dan *pressure drop* di sisi *shell*, serta divalidasi lebih lanjut menggunakan analisis numerik *Computational Fluid Dynamics* (CFD) guna mengkaji fenomena aliran dan perpindahan panas dua fase secara rinci.

Proses perancangan alat penukar kalor pada penelitian ini dilakukan melalui tiga pendekatan utama, yaitu perhitungan analitik, prediksi unjuk kerja menggunakan perangkat lunak komersial, serta simulasi numerik CFD. Tahapan perancangan diawali dengan proses *sizing* untuk menentukan spesifikasi utama, seperti jumlah *tube*, dimensi *shell*, dan konfigurasi *baffle*. Pada sisi *shell* digunakan metode Bell–Delaware untuk menghitung perpindahan panas dan penurunan tekanan dengan mempertimbangkan koreksi aliran, sedangkan pada sisi *tube* diterapkan korelasi Chen dan parameter Lockhart–Martinelli untuk mengevaluasi koefisien perpindahan panas pendidihan dan pressure drop aliran air–uap. Desain akhir dengan *molten salt* (60% $NaNO_3$–40% KNO_3) sebagai fluida panas dan *saturated water* sebagai fluida dingin kemudian dianalisis lebih lanjut menggunakan perangkat lunak HTRI Xchanger Suite dan Ansys Fluent.

Secara kuantitatif, hasil unjuk kerja antara metode analitik dan simulasi HTRI menunjukkan kesesuaian yang sangat baik, dengan nilai koefisien perpindahan kalor total masing-masing sebesar 374,93 W/m².°C dan 401,94 W/m².°C. Meskipun simulasi CFD memprediksi temperatur *outlet* dan *pressure drop* yang lebih tinggi akibat sensitivitas solver numerik terhadap fenomena aliran dua fase dan adanya ketidakseimbangan massa (*mass imbalance*), hasil perhitungan HTRI ditetapkan sebagai acuan tetap untuk parameter desain final karena keandalannya sesuai standar industri.

Kata Kunci: *Concentrated Solar Power*, Alat Penukar Kalor *Shell and Tube, Molten Salt,* Perancangan, *Evaporator,* HTRI, CFD

ABSTRACT

Solar energy has great potential to be utilized through *Concentrated Solar Power* (CSP) technology integrated with molten salt based *Thermal Energy Storage* (TES), enabling a more reliable power supply that can approach baseload operation. In this configuration, the *Molten Salt Steam Generator* (MSSG) is a key component that transfers heat from molten salt to the water–steam working fluid via a *shell and tube heat exchanger* consisting of a preheater, evaporator, and superheater. The evaporator plays a crucial role because it involves complex two phase heat transfer processes, thus requiring appropriate operating conditions and design to prevent performance degradation and material failure. To ensure thermal performance and system reliability, the design of the shell and tube evaporator generally follows industrial standards using the *Bell–Delaware* method to correct the shell-side heat transfer coefficient and pressure drop, and is further validated using numerical *Computational Fluid Dynamics* (CFD) analysis to investigate two phase flow and heat transfer in detail.

The design process of the heat exchanger in this study is carried out using three main approaches, namely analytical calculations, performance prediction using commercial software, and numerical *CFD* simulation. The design stage begins with a sizing process to determine the main specifications, such as the number of tubes, shell dimensions, and baffle configuration. On the shell side, the *Bell–Delaware* method is used to calculate heat transfer and pressure drop while accounting for flow correction factors, whereas on the tube side the *Chen* correlation and the *Lockhart–Martinelli* parameter are applied to evaluate the boiling heat transfer coefficient and the pressure drop of the water–steam flow. The final design, with molten salt (60% $NaNO_3$–40% KNO_3) as the hot fluid and saturated water as the cold fluid, is then further analyzed using *HTRI Xchanger Suite* and *Ansys Fluent*.

Quantitatively, the analytical and HTRI methods demonstrated strong agreement, yielding overall heat transfer coefficients of 374,93 $W/m^2 \cdot °C$ and 401,94 $W/m^2 \cdot °C$, respectively. However, the CFD simulation predicted higher quantitative values for outlet temperatures and pressure drops than the other two methods. This deviation is attributed to the sensitivity of the numerical solver to complex two-phase flow phenomena and mass imbalance at the outlet. As a result of these findings, the HTRI calculation results were established as the definitive reference for the final design parameters.

Keywords: Concentrated Solar Power, Shell and Tube Heat Exchanger, Molten Salt, Design, Evaporator, HTRI, CFD