

PENGEMBANGAN BAHAN BAKAR BERBASIS THORIUM PADA REAKTOR KLT-40S MENGGUNAKAN METODE TERKOPEL SERPENT 2 DAN OPENFOAM

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INTISARI

Reaktor nuklir merupakan sistem yang kompleks dimana berbagai aspek seperti neutronik dan termal hidraulik yang saling terkait dan memiliki efek umpan balik satu dengan yang lain. Analisis yang melibatkan efek umpan balik ini dapat dicapai dengan melakukan simulasi terkopel antar simulasi neutronik dengan termal hidraulik. Dalam penelitian ini telah dilakukan analisis pada performansi neutronik dan termal hidraulik reaktor KLT-40S (150 MWth).

Simulasi terkopel dilakukan dengan kode Serpent dan *computational fluid dynamics* (CFD) OpenFOAM. Pendekatan model pin digunakan dalam penelitian ini dengan variasi bahan bakar UO_2 dan $(\text{U}, \text{Th})\text{O}_2$. Penggunaan thorium bertujuan untuk meningkatkan keselamatan dan ketahanan proliferasi reaktor. Parameter yang diamati meliputi fluks neutron, k_∞ , densitas isotop Pu, dan juga profil temperatur pin. Perbandingan antara simulasi terkopel dan non-kopel juga diamati sebagai *benchmark* dalam penelitian ini.

Efek umpan balik antar simulasi telah diamati. k_∞ simulasi kopel dan non-kopel masing-masing adalah 1,5956 dan 1,5717. Peningkatan ini disebabkan karena distribusi temperatur simulasi kopel yang lebih rendah. Selain itu terdapat perbedaan densitas isotop antar simulasi terkopel dan non-kopel. Perbedaan terbesar antar simulasi terjadi pada beberapa step *burnup* akhir akibat rentang simulasi terkopel yang panjang. Perbedaan densitas untuk ^{235}U adalah 2,76%, ^{238}U adalah 0,28%, ^{239}Pu adalah 21,08%, dan ^{241}Pu adalah 49,99%.

Bahan bakar yang telah dikembangkan dalam penelitian ini adalah bahan bakar $(\text{U}, \text{Th})\text{O}_2$ dengan pengayaan 14.1% ^{233}U . Perbandingan k_∞ bahan bakar UO_2 dan $(\text{U}, \text{Th})\text{O}_2$ pada awal siklus masing-masing adalah 1,8418 dan 1,5956, hal ini menunjukkan bahan bakar berbasis thorium berpotensi untuk memperpanjang umur teras. Densitas akhir ^{239}Pu dan ^{241}Pu pada bahan bakar bekas $(\text{U}, \text{Th})\text{O}_2$, masing-masing sebesar $0,5921 \times 10^{-10} \text{ g/cm}^3$ dan $0,570 \times 10^{-12} \text{ g/cm}^3$. Selain Jumlah ^{239}Pu dan ^{241}Pu yang minim bahan bakar $(\text{U}, \text{Th})\text{O}_2$ juga mengandung ^{232}U dengan densitas



4,6198 g/cm³. Hal ini menunjukkan bahan bakar berbasis thorium memiliki ketahanan proliferasi yang lebih tinggi dibandingkan UO₂. Temperatur maksimum pada bahan bakar (U, Th)O₂ dan UO₂ di awal siklus masing-masing sebesar 859,75 K dan 869,35 K. Temperatur maksimum (U, Th)O₂ lebih rendah dari UO₂ dan memiliki potensi untuk meningkatkan keselamatan reaktor.

Kata kunci: terkopel, neutronik, termal hidraulik, KLT-40S

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DEVELOPMENT OF THORIUM BASED FUEL IN THE KLT-40S REACTOR USING THE SERPENT 2 AND OPENFOAM COUPLED METHOD

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ABSTRACT

There is numerous physical phenomenon which interconnect with each other in a nuclear reactor. One of them is a feedback loop between neutronics and thermal-hydraulics aspect. An approach to simulate this occurrence is a coupled analysis between neutronic and thermal-hydraulic simulations. In this research, an analysis on the neutronic and thermal-hydraulic performance of the KLT-40S (150 MWth) fuel pin has been carried out.

Within this framework, coupled simulation has been done with Serpent as the neutronic Monte Carlo code and OpenFOAM as the *computational fluid dynamics* (CFD) code. In this research, a variation of fuel materials of UO_2 and $(\text{U}, \text{Th})\text{O}_2$ was used. The use of thorium was to increase the safety and the proliferation resistance of the reactor. Firstly, a benchmark test between the coupled and non-coupled simulation has been investigated. Secondly, the k_∞ , neutron flux, temperature distribution, and spent fuel composition have been studied between the fuel materials mentioned.

The benchmark test showed a difference in k_∞ between the coupled and non-coupled simulation. The k_∞ of the coupled simulation at the beginning of the cycle (BOC) was higher at 1.5956 than the non-coupled at 1.5717. The increase of the k_∞ of the coupled simulation was caused by the lower overall temperature of the system. The highest differences of density for each corresponding isotope were as follows: 2.76% for ^{235}U ; 0.28% for ^{238}U ; 21.08% for ^{239}Pu ; and 49.99% for ^{241}Pu . The difference was particularly larger at the later time steps due to the wide coupling steps used in this study.

The fuel developed in this research was a mixture of $(\text{U}, \text{Th})\text{O}_2$ with an enrichment of 14.1% ^{233}U . The k_∞ at the beginning of the cycle of the $(\text{U}, \text{Th})\text{O}_2$ was higher at 1.8418 than the UO_2 at 1.5956. This showed the thorium-based fuel has a potential to lengthen the fuel cycle in the reactor. The ^{239}Pu and ^{241}Pu density of the $(\text{U}, \text{Th})\text{O}_2$ spent fuel was significantly lower than UO_2 at $0.5912 \times 10^{-10} \text{ g/cm}^3$



and $0.570 \times 10^{-12} \text{ g/cm}^3$ respectively. ^{232}U density at the end of the cycle was 4.6198 g/cm^3 . These two factors from $(\text{U, Th})\text{O}_2$ spent fuel showed that thorium based fuel has a higher proliferation resistance than UO_2 fuel. The maximum temperature of the $(\text{U, Th})\text{O}_2$ was 859.75 K while the UO_2 was 869.35 K . $(\text{U, Th})\text{O}_2$ had a lower maximum temperature than UO_2 which is desirable to increase nuclear reactor safety.

Keywords: coupled, neutronics, thermal-hydraulics, KLT-40S

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