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Alternative Power Conversion Cycles for He-cooled Fusion Reactor Concepts

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The He-cooled PPCS concepts using helium at 300 °C – 500 °C have power conversion systems using standard Rankine cycles. Their gross efficiency is mainly limited by the moderate He output temperature whilst the net efficiency (net power/fusion power) is relatively low due to the high power required by the auxiliaries, mainly pumping and heating. Possible improvements of the gross efficiency have been investigated, considering other types of conversion cycles: the indirect Brayton cycle using supercritical CO_2 as working fluid and the supercritical steam Rankine cycle.

The CO_2 has interesting physical properties (critical temperature near room temperature, moderate value of critical pressure, stability under 1400°C) and low intrinsic costs. Moreover, due to its sizeable molecular weight, CO_2 needs small turbines, compared to He and steam turbines. The supercritical steam Rankine cycle are already used in coal-fired power plants, so that the turbine technology can be considered mature.

Among all configurations analyzed, the one leading to the highest efficiencies corresponds to a supercritical Rankine, in which the heat transfer is improved dividing the blanket helium heat exchange in two stages. At the first stage the heat exchangers are used for steam generation only whilst at the second stage they are also used for superheating and reheating. The value obtained for the so-called “Cycle related Net Efficiency” (net power/reactor thermal power), 31.68%, represents a noticeable improvement compared to the one obtained for the sub-critical Rankine cycle of the reference PPCS model HCLL (Helium Cooled Lithium-Lead), which achieved a value for this ratio of 28.34%. A supercritical Rankine cycle with these characteristics represents nowadays a relatively mature technology, and investment cost should not rise considerably compared to those of a sub-critical Rankine cycle.