Dry cooling system options for the sCO_2 Brayton cycle for concentrated solar power plants

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Supercritical carbon dioxide (sCO_2) power cycles are expected to be the next generation of power cycles deployed to bring down the cost of concentrating solar thermal (CST) power generation and other thermal power plants [1]. One key challenge of sCO_2 power cycles is the type of cooling employed. This is because the locations most suited to CST power generation, those with good solar resource, are typically arid locations where no cooling water is available. Dry cooling of the sCO_2 power cycle means the cycle performance will be dependent on ambient temperature, where increasing ambient temperatures result in deterioration of cycle performance. There are a range of dry cooling system options, each with varying abilities to buffer the effect of ambient temperature on the cycle performance, and each comes with different trade-offs of capital cost and operational flexibility. The aim of this study is to determine the most suitable dry cooling system configuration for sCO_2 power cycles in the CST power generation context.

The sCO_2 Brayton cycle has a large amount of sensible heat remaining at the turbine exhaust, most of which can be effectively recuperated to preheat the compressor outlet streams [2]. However, the sensible heat that cannot be recuperated must be rejected to a heat sink. As there is no phase change involved in the sCO_2 cooling process it provides a smoother heat transfer profile with a less pronounced pinch point than that of the condensation process in the steam Rankine cycle [3]. This sensible heat rejection process has been shown to make the sCO_2 cycle suitable for direct cooling of sCO_2 in the NDDCT [4]. In this previous study, it was shown that the direct NDDCT performed well even at high ambient temperature, with sCO_2 outlet cooled to near the ambient temperature. This was due to a feedback effect in the recuperator, wherein the sCO_2 compressor inlet and outlet temperatures increase, leading to an increase in hot side recuperator outlet/NDDCT inlet. This in turn leads to ample driving force for air flow through the NDDCT. However, this option still leaves the cycle performance subject to varying ambient temperature as NDDCTs cannot cool past the dry bulb temperature. Another option, considered in this study, is to use a more active cooling system in addition to the primary passive cooling system, in order to achieve constant compressor inlet conditions. This would come at the expense of higher parasitic power consumption. As this additional supplementary cooling would only be required at times of high ambient temperature, which generally occur in the daytime periods of high insolation. Hence, there is the opportunity to directly power the active cooling system with solar photovoltaic (PV), removing the parasitic power consumption at the expense of additional capital expenditure. Finally, the third supplementary cooling system option considered is a heat driven single effect absorption cooling system. Such a system could utilise the otherwise unused heat available in the cold tank (250-300 ^{o}C) and would require minimal compression work, but comes with additional capital expenditure. On hot days there would presumably be ample heat collected in the CST system to provide for the additional heating required of the overcooled heat transfer fluid.

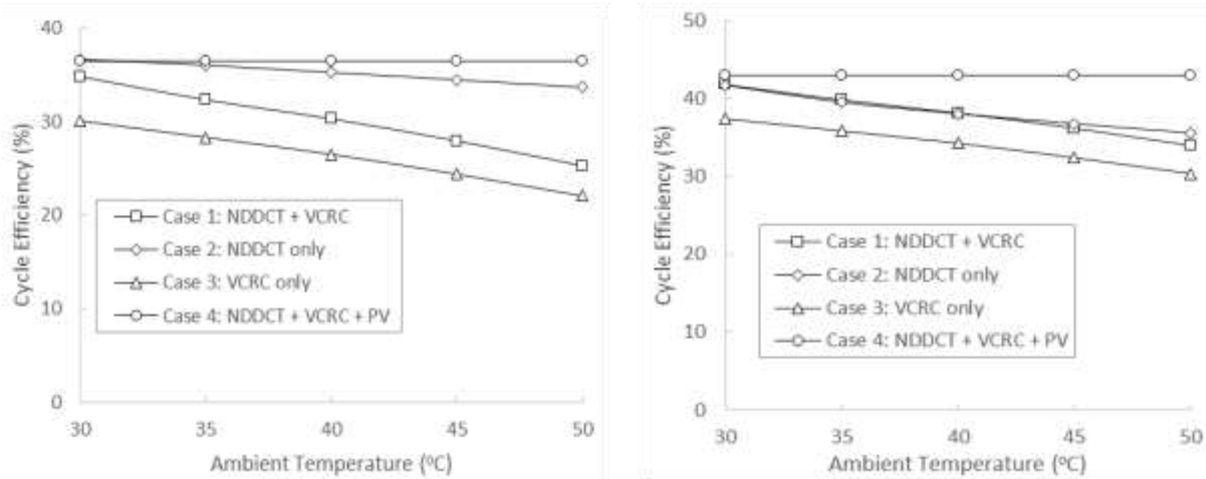

Figure 1: Cycle efficiency comparison for various cooling system cases for the recuperated cycle (left) and recompression cycle (right).

As shown in Figure 1, for the recuperated cycle the NDDCT only option outperforms the NDDCT + VCRC option according to cycle efficiency. The cycle efficiency deterioration due to increasing CIT is lower than that incurred by through refrigeration work in maintaining optimal CIT. This is due to the high specific work input (in terms of kWe VCRC consumption per MWe net) required, as shown in Figure 2. The recompression cycle NDDCT + VCRC case is very similar to the NDDCT only case, with the VCRC only case again performing significantly lower than both. The VCRC only case (Case 3) requires significant specific work input, whereas the combined NDDCT + VCRC cases require much lower specific work input.

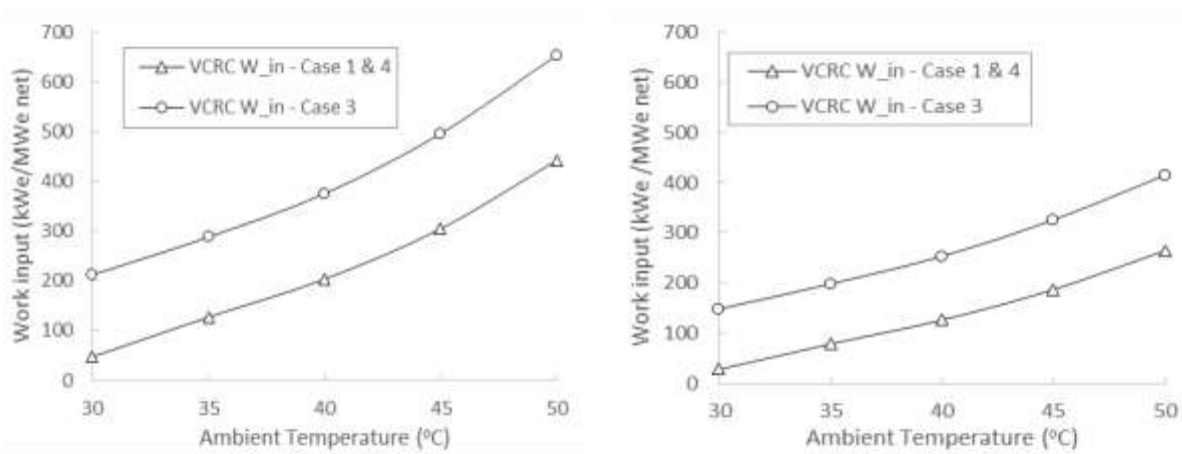

Figure 2: Work in to VCRC per MW net of CSP production for the recuperated cycle (left) and recompression cycle (right).

References

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