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Investigation of Supercritical Carbon Dioxide Air-cooled Heat Exchangers for Application in CST Power Cycles

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Supercritical carbon dioxide (sCO_2) is proposed as a superior working fluid in concentrated solar thermal (CST) power cycles due to the excellent heat transfer characteristics and high energy volumetric density. The benefits of a closed loop CO_2 Brayton power cycle include superior thermal efficiencies at high heat source temperatures, and a reduction in the size of turbomachinery of an order of magnitude, when compared to conventional steam Rankine cycles. These benefits in turn may reduce the normalised costs of power generation, and encourage the commercialisation and update of CST technology.

While the preferred thermal and physical properties of sCO_2 result in a high cycle thermal efficiency, the large property variations about the critical temperature increase the complexity of the cycle cooling process. Due to the likely arid locality of CST plants and the negative environmental impacts of wet cooling, a solution for sCO_2 cooling with nil or minimal water consumption is desired. It has been shown in recent sCO_2 Brayton cycle modelling that the most cost effective cooling system is likely to incorporate a direct sCO_2-air heat exchanger, without an intermediate water cycle.

Existing research into the cooling behaviour of sCO_2 in the proximity of the critical temperature is limited, and mostly restricted to application in the heat rejection process of refrigeration cycles. The geometry of heat exchangers and fluid properties differ for power cycle cooling applications, and no experiemental research is available on the behaviour of sCO_2 or the performance of air-cooled heat exchangers for power cycle applications. Recent numerical studies have shown that the large variations of density and other properties of sCO_2 about the critical temperature may cause unusual behaviour in larger diameter cooled tubes, such as significant variance in temperature and local heat transfer coefficient between the tube upper and lower surface. Additionally, many heat transfer correlations for sCO_2 exist, each developed from a different set of experimental data with relatively small tube sizes, and there is no consensus on which is the most appropriate for application in power cycle scaled cooling systems. The current uncertainty regarding the performance of these heat exchangers and the potential detrimental effects of buoyant flow characteristics is a significant knowledge gap, which should be addressed to inform the design of a utility-scale dry cooled sCO_2 power cycle.

This presentation describes a novel study which seeks to address the above knowledge gap by undertaking the first known experimental study into sCO_2 cooling with a focus on power cycle applications. The initial stages of this study utilise a numerical element-based crossflow heat exchange model to provide data on the theoretical performance of air-sCO_2 heat exchanegers using currently available literature. From this model, the sensitivity of various factors on cooling performance can be predicted, as can the size of cooling infrastructure required for a given cycle design and ambient temperature. The presentation will also introduce the on-going design of a novel test facility incorporating a sCO_2 air-cooled heat exchanger bundle mounted within a vertical wind tunnel at the University of Queensland's Pinjarra CO_2 cycle test facility. The facility will simulate Natural Draft Dry Cooling Tower air flow conditions, as well as forced convection conditions, and the recorded data will support the continued development of a sCO_2 power cycle for CST plants.