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Advanced SMRs using S-CO2 Power Conversion with Dry Cooling

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Abstract

This report concludes the LDRD entitled "Advanced SMRs using S-CO2 Power Conversion with Dry Cooling." The goal of this project was to demonstrate the feasibility of using sCO_2 as the working fluid in a dry-cooled natural circulation loop. The reason for doing this is to demonstrate that such a loop could be utilized in small modular reactors (SMRs) as a method for (a) passively removing decay heat from the reactor and (b) cooling the reactor without using the copious amounts of water needed for wet-cooled reactors. The dry-cooling aspect of this work is possible due to the working conditions of a sCO_2 Brayton power conversion cycle.

The loop was designed, built, and operated over the three-year life of the LDRD project. This report outlines some of the key accomplishments and some of the future work that we are continuing to try to complete in the future.

A more comprehensive report will be completed and submitted in the Fall of 2015.

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ANNUAL REPORT TEXT

1. PROJECT PURPOSE

Small modular reactors (SMRs) continue to be proposed around the world to meet ever-increasing electrical energy needs, particularly in areas where large-scale transmission is not feasible. The DOE has recently announced a program of $1 billion aimed at licensing of light-water SMRs, demonstrating a high priority on this technology.

Light-water SMRs are promising in the near term, however they require a large nearby water source for evaporative cooling, and ultimately suffer from the same waste issues and shutdown heat removal concerns as their larger predecessors. This proposal identifies two ways in which supercritical-CO2 (S-CO_2)is uniquely capable of addressing these problems:

First, recent studies have shown that the S-CO_2 power cycle is strongly compatible with dry-air cooling. Because the cycle is optimized to reject heat around 88°F, its efficiency does not degrade sharply with relatively high ambient temperatures, unlike steam plants. Turbomachinery size and capital cost both overwhelmingly favor S-CO_2 over steam. Therefore the dry-cooled S-CO_2 cycle is advantageous even when coupled to light-water SMRs.

Furthermore, next-generation SMRs will undoubtedly be fast reactors cooled by high-temperature gas or sodium, capable of operating 20 years or more without refueling. Their used-fuel value would be high, advancing reprocessing and reducing waste volume. S-CO_2 itself can be used effectively as the primary reactor coolant for a direct-cycle turbine. CO2 fluid properties near the critical point promote large natural circulation flowrates, allowing for passive decay heat removal for safe shutdown during accident scenarios.

This study will be aimed at experimentally investigating these two thermal-fluid phenomena.

This project is LDRD-funded because it advances state of the art, but is beyond the investment horizon for other customers. We are developing models and correlations of CO_2 fluid properties in the highly-compressible region near the critical point. As air-cooled natural circulation of supercritical fluids has not been experimentally investigated, this work is well within the scope of LDRD projects.

2. SUMMARY OF ACCOMPLISHMENTS

We designed, built, and operated an air-cooled natural circulation loop with supercritical carbon dioxide (sCO2) as the working fluid. In June of 2014, we accomplished the first known controlled air-cooled natural circulation of sCO2. We have since modified the loop to cool it with water. We ran the loop, collected data, and analyzed the data. We have modeled the loop in Relap5 and in FUEGO (computational fluid dynamics codes). From these models, we have calculated heat transfer coefficients, Nusselt number, and Grashof numbers, and developed correlations for these dimensionless parameters.

One presentation has been given and two others are under development. Two journal articles outlining the results are also under development.

We have demonstrated the potential of sCO2 as a working fluid in an air-cooled natural circulating decay-heat-removal loop for nuclear power. Calculations are ongoing to scale our results to that needed for realistic power operations. These calculations will be detailed in a report that is forthcoming.

3. SIGNIFICANCE

This project demonstrates the potential to place energy production in arid regions. For the US, the importance of this is most obvious in the southwestern portion of the country. However, water for power production is becoming scarcer and the water that is available is becoming more expensive. At some point the cost of water will become prohibitive and the air cooling capabilities demonstrated in this project will be a means of producing power without the need for water as a source of cooling.

This project has also demonstrated that control of naturally circulated sCO2 is feasible.

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