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C3Or3A-05: Experimental investigation of moisture freeze-out in a cryogenic heat exchanger for helium purification

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Purification of the process gas is vital for reliable operation of cryogenic systems. For helium cryogenic systems operating at 4.5 K or below, this is critical as any matter other than the process gas (helium) will freeze and act as a solid contaminant. Persistent low-level contamination (mainly the constituents of air and moisture) at levels greater than 1.0 ppmv, will degrade the performance of the refrigerator by freezing out on the heat transfer surface of heat exchangers as well as freezing out on other localized areas such as valves and turbo-expanders. Removal of low levels of moisture (1-100 ppmv) through fixed bed adsorbers loses effectiveness over the operational life, and the regeneration process can be tedious. In contrast, moisture removal by freeze-out process provides excellent control over a wide range of concentration and a relatively effective and quick turnaround for the regeneration process. However, the freeze-out process requires a heat exchanger design that is well suited for contaminant solidification distribution with a minimal impact on the flow distribution and heat exchange process. It also requires a better understanding of the moisture freeze-out from a process gas stream, subsequent frost formation on the heat exchanger surface, and the underlying conjugate heat and mass transfer processes. Frost formation in a cryogenic (300-80K) multi-pass tube in tube heat exchanger, integrated in a commercial helium purifier, is studied. An experimental test bench incorporating the commercial helium purifier and a novel low level contaminated (with 10-100 ppmv of moisture) process gas generator is developed. The moisture freeze-out process in the test heat exchanger is studied under controlled conditions as well as real world scenario. Transient data relating heat exchanger performance (NTU), associated pressure drop, and deposited frost mass are collected. The effect of moisture concentration and heat exchanger cooling profiles (due to flow imbalance) on the heat exchanger performance (NTU) degradation and frost deposition characteristics are investigated. Simulations from a 1D transient numerical model developed at FRIB have been used to get insights on the frost formation profile in the test heat exchanger and volume averaged frost properties. Outcomes relating the frost properties, frost collection capacity, and heat exchanger performance degradation are reported.

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