Optimization Calculations for a 30 HZ, 4 K Regenerator with Helium-3 Working Fluid

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Abstract - The NIST numerical software, REGEN3.3, which incorporates both He-4 and He-3 properties, was used to calculate the losses and second law efficiencies of 4 K regenerators operating at 30 Hz. Operating parameters, such as average pressure, pressure ratio, and warm-end temperature were varied to investigate the effect of non-ideal gas properties. Regenerator parameters such as matrix material and shape, hydraulic diameter, and regenerator geometry were varied to investigate losses due to non-ideal regenerator behavior. The results show that He-3 can increase the regenerator efficiency by a factor of at least two compared to a regenerator optimized for He-4. A layered regenerator of gadolinium oxysulfate (GOS) at the cold end and ErPr at the warm end is the best of many material combinations. A regenerator with parallel holes of about 20 % porosity showed only slight improvement over one with packed spheres. The regenerator warm-end temperature has little effect on its efficiency for temperatures below 35 K and pressures of 1.0 MPa and above. An optimized 4 K He-3 regenerator uses layered GOS and ErPr with the warm end at about 30 K and an average pressure of about 1.0 MPa. With those optimum conditions a reduced regenerator loss of 0.36 and a regenerator second law efficiency of 25 % are achieved.

Keywords - Cryocoolers, cryogenics, efficiency, Gifford-McMahon, helium-3, helium-4, numerical analysis, pulse tubes, real gas, refrigeration, regenerators, Stirling, theory

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