ABSTRACT

Miniature Stirling cryocooler is widely used for cooling IR detectors. In the present study, a numerical investigation is carried out on a regenerator for a miniature Stirling cryocooler, with Helium as the working fluid. The regenerator region made up of a stack of wire meshes is modelled as a porous medium. For modelling heat transfer in the regenerator, both the local thermal equilibrium (LTE) and the local thermal nonequilibrium (LTNE) models are used. The reciprocating motion of the compressor piston and the cold tip has been modelled with dynamic meshing. The thermo-physical properties of the working fluid and the wire mesh are considered to be varying with temperature. The maximum difference in the temperature obtained from the LTE and the LTNE models varies from +4% to -8% over the entire length of the cryocooler at t = 40s. The present study identified that the LTE and the LTNE models closely predict the overall temperature variation along with the regenerator. However, for capturing accurate heat transfer characteristics, including thermal saturation, the LTNE model has to be used, even though it is computationally expensive.

The performance of a miniature Stirling cryocooler depends primarily on the porosity of wire-meshes used in the regenerator. A low porosity regenerator requires higher input power to get the same pressure ratio to compress the working fluid due to a higher pressure drop than a high porosity regenerator. On the other hand, high porosity regenerator requires less power input. However, the thermal performance of the regenerator decreases as the porosity increases. In the present experimental study, uniform porosity and non-uniform porosity matrices were considered to obtain an optimum porous matrix of the regenerator for the cooling capacity of 0.5W @80K with Helium as the working fluid. In the parametric study, the wire-mesh number of 200, 300, 400 and 500 for the regenerator with the uniform porosity is considered. Based on the cool-down time and power input, wire-mesh number 400 is considered optimum. To reduce cool-down time and power consumption, non-uniform porous matrix regenerators were

considered with different combinations of wire meshes for a miniature Stirling cryocooler. The present study shows that non-uniform porous matrices reduce the power consumption or cool-down time considerably compared to the uniform porous matrix of the miniature Stirling cryocooler.

Miniature Stirling cryocoolers are high-endurance systems that operate with some moving parts and can reach 20K or lower. Stirling cryocoolers have vast applications, including military, space technologies, etc. In the present study, the size effect of the regenerator of a miniature Stirling cryocooler was analyzed using numerical and experimental investigations for three different sizes. For the numerical study, simulations were carried out with the axisymmetric computational model. Helium was considered the working fluid and a regenerator region modelled as a porous medium. The thermophysical properties of the working fluid, wire mesh, and regenerator material vary with temperature. For the experimental investigation, three different sizes of the regenerators were manufactured, keeping the exact dimensions of all other parts of the miniature Stirling cryocooler. Experimentally achieved minimum temperatures at the cold tip of a miniature Stirling cryocooler were compared with Walker's first approximation design theory, and found that the first approximation theory gives a reasonable estimate about the minimum attainable temperature.