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Experimental and theoretical investigation to study pressure drop in regenerators

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Stirling type Cryocoolers are required to cool the I-R detectors and have become essential in military and space-based applications due to its efficiency and compactness. At the core of a cryocooler lies the regenerator, a crucial component acting as a heat exchanger. This heat exchanger plays a vital role in the operation of the cryocooler due to its efficient heat transfer resulting in cooling of the working fluid. Optimum design of heat exchanger is the critical requirement for the cryocooler. This optimization primarily focusses at minimizing pressure drop within the regenerator and maximizing the heat transfer. As the cryocooler reaches steady state performance, less energy is expended due to reduced friction and pressure drop as the fluid moves through the regenerator. As a result, the overall cooling performance of the cryocooler improves.

The present study is aimed at experimental and numerical investigation to assess the pressure drop characteristics of the regenerator which uses meshes of stainless steel, such as SS 400 and SS 200 meshes, under varying ambient and cryogenic temperatures. Ansys Fluent software is used for numerical simulations to derive hydrodynamic parameters, such as mass flow rate, Darcy permeability and Forchheimer coefficient, which capture both viscous and inertial resistance. The mass flow rate represents the rate at which fluid flows through the regenerator, while the Darcy permeability characterizes the ability of the porous medium (the stainless steel meshes in this case) to allow fluid to pass through under the influence of a pressure gradient. The Forchheimer coefficient accounts for additional resistance due to inertial effects within the flow. These parameters are integrated into the momentum equation, which represents the balance of forces within the regenerator. By incorporating the volume-averaged hydrodynamic resistance, the momentum equation calculates the overall pressure drop across the regenerator.

A numerical model is developed and validated with the experimental data reported in the literature. An experimental set up is developed in our laboratory to measure the pressure drop across the regenerator. The setup is similar to a pulse tube cryocooler configuration, incorporating a pressure wave generator, an after-cooler for heat dissipation due to compression, a regenerator, an inertance tube as phase-shift mechanism, and a buffer volume to stabilize gas flow and pressure. Cold end and hot end heat exchangers are omitted. Experiments are conducted for various charge pressures and input powers at ambient conditions. Pressure transducers are used to measure the pressure drop across the regenerator, mounted at the inlet and outlet of the regenerator. Upon obtaining experimental results for the pressure drop across the regenerator, the hydrodynamic parameters specific to the regenerator in this setup are calculated using the developed numerical model. Investigation is carried out to predict pressure drop for cryogenic temperatures and for different charge pressures using these parameters. Experimental work is further carried out to study and compare the predictions with the actual experimental results.

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