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A Study on Energy Separation Mechanism in Ranque-Hilsch Vortex Tube

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1. Introduction

This thesis describes the experimental and model analysis on the energy separation mechanism in a counter flow Ranque-Hilsch vortex tube (VT). This thesis comprises 6 chapters; 1) Introduction, 2) Experimental Apparatus and Methods, 3) Development of Total Temperature Probe, which explains developed three total temperature probes and measurement accuracy, 4) Flow Measurement at Cold Exit, which reports the results of total temperature/pressure measurements and flow visualization at the cold flow exit (cold exit), 5) Mathematical Model Analysis of Compressible Vortex Flow, which describes a mathematical model analysis of isolated unconfined compressible vortex flow (VAB model) with a review of some literatures, and 6) Conclusions.

2. Results and Discussions

An evaluation experiment is conducted using the developed total temperature probes which are named as Type 1, 2, and 3 to determine the effects of probe angle along the centerline of a sonic jet nozzle on the measurement accuracy. Results show that the largest measurement error for Type 1, 2, and 3 are −1.3°C, −1.1°C, and −0.7°C, respectively, and the effect of the angle of the thermocouple on the total temperature measurement is negligibly small.

The experiments of the effects of the cold fraction on the measurement were carried out with the Type 3 total temperature probes and Pitot pressure probe. From the results, a negative and positive gauge pressure regions are measured. It implies the possibility of a direct/reversed flow at the cold exit. To clarify the flow direction, two kinds of flow visualization are conducted. From the results, a reversed flow is observed around the center of cold exit at a smaller cold fraction. The length of reversed flow increases as the cold fraction decreases, which implies the decrease in the pressure at the core of the vortex chamber. A lower pressure in the vortex chamber means a lower static/total temperatures at the core of vortex chamber and a higher static/total temperatures at the outer region of the vortex in the vortex chamber. This is the effect of cold fraction on the EMS at an arbitrary inlet pressure.

The VAB model is improved by replacing the laminar Prandtl number with a laminar plus turbulent Prandtl numbers. The analysis results show that a hotter gas in the peripheral region of the vortex is mainly caused by heat generated by viscous dissipation, and colder gas in the vortex core is mainly generated by viscous shear work done on the surface of the fluid element to the surrounding gas.

3. Conclusions

The objective of this study is to clarify the energy separation mechanism of VT. For the purpose of this objective, the experimental and analytical studies were carried out.

From the experimental results, a reversed flow is observed at the cold exit. The length of the reversed flow increases as the cold fraction decreases, which implies the decrease in the pressure and temperature at the core of the vortex chamber. This also leads to a higher static/total temperatures at the outer region of the vortex in the vortex chamber.

From the VAB model analysis results, it is understood that a hotter gas in the peripheral region of the vortex is mainly caused by heat generated by viscous dissipation, and colder gas in the vortex core is mainly generated by viscous shear work done on the surface of the fluid element to the surrounding gas.

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