## Abstract

The reverse Brayton cryocooler is an emerging technology in the cryogenic domain with significant applications such as high-temperature superconductor, liquified natural gas and space applications. Despite being reckoned as the technology of the future in the power sector, the high-temperature superconductor (HTS) based power cables are facing some challenges towards commercialisation as an alternative cost-effective solution to the existing technology. The refrigeration cost and efficiency of a Brayton cryocooler, which is gaining popularity as a subsystem in high-temperature superconductor technology, is the specific challenges as envisaged in the latest cryogenic roadmap.

This study aims at exploring the capability of a reverse Brayton cryocooler and developing a technological map in the domain of applications of HTS cable. A commercial process simulator, Aspen HYSYS®, is considered for the thermodynamic modelling that has been validated with the experimental data. The exergy, exergoeconomic and off-design models are developed to analyse the thermoeonomic performance of the cryocooler. The cycle is investigated for the selection of working fluid, optimisation of process parameters, the impact of design parameters, and estimation of the component sizes. The operational characteristics map is developed by analysing the cycle during off-design conditions. The basic configuration is modified based on the obtained results through different arrangement of the turbines. The exergoeconomic analysis of the best configurations is performed to recommend a suitable configuration of reverse Brayton cycle-based cryocooler for high-temperature superconductor cable.

Key findings of this analysis are the optimum process parameters, such as inlet pressure to the compressor and pressure ratio, and the performance characteristics of the basic configuration. Helium is found to be the most suitable working fluid for the cryocooler. While the heat exchanger is the most sensitive component from a thermodynamic performance point of view, the turbine is the costliest component of the cycle. The staging of turbomachinery has increased the thermodynamic performance of the cycle. It also improves both the cost of exergy destruction and refrigeration cost in one of the arrangements where two turbines are operated in parallel. The standardisation of cryogenic turbines is the best way to reduce the capital investment of cryogenic process plants. The final outcome of the analysis is a technological mapping that can be used to select RBC configurations along with the required process and equipment design parameters for

cryogenic applications having different heat loads at different temperature levels. The guidelines evolved out of this study may be employed for other turbine-based cryogenic refrigeration and liquefaction systems.

**Keywords:** *Reverse Brayton Cryocooler; Cryogenic Refrigeration; Exergy; Split Exergy; Exergoeconomics; HTS Cable; Off-design performance analysis.*