Abstract

Large-scale helium liquefier is a key subsystem of advanced installations like nuclear fusion reactors, particle accelerators, colliders etc., for cooling the superconducting magnets. Although there are large-scale helium liquefiers at several scientific establishments around the world, there is still scope for a systematic and methodical approach for achieving a high rate of liquefaction and low specific power consumption along with reasonable reliability of operation.

In this thesis, an attempt has been made to propose the guidelines for designing large-scale plants in a generalized manner leading to configurations that provide superior thermodynamic performance. A commercial simulator, Aspen HYSYS® has been employed with necessary customization and validation with operational data of two existing plants. Sensitivity of different parameters like total flow through expanders, distribution of flow among expanders, compressor discharge pressure, isentropic efficiency of expanders, heat exchanger effectiveness etc. on the performance of Collins cycle, which is the basic cycle for helium liquefaction, has been studied using the First Law of thermodynamics. Studies on Collins cycle using exergy approach have given directions to further improvement of helium liquefaction cycles and the different ways such as arrangement expanders, addition of reverse Brayton stages, introduction of intermediate pressure level and selection of different cold end configurations have been investigated.

Major findings of this study are the optimum total flow through expanders and its distribution among expanders, the appropriate discharge pressure for compressor, the option for adding surface area to heat exchangers, the proper choice of expander arrangement, the optimum number of Brayton stages required, identification of expanders to be operated in the intermediate pressure level, appropriate selection of cold end design etc. Configurational improvements and appropriate selection of operating parameters have provided a maximum cold box exergy efficiency of 61%. However, the thermodynamic efficiency has been trade-off for higher reliability and reduced cost. This demanded various configurational modifications and eventually reduced the exergy efficiency to 48.5%. The guidelines evolved out of this work may be employed for the design of large-scale helium liquefiers.

Keywords: Large-scale helium liquefier; Thermodynamic cycle design; Low temperature refrigeration; Parametric analysis; Exergy destruction; Exergy efficiency; Process simulation, Aspen HYSYS.