ABSTRACT

Cryogenic Ambient Air Vaporizer (AAV) is a star-shaped fin-tube heat exchanger designed to re-gasify a cryogenic liquid pumped through it. Renewable heat from ambient air acts as the heat source to vaporize cryogenic fluid that flows inside the tubes. AAVs are more popular for their low operating costs. Pump and the switching valves are the only moving components that make the operation highly reliable. The moisture of air freezes and deposits over the fin surfaces that is defrosted after each operation cycle to prevent deterioration of heat transfer beyond a limit. For continuous gas production, two sets of vaporizers switch flows between them after each operation cycle. While one operates in working mode, the other is switched off for complete defrosting. This has been termed as Full Block Switching (FBS) AAV. Though the operation is reliable, the size and capital cost of the AAVs are on the higher side. Moreover, accumulation of ice and frost and long defrosting time that are dependent on atmospheric conditions, particularly, the temperature and humidity, often create design and operational difficulties.

In this research, the concept of reverse flow vaporization (RFV) is proposed that eliminates the idle time during the defrosting cycle by allowing the continuous flow through both the vaporizer block all the time. It uses the concept of partial defrosting instead of complete defrosting that helps to improve the efficiency of operation. Compared with a conventional FBS system, the total heat transfer area required can be reduced by about 23% with RFV system for the 8-hours switching time. Taking advantage of varying frost deposition along the vaporizer length, the second novel configuration of air-based vaporization system called part block switching (PBS) is developed where only a part of the vaporizer that is under maximum frosting is switched off for defrosting. Compared with a conventional FBS system, the total heat transfer area required can be reduced by about 21% with PBS system for the 8-hours switching time.

Understanding the inter-relationship of the environmental condition, fin geometry, and growth of frost over the fin surface that adversely affects the flow of air through the vaporizer is the key to reduction of the size. A coupled dynamic numerical model that incorporates the phenomena of flow boiling of cryogen inside vaporizer tubes and mass transfer during the frost formation over the vaporizer surface is developed and solved implicitly. The development of natural convective airflow around the vaporizer block has also been analyzed three-dimensionally. A conjugated three-dimensional heat transfer model of an AAV is developed and solved in commercial CFD software.

All three configurations of AAVs, namely FBS, RFV and PBS, are compared to find the most appropriate vaporization configuration for cryogenic re-gasification. For cryogenic vaporization, RFV system is found to be suitable for a higher switching time of more than 8 hours while PBS system is suitable for a switching time of less than 8 hours. Genetic Algorithm optimizes the design of a multi-fin reverse flow vaporization system for continuous vaporization and minimizes its weight that is 35% lower than that of the single-fin conventional ambient air vaporizer. The thesis has also proposed a novel interconnection among the finned tubes that can enhance the natural convective heat transfer by 10%. With optimum fin tip distance, the footprint of the vaporizer block can be reduced by about 65% with the forced draft vaporizer for the identical vaporization capacity and ambient condition.

Keywords: Cryogenic vaporization; Ambient air vaporizer; Frost formation; Optimization; Natural convection; Forced convection