

## Abstract

Cooling to cryogenic temperature is necessary for many sensors used for detection of infrared radiation in military, civil, scientific and medical applications. The sensitivity, noise figure and speed of response of IR detectors improve at low temperature. The most commonly used detector is Mercury Cadmium Telluride (MCT) which operates at a temperature around 80 K for wavelengths in the range of 8-14  $\mu\text{m}$ . The low temperature necessitates the application of a cryogenic cooler, operating either in closed or in open cycle. The coolers, used in missile or airborne systems, need to be small, light weight and reliable. The J.T. cooler operating in open cycle is ideal for such low power, short duration duties. Although J.T. mini-coolers have been in use for many years, there is a serious dearth of information in open literature. This project focuses on indigenous development of J.T. mini-coolers (0.5 – 5 Watts) at 80 K and covers both theoretical and experimental studies.

The J.T. cooler mainly comprises of a finned tube heat exchanger, an expansion orifice and the insulating jacket. The sub-components associated with them are mandrel, header, sealing thread, and outlet nipple. The scope of this research programme may be summarized as follows :

- Process design and analysis of J.T. cooler,
- Development of techniques for fabrication of miniature coolers,
- Design of cooler and associated equipment for experimental studies, and
- Experimental observations and analysis

In a J.T. mini-cooler, high-pressure gas at ambient temperature is first cooled by the low-pressure return stream in a counterflow heat exchanger. The pre-cooled gas is expanded through an orifice, getting cooled further and producing some liquid. The deterioration in performance in heat exchanger occurs due to finite surface area, axial conduction through separating walls, heat leak from the surroundings etc. New analytical relationships have been derived for the performance of a counterflow heat exchanger with the help of a mathematical model where heat conduction along the outside wall has been considered to be significant and the heat exchanger is subjected to heat loss at the cold end. The net refrigeration output of the cooler has been expressed in terms of

dimensionless parameters, which, in turn, are functions of the geometrical and process parameters of the cooler. Extensive evaluation of the refrigeration capacity has been done to bring out the dependence of the refrigerating effect on relevant geometrical and process parameters.

These coolers are expected to perform in military applications; they have to be rugged and reliable. Therefore, a simple fabrication technique has been adopted to make all the components reproducible. Since the mini-cooler components are very small, the selection of material for fabrication of individual components, machining precision and assembly technique are critical. The technology of fabrication has been established, including some new and innovative steps.

The mandrel provides the support to the other components and gives shape to the cooler. A solid micarta rod was used as a mandrel instead of a thin walled s.s. tube that is commonly used. To ensure proper winding, threaded grooves were made in the mandrel. The pitch of the groove was chosen in such a way that the finned tubing was laid with a very small axial gap between the turns. This innovative step has significantly improved reproducibility and reliability.

The expansion nozzle was another component that needed development effort. Various alternatives have been tried for fabricating the expansion nozzle. Drilling holes by laser in a brass cap gave the most successful technique. After the cooler was assembled it was inserted in a double walled insulating jacket.

A standard prototype cooler has been designed and fabricated for experimental studies. Considering the end use requirement, an appropriate cooler has been fabricated. The heat exchanger was designed using standard correlations for heat transfer coefficients. The diameter of the expansion orifice was computed considering sonic velocity at the throat, and the orifice was drilled by laser. A glass dewar was designed and built to serve as an insulating jacket.

The cooler was tested for thermal performance using an in house cooling system, which consisted of a high pressure gas bottle, molecular sieve filter, solenoid valve, regulating valve, flexible tube and cooler-dewar assembly. The effect of nozzle size, operating pressure and orientation etc. on flow rate, cool down time, hold on time have been studied. The cool down and liquid hold-on times are the most important parameters for the end user. Various other tests, such as on-off capability and gas conservation studies have been carried out to see the practical utility of the cooler and satisfactory performance has been reported for future applications. Thus a J.T. mini-cooler has been successfully designed, fabricated, tested and delivered for critical military applications.