Case Study: Thermal Management in Harvard Medical School Tissue Analysis Instrumentation

Advanced Thermal Solutions, Inc. — September 2016

Designers of today’s highly advanced medical diagnostic equipment must overcome many of the same thermal challenges common to telecommunications, industrial and information technology electronics.

In addition, medical diagnostic devices present unique design issues and boundary conditions that factor into thermal solutions. These include isothermal and cyclic temperature demands, precise test repeatability, and maintaining the patient’s safety and comfort.

These kinds of issues were presented by Harvard Medical School to the experts at Advanced Thermal Solutions, Inc. (ATS) when it needed a cooling solution for the diagnostic equipment it was relying on for the analysis and observation of human tissue samples in a controlled laboratory setting. This was the school’s Frozen Tissue Microarrayer System.

ATS engineers had to provide thermal solutions to meet a range of design goals:

- Provide long-term temperature control for tissue samples embedded in an optimum cutting temperature fluid.
- Create a cooling system to maintain tissue samples below -70°C for six hours.
- Ensure operator visibility of the samples.
- Eliminate humidity and frost within the system to prevent sample contamination.

ATS Cooling Solutions

ATS engineers developed highly effective thermal solutions to meet all the design requirements of the diagnostic equipment. A reservoir in the device holds the liquid cooling medium and tissue samples are loaded through an opening at the top. Through a duct, cool air is circulated over the top of the samples to maintain temperature and humidity requirements.

As seen in Fig. 1, the diagnostic system consists of:

- Frozen tissue curing
- Tissue sample loading area at the top of the cooling system (seen on the left)
- Duct system (on both sides of system) to circulate cool air
- Ice/alcohol reservoir at the system’s bottom to contain the cooling medium
Conduction Cooling Design

In operation, tissue samples are loaded into removable aluminum cassettes that fit tightly into a metal receiver (top left, Fig. 2). The receiver contacts the cassette on five sides which allows for cooling of the samples by conduction. The receiver is lowered into a reservoir containing a slurry of dry ice and ethyl alcohol. The receiver is maintained at a constant temperature until the dry ice evaporates. The reservoir is double-walled and insulated to extend the evaporation time of the dry ice.

The receiver also features integral fins that increase surface area for drawing heat downward from the base of the cassettes into the icy slurry (bottom left, Fig. 2). Fins are based on the same ATS heat sink design principles used in the company’s high performance maxiFLOW™ heat sinks.

Using analytical modeling, ATS engineers determined that 10 fins were the optimal number for cooling the cassette receiver and its contents. CFD simulations also showed that the 10-fin concept resulted in an optimal design. The engineers validated their analytical and CFD results through empirical testing. It was determined that extending 10 fins into the slurry provided the cooling performance to maintain tissue sample temperatures below the -70°C threshold for 9.75 hours.

Further temperature testing using thermocouples showed only a 2.5°C difference between the coldest points at the bottom of the fins and the tissue samples in the cassette. This proved that the design overcame thermal conduction resistance and could effectively maintain the samples below their critical temperature.

Convection Cooling Design

The above conduction cooling design provided only part of the solution. There were additional needs to maintain the temperature at the top of the samples and to decrease the relative humidity of the cool air from the ambient air in the lab. ATS engineers designed a convection cooling system to fulfill these requirements.

A heat exchanger was installed with its fins in the dry ice/alcohol slurry and its other side extending into a duct to cool the air passing over it. This approach uses the same cooling medium for both convection and conduction to ensure there is no temperature differential throughout the sample and that the sample is as isothermal as possible.
Air is pushed by a counter-rotating fan through the duct and into the heat exchanger. The heat exchanger forms a thermal link between this air and the slurry mixture. The heat exchanger was designed with an optimum balance between its surface area and the resulting pressure drop to ensure the fan was operating with the most effectiveness.

Once the air passes the heat exchanger, it moves through the ducts and into a diffuser at the top of the system. The diffuser disperses the air over the sample creating a barrier between the tissue and the ambient environment of the lab so outside moisture and heat are not transferred in.

The ATS engineers tested this design using an array of thermocouples and ATS hotwire anemometer Candlestick Sensors connected to an ATS ATVS-2020™, a temperature and air velocity scanner. They determined there was too much mixing between the air flowing over the samples and ambient air. The diffuser was redesigned with a new connection to the duct and an optimized outlet radius (see Fig 4).

In the ducts, a molecular sieve desiccant housed in a honeycomb structure was used to reduce the dew point of the air to -84.4°C, which was well below the -72°C air temperature in the duct.

**Conclusion**

ATS engineers performed a final series of tests of the Frozen Tissue Microarrayer System using Candlestick Sensors, thermocouples and the ATVS 2020™ scanner. The tissue temperature stayed constant over the required six-hour period and well below the -70°C threshold. In fact, testing determined that the tissue temperature remained below the threshold for nearly eight hours before warming above a usable temperature (Fig 5). The multi-part cooling system was a success, meeting the original design objectives provided by Harvard Medical School.

The process of designing cooling solutions for the Frozen Tissue Microarrayer demonstrated that thermal design practices used throughout electronics cooling can be applied in the medical device industry. Fin efficiency, thermal resistance, and pressure drop calculations are standard regardless of the application. Thermal solutions should be considered early in the design process so they can be incorporated into the overall system as efficiently as possible.

ATS’ team of experts, used traditional thermal calculations, CFD simulations, empirical testing, and its leading-edge heat sink technology to successfully design the thermal solution for this medical equipment application. The ATS design allowed Harvard Medical School to test tissue samples while meeting its strict requirements.

Visit www.qats.com, call 781-769-2800 or email us at ats-hq@qats.com to learn more about ATS and its Thermal Management Analysis and Design Services.