Heating and Cooling of Incubator Chambers

Laird Thermal Systems Application Note
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Introduction

Incubators, used for cell and tissue cultivation in hospital and laboratory settings, grow and maintain cell and tissue samples under controlled conditions for hours, weeks, or even months. They create the ideal environment for cell and tissue sample growth by maintaining optimum levels for temperature, humidity, carbon dioxide, and oxygen. Precision control of these factors enables research and experimental work in industries where cell culture is vital, such as zoology, microbiology, pharmaceutical research, food science, and cosmetics.

Accurate and precise control of temperature is especially important for cell growth. Excursions above and below the optimum mammalian body temperature of 37°C, even by as little as 6°C, negatively impact cell health. If too cold, growth slows, sometimes permanently; if too hot, sensitive proteins begin to denature.

Using compact thermoelectric cooler assemblies instead of compressor-based thermal management solutions provide a more efficient and cost-effective option. In addition, new government restrictions of traditional and natural refrigerants central to compressor-based systems make thermoelectrics a more advantageous solution for temperature stabilization in incubators.

Incubator Requirements

Control of temperature, humidity, carbon dioxide, and oxygen levels must be maintained in the incubators for proper cell culture to occur. The heat load requirements can range from 30 to more than 400 Watts based on chamber size. For CO_2 incubators, relative humidity levels of 95 to 98 percent and specified CO_2 concentrations ranging from 0.3 to 19.9 percent also must be maintained.

Design Challenges

Incubator manufacturers face many thermal management design challenges ranging from space constraints, airflow, moisture, and dust, to ease of cleaning.

Tight space constraints within incubators require thermal control units to have a compact form factor, maximizing chamber volume. The thermal solution must include an efficient, effective heat exchanger/fan, operating within limited space. Achieving heating and cooling within this limited volume requires units with high heat-flux densities.

The second challenge is ensuring consistent airflow throughout the chamber. Incubators feature fans or blowers with baffles to distribute air gently and evenly over the samples. However, fans and other components must be protected from moisture and humidity, which can cause corrosion that quickly degrades the performance of mechanical components like fans. It can be difficult, however, to balance the high humidity levels needed for proper operation of the incubator with condensation forming inside the unit. Features such as gasket sealing, potting—or even more advanced sealing options—will eradicate condensation leakage.

Finally, from an operational standpoint, dust may be a concern. Depending on lab activity around the incubator and air quality, dust can accumulate in the fan/heatsink assembly, increasing thermal resistance, thereby reducing performance. To maintain good thermal performance and longer incubator life, keep all obstructions away from the air inlet, and filter all incoming air. The incubator design also must account for biohazard safety protocols by incorporating easy-to-clean and -sterilize interiors and shelves.

Traditional Solutions

Typically, in a CO_2 incubator, an air or water jacket maintains an even temperature. Since water has a much greater specific heat than air, water temperature changes much more slowly, thereby regulating the temperature inside the lab incubator. The water jacket, a water-filled casing surrounding the incubator, has inlet and outlet ports which circulate water through the chamber walls and to an external heating and/or cooling device. The water exchanges heat with the inner chamber via natural convection and provides a fairly uniform interior temperature and thermal buffer against outside air. The down side is water jackets may leak; and since they contain a significant volume of water, they are very heavy and usually need to be emptied before moving. After moving, the refill and restart process requires about 24 hours to return to a stable operating temperature, leading to significant downtime.

Using a similar casing to the water design, an electric coil or compressor-based system heats air within the jacket, which radiates heat directly to the cell cultures. Some air-jacketed models rely strictly on natural convection to distribute heat evenly inside the chamber, while others add fans. Forced convection, however, increases evaporation from the cultures, desiccating small samples, even when adding a humidity pan. In addition, compressor-based air jackets add unwanted vibration and noise to the lab environment, while generally occupying a large amount of space.

Recent government regulations banning the use of specific refrigerants, particularly in Europe, are motivating incubator manufacturers to look at solid-state thermoelectric temperature control systems as an alternative to compressor-based systems. Older compressor-based systems utilize high global-warming-potential HFC refrigerants including R134a and R404A. Modern compressor-based systems now use a variety of natural refrigerants: R744 (carbon dioxide), R717 (ammonia), R290 (propane), R600a (isobutene), and R1270 (propylene). Each natural refrigerant, however, presents design challenges such as increased pressure, high toxicity, flammability, asphyxiation, and relatively poor performance. The flammable nature of some natural refrigerants makes them hazardous to transport.

Peltier Heating/Cooling

Environmentally friendly thermoelectric temperature control systems offer accurate and precise heating and cooling inside the chamber, keeping samples safe from temperature changes. The many advantages of using thermoelectric cooler assemblies for incubator thermal management include both cooling and heating modes, precise temperature control, rapid cool-down or heat -up ramp rates, and a compact form factor. All of this is accomplished without the use of any refrigerants—natural or synthetic.

Thermoelectric cooler assemblies use solid-state heat pumps known as thermoelectric coolers. Via the Peltier effect, these thermoelectric coolers can move heat from a low temperature to a higher temperature to either cool or heat depending on sample placement. When DC current flows through the thermoelectric cooler, one side gets hot, while the opposite side gets cold. If you reverse the direction of current flow, then the two sides reverse their function. Manufacturers of thermoelectric coolers define two specifications for thermoelectric coolers: ΔT_{Max} and Qc_{Max}. ΔT_{Max} is the maximum temperature differential with no heat flow ($Qc = 0$). Qc_{Max} is the maximum heat flow when no temperature difference exists ($\Delta T = 0$). For most single-stage thermoelectric coolers, ΔT_{Max} hovers near 70°C. However, a lot of this temperature differential can be lost thru thermal resistances of heat sinks. If greater cooling capacity is demanded, then more thermoelectric coolers are required. This can be done by wiring thermoelectric coolers in series or parallel to accommodate 12 or 24 VDC. Real-world operation of thermoelectric coolers and thermoelectric cooler assemblies involves the combination of ΔT and Qc to meet incubator heating and cooling requirements for temperature stabilization.

The combination of a closed-loop temperature controller with a thermoelectric cooler assembly creates a highly responsive, accurate and precise thermal management system. A temperature controller, specifically designed to control thermoelectric cooler assemblies, takes feedback from a temperature sensor to vary the output of the power supply to control the temperature of an enclosure. Temperature controllers can accommodate a variety of control options to deliver energy savings and offer safety alerts. I/O contacts are available for fans, thermoelectric coolers, alarm/status LEDs, thermistors, fan tachometer sensors, and an overheat thermostat.

Laird Thermal Solutions for Incubators

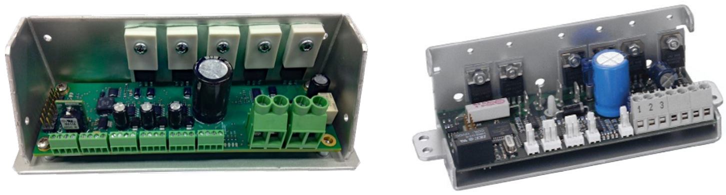
Laird Thermal Systems produces a wide array of thermoelectric cooler assemblies and temperature controller combinations optimized for this application. Any one of the SuperCool thermoelectric cooler assembly series outfitted with a SR-54 or PR-59 temperature controller offers significant design advantages over traditional technologies. All of the SuperCool series feature a high-performance heatsink design, incorporating heat pipes to improve heat dissipation and fan shroud assembly. Lowering the thermal resistance of the heat exchanger increases the heat-pumping ability, so these thermoelectric cooler assemblies can operate at a higher coefficient of performance (COP), reducing power consumption relative to competing technologies. All this capability is packed into a compact form factor.

The SuperCool Series gives design engineers three different heat transfer mechanisms with three standard thermoelectric cooler assemblies: Liquid-to-Air, Direct-to-Air, or Air-to-Air. These assemblies offer cooling capacities of 166, 193, and 202 Watts, respectively, when measured at ΔT = 0°C with a nominal operating voltage of 24 VDC. They can be easily mounted onto vertical walls using fastening machine screw hardware.

SuperCool Series: SAA-170-24-22, SDA-195-24-02, SLA-205-24-02

For temperature control, the SR-54 programmable microcontroller provides thermal stability to within ±0.13°C of the set point in both heating and cooling modes. The SR-54 allows the incubator to reach the set-point temperature quickly without overshooting. Its monitoring capabilities track potential issues, including problematic fans, thermoelectric coolers, and thermostats for quick fault troubleshooting, maximizing incubator uptime. Variable fan speed reduces operational noise, since the fans only run on high speed during the initial temperature ramp and then lower their speed when the incubator temperature has reached steady-state.

Another option is the PR-59 temperature controller with power regulation that is selectable and user-configurable for PID (proportional-integral-derivative), thermostat ON/OFF, or POWER, protecting equipment and optimizing performance. The PR-59 programmable microcontroller delivers control stability to within ±0.05°C of the set point in both heating and cooling modes. By connecting to a PC with associated software, temperature set points and other parameters can be selected.



SR-54 and PR-59 Temperature Controllers

Laird Thermal Systems can customize thermoelectric cooler assembly solutions based on specific application needs. Customers usually begin with a standard thermoelectric cooler assembly and adjust the form factor by modifying heat sinks, mounting locations, and air flow passages to work around obstructions. Barrier protection around the thermoelectric cooler cavity prevents condensation issues from impacting thermoelectric cooler assembly operation. Laird Thermal Systems understands how to modify designs to boost performance or efficiency, optimizing for the desired thermal-management effect. Many years of experience have stocked a large library with reference designs for similar applications, enabling quick response with new custom designs.

Results

Using thermoelectric cooler assemblies for incubator temperature control, rather than traditional technologies, achieves an efficient, thermally stable, compact, reliable, low-maintenance and low-cost-of-ownership solution to CO_2 incubator thermal management.

Thermal Systems can partner closely with customers across the entire product development lifecycle to reduce risk and accelerate time to market. Depending on the customer needs they can provide various levels of vertical integration. Some customers purchase Laird Thermal Systems' thermoelectric cooler assemblies and build their own custom solutions while other design their own solutions and use Laird Thermal Systems as a contract manufacturer to build them. Still, others prefer the entire solution, from design to manufacturing.

About Laird Thermal Systems

Laird Thermal Systems develops thermal management solutions for demanding applications across global medical, industrial, transportation and telecommunications markets. We manufacture one of the most diverse product portfolios in the industry ranging from active thermoelectric coolers and assemblies to temperature controllers and liquid cooling systems. Our engineers use advanced thermal modeling and management techniques to solve complex heat and temperature control problems. By offering a broad range of design, prototyping and in-house testing capabilities, we partner closely with our customers across the entire product development lifecycle to reduce risk and accelerate their time-to-market. Our global manufacturing and support resources help customers maximize productivity, uptime, performance and product quality. Laird Thermal Systems is the optimum choice for standard or custom thermal solutions. Learn more by visiting www.lairdthermal.com

Contact Laird Thermal Systems

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