ThermOmegaTech®

DESIGNING FOR EXTREME ENVIRONMENTS

FROM SEA TO SPACE AND EVERYWHERE IN BETWEEN: 7 EXTREME ENVIRONMENTS FOR DESIGNERS

Avionics, Space and Defense applications rely on mission-critical components to ensure proper functioning in extreme environments. In the many instances where "mission-critical" means that lives depend on successful operation, harsh conditions present development challenges that engineers must be aware of and factor into their designs.

Extreme Cold

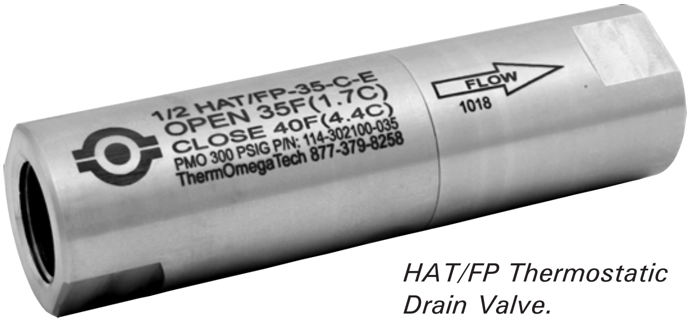
Extremely cold environments, ranging from arctic at the Earth's poles (-90.4°F / -68°C) to cryogenic in the vacuum of space (-455°F / -270.6°C), can cause materials to become brittle or render them inoperable. Moveable components become stiff, batteries slow down or shut off, and temperature-based components become unable to reach their operating range.

While the conditions of space are certainly more extreme than Earth-based environments, the same design principles apply to an extent.

Human-handled devices should be designed with larger buttons and levers that are easier to push or pull, even when hampered by bulky clothing. Where possible, electrical power sources should be eliminated by relying on mechanically operated substitutions.

When batteries must be used to power a device, ensure they are fully insulated from the cold or temperature regulated by ambient heat or an included heat source. For heat influenced devices, keep vital components heated within an active range to ensure operation to thermal variation. For elastic materials (such as the ubiquitous O-ring), select materials with the widest temperature range, such as Fluorosilicone, that are compatible with the environment.

In applications where water must be supplied to critical systems, such as on-board dry-docked ships, additional components should be used to prevent freeze-ups that could interrupt systems or damage piping. Thermostatic drain valves can be used to both prevent lines from freezing and conserve water usage in areas that are either continuously frigid or simply susceptible to cold weather.



HAT/FP Thermostatic Drain Valve.

These mechanically operated valves are typically closed. Once temperatures dip toward freezing, the valve will automatically open to bleed off the cold water from the supply lines and prevent freezing. The valve will close again once it senses the warmer backfilled water, conserving the supply.

These valves will keep operating systems running and minimize system interruptions, no matter how cold it gets.

Extreme Heat

On the other end of the Kelvin scale are environments with extreme heat. Death Valley is the hottest place on Earth, with the highest recorded temperature of 134°F (56.6°C). Most machinery will be able to operate normally in these conditions, with little requirements for design modifications. The primary concern for equipment operating in Earth-based deserts is in relation to small particles of dust and sand entering systems and causing component degradation.

To avoid shortened operating lifespans, designers should ensure minimal access points into a device's interior and an IP rating of at least IP66, otherwise known as "dust tight."

Death Valley temperatures are not extreme when compared to the heat outside our planet's atmosphere. Without the ozone layer as protection to filter out the Sun's heat, those directly in its rays can expect temperatures to reach 250°F (121°C). As outer space's ambient temperature can quickly vary from extreme cold to extreme heat, devices and ships must be well insulated from all temperatures whether equipment is facing the Sun or not.

Design engineers should include thick, insulated walls and a temperature regulation unit for human-operated vehicles to avoid potentially damaging thermal variation.

Outer Space

We've already discussed the extreme temperatures found in space and how designers can prepare for them, but the intricacies of space travel are not limited to extreme thermal variation. For systems sent into the upper atmosphere and beyond into the stars, considerations must be made for reducing payload weight, prolonging service life, and minimizing battery drain.

Weight: The cost to launch 1 lb. of anything into space – food, medical supplies, etc. – can range from $1,000 up to as much as $10,000. (To put this into perspective, a single block of butter in your kitchen is 1 lb.) Designers must do all they can to keep payload weight down. This is primarily achieved by swapping out raw materials for lighter ones, such as high-strength 7075 forged aluminum in place of steel and designing components as compactly as possible.

Service Life: Most systems sent up into space are intended to stay in the atmosphere for more than 24 hours – think satellites, the International Space Station, and the Mars Rover – so they must be designed with a long service life in mind.

Designers should include high-quality parts with extensive cycle tests to withstand many modulations and constant operation over years or even decades.

In addition, for eventual human-crewed long-haul space voyages, vital components should be designed to be easily swapped out with a spare without having to dissect and disassemble the entire system in which it resides.

Batteries: Electricity in space is generated from a single source that is consistently available – solar power via the Sun. Like on Earth, this is collected via solar panels and is stored in a regular, albeit large, battery. These systems do not have an infinite lifespan. Solar panels crack, and batteries eventually refuse to hold a charge.

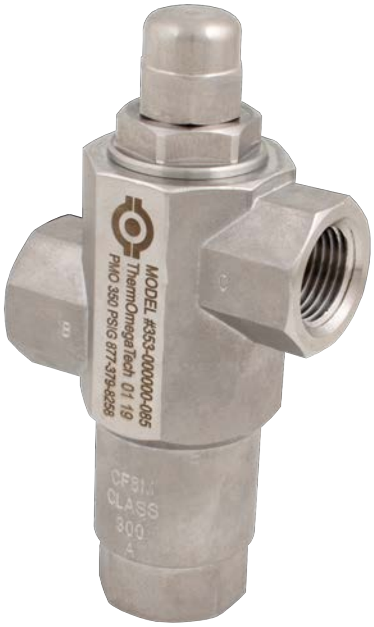
Designers should consider using mechanically operated thermostatic valves in their temperature regulation systems to reduce strain on critical power supplies. These valves operate with no power source, based solely on thermal variations, and thus do not affect central power sources.

Unlike electrical components, thermostatic actuators monitor and respond to temperature variations in media such as air, water, glycol, steam, and others.

An example of thermal actuator technology in action would be a space vehicle that uses self-powered mixing/diverting valves for environmental temperature control.

When the ambient temperature is below the valve's "set-point," the internal spool adjusts to maintain the desired setting. This is accomplished by the valve's internal thermal actuator, which senses the change and adjusts accordingly via phase change technology.

Utilizing a self-contained thermal actuator triggered by real-time and continuous temperature variations eliminates power needs for cabin air temperature regulation, thereby reducing overall strain on onboard batteries.



Thermostatic Temperature Control Valve.

Wet and Salt-Wet

Both fresh and saltwater are notorious for quickly rusting metals and degrading all other materials. Any product or machinery used on or near water must be designed with the damaging effects of wet and salty conditions in mind or risk severely shortened operating life spans.

Saltwater's corrosiveness can be mitigated by using the proper metals on any water-based systems that come directly into contact with it.

Designs should use corrosive-resistant metals and steer well and clear away from iron, as it is especially prone to immediate rusting.

While the use of unique, high-grade materials that resist the effects of saltwater is often costly, their inclusion extends operating life and reduces maintenance rates. For example, most boats use a sacrificial zinc anode block (due to its low nobility on the galvanic series chart) to counteract the effects of corrosion of other metal components exposed to the elements.

Protecting internal electrical components is vital for products used around water. To prevent unnecessary replacement costs each time one is dropped in a puddle or off the side of a ship), designs should be rated to IP65 or above, depending on their exposure rates or submersion needs.

High Pressure

While corrosion is the primary concern of water-based operation at sea level, high pressure is a more pressing matter when operating well below it.

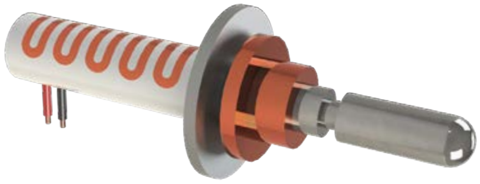
The deepest portion of the recorded ocean is found in the Western Pacific Ocean - Marianas Trench. Reaching 11,034 meters (36,201 feet) deep in some places, the water pressure is more than 16,000 PSI at the bottom. Water pressure crushes from all sides at these depths, and underwater vehicles not appropriately designed would be crushed like a soda can. For deep-sea explorers, these are deadly conditions.

For remote operated and human-occupied expeditions, designers' primary method of ensuring a successful voyage is wall thickness and vehicle shape.

Designs should include thick walls and an overall round shape to equalize pressure and avoid undue stress central to any exterior points. All observation windows should be small, circular, and feature extremely thick plexiglass.

For unmanned deep-sea excursions, the use of electrical devices can also pose design issues. Batteries can malfunction due to cold oceanic temperatures, wires can become loose, and the threat of even a tiny hair-line leak can introduce board-destroying water into the system.

Minimizing the inclusion of electrical components can reduce overall complexity and increase long-term reliability for devices that may stay underwater for weeks or months at a time. One such case for thermostatic deep-sea design features an instrumentation pod used to locate oil and gas deposits underneath the ocean floor using sonar technology.



Thermostatic Valve Design for Deep Sea Buoy Release.

Instead of attaching a floating buoy to the sunken pod where it could be spotted by competitors or damaged by passing ships, the buoy was sunken to the sea floor along with the instrumentation pod.

Once sonar testing was completed, a nearby ship released an ultrasonic activation signal, triggering a battery pack to apply power to a PTC resistive foil heater, heating the thermostatic actuator which quickly modulated to release a latch, thus sending the buoy to the surface where it could be retrieved.

By designing the buoy release mechanism around a heat-activated thermostatic actuator triggered by a remote signal, the need for additional electronic components was eliminated.

There was no need for large batteries to retrieve the pod that could have died before activation, leaving the pod to be lost to the depths of the sea.

For designers with similar deep-sea devices, attempts should be made to minimize the use of substantially sized and continuously on battery packs that may die before activation, as well as overcomplicated circuitry that could fail due to defects or the entrance of liquids.

Explosive Atmospheres

Industrial environments, especially oil and gas manufacturing facilities, often have gas levels that pose an explosion hazard and make operating electrical devices an inherent risk.

For products that must function in these temperamental environments, designers must either ensure they are fully insulated from sparks or remove the electrical components entirely.

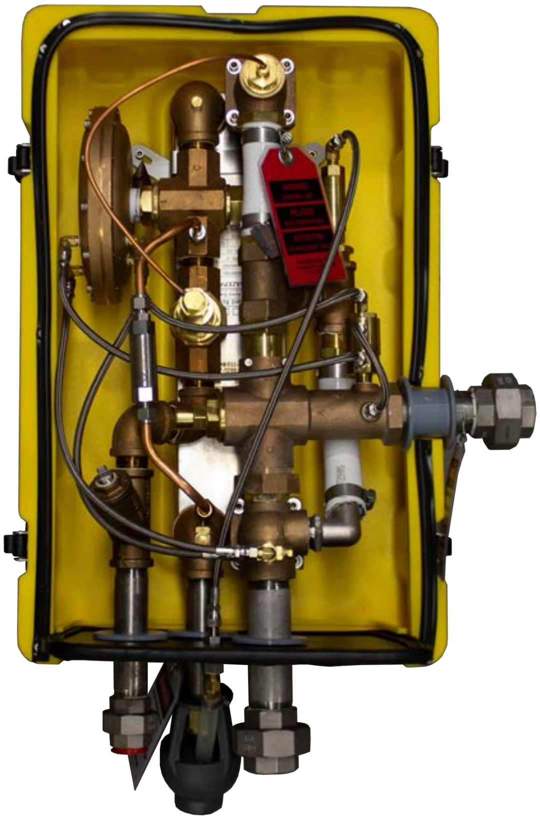
Suppose a product must have an electrical component inside it while operating in an explosion-risk area. In that case, the interior of the device must either be fully insulated to prevent sparks or the electrical energy inside of it capped so that the device is incapable of releasing enough energy to generate a spark.

However, these contingencies can be difficult to achieve due to high costs and the engineering challenges.

To eliminate spark risks and avoid the design challenges above, non-electrical products may be selected in place of electrical devices. These devices should be entirely mechanical and not draw on any power to operate effectively.

In many environments and processes, thermostatic actuator technology can be used in place of electrically controlled devices. The actuators are built into a valve body to monitor and respond to temperature variations and operate 100% mechanically.

As the temperature increases to the valve's set-point, the paraffin wax pellet at the heart of the thermal actuator changes into its liquid phase, undergoing thermal expansion and increasing volume.



Therm-O-Mix Tepid Water Supply Station.

This expansion extends the piston at a precise and repeatable movement to open the valve and allow flow. Once the temperature drops below the set-point, the wax contracts back to its solid state, retracting the piston and closing the valve.

Thermostatic technology does not rely on electricity to function and thus is incapable of producing a spark, making it the ideal solution for explosive environments.

This is particularly relevant to emergency safety shower and face/eyewash stations in manufacturing facilities that can rely on pressure activation when delivering tepid water supply to point-of-use fixtures and use only a facility's existing steam and cold-water supply to produce tepid water for emergency fixture use.

This typically allows for a more cost-effective solution and one-step "plug and play" operation by cutting out the additional insulating step.

Rough Handling

Extreme environmental conditions extend to user interaction with products. While a design may function perfectly in prototyping and factory QA conditions, full functionality relies on successful operation during normal and intended daily use.

Engineers should expect and prepare the products they design to withstand daily use, including compressive forces, abrasions, vibration, thermal variation, humidity, potentially corrosive liquids, and more. While accounting for every potential real-life interaction is virtually impossible, engineers can plan ahead.

Rugged designs should have thick walls and reinforced bosses, be made of rigid materials (either thick plastics or metal), use appropriate seals, and avoid adhesives prone to fail over time – choose sturdier screws, bolts, and ties in their place whenever possible. Take extra time prototyping to mistreat a product, recreating potential trying environments to test for weak points that can be engineered out or around to ensure a product that can keep up.

Extreme conditions require extreme creativity on the part of design engineers, making sure to account for unusual factors found in the depths of the sea or the upper reaches of our atmosphere and beyond.

While no designer can account for every possible future their products may encounter, by factoring in and planning for common hazards associated with specific operating ranges and situations, they can give their systems the best shot for successfully operating under mission-critical conditions.