Optimize Temperature Conditioning and Verification for Industrial Sensor/Transmitter Device Manufacturing

Ensuring the measurement quality of devices over their specified operating range, especially industrial sensors, they typically need thermal testing at different stages of the production cycle.

It requires that engineering look not only at device size and test specifications, but also to consider test access, and operations need to conserve floor space and maximize flexibility.

Achieving quality goals involves many points of thermal stress including conditioning, verification, calibration, life testing, design qualification, failure analysis, quality checks, and regulatory audits.

Production throughput is an increasing challenge as industrial applications call for higher operating temperatures.

Optimizing controlled thermal environments for producing these industrial measurement devices hinges on four areas:

1. Test being performed
2. Unit under test (UUT)
3. Throughput goals
4. Facility infrastructure

Figure 1: *Many industrial sensors need to operate at 200°C and above for long periods of time.*

All manufacturing processes are subject to many interrelated variables. The test environment is no different and, as such, we will discuss the above points throughout the article, rather than in sequence.

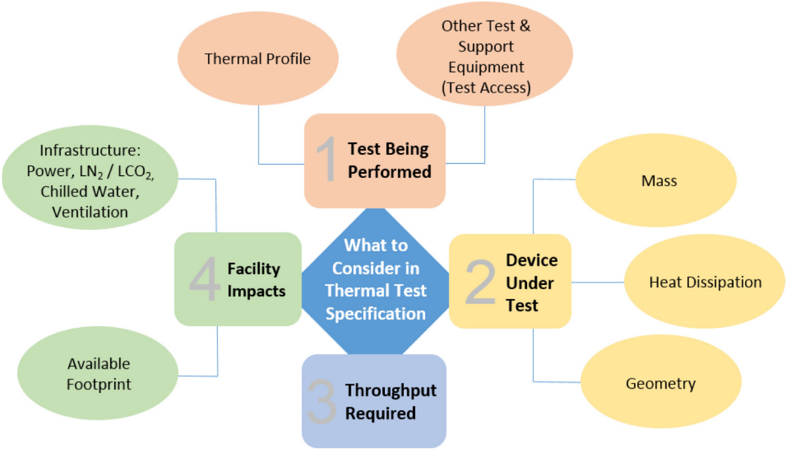


Figure 2: *Four main factors influence the optimal test environment. Configuring a controlled temperature environment depends on how you manage four primary areas: test requirements, devices being tested, throughput, and facility infrastructure.*

Understanding the Test Environment

Most process measurement devices (flow, pressure, level, etc.) have at least one thing in common – the need for temperature compensation.

As the physical size, thermal mass, and need for stimulation increase with each assembly step, the test environment must also grow. Typically, no single environment can effectively do it all. For example, a small chamber containing low mass PCBs provides a more efficient enclosure than an oversized volume of space.

Alternatively, subassemblies may need more thermal capacity and volume to meet reliability testing. Moreover, the space available in a lab or manufacturing floor offer other challenges to proper chamber sizing. Variables that can affect chamber size and configuration are illustrated in **Figure 2.**

Matching Test Environment to Throughput Goals

Your device (circuit, sensor, assembled housing) size, mass, and number of UUTs (Units Under Test) will factor into determining enclosure size. However, the amount of real estate needed on the plant floor for different phases of production is not necessarily fixed. Thoughtful consideration of configuration options can improve productivity and economize on floor space.

Three examples of thermal enclosures configured to optimize throughput are shown below.

Circuit conditioning and pre-production example

The electronics for processing sensor signals tend to be small, low mass items. Often, these circuits can be conditioned in a small enclosure driven by a thermal cycler with a large Delta T (difference between thermal source capability and set point temperature). This type of system can also accommodate multiple circuit boards.

For devices sensitive to thermal shock, enclosure designs can disperse air around the circuits to prevent direct exposure to the temperature source, as shown in **Figure 3** right.

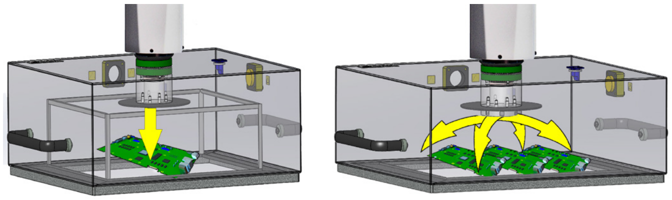
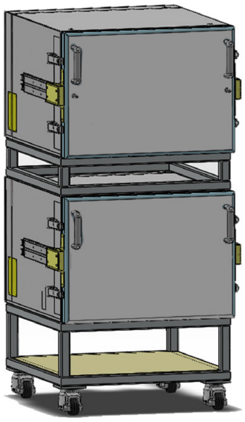


Figure 3: *A portable, air-driven, temperature inducing system targets UUT directly (left) or indirectly at sides of enclosure (right).*



Subassembly testing example

With the build out of devices – applying transducers and housings – larger thermal enclosures are often required. Large chambers consume a lot of floor space, which typically comes at a premium. Stacking of single-zone chambers with independent controls, as shown in **Figure 4**, is a way to double use of floor space per a given area.

Figure 4: *Stacking thermal chambers doubles available floor space.*

Final system qualification example

Finished sensor and transmitter products have different areas of temperature sensitivity. The sensing electronics, for example, may not exceed 85°C, while the seals of a pressure transmitter may need to be tested at 125°C.

Multiple zones (2, 3, 4 or more) provide separately controlled temperature environments. It permits simultaneous testing of devices at different temperatures. A 3-zone chamber, shown in **Figure 5**, is an example where the center zone simulates high heat conditions of pipeline flow. The outer zones can be programmed to meet operating temperature extremes of the instrumented electronics.

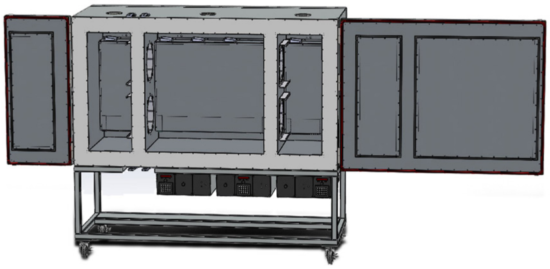


Figure 5: *Multiple zones allow simultaneous device testing at different temperatures.*

How User Access Affects Throughput

Plan for user access and how it affects production. Various test setups need different amounts of user involvement and real estate. Consider what physical and visual access to UUTs suit your test needs and available floor space.

What do operators need to effectively and safely set up tests? For example, it may be more convenient to attach cables or measurement connections to the UUT outside of the chamber where there is more room to work. That way loading and unloading of devices is faster. Adding notches (**Figure 7**) to the chamber, in place of or in addition to ports, provide this capability.

During transmitter calibration a different configuration may be needed. For example, you may need to access a pressure source at one side of the chamber. But normal loading of devices may be from another side. Multi-door configurations can optimize user convenience and test productivity.

What about visibility? Windows and lights provide visual access to the UUT. Do you need to economize on floor space in the production or reliability test lab? Chamber stacking and casters are a few ways to increase use of space, as well as flexibility to configure how floor space is used. **Figure 6** illustrates these configurations.

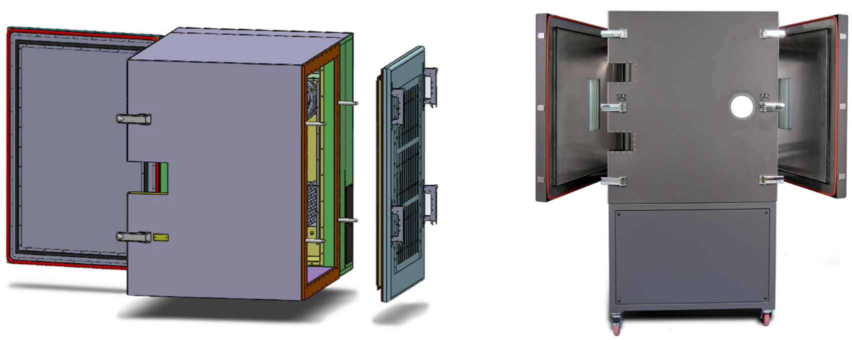
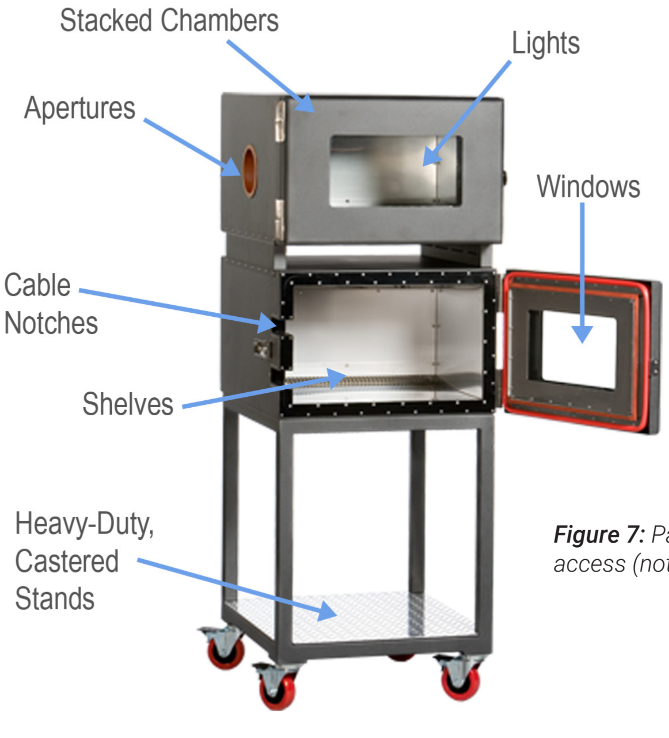


Figure 6: *Combination hinged and removable door (left). Multiple hinged doors – opposing or adjacent sides (right).*



There are many considerations for optimizing throughput from a chamber configuration standpoint, (see **Figure 7**). Users need to make physical connections, load and unload devices, and perform these tasks within the confines of available floor space.

Figure 7: *Partial summary of thermal chamber configurations – physical and visual access (notches, ports, shelves, windows, lights), stacked chambers, and mobility.*

The specified temperature range, thermal cycling, and duration of test will determine the minimum requirements for chamber performance. If the spec calls for testing at -40°C, for example, clearly you need a system that can achieve at least that temperature for a passive UUT.

However, that system may take a very long time to get there or, not at all if the device has an active load. We'll discuss temperature transitions below. The cooling method, system controls, and enclosure design will each factor into optimizing the efficiency and speed of test outcomes. Specifying a thermal system is often driven by how demanding is the test specifications, as well as facility infrastructure. An overview of these considerations are described below.

Cryogenic or compressor-based cooling

Compressor-based cooling uses compressors and conventional refrigerants in a closed-loop system; cryogenic cooling uses expendable Liquid Nitrogen (LN_2) or Liquid Carbon Dioxide (LCO_2) in an open loop system. **Figure 8** shows a cooling curve for each method and **Figure 9** shows their respective temperature ranges.

Specifications that require extreme temperature ranges, fast transitions, or management of high heat dissipation will need the cooling power of cryogenics. A facility equipped to handle bulk delivery and use of liquefied gases is another reason to employ a system with cryogenic cooling.

Compressor-based systems are better suited for long dwell times because a closed-loop system does not require expendable coolants. It also becomes a consideration when there are no facilities for handling cryogenic materials.

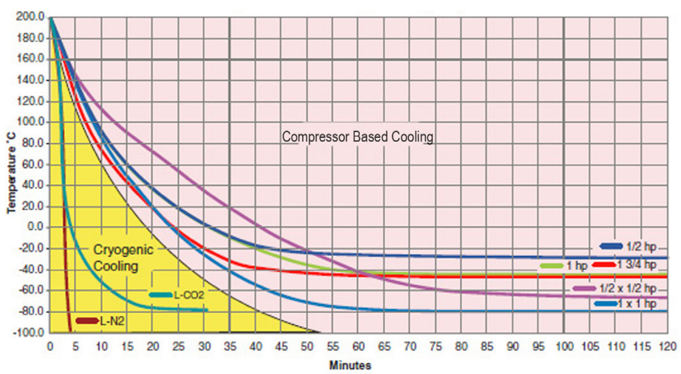


Figure 8: *Cryo vs. Compressor based performance. Cooling curves for LN_2, LCO_2 and various sized compressor units.*

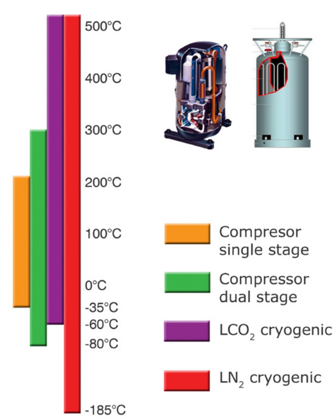


Figure 9*: Temperature range of various cooling methods*

Heat transfer capacity determines thermal response time

Industrial measurement devices, particularly in aerospace, automotive, and oil & gas, continue to extend their operating range to 150°C, 200°C, and above. As specified temperature ranges increase, so does the need for greater test system performance. Otherwise, the time to transition between hot and cold set points that are further apart will increase significantly. This is especially true when going cold. The performance relationship between device size and chamber volume is shown in **Figure 10**.

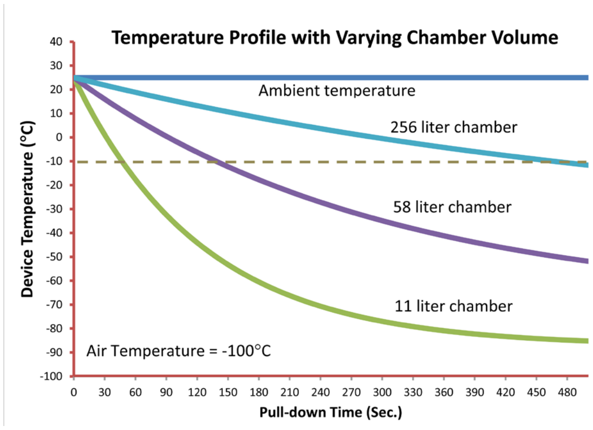
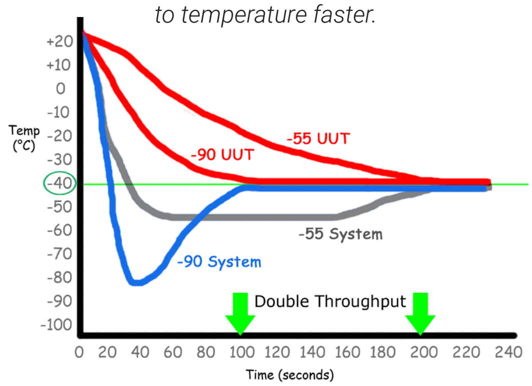


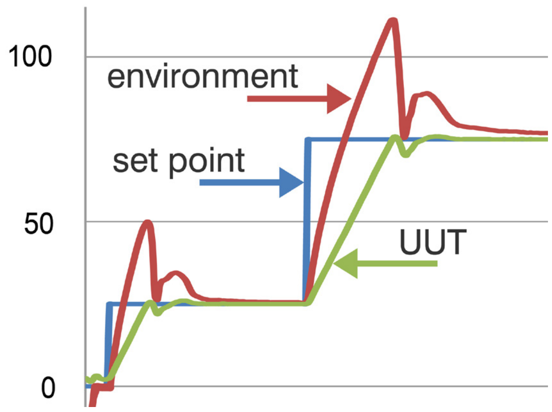
Figure 10*: Performance relationship between device size and chamber volume. Using the same UUT under the same load, a properly sized environment reached -10°C in 50 sec, or 3 to 9 times faster than the larger chambers.*

Two main variables determine system throughput: 1) the temperature difference between system capacity and the specified set point (dT) and 2) chamber air flow properties (Hc). When you add the surface area (A) of your UUT, heat transfer (Q) can be expressed by the equation Q=Hc*A*dT.

For example, a system capable of reaching -55°C (with no load) used to cool a UUT to a set point of -40°C takes 200 seconds. Introduce a different system with a thermal capacity of -90°C (same chamber volume and UUT) and the set point is reached in 100 seconds, cutting ramp time by one half. **Figure 11** depicts the difference in response between two systems of different capacity.

Figure 11: *Heat transfer capacity determines environment response time. Low-temperature cooling capability and flow rate will bring UUT to temperature faster.*





Controlling the test

Bringing the test environment to temperature quickly and accurately relies on the design of the controls, as well as the cooling capacity and enclosure specification.

When fast transition times are important, software algorithms need to drive the environment past its set point. This is followed by equally rapid control to reach equilibrium at the desired temperature. **Figure 12** illustrates this point. This is accomplished by programming the controls by one of two methods: either from an earlier characterization of the chamber or controlling the temperature based on monitoring the UUT. For more about UUT control.

Figure 12: *Environment control using temperature of UUT. Control algorithms drive chamber temperature past set point to speed UUT getting to temperature.*

Maintaining uniformity

All environments experience thermal loss to ambient due to inefficiencies in the enclosure walls. That loss will increase as the enclosure temperature moves away from ambient.

What impact can this have? The larger the enclosure the more circulation the UUT needs to maintain a uniform temperature. For example, if a chamber has insufficient circulation (undersized air flow or oversized space) or has not been characterized, the UUT can vary as much as 5°C at 175°C. An example of increasing heat loss is shown in **Figure 13**.

A properly sized chamber – optimized for air flow, insulation, and control will minimize thermal loss and improve uniformity. Positioning the UUT away from chamber walls can also improve uniformity.

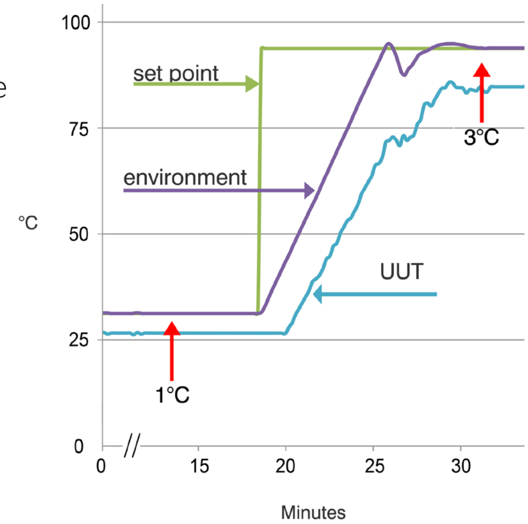


Figure 13: *Example of heat loss due to insufficient air flow. In this case, the UUT never reaches its set points.*

Ensuring test accuracy

Regardless of chamber design, the test environment should provide accurate and consistent performance throughout its temperature range. While a controller can adjust quickly to maintain stable temperatures within a degree or less, there may be other influences that can affect accuracy.

The equipment itself can induce unintended problems to the test or calibration results. Stimulating pressure sensors, for example, needs an environment with a stable atmosphere. Vaporization of a cryo gas can induce pressure, skewing sensor measurements. Additionally, blowers used to create air flow can add unwanted vibration to the environment when testing accelerometers.

There are techniques to reduce equipment noise to negligible levels. Equipment-generated influences on sensor measurements should be a consideration when specifying thermal environments.

Summary

Many types of industrial sensors and transmitters require temperature compensation. Various types are listed in **Figure 14**.

Figure 14: *Example of devices using volumetric flow measurement that need temperature compensation.*

Differential Pressure	Velocity	Positive Displacement
Elbow Tap	Conada Effect	Nutating Disk
Flow Tube	Electro-magnetic	Oval Gear
Flow Nozzle	Swirl	Reciprocating Piston
Orifice Plate	Turbine	Rotary Vane
Pitot Tube	Ultrasonic, Doppler	
Target	Ultrasonic, Transit-Time	
Variable-Area	Vortex Shedding	
Venturi Tube		

Manufacturing these devices typically requires a range of precision thermal environments to accommodate the product life cycle – conditioning, verification, calibration, life testing, design qualification, failure analysis, quality, and regulatory audits.

New sensor and electronic technologies are allowing devices to operate at wider temperature extremes. This presents challenges to achieving production throughput goals. While many controlled environments can support testing to design requirements, they may be slow to perform.

Failing to consider every aspect of configuring a thermal test system can add time to production output. These include user access, floor space, cooling capacity, control functions, enclosure sizing and thermal properties, system-induced noise, and placement of UUTs.

Increasing application requirements – automotive, chemical, oil, and gas – are all the more reason to seek the proper balance between the device, test specification, thermal system, and facility infrastructure. They are essential to efficient production of sensor and transmitter devices.

Reference materials:

- 3 Factors that Determine a Cooling Method for Electronics Testing
- UUT Control Application Note
- Thermal Chamber Configuration Examples