



TRIDENT

Thermal Conductivity Instrument User Manual

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Version: 4.2



Conforms to ASTM D7984, D5334, D5930, ISO 22007-2, GB/T 32064

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Appendix TU - Disclaimer

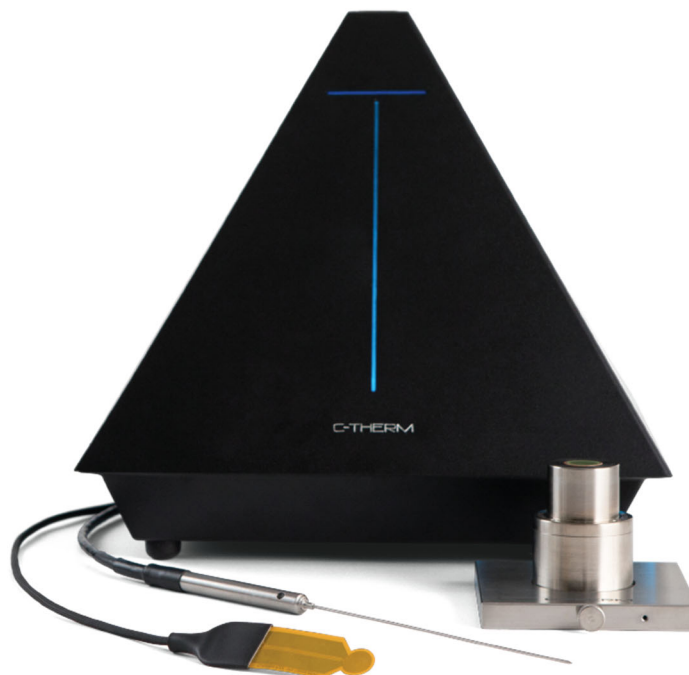
Introduction

Thank you for your investment in a Trident Thermal Conductivity Instrument. Trident is built on C-Therm's reputation for world class thermal conductivity instruments and satisfies the most common ASTM and ISO industry standards. By combining three industry measurement methods in one instrument, Trident meets the needs of today's labs and is future proof for the challenges of tomorrow. With proper product knowledge and safe use, this product will provide years of high-performance testing in characterizing the heat transfer properties of your materials.

The fourth generation of the C-Therm thermal conductivity technology maximizes options for rapid, non-destructive thermal testing. Trident is designed to provide simple, highly accurate thermal characterization of thermal conductivity and thermal effusivity for in-lab use, quality control, and production environments, and requires minimal sample preparation.

Trident offers the precision of MTPS (Modified Transient Plane Source Method), the flexibility of TPS (Transient Plane Source Method), and the robustness of TLS (Needle Transient Line Source Method), all in one modular package. These options support a wide range of applications without sacrificing ease of use. Please see Appendix A for Trident Controller specification.

This manual outlines the operating instructions for each of the following three methods:





Modified Transient Plane Source (MTPS)

Simple and precise. The MTPS method employs a single-sided, factory-calibrated sensor to directly measure thermal conductivity and diffusivity of materials. The MTPS method has the highest precision, highest sensitivity, shortest test time, and is the easiest to use among all three techniques. The method conforms to ASTM D7984.



FLEX Transient Plane Source (TPS)

The TPS method employs a double-sided sensor to determine thermal conductivity. Recommended for more experienced users, TPS provides the greatest flexibility and control over experimental parameters (e.g., test time & power) and avoids the use of any contact agents. The method conforms to ISO 22007-2.



NEEDLE Transient Line Source (TLS)

The TLS method employs a needle probe to characterize the thermal conductivity of viscous and granular materials. It is the most robust sensor for thermal conductivity testing. The method conforms to ASTM Standards D5334 and D5930.

The key capabilities and benefits of the Trident system include the ability to test:

- Solids, liquids, powders, pastes and textiles
- A wide range of temperature
- Accuracy and High Precision
- Non-destructive testing
- Ability to test samples with little to no preparation
- Ability to test small sample sizes

Overall, the level of training and expertise required varies based on the method. The instrument requires a base level of scientific and technical competence in order to operate it safely. Before putting the instrument into operation, please take the opportunity to thoroughly review this manual.

1.1 Putting Trident to Work

The simplest and quickest methods to implement and use are MTPS and TLS. These techniques require minimal to moderate sample preparation and operator training.

The MTPS method simply requires the operator to place the sample on the one-sided heater/sensor, add the supplied weight and click “Start Test”. Analytical results for the sample are available within seconds of mounting it on the sensor. No sample preparation is needed, and an operator can be trained in minutes.

The use of TLS Needle requires somewhat more operator training since, for example, powder and soil samples must be reproducibly packed into sample holders and the melting of samples for melt studies requires that heating and cooling characteristics are reproducible. These requirements for TLS result in somewhat longer cycle times for TLS analyses as compared with MTPS.

The FLEX TPS method requires significantly more sample preparation and operator training than either the TLS or MTPS. The need for perfectly flat sample surfaces to “sandwich” the sensor adds to both operator training requirements and sample preparation time. While more complex to operate, FLEX TPS provides powerful advanced capabilities.




All three methods are broadly applicable in terms of sample sizes and provide complementary material testing. MTPS and TLS methods can be easily configured to analyze liquids, powders and pastes. The MTPS method can be used with monolithic solids not readily probed by TLS, while the TLS probes can conveniently determine thermal properties of materials which would be physically aggressive to the MTPS probe, such as melted plastic. The TPS method can be used with aggregates and liquid samples.

The choice of an analytical method is most often dictated by the expected value of the properties of interest of the sample under test and the physical conditions (i.e., temperature, pressure) for the material application. The physical state of the material and its mechanical properties during testing should also be considered.

In terms of thermal conductivity, the MTPS probe offers the widest analytical range, with extensive measurable thermal conductivity range under physical conditions including a broad range in temperature and in pressure (with appropriate testing accessories). Please see Appendix B for specification.

The TPS method is more broadly applicable for high-temperature analyses than either the MTPS or TLS method. Please see Appendix C for specification.

The TLS method is more limited in its thermal conductivity range yet offers maximum robustness. TLS is the sole method recommended for use with tarry materials. Please see Appendix D for specification.

Method	 MTPS GUARD RING TECHNOLOGY	 FLEX TRANSIENT PLANE SOURCE	 NEEDLE TRANSIENT LINE SOURCE
	Modified Transient Plane Source (MTPS)	Transient Plane Source (TPS)	Transient Line Source (TLS)
Sample Preparation	None Sample simply rests on top of sensor. A few drops of contact agent may be required depending on the material type.	Moderate to Significant Samples should be homogeneous, shaped samples that have very flat, smoothed mating surfaces that sandwich the sensor	None to Minimal Ranges from no preparation for simple soil probes to containment and heating for molten plastic samples
Operator Training Requirements	Minimal	Significant	Minimal to Moderate
Non-Destructive	Yes	No	Sample Dependent
Method Development	Minimal	Significant	Minimal to Moderate
Material Phases	Solids, Liquids, Powders, Pastes	Solids, Liquids, Powders, Pastes	Solids, High-Viscosity Liquids, Powders, Pastes, Gels, Slurries, Melts

C-Therm software provides full data acquisition and analysis in one user interface, allowing full control of all three methods.

1.2 Warnings & Liability

C-Therm shall not accept liability (including warranty support) for consequences associated with experiments conducted using the instrument improperly. Any consequence resulting from failure to comply with the advice and recommendations provided in this manual is the user's full responsibility. Furthermore, any non-authorized modification to the instrument voids all warranty coverage and support for the instrument.

The installation and connection of different peripheral or accessories demand strict compliance with the instructions and warnings given in their respective manual. When using peripheral equipment with our instruments (such as a high-pressure cell, thermostat-controlled bath, thermal chamber, etc.), refer to the specific user manuals provided with each peripheral item in order to guarantee correct operation and adequate safety of these items for your application.

Once the instrument is correctly installed, the customer shall ensure that the people who use it have the necessary product and safety training.

The customer is advised that the sensors are consumables. The life expectancy is determined by the operating conditions and usage profile. Frequent thermal cycling of the sensor(s) can

cause faster aging of the components. It is the user's responsibility to ensure the materials to be tested will not damage the sensor(s) and appropriate care in handling of the sensor(s) is taken.

C-Therm product specifications, technical instructions and best practice recommendations are liable to change without notice. Contact support@ctherm.com for most current document revisions.

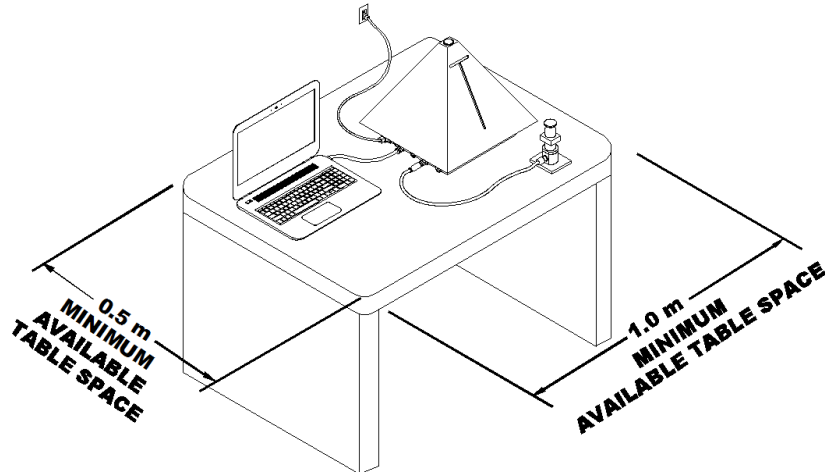
This document cannot anticipate all possible hazards associated with testing your samples and does not attempt to. It is necessary for you to conduct a full safety assessment of any testing you are considering, identify potential hazards, and take steps to mitigate these hazards. C-Therm Technologies Ltd. will not be held liable for any damages caused by the user's failure to take appropriate steps to mitigate hazards associated with their samples and testing protocol or associated with the user's failure to heed the safety precautions identified herein.

2.0 INSTRUMENT SETUP

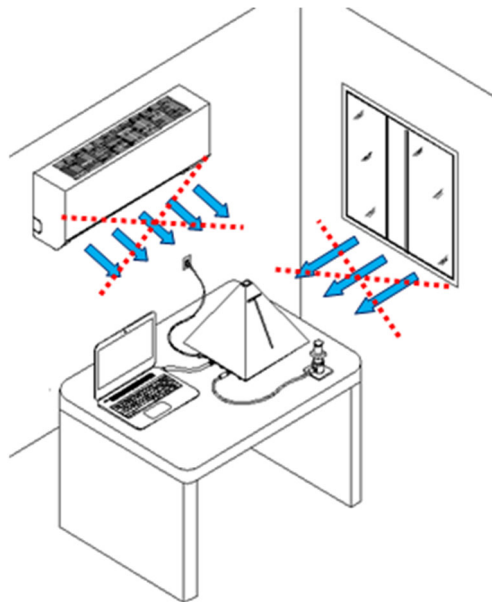
2.1 General Instrument Setup

The Trident system should be positioned so the following requirements are met:

- Minimum of 1.0 x 0.5 m of table space available for instrument and samples, with nearby power socket for the Trident controller and laptop. Additional space and power may be required for thermal chamber or furnace if purchased.



- Table or countertop should be flat and level, clean, and dry. The controller is not water-tight and therefore care should be taken to avoid spraying or soaking the control box with water.
- Stable, grounded power supply unaffected by any other large instruments in the vicinity, 2 x 15A outlet (either 115V or 220V).
- Trident should not be placed directly under a ventilation outlet, as convection from forced air flow may affect test results.



- Background Interference - Trident has been tested and certified to North American (FCC Part 15) and European electromagnetic immunity standards (IEC/EN 61000, EN 55022), and is immune to radiated and conducted electromagnetic fields as defined in these standards. However, the presence of rich electromagnetic environment (NMR, Mass Spec, or similar instruments) may cause interference, either via radiation or conductance through the power lines. Installation should not be close to any of these instruments. If proximity cannot be avoided, additional measures such as shielding and isolating the Trident from the electromagnetic environment and power lines may be necessary
- Lab temperature should be kept between 19°C - 27°C. Ambient temperatures higher or lower than this may affect the performance of the control electronics. While the sensor and cable may be exposed to much higher or lower temperatures, the controller should not be. Use of a thermal chamber with a port for cable feed-through is required for testing outside the range of 19°C - 27°C.
- It is recommended that the Trident system should be powered on and allowed to warm up for a minimum of 1 hour prior to using to achieve optimal performance.
- Please refer to the sensor-specific guidelines for further system setup:
 - MTPS Operating Instructions
 - FLEX (TPS) Operating Instructions
 - NEEDLE Operating Instructions

2.2 Software Compatibility

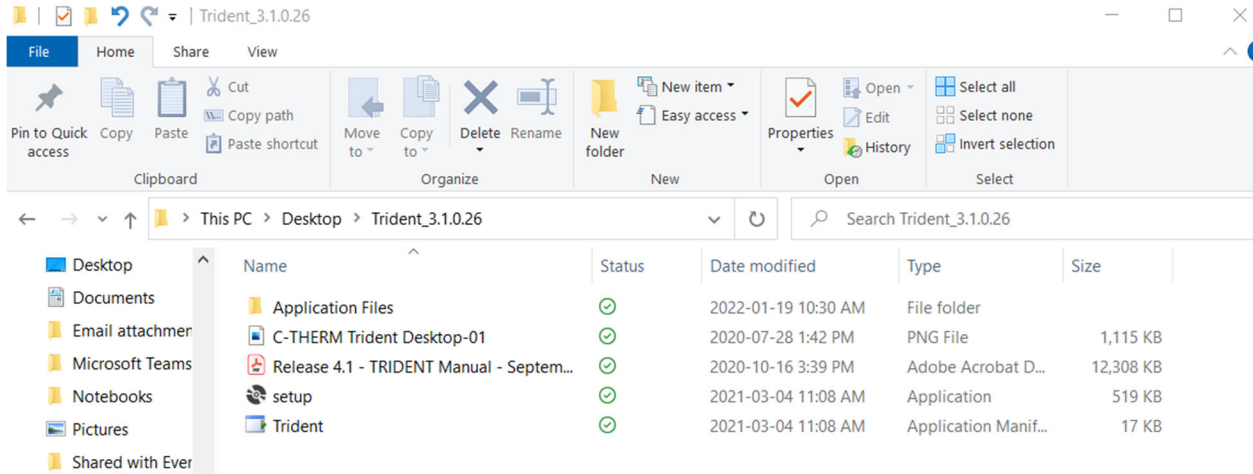
The Trident software is compatible with Microsoft Windows 10 Home and Pro editions. Windows for Education and Windows Enterprise compatibility is dependent on IT restrictions and is not supported. Please see Appendix E for more detailed computer specifications.

2.3 Laptop Setup

NOTE: Turn Trident controller on for one hour for stabilization.

2.3.1 Install Trident software

1. Connect C-Therm USB key to the laptop.
2. Create a folder on the desktop named “Trident 3.1.0.26 Software Install Files” (Update version as required).



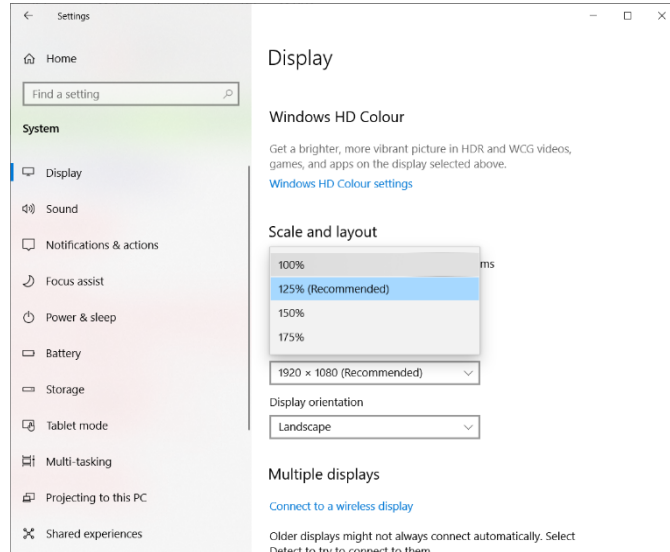
3. Copy the files from the USB key to the newly created folder.
4. Double-click the Setup.exe file from the desktop folder to install the software.

NOTE: Install from the desktop folder instead of the USB key so that future software updates may be installed from the desktop.

2.3.2 Complete the laptop setup

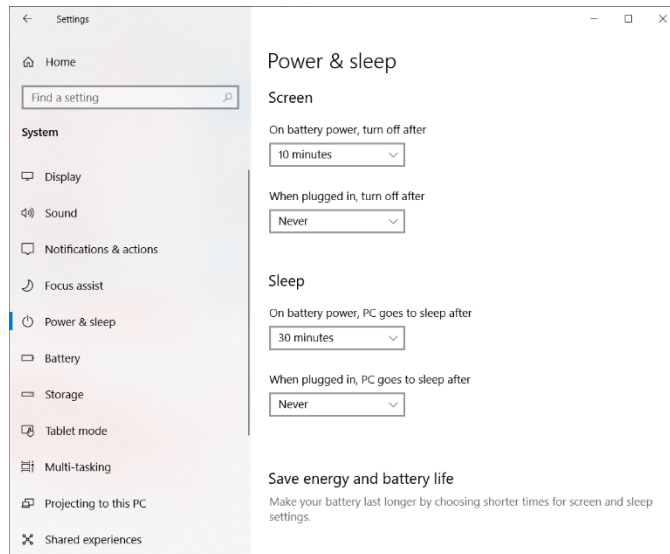
1. Open the computer settings from the Windows menu.
2. Select the System settings.
3. Select the Display settings.

4. Set screen resolution to 125%.

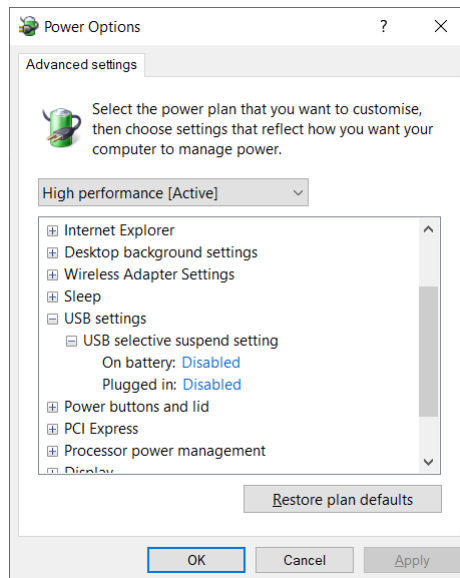
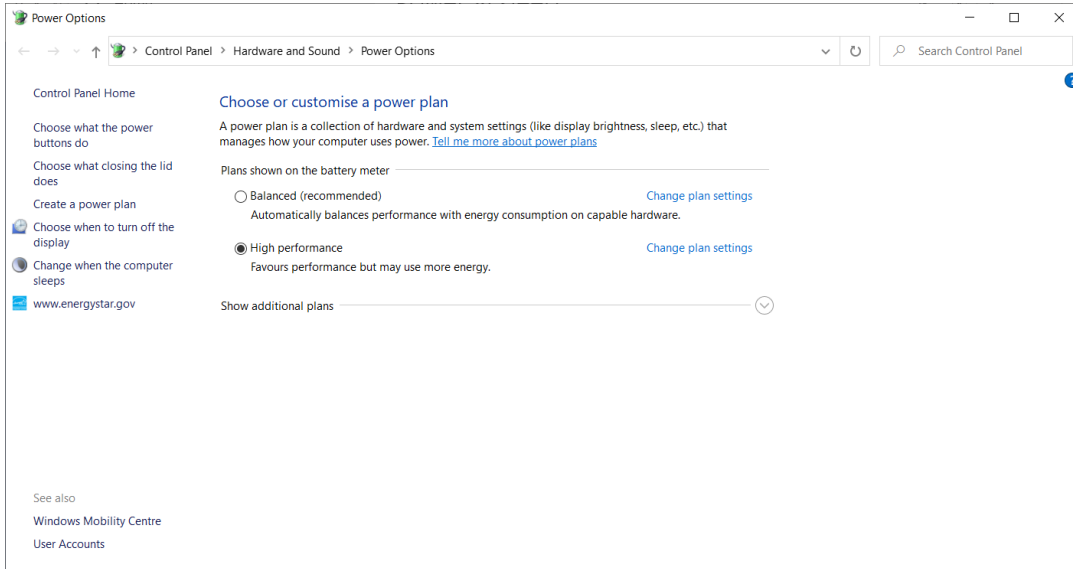


5. Select the Power & Sleep settings.

6. Set both “plugged in” options to Never



7. Click the Change Advanced Power Settings option.



8. Open the USB settings sub-menu.

9. Open the USB Selective Suspend settings.

10. Set both “On Battery” and “Plugged In” to Disabled.

11. Click the OK button and close out of the old Control Panel settings.

12. From the Settings home page, select Time & Language.

13. Set the time zone of your location.

NOTE: Results are displayed in UTC, not local time.

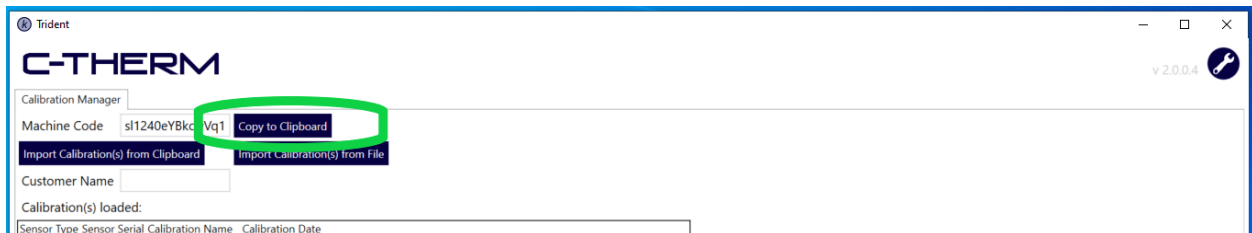
14. Return to the Settings Home window and select Update & Security.
15. Run Windows Update.
16. Restart the PC.
17. Repeat steps 15 and 16 until no further updates are available.

2.4 Generate the machine code

1. Open the Trident software.
2. Click the Wrench icon in the upper right corner of the software.



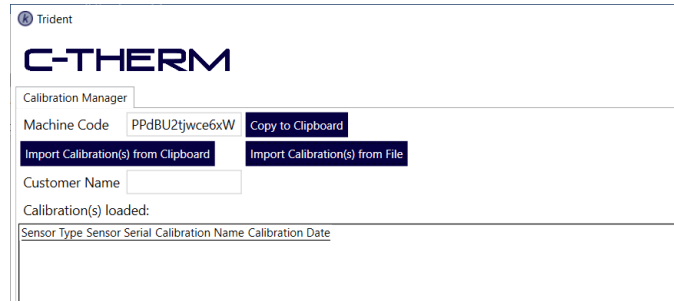
3. Open Notepad on the laptop.
4. Click the Copy to Clipboard button next to the Machine Code field.



5. Paste the machine code into Notepad and save it to the USB key.

2.5 Authorization file

1. Connect the USB key to your laptop.
2. Copy the authorization file to the Documents\C-Therm folder.
3. Click the Import Calibration(s) from File button.

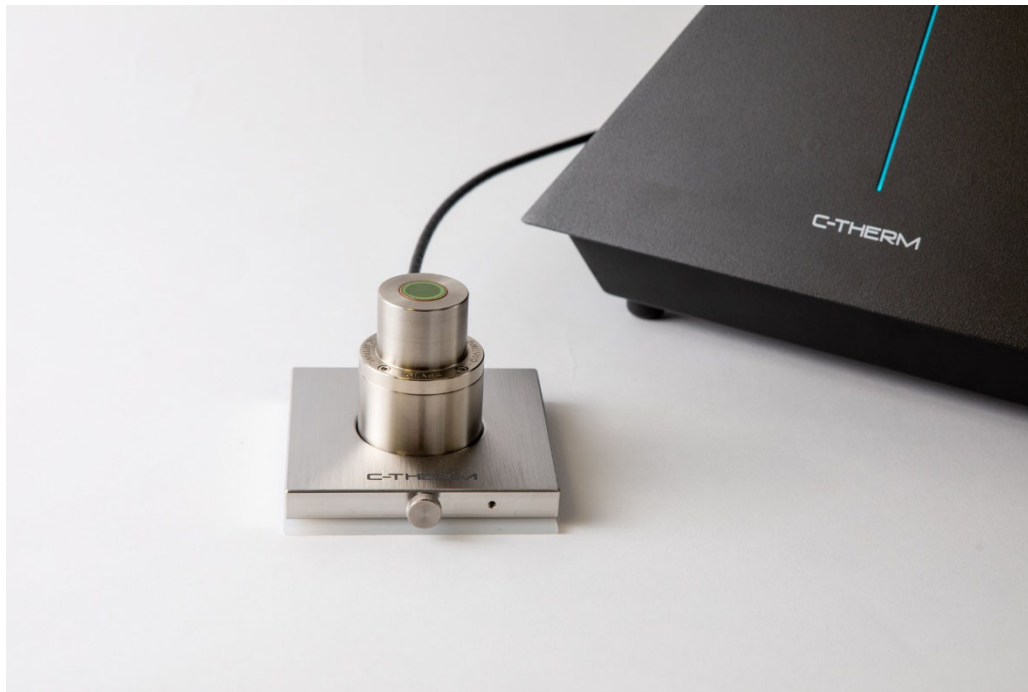


4. Select the authorization file in Documents\C-Therm.

Authorization file can be obtained from C-Therm and will require the machine code for the laptop generated in the previous section.

3.0 MTPS OPERATING INSTRUCTIONS

Simple and precise. The MTPS method employs a single-sided sensor to directly measure thermal conductivity and effusivity of materials. The MTPS method has the highest precision, highest sensitivity, shortest test time, and is the easiest to use among all three techniques.



3.1 Principle Of Operation

The Modified Transient Plane Source (MTPS) Method (ASTM D7984-16) requires only a single-sided interface with the sample during the measurement of thermal properties. Typically, the measurement pulse is between 1 to 3 seconds. Thermal conductivity and effusivity are measured, providing a detailed overview of the heat transfer properties of the sample material. The calibrated

method enables the fastest testing, greatest ease-of-use and highest reproducibility of the 3 methods offered with Trident.

3.2 How It Works

The following section provides detailed information as to the theory of operation of the MTPS method, including significant detail on how the factory calibration is performed. The MTPS method is the simplest to operate from an end-user's perspective and for those not inclined to delve into the underlying theory, the manufacturers would advise to refer to section 3.4 for the operating instructions.

The Modified Transient Plane Source (MTPS) Method employs a one-sided interfacial heater/sensor surrounded by an integrated heated guard ring. The heater/sensor applies a transient heat pulse to the sample. The heated guard ring provides a thermal barrier that surrounds the heater/sensor and negates lateral heat transfer at the sensor/sample interface. C-Therm's MTPS sensor design is composed of a heater/sensor/guard ring assembly mounted on top of an insulative backing material to ensure that nearly all the heat transferred in a measurement occurs between the heater/sensor/guard ring and the sample.



In operation, the sensor is placed in intimate contact with a sample, as illustrated above. To ensure reproducibility in the contact between the sample and the heater/sensor and to minimize thermal contact resistance, a specific weight is typically placed on the sample. A current pulse is simultaneously applied to both the spiral heater/sensor and the guard ring. The presence of a heated guard ring ensures that heat transfer between the heater/sensor spiral, and the sample approximates one-dimensional heat flow. This specific incorporation of the guard ring in the design of the sensor is a significant innovation C-Therm developed for single-sided testing. No other vendor offers the patented guard ring technology, which is critical in achieving uni-directional heat flow.



The following section provides detail as to the sensor's calibration. The MTPS sensor is provided as a simple "plug and play" testing capability. While users are not required to provide calibration, they may find the following information helpful in better understanding the principles of operation to the MTPS method.

The sensor temperature is factory calibrated using the relationship:

$$R(T) = R_0 + A \cdot T$$

and $R(T)$ is the resistance of the sensor at a given temperature, R_0 is the resistance of the sensor at 0°C , T is the temperature and A is the slope of the graph of resistance vs. temperature. The slope is equal to:

$$A = R_0 \cdot TCR$$

where TCR is the temperature coefficient of resistance of the sensor. TCR is constant over the measured temperature range and the sensor is calibrated to determine the TCR within this range. Once the MTPS sensor has undergone TCR calibration, the instantaneous surface temperature of the sensor is then:

$$T = \frac{R(T) - R_0}{A}$$

The MTPS measures the sensor resistance directly:

$$R = \frac{V_0}{I}$$

or calculates it from the initial voltage, V_0 or power:

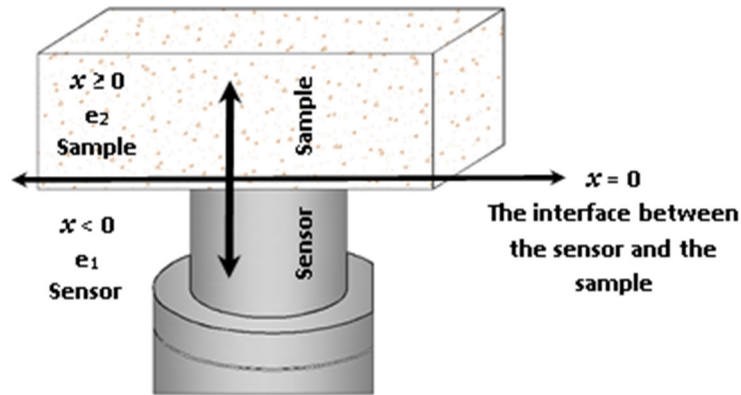
$$R = \frac{V_0^2}{P}$$

When in contact with sample material, the short current pulse is applied to the heater/sensor to raise its temperature by 1 to 3°C . The rate at which the temperature at the heater/sample interface climbs during the current pulse is proportional to both the input power and the thermal losses due to conduction away from the interface by the sensor substrate and the sample.

Knowledge of the instantaneous temperature of the sensor allows the determination of the thermal characteristics of a material in contact with the sensor. The heat equation for the sensor in contact with the sample and with a constant supply of heat per second per volume, G' , is given by:

$$\rho C_p \frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x^2} + G'$$

Assuming that two semi-infinite media are in contact with the heat generated at the interface and that one medium is represented by the effusivity, e_1 , of the sensor and that the other, e_2 , is the tested sample material.



Then, when temperature of both media at the interface is identical and in thermal equilibrium after contact has been established, the solutions for the sensor and sample are:

$$\text{(Sensor)} \quad \Delta T_1(x, t) = \frac{2G\sqrt{t}}{e_1 + e_2} \operatorname{ierfc} \frac{|x|}{2\sqrt{a_1 t}} \text{ for } x < 0, t > 0$$

$$\text{(Sample)} \quad \Delta T_2(x, t) = \frac{2G\sqrt{t}}{e_1 + e_2} \operatorname{ierfc} \frac{|x|}{2\sqrt{a_2 t}} \text{ for } x \geq 0, t > 0$$

where:

- ΔT = the change in sensor surface temperature ($^{\circ}\text{C}$);
- G = the power flux supplied to the sensor (W/m^2);
- t = time measured from the start of the process (sec);
- e_1 = equivalent effusivity of the sensor ($= \sqrt{\kappa_1 \cdot C_{p1} \cdot \rho_1}, \frac{\text{W}\sqrt{\text{s}}}{\text{m}^2\text{K}}$);
- e_2 = effusivity of the sample material ($= \sqrt{\kappa_2 \cdot C_{p2} \cdot \rho_2}, \frac{\text{W}\sqrt{\text{s}}}{\text{m}^2\text{K}}$);
- a_1 = equivalent diffusivity of the sensor, m^2/s ;
- a_2 = diffusivity of the sample material, m^2/s ;
- k_1 = equivalent thermal conductivity of the sensor, W/mK ;
- k_2 = thermal conductivity of the sample material, W/mK ;
- r_1 = equivalent density of the sensor, kg/m^3 ;
- r_2 = density of the sample material, kg/m^3 ;
- C_{p1} = equivalent heat capacity of the sensor, J/kgK ;
- C_{p2} = heat capacity of the sample material, J/kgK ;



- *ierfc* = integral of the error function

If no thermal contact resistance exists at the interface between the sensor and the sample, then $T_1(x=0, t) = T_2(x=0, t)$ at all points having $x=0$ and the equations become:

$$\Delta T(x = 0, t) = \frac{2G\sqrt{t}}{e_1 + e_2} \cdot 0.5642 = \frac{1.1284G\sqrt{t}}{e_1 + e_2}$$

The change in resistance of the sensor at time, t , is:

$$\Delta R(t) = R(t) - R(t = 0) = A \cdot \Delta T(x = 0, t)$$

And, from $V=IR$, the voltage change at time, t , is:

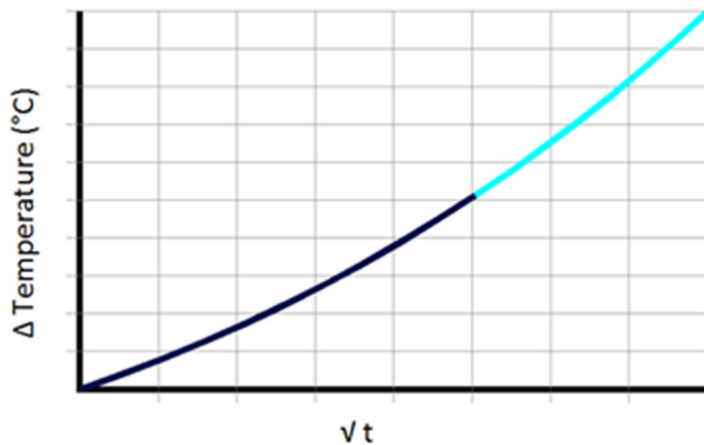
$$\Delta V(t) = I \cdot \Delta R(t) = I \cdot A \cdot \Delta T(x = 0, t)$$

$$= \frac{1.1284I \cdot A \cdot G\sqrt{t}}{e_1 + e_2}$$

$$= m\sqrt{t}$$

$$\text{where } m = \frac{1.1284I \cdot A \cdot G}{e_1 + e_2}$$

Below is a plot of voltage change vs. the square root of time.



Once the system has stabilized, the graph shows a linear response with slope m . The inverse of the slope, m , can be written:

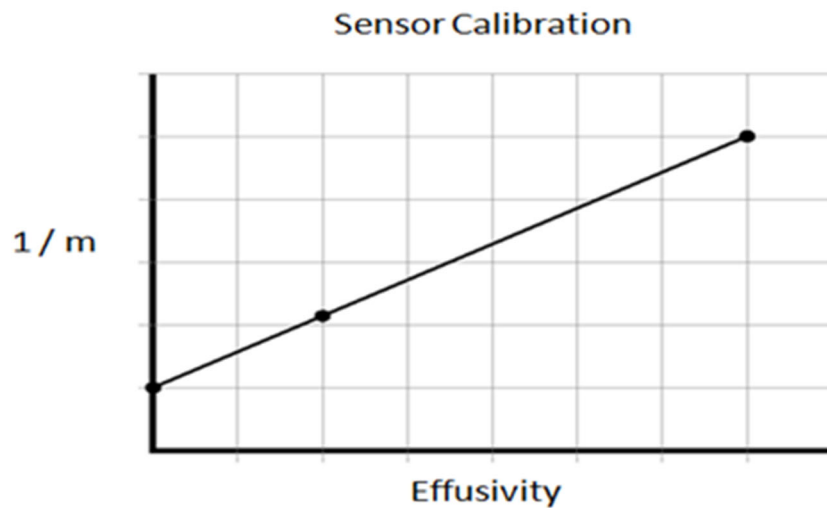
$$\frac{1}{m} = \frac{e_1 + e_2}{1.1284I \cdot A \cdot G} = \frac{e_1}{1.1284I \cdot A \cdot G} + \frac{e_2}{1.1284I \cdot A \cdot G}$$

If we consider a measurement in which the “sample” is a vacuum, then e_2 is the effusivity of vacuum, $e_2 = 0$, and the equation reduces to:

$$\frac{1}{m}(\text{vacuum}) = \frac{e_1}{1.1284I \cdot A \cdot G}$$

Values of the voltage/time slope, m , for a series of calibration materials with known effusivities can be determined experimentally using the MTPS sensor and a plot of $1/m$ for these materials is linear.

The slope of the effusivity calibration curve is M and the equation of the calibration line is:



$$\frac{1}{m} = M \times e_2 + C$$

where e_2 is the effusivity of the sample, C is the $1/m$ value of the sensor for vacuum, and the slope M is equal to:

$$M = \frac{1}{1.1284I \cdot A \cdot G}$$

Since:

$$C = \text{intercept} = \frac{1}{m}(\text{vacuum}) = \frac{e_1}{1.1284I \cdot A \cdot G}$$



then the equivalent effusivity of the sensor, e_1 , is given by:

$$\frac{C}{M} = \left(\frac{e_1}{1.1284I \cdot A \cdot G} \right) \times \left(\frac{1.1284I \cdot A \cdot G}{1} \right) = e_1$$

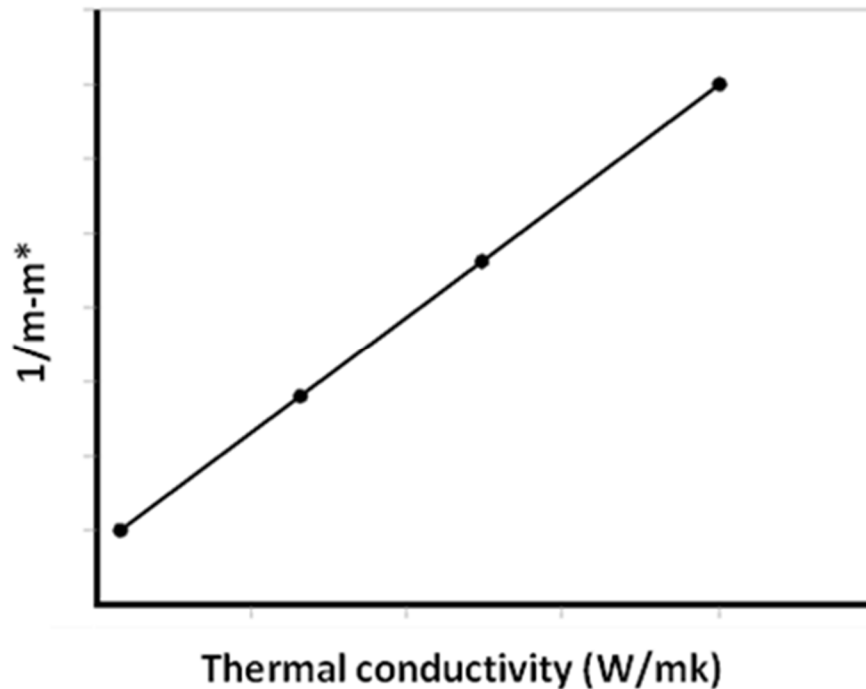
Thus, the effusivity calibration curve allows the determination of effusivity values for both the sensor and the sample. Knowledge of the slope of the voltage vs sqrt (time) response of the MTPS sensor provides $1/m$ values for unknown samples. So long as those $1/m$ value of the unknown material lies within the range of the $1/m$ calibration curve determined using calibration materials of known effusivity, the effusivity of the unknown sample, e_2 , can be determined from the graph of $1/m$ vs effusivity above, or from the equation immediately below that plot.

Two methods may be used to determine the thermal conductivity of a test sample. When the density, r , and specific heat, C_p , of the test sample are known, the thermal conductivity, k , can be calculated using the effusivity, determined as described above, and the relationship:

$$k = \frac{\varepsilon_2^2}{\rho \cdot C_p}$$

When the density and specific heat of the sample is unknown, the thermal conductivity can be determined using a graphical method like, but not identical with, that used for the determination of effusivity. The same $1/m$ data determined for the measurement of sample effusivity is used as input to a unique algorithm (the m^* algorithm) that employs an iterative process and the thermal conductivity of known materials to create a sensor calibration curve for thermal conductivity. The thermal conductivity calibration relationship has the form:

$$\frac{1}{m - m^*} = Slope \cdot k + Intercept$$



$$k = \left[\frac{\frac{1}{m - m^*} - Intercept}{Slope} \right]$$

where: m is the value of the slope determined for the voltage vs. \sqrt{time} curve of the sample, shown in the equation above. “*Slope*” is the slope and “*Intercept*” is the intercept of the $\frac{1}{(m-m^*)}$ vs. thermal conductivity calibration curve shown in the figure above, and m^* is a calibration factor that linearizes the measured $1/m$ with the known conductivities of the calibration materials as shown in the figure above. Typically, the m^* method of determining the thermal conductivity is used unless the material is known to have a volumetric heat capacity that falls outside the calibrated range for the calibration selected. Reference the table in Step 3 of Section 3.11.

In the procedure for thermal conductivity calibration, values for m are determined for a series of calibration standards of known thermal conductivity that bracket the expected value of the test sample. The values for m and thermal conductivity of the calibration standards are then used as input to an iterative linear regression to solve the equation above. m^* is treated as a variable fitting parameter during the regression with the value iteratively adjusted to provide the best least squares fit of the relationship to the data.

Maintaining high accuracy and precision across a broad range of thermal conductivity and effusivity using the MTPS technique requires that the sensor calibration is sub-divided into ranges



that bracket the expected sample value, and the power and timing parameters must be optimized for a given group of materials. For example, longer test time and lower power settings are optimal for achieving a deeper depth of penetration when measuring insulation materials like foams. Conversely, shorter test time and higher power settings are optimal for higher-conductivity metals where the pulse travels very quickly through the material and a shorter test time provides for more flexibility in limiting the thickness requirements of the sample. Each group of materials has its own calibration curve.

One thing to note is that the above discussion illustrates the theory of operation of the Modified Transient Plane Source method. However, on the user experience side, all MTPS sensors are factory calibrated. No user calibration is required, and the sensors are 'plug and play'. The MTPS sensor can accurately measure thermal conductivity of materials in seconds, fast and easy to use.

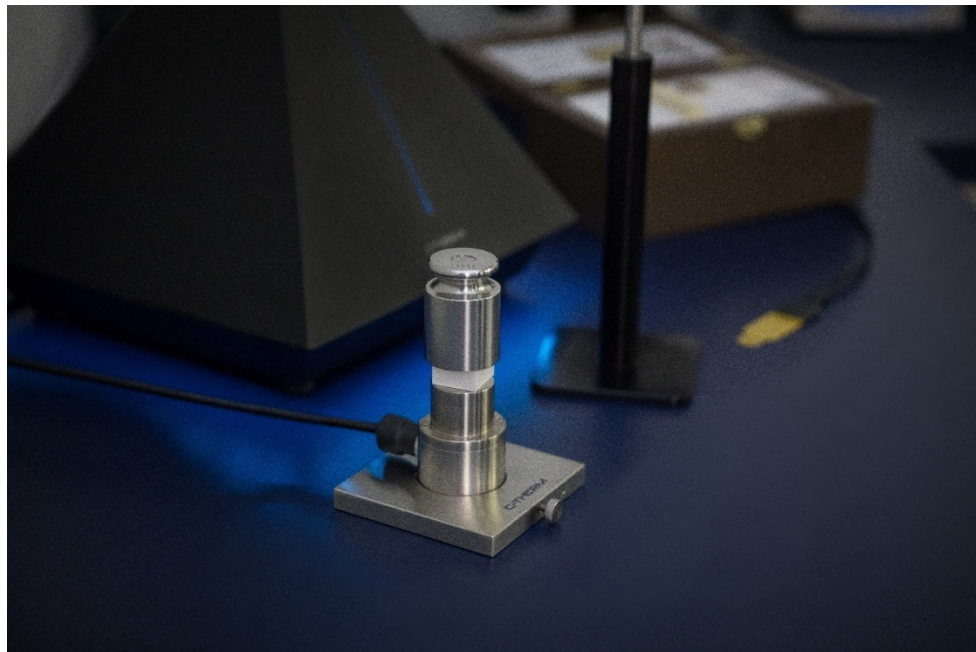
3.3 Specifications and Recommended Applications

Please see Appendix B for MTPS sensor specification and recommended applications.

3.4 Required Equipment

The necessary equipment for the operation of the MTPS sensor is given below:

- Trident Controller
- USB Cable
- Power Cable
- Reference Material Kit
- MTPS Sensor
- Baseplate
- Silicone Mat
- Contact Agent – Distilled Water or Thermal Grease
- Pipette for Dispensing Contact Agent



3.5 Optional Hardware and Accessories

- CTA Compression Test Accessory – See Appendix L
- High Pressure Cell
- High Temperature Sensor
- MTPS Liquids & Powders Test Cell – See Appendix M

3.6 Verifying Condition of Sensor

Examine the sensor surface for any marks or scratches. The sealant ring around the chip must be smooth and have no gaps or visible damage.

Examine the cable and confirm it is smooth, shiny, moderately stiff and free of discolouration or deformation. The connector should be rigid, clean, and free of discolouration or scorch marks. The pins in the connector should be straight, clean, and free of visible corrosion or pitting. It must not be loose where it connects to the base of the sensor.

If any of these parts of the sensor show visible damage or are not operating within acceptable parameters, contact your C-Therm Representative or support@ctherm.com.

3.7 Recommended Handling Practices

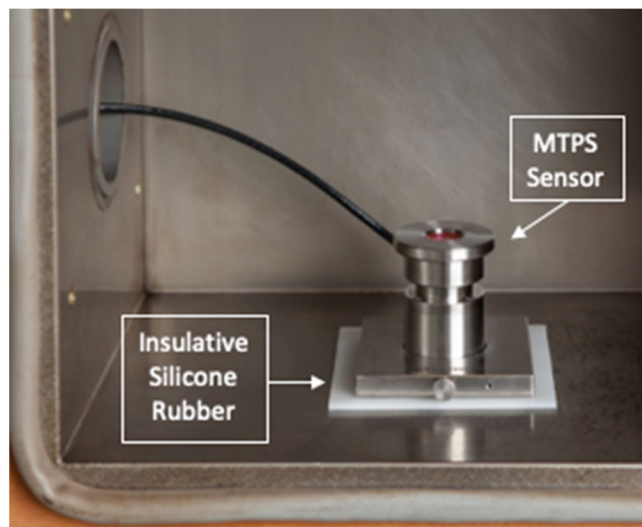
Glass Coating – Users must avoid blunt force or trauma to the glass surface of the sensor. Care should be taken in placing and removing samples, especially to avoid dropping the sample or the weight on the sensor. To avoid pulling force on the sensor surface it is recommended the sample and weight are removed by a lateral motion rather than a vertical motion. Samples should be



relatively smooth, with no sharp points or rough edges which could scratch or fracture the glass. (Note - Rough or abrasive samples which cannot be smoothed are better suited for the TPS method.)

Sample Weight – The sensor should not be exposed to excessive weight loading on the sensor. No more than 4 kg of weight should be permitted on the sensor. Each system configured with a MTPS sensor is accompanied by a 500 g weight recommended to ensure good contact between solid samples and the sensor surface. If the sample to be measured weighs more than 150 g, omit the weight as the sample is heavy enough to ensure good contact.

Silicone Rubber Mat – A silicone rubber mat is supplied with each MTPS sensor. Place the insulative silicone rubber mat underneath the baseplate prior to testing to ensure the MTPS sensor is electrically isolated. This is especially important for use in a Thermal Chamber (see Appendix H) for more instructions on operation with a Thermal Chamber) or on a metal work surface.



Temperature - The standard operating range of the MTPS sensor is -50° to 200°C . The sensor should not be exposed to dramatic temperature shocks as this may cause damage. The sensor should not be heated or cooled at a rate greater than 1°C per minute. High ramp rates can be used but only for 50°C steps at no more than 50°C per hour. Due to the finite heat capacity of the sensor, when testing materials at temperatures other than room temperature, users must allow adequate time for the sensor and sample to stabilize at the desired temperature prior to taking a measurement. Stability is defined as temperature variation within 0.5°C for 10 min of temperature monitoring. Testing materials while the environmental temperature is ramping will produce invalid results as the environment, sensor and mass need to reach equilibrium prior to start of the test. Special caution should also be exerted in testing a material through a phase change or transition. During a phase change or transition, materials can bond to the surface of the sensor and special

care is required in the sample's removal and cleaning of the sensor. Materials should not be permitted to cool from a liquid to solid state while on the sensor OR should be reheated and removed while in their molten phase if the material was permitted to solidify on the surface of the sensor. Note that during a phase change any endothermic or exothermic event may have an adverse impact on the accuracy of the measurement taken at that time. The transient method assumes isothermal stability at the start of the measurement.

Chemical Compatibility – The standard RTV (Room Temperature Vulcanized) Silicone Sealant applied to the MTPS sensor provides a protective barrier around the glass surface of the sensor and is necessary to protect the internal components of the sensor housing. The sealant can however be damaged by certain chemically aggressive substances and users must be careful in protecting the integrity of the sensor by exerting caution in the materials they place in direct contact with the sensor surface. The sensor has been thoroughly tested across a broad range of materials and an extensive list of the materials which are safe to test directly with the sensor are provided in Appendix G. Should users wish to test a material which is not listed on the safe list – C-Therm advises them to administer a test on the RTV test tabs provided to ensure the sample material is chemically non-aggressive to the RTV sealant (Appendix G) and will be safe to place in direct contact with the sensor. Should it be determined the material is chemically aggressive to the RTV, users are advised NOT to expose the sensor directly to the material. Users should contact their C-Therm Representative for further instruction on a modified test procedure. Users testing organic fluids should contact their C-Therm representative for information on the alternative FRV sealant.

Testing Metals - Testing materials above 110 W/mK requires the selection of the High Metals calibration which utilizes a higher-power setting. Metals between 15 and 110 W/mK require use of the Low Metals calibration. Note that due to limitations of the guard ring, metals above 110 W/mK require additional sample preparation in limiting the diameter of the sample. Details provided in Section 3.1.

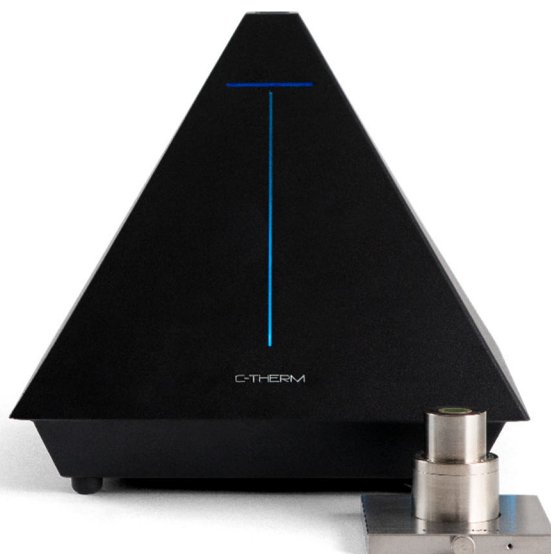
Connecting/Disconnecting Sensors - Do NOT connect or disconnect the sensors while the unit is powered on. Swapping sensors while power is on may cause damage to the system. The sensor body should only be moved by grasping it. (Never move the sensor by the cable.) Grasp the rigid sensor connector with one hand and the Trident controller with the other. Pull on the connector while holding the controller in place to disconnect the sensor Do NOT pull on the cable.

Cables - The cable connecting the sensor to the controller can be damaged if not handled with care. Kinks are to be avoided. The minimum bend radius is 2.5 inches. The regions near the connectors are especially vulnerable to damage from excessive bending.



Failure to adhere to these testing advisories and guidelines can result in inaccurate results being reported by the instrument, may cause damage to the sensor, and will void all manufacturer warranties and performance specifications.

3.8 Trident System Setup with MTPS Sensor



TRIDENT WARNING: DO NOT CONNECT OR DISCONNECT ANY SENSOR WHILE THE CONTROLLER IS TURNED ON

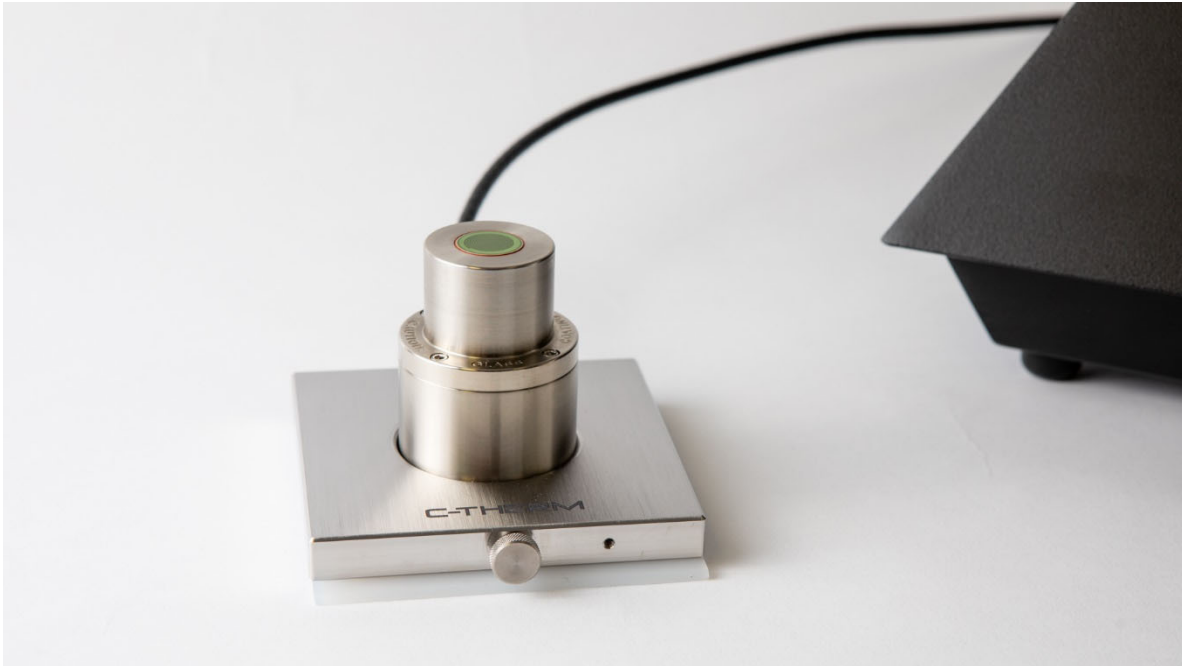
Note: All sensors must be connected to the appropriate port as indicated by the label to the left of the port. Sensors connected to an incorrect port will not function.

1. Place the Trident controller on the countertop, with sensor connections on the side. Do not plug in or power the system.
2. Plug the power cable and USB cable into the Trident.





3. Place the MTPS sensor on the baseplate and provided silicone mat.



4. Connect the sensor to the sensor port on the back of the Trident controller, to the right of the MTPS label. Grip the end of the sensor cable by the connector and push into place until a click is heard. The white dot on the sensor should be facing up and will align with the mark on the port when correctly positioned.



5. Connect the communications USB cable to the PC.
6. Rotate the controller, being careful not to knock over the sensor, so the front of the Trident controller is facing forward.
7. Verify that the power button is still off.
8. Plug the power cable into the outlet.
9. Turn the Trident controller on via the power button on the top of the controller.

10. Open the Trident software and perform reference material tests or calibrations to verify the Trident system is operational. See the Section 3.9 Reference Material Tests for instructions on performing reference material tests.

3.9 Reference Material Tests

Reference material tests verify the function of the Trident MTPS system and factory calibrations pre-loaded on the sensor. They are not a one-point calibration and do not replace factory calibration.

Reference material tests are quick and easy. C-Therm recommends running them regularly for system validation and to provide records of hardware and calibration validity for quality control systems. Reference material tests are typically run at ambient temperature conditions between 20°C-25°C. A reference material is provided for each calibration included in the purchased configuration. Please note that only the reference materials relevant to the modules purchased will be included.





The table below lists the reference material for each calibration.

Method	Material	Calibration	Max RSD (%)	Accuracy Spec (%)	Contact Agent
MTPS	Distilled Water	Liquids and Powders	1.0%	5%	None
MTPS	LAF 4530*	Insulation	1.0%	5%	None
MTPS	Pyrex	Polymers	1.0%	5%	Water
MTPS	Pyroceram	Ceramics	1.0%	5%	Water
MTPS	Stainless Steel*	Low Metals	2.5%	5%	Water
MTPS	Copper	High Metals	2.5%	5%	Water
MTPS	EPS*	Aerogels	2.5%	5%	None
MTPS	Polyfelt*	Textiles 1	2.5%	5%	None
MTPS	Distilled Water	Textiles 2	2.5%	5%	None

****Please note that reference materials listed with an Asterix (*) will have a bin or batch number indicated in the authorization file due to material variability.**

3.9.1 Preparing the Sample for the Reference Material Test

Prepare the sample for testing according to the instructions in the following table. Ensure that the sample is clean and free of debris before starting.

Please note that contact agents must not be used with insulators, aerogels or textiles samples.

Method	Material	Setup Instructions
MTPS	Distilled Water	Place the Liquids and Powders Test Cell on the sensor. Pour 1.2 mL. distilled water into the cell and place the liquids lid on the cell.
MTPS	LAF 4530, EPS	Gently tap the sample to remove dust. Place the sample on the sensor with the test area in contact with sensor chip. Place the weight on top of the sample, centering it carefully. Do not use a contact agent.
MTPS	Pyrex, Pyroceram, Stainless Steel	Place 3 drops of water on the sensor chip. Place the sample on the sensor, ensuring that it is set down evenly to ensure optimal contact. Place the weight on top of the sample so it is centered over both sensor and sample.
MTPS	Copper	Place the metal sample holder on the sensor. Place 3 drops of water on the sensor chip. Place the sample in the holder, ensuring that it is set down evenly to ensure optimal contact. Place the weight on the sample so it is centered over both sensor and sample.
MTPS	PolyFelt	Condition the environment to 23°C ±1°C, 65% ±5% Relative Humidity. Position the MTPS sensor in the Compression Test Accessory (CTA). Place the PolyFelt sample on the sensor. If there is a dot marked on the PolyFelt sample, place the unmarked side of the sample on the MTPS sensor. Apply 500 g Force to the sample. Allow the setup to sit for 5 minutes and adjust the applied force if it is outside 475 to 525 g force.



3.9.2 Performing the Reference Material Test

1. Select Reference Test.
2. Select Method MTPS – ASTM D7984.



The screenshot shows the C-THERM software interface. The 'Run Test' section is active, with 'Reference Test' selected. The 'Method' is set to 'MTPS (ASTM D7984)', 'Calibration' is 'Aerogels', and 'Reference Material' is 'EPS-C'. The 'Measurements' are set to 5. The 'Expected Values' table shows:

Property	Min	Nominal	Max
Thermal Conductivity (W/mK)	0.0317	0.0334	0.0351
Effusivity (Ws ^{1/2} /m ² K)	39.8	41.9	44.0

The 'Test Summary' table shows:

Property	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

The 'Test Details' section includes fields for 'Test ID', 'Status (Thermal Conductivity)', and 'Status (Thermal Effusivity)'. A 'Start Test' button is visible in the top right corner.

3. Choose the desired Calibration from the dropdown menu.

The screenshot shows the C-THERM software interface. The 'Calibration' dropdown menu is open, showing options: Aerogels, Insulation, Liquids & Powders, Polymers (highlighted), Ceramics, Low Metals, and High Metals. The 'Method' is set to 'MTPS (ASTM D7984)'. The 'Reference Material' is set to 'Aerogels'. The 'Measurements' field is set to '5'. The 'Expected Values' section shows: Thermal Conductivity (W/mK): Min 0.0317, Nominal 0.0334, Max 0.0351; Effusivity (Ws^{1/2}/m²K): Min 39.8, Nominal 41.9, Max 44.0. The 'Test Summary' table is as follows:

Test Summary:	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

4. The Reference Material will populate automatically.

5. The correct Bin for the reference material is displayed after the calibration is selected.

6. Select desired number of Measurements. For a reference material test 10 measurements are recommended.

- The data for each measurement will populate after it is acquired, and the system will stabilize and move onto the next measurement. The test can be stopped at anytime by clicking the Stop Test button.

Method: MTPS (ASTM D7984) | Calibration: Polymers | Reference Material: Pyrex | Measurements: 5

Expected Values:

Property	Min	Nominal	Max
Thermal Conductivity (W/mK)	1.0859	1.1430	1.2002
Effusivity (Ws ^{1/2} /m ² K)	1.366.0	1.437.9	1.509.8

Start Test (Stop Test) button highlighted.

Measurement #1 Graph: Δ Temperature (°C) vs. √t

Test Summary:

Property	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

Test Details:

Test ID:

Status (Thermal Conductivity):

Status (Thermal Effusivity):

Acquiring Data

- Allow test to complete. All measurements will be populated as follows, with the most recent Voltage-Time Chart visible to the left of the data window.

Method: MTPS (ASTM D7984) | Calibration: Polymers | Reference Material: Pyrex | Measurements: 5

Expected Values:

Property	Min	Nominal	Max
Thermal Conductivity (W/mK)	1.0859	1.1430	1.2002
Effusivity (Ws ^{1/2} /m ² K)	1.366.0	1.437.9	1.509.8

Start Test (Stop Test) button disabled.

Measurement #5 Graph: Δ Temperature (°C) vs. √t

Test Summary:

Property	Average	% RSD
Thermal Conductivity (W/mK)	1.1266	0.1689
Effusivity (Ws ^{1/2} /m ² K)	1.429.8	0.1190

Test Details:

Test ID: MTPS-Ref-Polymers-2020-07-14-11:41:43A

Status (Thermal Conductivity): Pass

Status (Thermal Effusivity): Pass

Acquiring Data



- Click on the desired Measurement Number line to view the Voltage-Time Chart for each specific measurement. The Test Results window provides a summary of the measurement results within the Test, including average Thermal Conductivity and Effusivity, and % RSD. The Test Details window displays a Pass or Fail status based on the average results and data variation (measured by % relative standard deviation) compared to the Expected Values and specifications of the selected reference material (which may be found in a table at the start of Section 3.9). Note that quite often the first measurement produced has a higher variability. This is attributed the inertia within the overall system. A typical sample protocol is to discard the first measurement. You can deselect measurements to exclude outliers, if required, and recalculate Test Results. The first measurement is typically deselected. No more than 1 in 10 measurements may be deselected overall.

Trident

C-THERM v2.0.0.4

Run Test
 Reference Test
 Previous Tests

Method: MTPS (ASTM D7984)
 Calibration: Polymers
 Reference Material: Pyrex

Measurements: 5
 Expected Values:
 Thermal Conductivity (W/mK): Min 1,085.9 Nominal 1,143.0 Max 1,200.2
 Effusivity (Ws²/m³K): Min 1,366.0 Nominal 1,437.9 Max 1,509.8

Start Test Stop Test

Recent Tests

Method	Test ID	#	Valid k (W/mK)	Error %	Effusivity (Ws ² /m ³ K)	Error %	R ²	1/m	Temp (°C)
MTPSREF	MTPS-Ref-Polymers-2f	1	1.1299	1.1474	1.432.7	0.3615	0.9999	39.3	23.3
MTPSREF	MTPS-Ref-Polymers-2f	2	1.1264	1.4481	1.429.6	0.5752	0.9999	39.2	23.3
MTPSREF	MTPS-Ref-Polymers-2f	3	1.1256	1.5203	1.428.9	0.6265	0.9999	39.2	23.3
MTPSREF	MTPS-Ref-Polymers-2f	4	1.1271	1.3940	1.430.2	0.5367	0.9999	39.2	23.2
MTPSREF	MTPS-Ref-Polymers-2f	5	1.1241	1.6514	1.427.6	0.7197	0.9999	39.2	23.2

Measurement #5

Test Summary:

	Average	% RSD
Thermal Conductivity (W/mK)	1.1266	0.1689
Effusivity (Ws ² /m ³ K)	1.429.8	0.1190

Test Details:

Test ID: MTPS-Ref-Polymers-2020-07-14-11:41:43A
 Status (Thermal Conductivity): Pass
 Status (Thermal Effusivity): Pass

Run Test
Reference Test
Previous Tests

Method: **MTPS (ASTM D7984)**
Calibration: **Polymers**
Reference Material: **Pyrex**

Measurements: **5**
Expected Values:
Thermal Conductivity (W/mK): Min 1,085.9 Nominal 1,143.0 Max 1,200.2
Effusivity (Ws^{1/2}/m²K): Min 1,366.0 Nominal 1,437.9 Max 1,509.8

Measurement #1

#	Valid k (W/mK)	Error %	Effusivity (Ws ^{1/2} /m ² K)	Error %	R ²	1/m	Temp (°C)
1	1,129.9	1,147.4	1,432.7	0.2615	0.9999	39.3	23.3
2	1,126.4	1,448.1	1,429.6	0.5752	0.9999	39.2	23.3
3	1,125.6	1,520.3	1,428.9	0.6365	0.9999	39.2	23.3
4	1,127.1	1,394.0	1,430.2	0.5367	0.9999	39.2	23.2
5	1,124.1	1,651.4	1,427.6	0.7197	0.9999	39.2	23.2

Test Summary:
Average Thermal Conductivity (W/mK): 1,125.9 % RSD: 0.1125
Average Effusivity (Ws^{1/2}/m²K): 1,429.1 % RSD: 0.0793

Test Details:
Test ID: **MTPS-Ref-Polymers-2020-07-14-11:41:43A**
Status (Thermal Conductivity): **Pass**
Status (Thermal Effusivity): **Pass**

- Click the Export icon to export the results. It is recommended that a file name similar to the default file name is given to denote the Reference Test. Below is an example of an automatically assigned file name.

Run Test
Reference Test
Previous Tests

Method: **MTPS (ASTM D7984)**
Calibration: **Polymers**
Reference Material: **Pyrex**

Measurements: **5**
Expected Values:
Thermal Conductivity (W/mK): Min 1,085.9 Nominal 1,143.0 Max 1,200.2
Effusivity (Ws^{1/2}/m²K): Min 1,366.0 Nominal 1,437.9 Max 1,509.8

Measurement #1

#	Valid k (W/mK)	Error %	Effusivity (Ws ^{1/2} /m ² K)	Error %	R ²	1/m	Temp (°C)
1	1,129.9	1,147.4	1,432.7	0.2615	0.9999	39.3	23.3
2	1,126.4	1,448.1	1,429.6	0.5752	0.9999	39.2	23.3
3	1,125.6	1,520.3	1,428.9	0.6365	0.9999	39.2	23.3
4	1,127.1	1,394.0	1,430.2	0.5367	0.9999	39.2	23.2
5	1,124.1	1,651.4	1,427.6	0.7197	0.9999	39.2	23.2

Test Summary:
Average Thermal Conductivity (W/mK): 1,125.9 % RSD: 0.1125
Average Effusivity (Ws^{1/2}/m²K): 1,429.1 % RSD: 0.0793

Test Details:
Test ID: **MTPS-Ref-Polymers-2020-07-14-11:41:43A**
Status (Thermal Conductivity): **Pass**
Status (Thermal Effusivity): **Pass**

Save As
File name: **MTPS-Ref-Polymers-2020-07-14-11:41:43A**
Save as type: **CSV Files**

- The most recent tests can be accessed in the window to the left as pictured above.
- Select Previous Test to view all completed and saved tests.



15. To view only Reference Tests, select Previous Tests and choose Method MTPS (ASTM D7984) Reference Test.

The screenshot shows the C-THERM software interface. On the left, there are three panels: 'Run Test', 'Reference Test', and 'Previous Tests'. The 'Previous Tests' panel is active, showing a list of tests. An arrow points to the entry 'MTPS (ASTM D7984) Reference Test'. To the right, a data table is visible with columns for '#', 'Valid k (W/mK)', 'Error %', 'Effusivity (Ws/m²K)', 'Error %', 'R²', 'l/m', and 'Temp (°C)'. The table contains five rows of data.

#	Valid k (W/mK)	Error %	Effusivity (Ws/m²K)	Error %	R²	l/m	Temp (°C)
1	0.2910	125.8865	101.9017	0.9989	0.9999	14.9	23.2
2	-0.2952	125.8284	101.7545	0.9989	0.9999	14.9	23.2
3	-0.2958	125.8774	101.8002	0.9990	0.9999	14.9	23.3
4	-0.2964	125.9358	101.8545	0.9990	0.9999	14.9	23.3
5	-0.2956	125.8604	101.7943	0.9990	0.9999	14.9	23.3

16. Select the desired test from the list of Previous Tests. The results will populate in the following format.

The screenshot shows the C-THERM software interface displaying a detailed test result for 'MTPS (ASTM D7984) Reference Test'. The interface is divided into several sections:

- Previous Tests:** A list of tests is shown, with 'MTPS (ASTM D7984) Reference Test' selected.
- Measurement #1:** A graph showing Temperature (°C) on the y-axis (0 to 1) versus distance (l) on the x-axis (0 to 1). A blue line represents the temperature profile.
- Test Summary:** A table showing average values and % RSD for Thermal Conductivity and Effusivity.
- Test Details:** A section showing the Test ID and status for Thermal Conductivity and Effusivity.

#	Valid k (W/mK)	Error %	Effusivity (Ws/m²K)	Error %	R²	l/m	Temp (°C)
1	1.1299	1.1424	1.432.7	0.3815	0.9999	39.2	23.3
2	1.1264	1.4481	1.429.6	0.5752	0.9999	39.2	23.3
3	1.1256	1.5203	1.428.9	0.6265	0.9999	39.2	23.3
4	1.1271	1.3940	1.430.2	0.5367	0.9999	39.2	23.2
5	1.1281	1.6514	1.427.6	0.7197	0.9999	39.2	23.2

	Average	% RSD
Thermal Conductivity (W/mK)	1.1266	0.1689
Effusivity (Ws/m²K)	1,429.8	0.1190

Test Details:

Test ID: MTPS-Ref-Polymers-2020-07-14-11.41x
 Status (Thermal Conductivity): Pass
 Status (Thermal Effusivity): Pass

17. Below is an example of a test with an out of spec measurement. Note that the Error % in each measurement will be flagged red if it does not lie within expected value range. In the Test Details window, the Status for Thermal Conductivity and Thermal Effusivity will read Fail, in red, if the average of measurements included lies outside the expected range. If this occurs, see below on steps to troubleshoot.

Method: MTPS (ASTM D7984) | **Measurements:** 5

Calibration: Polymers | **Reference Material:** Pyrex

Expected Values:
 Thermal Conductivity (W/mK): Min 1.0859, Nominal 1.1430, Max 1.2002
 Effusivity (Ws^{1/2}/m²K): Min 1,366.0, Nominal 1,437.9, Max 1,509.8

#	Valid & (W/mK)	Error %	Effusivity (Ws ^{1/2} /m ² K)	Error %	R ²	1/m	Temp (°C)
1	✓ -0.2970	125.9865	-27.3	101.9017	0.9990	14.9	23.2
2	✓ -0.2952	125.9286	-25.2	101.7545	0.9989	14.9	23.2
3	✓ -0.2958	125.9286	-25.9	101.8002	0.9990	14.9	23.3
4	✓ -0.2964	125.9286	-26.7	101.8545	0.9990	14.9	23.3
5	✓ -0.2956	125.9286	-25.7	101.7843	0.9990	14.9	23.3

Test Summary:

	Average	% RSD
Thermal Conductivity (W/mK)	-0.2960	-0.2181
Effusivity (Ws ^{1/2} /m ² K)	-26.2	-2.8905

Test Details:
 Test ID: MTPS-Ref-Polymers-2020-07-14-11:54:52A
 Status (Thermal Conductivity): **Fail**
 Status (Thermal Effusivity): **Fail**

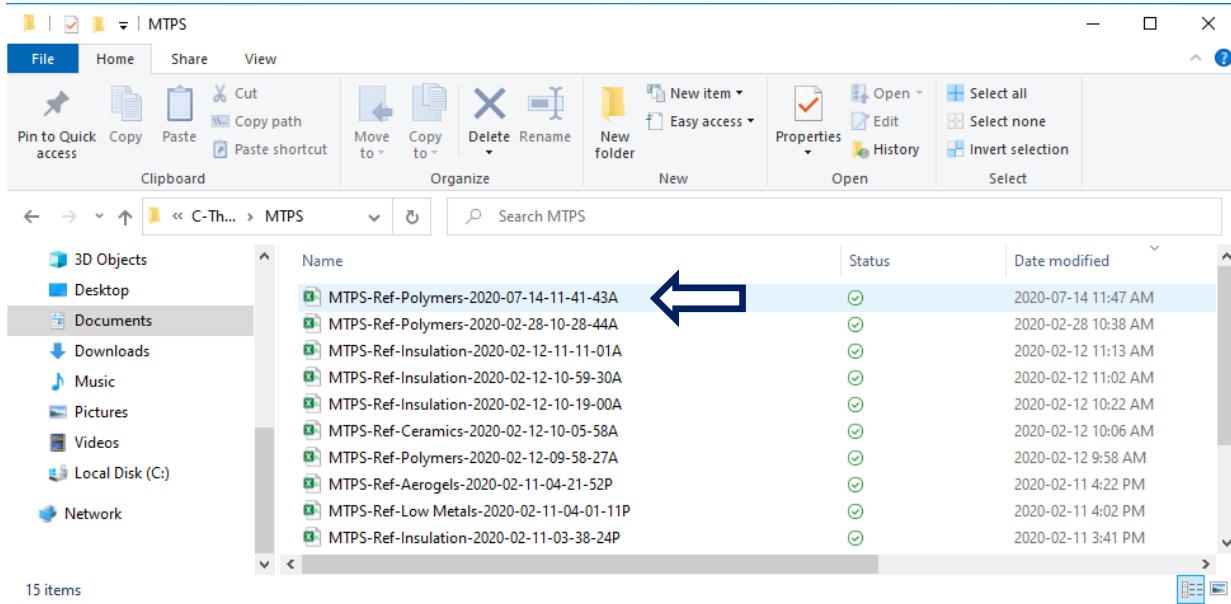
18. Results can also be viewed in CSV format. Go to Documents and open the C-Therm folder. Select the MTPS folder.

File Explorer path: This PC > Documents > C-Therm

Name	Status	Date modified	Type	Size
Flex	✓	2019-10-17 2:14 PM	File folder	
MTPS	✓	2020-02-28 10:38 AM	File folder	
TCi_4	✓	2020-02-18 11:51 AM	File folder	
TLS	✓	2019-10-17 2:14 PM	File folder	



19. Select the desired Test and Open to view Test Details and Results in this format.



#Sensor Serial: H858								
#Test ID: MTPS-Ref-Ceramics-2022-04-21-11:50:14A								
#Instrument: C-Therm Trident								
#Calibration: Ceramics								
#Material: Pyroceram								
#Contact Agent: Water								
#k Status: Pass								
#Effusivity Status: Pass								
#Average Thermal Conductivity (W/mK): 4.12880804386678								
#Thermal Conductivity %RSD: 0.616563909675044								
#Average Effusivity (Ws^(1/2) / Km^2): 2974.72811698027								
#Effusivity %RSD: 0.401871374485105								
	Valid	Conductivi	Error %	Effusivity	Error %	R Squared	Delta T	Temperature
		W/mK		Ws^(1/2) / Km^2			degC	degC
1	TRUE	4.094388	0.379856	2958.564	0.222369	0.999932	65.75109	25.01915
2	TRUE	4.127418	0.423806	2974.084	0.748095	0.999921	66.04644	25.02209
3	TRUE	4.159139	1.195598	2988.963	1.252118	0.999969	66.33054	25.04403
4	TRUE	4.11215	0.052303	2966.913	0.505184	0.999921	65.91124	25.05559
5	TRUE	4.136855	0.653405	2978.513	0.898123	0.999873	66.13254	25.07028

In general, passing results for Reference Materials indicate that the sensor calibration is accurate. It is best practice to run regular Reference Material Tests to ensure sensor calibration validity.

It is recommended MTPS sensors be factory recalibrated at C-Therm. To arrange this, contact support@ctherm.com and mail sensor only to C-Therm.

3.9.3 Failing Reference Test Steps

In case of failing test results, consider the following potential causes:

Potential Causes	Corrective Action
<i>Has the Trident Controller been turned on for a full hour?</i>	Allow Trident Controller to complete full hour warmup.
<i>Is there any visible damage to the sensor chip or cable?</i>	Check sensor for any signs of damage.
<i>Are the temperature measurements stable?</i>	Verify no vents or outputs are located near the Trident system. Unless all parts were stored under stable conditions in the test environment, allow reference materials, MTPS sensor, contact agents and weight to equilibrate for 2 hours prior to testing. Temperature stability is required to be less than 0.5°C over 10 minutes, ideally less than 0.1°C over 10 minutes. Consider using an isolation box around the MTPS sensor and samples for additional stabilization.
<i>Are the reference materials damaged, coated in another material, or marked?</i>	Clean samples or contact C-Therm for replacement materials in case of damage.
<i>Is the RSD on either Thermal Conductivity or Thermal Effusivity high?</i>	Try removing the checkmark in the “Valid” column for the first measurement. If that does not change the result to a pass, try a longer stabilization time.
<i>Are any measurements in the results visible outliers?</i>	If the test was disrupted, re-run the test. Otherwise, one in ten measurements may be removed as outliers.



Reference Material	Calibration	Thermal Conductivity (W/mK)	Thermal Effusivity	RSD Limit
	Liquids and Powders,			
Distilled Water	Textiles 2	0.609	1594	1.0%
LAF 4530-A*	Insulation	0.070	161	1.0%
LAF 4530-B*	Insulation	0.069	203	1.0%
LAF 4530-C*	Insulation	0.067	199	1.0%
Pyrex	Polymers	1.143	1437	1.0%
Pyroceram	Ceramics	4.08	2952	1.0%
Stainless Steel-F1*	Low Metals	15.506	7617.8	2.5%
Copper	High Metals	398	36991	2.5%
EPS-A*	Aerogels	0.0331	44.65	2.5%
EPS-B*	Aerogels	0.0333	43.28	2.5%
EPS-C*	Aerogels	0.0334	41.86	2.5%
EPS-D*	Aerogels	0.0335	40.37	2.5%
Poly Felt-A*	Textiles 1	0.0355	57	2.5%
Poly Felt-B*	Textiles 1	0.036	59	2.5%
Poly Felt-C*	Textiles 1	0.0365	61	2.5%
Poly Felt-D*	Textiles 1	0.037	63	2.5%
Poly Felt-E*	Textiles 1	0.0375	65	2.5%
Poly Felt-F*	Textiles 1	0.038	67	2.5%
Poly Felt-G*	Textiles 1	0.038	69	2.5%
Poly Felt-J*	Textiles 1	0.035	55	2.5%
Glycerine	TLS Module	0.285		NA
Stainless Steel 304**	TPS Module	Refer to reference material certificate provided		NA

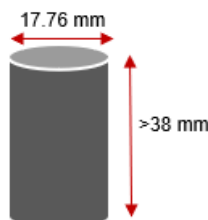
For support, please contact support@ctherm.com

3.10 Sample Preparation

Sample contact with the sensor surface is critical to obtaining good quality, repeatable measurements. Ensure that all solid samples are clean. Tap any loose dust off and inspect the samples to ensure that the surface is smooth and free of sharp surfaces. Use the table below to prepare the sample for testing.

Please note that contact agents must not be used with insulators, aerogels, or textiles.

Material Type	Minimum Sample Thickness/Volume*	Setup Instructions
Liquids	1.2 mL	Pour liquid into the Liquids and Powders Test Cell and place the liquids lid on the cell. Ensure the sample and sensor surface are free of bubbles,
Powders	1.8 mL	Place powder into the Liquids and Powders Test Cell and place weight on powder.
Pastes	1.8 mL	Load paste into a syringe and eject the required amount onto the center of the sensor, ensuring no air bubbles and ensuring the air is pushed away from the sensor.
Aerogels	4 mm	Place the sample on the sensor with the test area in contact with sensor chip. Place the weight on top of the sample, centering it carefully.
Textiles	1 mm	Prepare sample per ASTM D7984 best practices.
Insulators	2 mm	Place the sample on the sensor with the test area in contact with sensor chip. Place the weight on top of the sample, centering it carefully.
Polymers	2 mm	Place 3 drops of water on the sensor chip.
Ceramics	4 mm	Place the sample on the sensor, ensuring that it is set down evenly to ensure optimal contact. Place the weight on the sensor so it is centered over the sensor and sample.
Metals < 90 W/mK	13mm	Place the metal sample holder on the sensor. Place 3 drops of water on the sensor chip. Place the sample in the holder, ensuring that it is set down evenly to ensure optimal contact. Place the weight on the sensor so it is centered over the sensor and sample.
Metals >90 W/mK	Diameter Requirement: 17.76 mm \pm 0.05 mm Minimum thickness: 38.1 mm	



***Minimum sample thickness/volume is provided as a guideline only for material testing and thicker samples may be required depending on material composition.**



In cases where the sample would likely absorb water the recommended contact agent is Wakefield 120 Thermal Joint Compound instead. Update the contact agent selection in the software to ensure the Wakefield thermal grease coefficients are applied to the measurements.

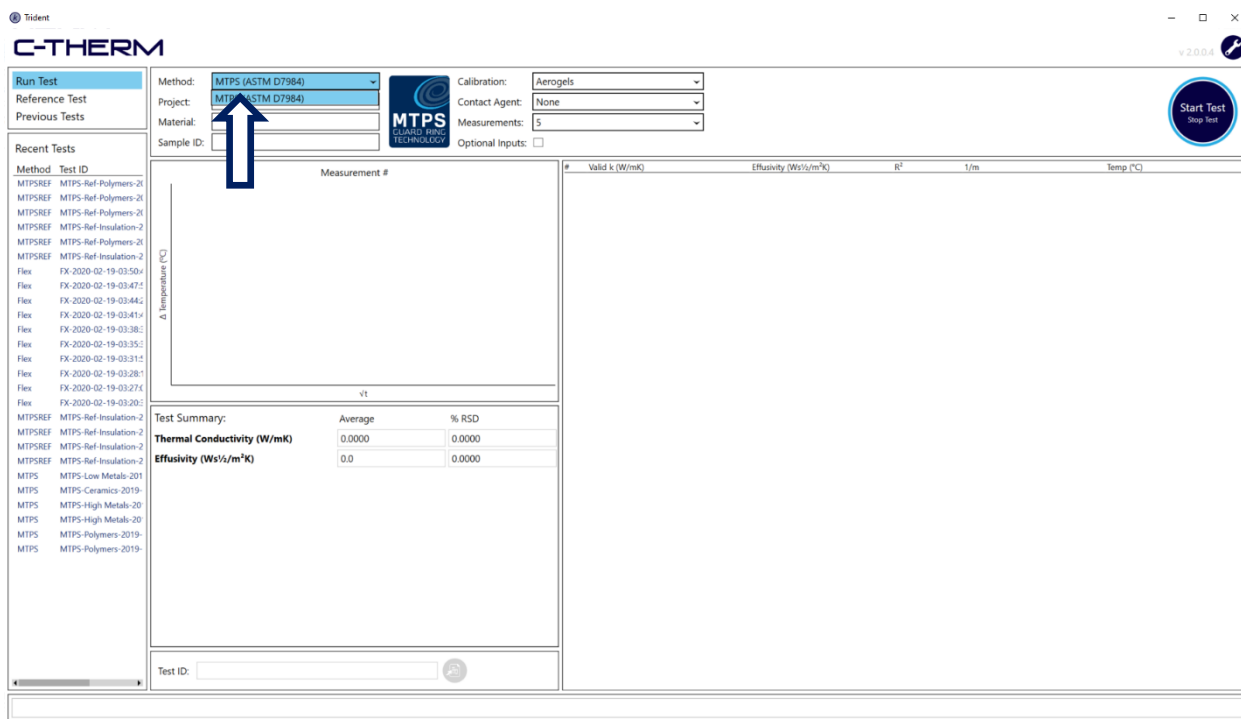
Note: If the sample has an uneven surface, test it with a fingertip. If the sample feels noticeably rough, contact C-Therm Applications Support to discuss best practices for testing the sample. Rough samples may pose risk to the sensor.

For support, please contact support@ctherm.com

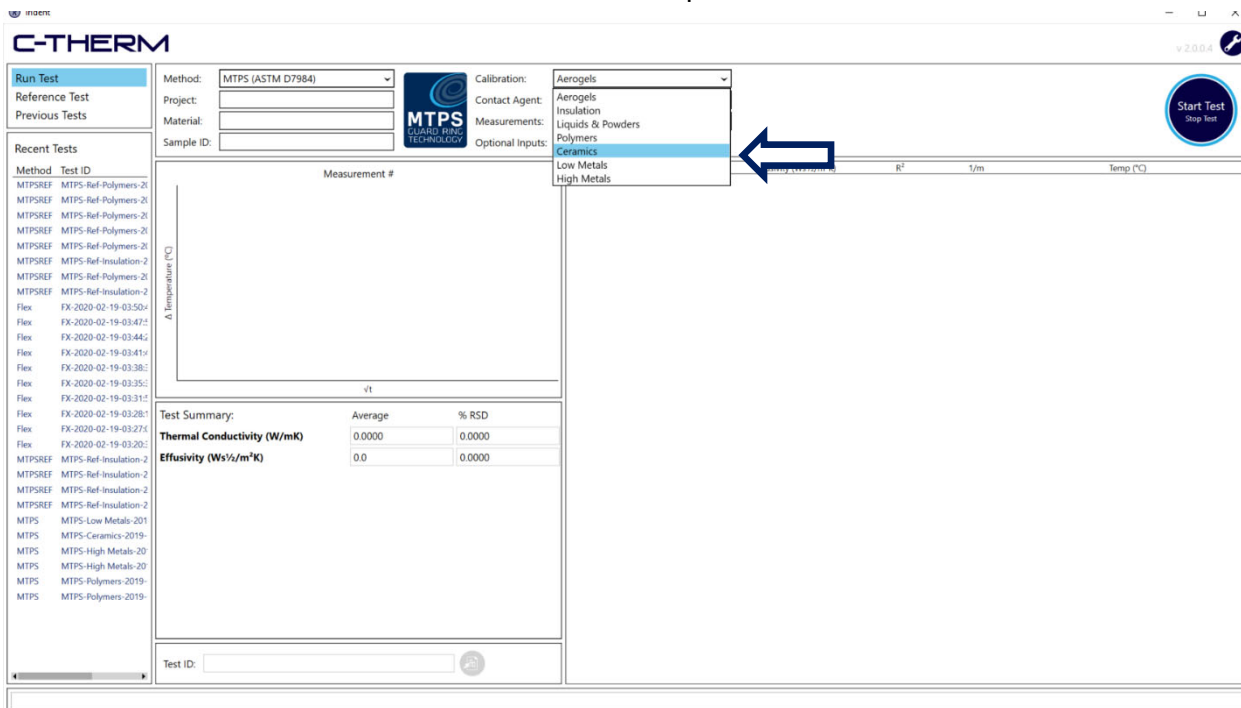
This document cannot anticipate all possible hazards associated with testing your samples and does not attempt to. It is necessary for you to conduct a full safety assessment of any testing you are considering, identify potential hazards, and take steps to mitigate these hazards. C-Therm Technologies Ltd. will not be held liable for any damages caused by the user's failure to take appropriate steps to mitigate hazards associated with their samples and testing protocol or associated with the user's failure to heed the safety precautions identified herein.

3.1.1 Running a Test

1. Double-click the Trident icon to launch the software.



2. Select the MTPS – ASTM D7984 method from the drop-down list.
3. Select the Calibration to be tested from the drop-down list.





To choose the appropriate calibration, reference the following table and choose the class of materials which most closely matches your sample material:

Calibration	k Range (W/mK)	Effusivity Range	RhoCp Range (MJ/m ³ K)	Preset Sensor Power (W)	Preset Calc. Time Boundaries (s)	Interval Cooling Time
Aerogels	0.02-0.038	15-46	0.044-0.061	0.18	1.2 - 2.7	90
Liquids and Powders	0-0.61	0-1660	1.1-4.5	0.35	0.5 - 1	60
Insulation	0.04-0.12	50-290	0.31-0.69	0.18	1.2 - 2.7	90
Polymers	0.13-1.2	570-1450	1.3-2.0	0.35	0.5 - 1	60
Ceramics	1.1-29	1400-8600	1.8-2.7	0.35	0.5 - 1	60
Low Metals	15-90	7500-17,000	2.4-4.4	0.35	0.5 - 1	60
High Metals	85-500	16500-38,000	2.4-3.4	0.35	0.5 - 1	60
Textiles 1	0.03-0.12	50-290	0.31-0.69	0.18	0.4 – 1.4	90
Textiles 2	0.11-0.61	275-1660	1.1-4.5	0.18	0.4 – 1.4	90

The above table also summarizes the standard calibration parameters and test conditions. Please note these can be customized at the factory level on special request.

4. Enter the Project name.
5. Enter the Material name.
6. Enter the Sample ID (optional)

7. Select the Contact Agent to be used from the drop-down menu.

The screenshot shows the C-THERM software interface. The 'Contact Agent' dropdown menu is open, displaying a list of options: 'None', 'Water (0°C to 70°C)', 'Ceramic Sample', 'Thermal Paste (15°C to 210°C)', and 'Glycol (-60°C to 35°C)'. A blue arrow points to the 'Ceramic Sample' option. The interface also shows a 'Test Summary' table with columns for 'Average' and '% RSD'.

Test Summary:	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

8. Select the number of measurements to take (5 – 10 recommended).

The screenshot shows the C-THERM software interface. The 'Measurements' dropdown menu is open, displaying a list of options: '1', '2', '3', '4', '5', '6', '7', '8', '9', '10', and '∞'. The number '5' is selected. The interface also shows a 'Test Summary' table with columns for 'Average' and '% RSD'.

Test Summary:	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000



9. Click the Start Test button.

The screenshot shows the C-THERM software interface. On the left, there is a sidebar with 'Run Test' selected. The main area contains a form for test parameters: Method (MTPS ASTM D7984), Project (Test Series 1), Material (Ceramic Sample), Sample ID (001), Calibration (Ceramics), Contact Agent (Water (0°C to 70°C)), and Measurements (5). A blue arrow points to the 'Start Test' button in the top right corner. Below the form is a graph area with a y-axis labeled 'Δ Temperature (°C)' and an x-axis labeled 't'. A 'Test Summary' table is also visible.

	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

10. The status bar, bottom, will indicate when the system is stabilizing or acquiring data.

This screenshot is identical to the one above, but with a blue arrow pointing to the status bar at the bottom of the window, which displays the word 'Stabilizing'.

- The data for each measurement will populate after it is acquired, and the system will stabilize and move onto the next measurement. The test can be stopped at anytime by clicking the Stop Test button.

The screenshot displays the C-THERM software interface. At the top, there are navigation buttons: "Run Test", "Reference Test", and "Previous Tests". The "Run Test" button is highlighted. Below these are input fields for "Method" (MTPS (ASTM D7984)), "Project" (Test Series 1), "Material" (Ceramic Sample), and "Sample ID" (001). To the right, there are dropdown menus for "Calibration" (Ceramics), "Contact Agent" (Water (0°C to 70°C)), and "Measurements" (5). A "Start Test / Stop Test" button is located on the right side, with a blue arrow pointing to it.

The main area is divided into three sections:

- Recent Tests:** A list of test entries with columns for "Method" and "Test ID".
- Measurement #1:** A graph showing Δ Temperature (°C) on the y-axis (ranging from 0 to 0.6) versus Δt on the x-axis (ranging from 0.25 to 0.95). A blue line shows a linear increase in temperature over time.
- Test Summary:** A table with columns for "Average" and "% RSD".

Parameter	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

At the bottom right, there is a "Test ID:" input field with a search icon. A blue arrow points to the "Acquiring Data" status bar at the bottom of the window.



- Allow test to complete. All measurements will be populated as follows, with the most recent Voltage-Time Chart visible to the left of the data window

The screenshot shows the C-THERM software interface. On the left, there is a sidebar with 'Run Test', 'Reference Test', and 'Previous Tests' buttons. Below that is a 'Recent Tests' list. The main area is divided into a control panel at the top and a data display area. The control panel includes fields for Method (MTPS ASTM D7984), Project (Test Series 1), Material (Ceramic Sample), Sample ID (001), Calibration (Ceramics), Contact Agent (Water (0°C to 70°C)), Measurements (5), and Optional Inputs. The data display area features a 'Measurement #5' graph showing Δ Temperature (°C) vs. vt. Below the graph is a 'Test Summary' table:

	Average	% RSD
Thermal Conductivity (W/mK)	4.0709	0.4549
Effusivity (Ws ^{1/2} /m ² K)	2.957.8	0.2875

To the right of the graph is a table with 6 columns: #, Valid k (W/mK), Effusivity (Ws^{1/2}/m²K), R², l/m, and Temp (°C). A blue arrow points to the row for measurement 5, which is highlighted in blue.

#	Valid k (W/mK)	Effusivity (Ws ^{1/2} /m ² K)	R ²	l/m	Temp (°C)
1	4.0656	2.955.4	0.9999	66.3	23.1
2	4.0670	2.956.0	0.9999	66.3	23.0
3	4.0563	2.951.1	0.9999	66.2	23.0
4	4.1070	2.974.4	0.9999	66.6	23.0
5	4.0584	2.952.1	0.9999	66.2	23.0

- Click on the desired Measurement Number line to view the raw data Voltage-Time Chart for each specific measurement. The Test Results window provides a summary of the measurement results within the Test, including average Thermal Conductivity and Effusivity, and % RSD. You can deselect measurements to exclude outliers, if required, and recalculate Test Results and Details.

The screenshot shows the C-THERM software interface with 'Measurement #4' selected. The 'Test Summary' table is updated with the following values:

	Average	% RSD
Thermal Conductivity (W/mK)	4.0618	0.1121
Effusivity (Ws ^{1/2} /m ² K)	2.953.6	0.0709

The table on the right is also updated, with measurement 4 highlighted in blue. A blue arrow points to the row for measurement 4, and another blue arrow points to the graph area.

#	Valid k (W/mK)	Effusivity (Ws ^{1/2} /m ² K)	R ²	l/m	Temp (°C)
1	4.0656	2.955.4	0.9999	66.3	23.1
2	4.0670	2.956.0	0.9999	66.3	23.0
3	4.0563	2.951.1	0.9999	66.2	23.0
4	4.1070	2.974.4	0.9999	66.6	23.0
5	4.0584	2.952.1	0.9999	66.2	23.0

3.11.1 Running A Test with Optional Inputs

If desired, tests can be run with Optional Inputs, in determining the thermal conductivity as a calculated value from the measured thermal effusivity value with a known density and mass specific heat capacity inputted by the user. This offers a secondary means of calculating the thermal conductivity and can further improve the accuracy of the determined value.

1. Click Optional Inputs.

The screenshot shows the C-THERM software interface. On the left is a sidebar with 'Run Test', 'Reference Test', and 'Previous Tests' buttons, and a 'Recent Tests' list. The main area contains test configuration fields: Method (MTPS ASTM D7984), Project (Test Series 2), Material (Pyrex), and Sample ID (Batch B). Calibration is set to Polymers, Contact Agent to Water (0°C to 70°C), and Measurements to ∞. The 'Optional Inputs' section is checked, with fields for Density (kg/m³) and Heat Capacity (J/kgK), both set to 0. A 'Start Test' button is in the top right. A large graph area is in the center, and a 'Test Summary' table is at the bottom left.

Method	Test ID
MTPS	MTPS-Ceramics-2020
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Insulation-2
MTPSREF	MTPS-Ref-Polymers-2t
MTPSREF	MTPS-Ref-Insulation-2
Flex	FX-2020-02-19-03:50v
Flex	FX-2020-02-19-03:47v
Flex	FX-2020-02-19-03:44v
Flex	FX-2020-02-19-03:41v
Flex	FX-2020-02-19-03:38v
Flex	FX-2020-02-19-03:35v
Flex	FX-2020-02-19-03:31v
Flex	FX-2020-02-19-03:28v
Flex	FX-2020-02-19-03:27v
Flex	FX-2020-02-19-03:20v
MTPSREF	MTPS-Ref-Insulation-2
MTPSREF	MTPS-Ref-Insulation-2
MTPS	MTPS-Low Metals-201
MTPS	MTPS-Ceramics-2019
MTPS	MTPS-High Metals-20
MTPS	MTPS-High Metals-20
MTPS	MTPS-Polymers-2019
MTPS	MTPS-Polymers-2019

Test Summary:	Average	% RSD
Thermal Conductivity (W/mK)	0.0000	0.0000
Effusivity (Ws ^{1/2} /m ² K)	0.0	0.0000

4. If only density is provided, then the Derived Heat Capacity will be populated.

The screenshot shows the C-THERM software interface. On the left is a sidebar with 'Run Test' selected. The main area contains a 'Test Summary' table and a data table. A blue arrow points to the 'Derived Heat Capacity (J/kgK)' field in the summary table, which is populated with the value 803.

Test Summary:		Average	% RSD
Thermal Conductivity (W/mK)		1.1204	0.6140
Effusivity (Ws ^{1/2} /m ² K)		1,424.2	0.4325
Calculated Thermal Conductivity (W/mK)		0.0000	0.0000
Derived Heat Capacity (J/kgK)		803	

#	Valid k (W/mK)	Effusivity (Ws ^{1/2} /m ² K)	R ²	1/m	Temp (°C)
1	✓ 1.1279	1,430.9	0.9999	39.2	22.8
2	✓ 1.1279	1,430.9	0.9999	39.2	22.8
3	✓ 1.1168	1,421.0	0.9999	39.0	22.8
4	✓ 1.1192	1,423.1	0.9999	39.1	22.8
5	✓ 1.1099	1,414.8	0.9999	38.9	22.9

3.11.2 Monitoring Temperature

Temperature monitoring can be captured through any Run Test function and can be observed in the column to the right. Users wishing to run a temperature assessment before testing a sample can select Run Test, choose the “Insulation” calibration, and run the test with no sample placed on the sensor.

This close-up shows the 'Optional Inputs' section where 'Density (kg/m³)' is set to 2254 and 'Heat Capacity (J/kgK)' is set to 0. A blue arrow points to the 'Start Test' button. Below is the data table with row 5 highlighted.

#	Valid k (W/mK)	Effusivity (Ws ^{1/2} /m ² K)	R ²	1/m	Temp (°C)
1	✓ 1.1279	1,430.9	0.9999	39.2	22.8
2	✓ 1.1279	1,430.9	0.9999	39.2	22.8
3	✓ 1.1168	1,421.0	0.9999	39.0	22.8
4	✓ 1.1192	1,423.1	0.9999	39.1	22.8
5	✓ 1.1099	1,414.8	0.9999	38.9	22.9



3.12 Data Analysis

3.12.1 Data Validation

Verify that the cells of the thermal conductivity and thermal effusivity results are not colored red or blank. The values of the thermal conductivity will be in red font if outside of the valid test range, and the cell will be blank with a red background if more than 15% out of the calibrated range, indicating an invalid measurement.

Condition	Font color	Cell background
Valid data range	Black	White
Data within 15% of valid range*	Red	White
Invalid test result (too high/low)*	Blank	Red

If the test condition is marked with an * in the table above, it is recommended to re-test the sample using a calibration more suitable for the sample material.

It is also suggested to check the displayed RSD value and ensure that it is within the limits indicated for the calibration as referenced in the table below. Note that the RSD specification is stated for 10 sequential measurements of the sample without moving the sample between measurements. It will also depend upon the sample homogeneity and environmental stability conditions. Actual test results may vary as a result of these factors.

If the RSD is outside of recommended limits, outlier measurements may be deselected. The first measurement can always be deselected. Otherwise, no more than 1 in 10 measurements may be deselected.

As an additional optional check, it is recommended to check the R^2 value in the test results table. This should be in all cases > 0.995 . A lower result may indicate hardware damage, malfunction, or may indicate interference from sources of large electromagnetic fields, such as GC/MS, NMR, or ESR equipment.

Calibration	Max RSD (%)*	k Range (W/mK)	Effusivity Range	RhoCp Range (10 ⁶ J/m ³ K)
Aerogels	2.5%	0.02-0.038	15-46	0.044-0.061
Liquids and Powders	1.0%	0-0.61	0-1660	1.1-4.5
Insulation	1.0%	0.04-0.12	50-290	0.31-0.69
Polymers	1.0%	0.13-1.2	570-1450	1.3-2.0
Ceramics	1.0%	1.1-29	1400-8600	1.8-2.7
Low Metals	2.5%	15-100	7500-18,500	2.4-4.4
High Metals	2.5%	85-500	16500-38,000	2.4-3.4
Textiles 1	2.5%	0.03-0.12	50-290	0.31-0.69
Textiles 2	2.5%	0.11-0.61	275-1660	1.1-4.5

***RSD statement assumes that material is homogeneous, and that water is used as the contact agent for Polymers, Ceramics, Low Metals and High Metals. Heterogeneous materials and testing with Wakefield 120 contact agent may have higher RSD values.**

Finally, it is recommended to review the sensor temperature column. If the sensor temperature between successive tests drifts by more than 0.2°C, it is likely the sensor has not adequately equilibrated with the sensor and environment, or that the ambient laboratory environment is not sufficiently stable.

3.12.2 Exporting Data

Data can be exported for later analysis. Click the Export icon below the test details to save the file to CSV format.





Saved files are located in the “Documents\C-Therm\MTPS\” folder. Below is an example of an automatically assigned file name. It is recommended that users rename tests with a naming convention which allows for easy identification of specific tests results in internal records.

An example of an exported CSV is shown below.

Valid	Conductivity W/mK	Effusivity Ws ^{1/2} /m ² K	R Squared	Delta T degC	Temperature degC	
1	TRUE	4.065579	2955.367	0.999855	66.26518	23.0541
2	TRUE	4.066984	2956.013	0.999866	66.27606	23.03287
3	TRUE	4.056299	2951.098	0.9999	66.18524	23.03685
4	FALSE	4.106979	2974.375	0.999861	66.61539	23.01362
5	TRUE	4.058417	2952.073	0.999906	66.20241	23.01976

Individual measurement lines may also be copied and pasted as needed from the test window.

3.12.3 Opening a Previous Test

Recent tests for each method are listed in the left sidebar.

The screenshot shows the C-THERM software interface. On the left, the 'Recent Tests' sidebar is active, displaying a list of tests. A blue arrow points to the 'Previous Tests' button. The main window displays a graph for 'Measurement #4' showing Δ Temperature (°C) vs \sqrt{t} . Below the graph is a 'Test Summary' table:

	Average	% RSD
Thermal Conductivity (W/mK)	4.0618	0.1121
Effusivity (Ws^{1/2}/m²K)	2,953.6	0.0709

At the bottom right, a table lists test results:

#	Valid k (W/mK)	Effusivity (Ws ^{1/2} /m ² K)	R ²	1/m	Temp (°C)
1	4.0656	2,955.4	0.9999	66.3	23.0
2	4.0670	2,956.0	0.9999	66.3	23.0
3	4.0563	2,951.1	0.9999	66.2	23.0
4	4.1070	2,974.4	0.9999	66.6	23.0
5	4.0584	2,952.1	0.9999	66.2	23.0

To open tests not displayed in the Recent Tests window, click Previous Tests and an additional list of tests is displayed. Material and test notes are displayed for each test in the list.

The screenshot shows the C-THERM software interface with the 'Previous Tests' sidebar active. A blue arrow points to the 'Previous Tests' button. The main window displays a graph for 'Measurement #1' showing Δ Temperature (°C) vs \sqrt{t} . Below the graph is a 'Test Summary' table:

	Average	% RSD
Thermal Conductivity (W/mK)	4.0618	0.1121
Effusivity (Ws^{1/2}/m²K)	2,953.6	0.0709

At the bottom right, a table lists test results:

#	Valid k (W/mK)	Effusivity (Ws ^{1/2} /m ² K)	R ²	1/m	Temp (°C)
1	4.0656	2,955.4	0.9999	66.3	23.0
2	4.0670	2,956.0	0.9999	66.3	23.0
3	4.0563	2,951.1	0.9999	66.2	23.0
4	4.1070	2,974.4	0.9999	66.6	23.0
5	4.0584	2,952.1	0.9999	66.2	23.0

The 'Previous Tests' sidebar shows a list of tests, including 'Ceramic Sample 001' which is highlighted with a blue arrow.



3.13 Calibration

MTPS sensors are factory calibrated and do not require recalibration unless the reference material tests fail, or an updated calibration certificate is required. It is recommended to run regular reference material tests to verify the continued function of the calibrations. Annual service plans are available.

3.14 Maintenance

3.14.1 Cleaning Instructions

MTPS sensors may be wiped down with any of the following solvents and a wipe. Avoid the use of any abrasive materials on the sensor. Choose a solvent that is not reactive with the samples recently tested.

- Soap and water
- Isopropyl Alcohol
- Acetone (except FRV sealant sensors)
- ArctiClean Thermal Grease Remover, used as directed on packaging



DO NOT IMMERSE MTPS SENSOR HOUSING IN ANY FLUID AS THE CABLE CONNECTION IS NOT LIQUID-PROOF

The Trident controller may be wiped down with a damp cloth. Ensure that the power is off, and all cables are disconnected. Do not connect any cables until Trident controller is completely dry. The Trident controller is not waterproof and should be protected from water.

3.14.2 Storage Instructions

Retain the packaging provided with the Trident system for storage or servicing at C-Therm Technologies Ltd. If the Trident system will be unused for any period, it may be stored safely in the original packaging.

Upon completion of testing and/or any cleaning the MTPS sensor may be stored in the provided case or left connected to the Trident system with the protective covering in place. Ensure that the sensor will not be impacted or damaged while not in use. It is also recommended to store the provided reference samples in the provided case to avoid loss or damage.

3.14.3 Replacement Criteria for Consumables

MTPS sensors are consumable and will last for several years with appropriate handling. The life expectancy is determined by the operating conditions and usage profile. Frequent thermal cycling of the sensor(s) can cause faster aging of the components. It is the user's responsibility to ensure the materials to be tested will not damage the sensor(s) and appropriate care in handling of the sensor(s) is taken.



Signs of damage to the MTPS sensor include:

- Fine fracture lines on the sensor chip surface
- Changes in sensor chip colour or surface appearance not removed by proper cleaning
- Damage to the sealant around the sensor chip
- Wear at the cable connection points

For support & service, please contact support@ctherm.com

4.0 FLEX TPS OPERATING INSTRUCTIONS

The FLEX TPS method employs a double-sided sensor to simultaneously determine thermal conductivity, thermal diffusivity and derive specific heat capacity of materials from a single measurement. Recommended for experienced users, FLEX TPS provides the greatest flexibility and control over experimental parameters and avoids the use of any contact agents.



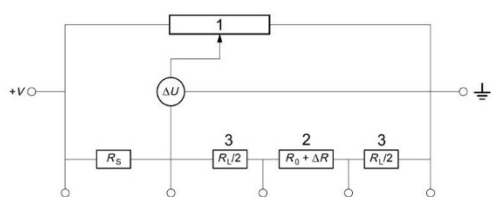
4.1 Principle of Operation

The C-Therm Trident Thermal Conductivity Analyzer Flex configuration employs the Transient Plane Source (TPS) technique in characterizing the thermal conductivity, thermal diffusivity, and specific heat capacity of materials, conforming to ISO Standard 22007-2. It employs a double-sided sensor, and the user iteratively develops the timing and power parameters. Intended for rough and heterogeneous materials not well-suited to a single-sided test method, this configuration allows researchers the maximum versatility in test parameters and experimental design.

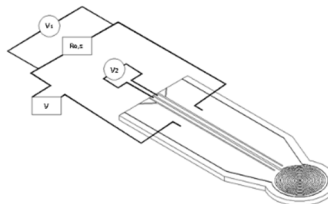
4.2 How it Works

Notice to Reader: The FLEX TPS method requires greater expertise on the part of the user, it is recommended to familiarize yourself with the underlying theory and principles of operation to the FLEX TPS method.

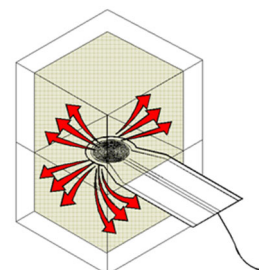
The Transient Plane Source Method (TPS) ISO 22007-2,¹ uses a heated disc composed of a bifilar nickel spiral (contains two closely spaced spiral windings) encapsulated in a dielectric material such as polyimide. During a measurement, the sensor is positioned between two identical samples of the material being measured as shown; a pulse of constant electrical power (up to minutes in duration) is applied to the spiral heater and the increase in temperature in the spiral is measured. The spiral in the sensor serves as both the source of heat and a dynamic temperature sensor during a measurement. The sensor and bridge circuitry are shown below, including the DC power supply (V), standard resistance (R_s), and measurement points for the sensor voltage drop (V₂) and the voltage drop across the standard resistor (V₁)



(L) Electrical Schematic of FLEX TPS Thermal Conductivity Sensor.



(C) Electrical Schematic of FLEX TPS Thermal Conductivity Sensor.



(R) Flex TPS sensor sandwiched between two identical samples.

The sensor temperature response is factory calibrated using the temperature coefficient of resistance, TCR, of the nickel spiral. TCR relates to the change in metal resistance with a change in temperature. The use of this relationship, as employed in this application is described in ISO Standard 22007-2² and TCR is defined in the British Standards Institute's BS EN 60751 Standard³. BS EN 60751 defines a quadratic or cubic model for the temperature-resistance characteristics of a metal. For example, in the case of a platinum resistor, the temperature-resistance characteristic has the following form:

$$R(T) = R_0[1 + A \cdot T + BT^2] \quad \text{for } 0 < T < 850^\circ\text{C}$$

¹ International Standards Organization, Plastics - Determination of thermal conductivity and thermal diffusivity - Part 2 Transient plane heat source (hot disc) method, Geneva: International Standards Organization, 2008.

² International Standards Organization, Plastics - Determination of thermal conductivity and thermal diffusivity - Part 2 Transient plane heat source (hot disc) method, Geneva: International Standards Organization, 2008.

³ "BS EN 60751 Industrial platinum resistance thermometer sensors," 1996.

$$R_T = R_0[1 + AT + BT^2 + C(T - 100)T^3] \quad \text{for } -200 < T < 0^\circ\text{C}$$

Where $R(T)$ is the resistance of the metal at a given temperature, R_0 is the resistance of metal at 0°C , T is the temperature, and A , B , and C are constants.

The current and time of the electrical pulse are calibrated to cause an expected temperature rise of one to several degrees in the sensor, based on the power delivered and the known TCR of the nickel spiral. As the temperature rises in the sensor, there is a corresponding increase in its resistance, and this produces a measurable change in the voltage drop over the sensor. To retain accuracy in the operational model of the TPS measurement, the duration of the measurement must be short for the thermal diffusivity of the sample. This allows the approximation that the sensor can be considered as being in contact with an infinite solid. Under this assumption, the sensor temperature is influenced only by the power input and the thermal transport properties of the solid in contact with the sensor, and not by any boundary effects.

The behavior of the TPS sensor during the transient pulse can be understood in terms of its time-dependent resistance, described by the equation (for small increases in temperature ΔT):

$$R(t) = R_0[1 + a\overline{\Delta T(t)}]$$

where $R(t)$ is the time-dependent resistance, R_0 the initial resistance of the TPS element before the transient pulse, the TCR of the sensor element, and $\overline{\Delta T(t)}$ is the mean value of the time-dependent temperature increase in the TPS sensor element. The temperature increase is dependent on the supplied power, the geometry of the sensor and the properties of the sample. It can also be expressed as $\Delta T(\tau)$ where the variable t is a non-dimensional characteristic time parameter and is defined as:

$$\tau = (t/\theta)^{1/2}, \quad \theta = r^2/\alpha$$

Where t is the time as measured from the start of the transient pulse, r the radius of the sensor spiral (largest ring) and α is the thermal diffusivity of the sample material.

In the case of a spiral sensor element (other geometries are possible), the time-dependent temperature increase of the sensor is given by:

$$\overline{\Delta T(\tau)} = \frac{P}{\pi^{3/2}r\kappa}D(\tau)$$

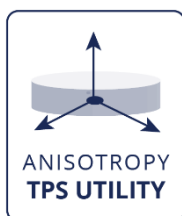
Where $\overline{\Delta T(\tau)}$ is the mean temperature rise of the sensor, P is the input power to the sensor, r is the sensor radius, κ is the thermal conductivity of the sample, and $D(t)$ is a shape function specific to the sensor geometry and depends on the thermal diffusivity of the sample α and on dimensionless time, τ .

The mean temperature function can be modified to take into account the thermal resistance between the sample and the sensor:

$$\Delta T(\tau) = A + \frac{P}{\pi^{3/2} r \kappa} D \left[\left(\frac{\alpha(t - t_c)}{r^2} \right)^{1/2} \right]$$

where A is the temperature drop on the total thermal resistance between the sensor and the sample, α is the thermal diffusivity and it is a time correction that takes into account thermal inertia of the sensor and various delays in the electronics of the apparatus. The equation above is true if and only if the thermal resistances on both sides of the sensor are equal, resulting in steady and equal heat flux to each side.

The TPS method can be further adapted for more challenging testing requirements with its specialized utilities available on Trident. These includes the *Anisotropy*, *Slab* and *Thin Films* utilities. Please see Appendix N, P and Q for Tech Tips and Application Highlights on these utilities.



4.3 Specifications and Recommended Applications

Please see Appendix C for TPS sensor specifications and recommended applications.

4.4 Required Equipment

The necessary equipment for the operation of the TPS is given below:

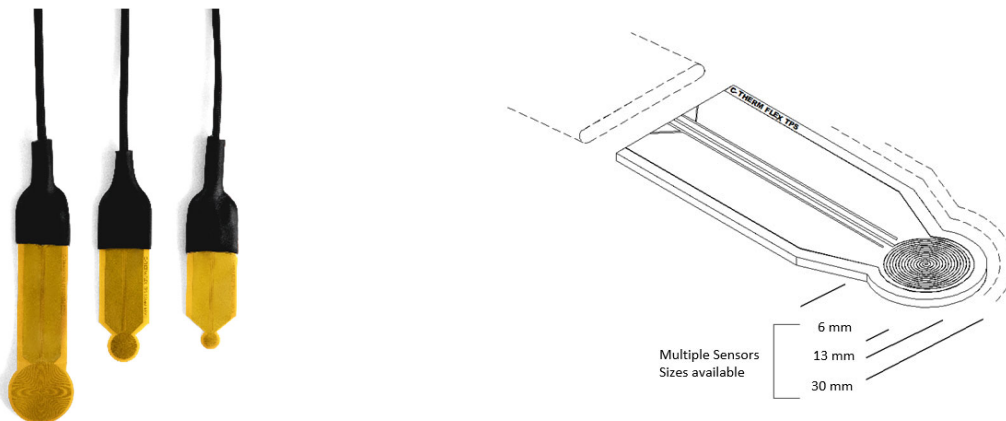
- Trident controller
- USB Cable
- Power Cable
- Reference Material Kit
- Flex TPS sensor
- Sample specimens, consisting of two (2) identical pieces of material



FLEX TPS Sensor sandwiched between stainless steel reference materials.

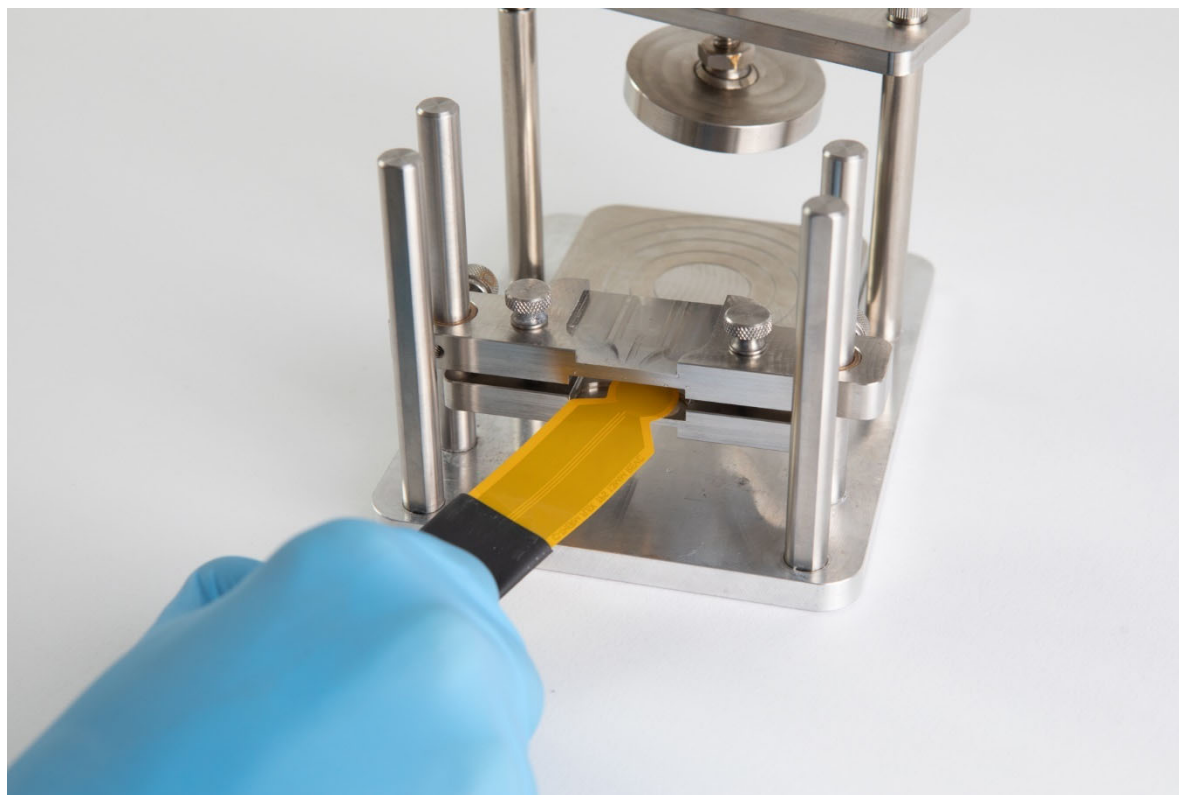
4.5 Optional Hardware and Accessories

Different sensor sizes exist for Trident TPS. The three most common sizes, 6 mm, 13 mm, and 30 mm are shown in the image below. It is important to select the sensor size most appropriate to the application. Guidance on sensor selection is provided in later sections.



Optional equipment for the operation of the TPS is given below:

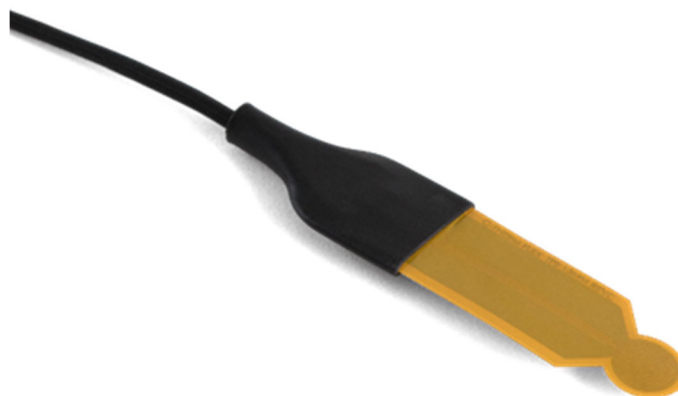
- Optional: weight or clamp to provide additional contact pressure
- Optional: thermal chamber to test outside ambient conditions



The C-Therm FLEX TPS sample clamp provides contact force to the sample/sensor stack in reducing contact resistance error in the measurement.

4.6 Verifying Condition of Sensor

Visually inspect the sensor and cable for damage. The yellow active region of the sensor should be smooth and unblemished (no scorch marks or discoloration of the polyimide film, tears, kinks, or fold marks).



Examine the cable and confirm it is smooth, flexible, not frayed, and free of discolouration or deformation. The connector should be rigid, clean, and free of discolouration or scorch marks. The pins in the connector should be straight, clean and free of visible corrosion or pitting. It must not be loose where it connects to the base of the sensor.

If any of these parts of the sensor show visible damage or are not operating within acceptable parameters, contact your C-Therm Representative or support@ctherm.com.

4.7 Recommended Handling Practices

Care should be taken in placing and removing samples, to avoid bends or kinks to the TPS sensor. The sensor should be stored in a reinforced sleeve and care should be taken to slide it in gently so that it does not wrinkle or bend.

Connecting/Disconnecting Sensors - Do NOT connect or disconnect the sensors while the unit is powered on. Swapping sensors while power is on may cause damage to the system. Be sure to grip the connector to connect or disconnect. Do NOT pull on the cable.

Cables - The cable connecting the sensor to the controller can be damaged if not handled with care. Kinks are to be avoided. The minimum bend radius is 2.5 inches. The regions near the connectors are especially vulnerable to damage from excessive bending.

Do not apply power to the sensor without it sandwiched between a sample. Doing so may cause the sensor to overheat and malfunction.



Do not apply power to the sensor while holding it. Without an appropriate sample to act as a heat sink, the sensor can get hot when powered.

Always err on the side of applying too little power to a sample. Applying too much power to the sample may cause it to overheat and may result in damage to the sample.

ONLY the yellow part of the sensor may be submerged in liquid. Under no circumstances should the black or grey parts of the cable connection and heat shrink be submerged in liquid.



Do not use a sensor with a torn or damaged plastic film. Doing so poses a hazard of electric shock.

Only clean the sensor when it is unplugged, and the controller is turned off. Failure to do so may result in electric shock. Do not immerse the sensor in fluid when cleaning. Use a damp, not wet, cloth.

This document cannot anticipate all possible hazards associated with testing your samples and does not attempt to. It is necessary for you to conduct a full safety assessment of any testing you are considering, identify potential hazards, and take steps to mitigate these hazards. C-Therm will not be held liable for any damages caused by the user's failure to take appropriate steps to mitigate hazards associated with their samples and testing protocol or associated with the user's failure to heed the safety precautions identified herein.

4.8 Trident System Setup with TPS Sensor



TRIDENT WARNING: DO NOT CONNECT OR DISCONNECT ANY SENSOR WHILE THE CONTROLLER IS TURNED ON

Note: All sensors must be connected to the appropriate port as indicated by the label to the left of the port. Sensors connected to an incorrect port will not function.

1. Place the Trident controller on the countertop, with sensor connections on the side. Do not plug in or power the system.
2. Plug the power cable and USB cable into the Trident.



3. Connect the sensor to the sensor port on the back of the Trident controller, to the right of the FLEX label. Grip the end of the sensor cable by the connector and push into place until a click is heard. The white dot on the sensor should be facing up and will align with the mark on the port when correctly positioned. Note that a different port is required for the Thin Films utility. Use the labelled port.

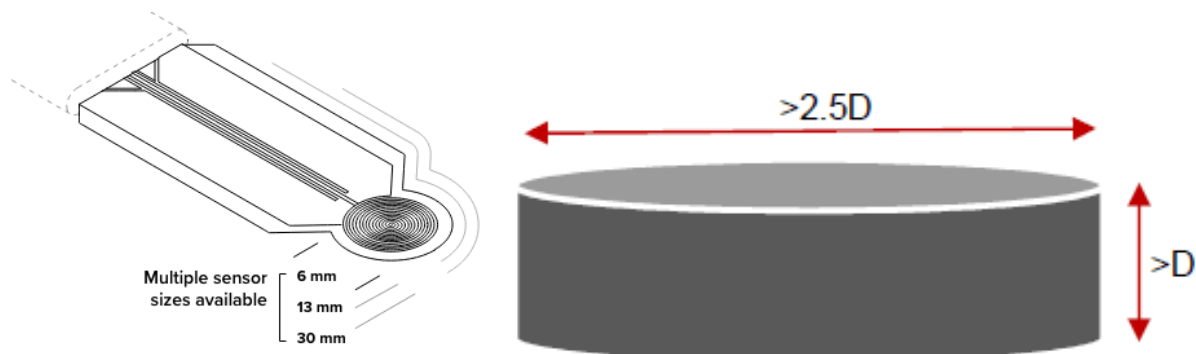


4. Connect the communications USB cable to the PC.
5. Rotate the controller, carefully, so the front of the Trident controller is facing forward.
6. Verify that the power button is still off.
7. Plug the power cable into the outlet.
8. Turn the Trident controller on via the power button on the top of the controller.
9. Open the Trident software and perform reference material tests to verify the Trident system is operational.

4.9 Reference Material Tests

Please refer to instructions for Sample Preparation and Running a Test, then complete steps with the stainless steel reference material provided.

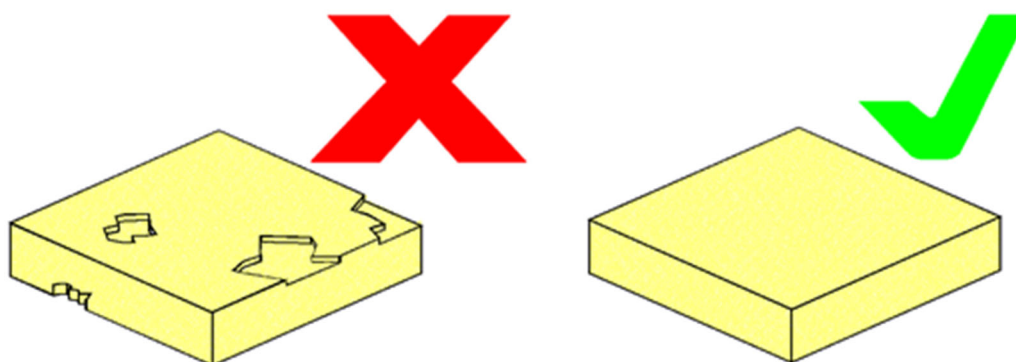
4.10 Sample Preparation



1. Select or machine two identical sample specimens of sufficient size for testing



2. It is recommended that 2 samples of equal thickness and surface area be used with the TPS sensor. The suggested sample thickness and diameter (or edge if square) are $>D$ and $>2.5D$, respectively, where D is the sensor diameter.
3. Specimens should be flat, planar, and smooth. The samples must be flush against each other. Below are examples of inappropriate and appropriate sample specimens for testing.



4. At minimum, samples must be large enough to satisfy test validity requirements laid out in section 4.12.1.

4.10.1 Loading the Sample

1. Place the first sample on a flat surface.
2. Place the sensor on top of the first sample (trying to center the sensor as much as possible).
3. Place the second sample on top of the sensor.

- Place a suitable weight (such as one of the provided stainless steel reference samples) on top of the stack to ensure good contact between sample and sensor. If the sample is heavy (such as stainless steel), no weight is needed. A completed sample stack is shown below.



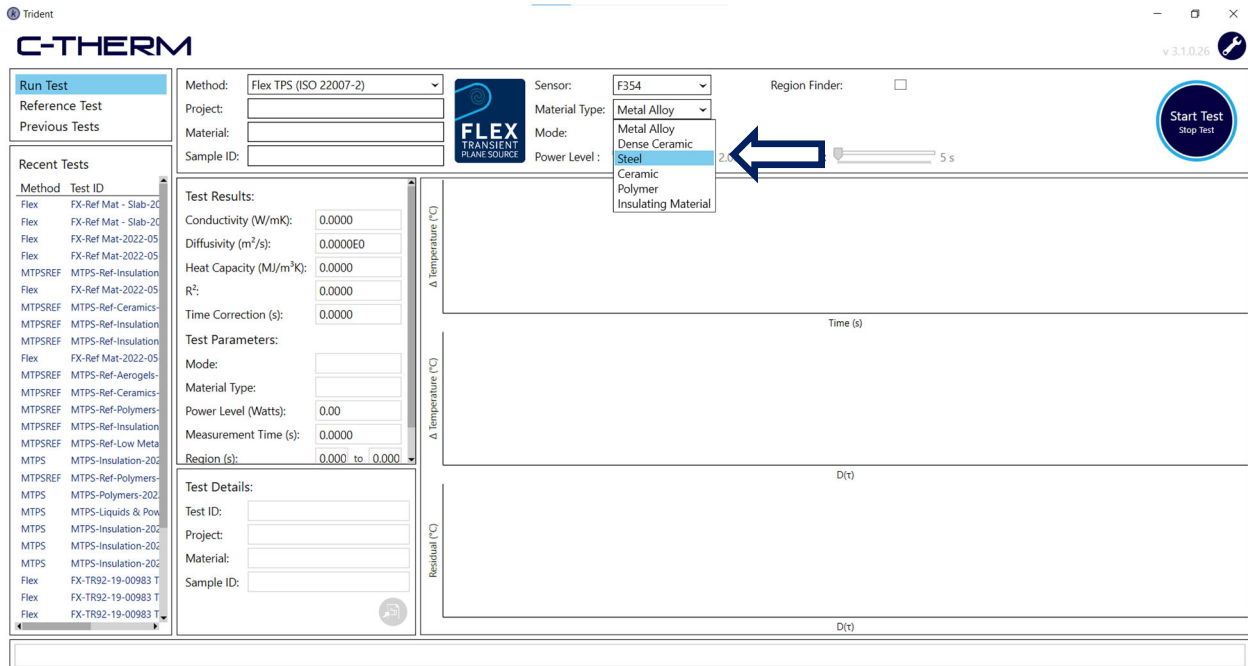
4.11 Running A Test

- Double-click the Trident icon to launch the software
- Select the Method – Flex TPS (ISO 22007). The sensor serial number, default Material Type and Mode will be populated.

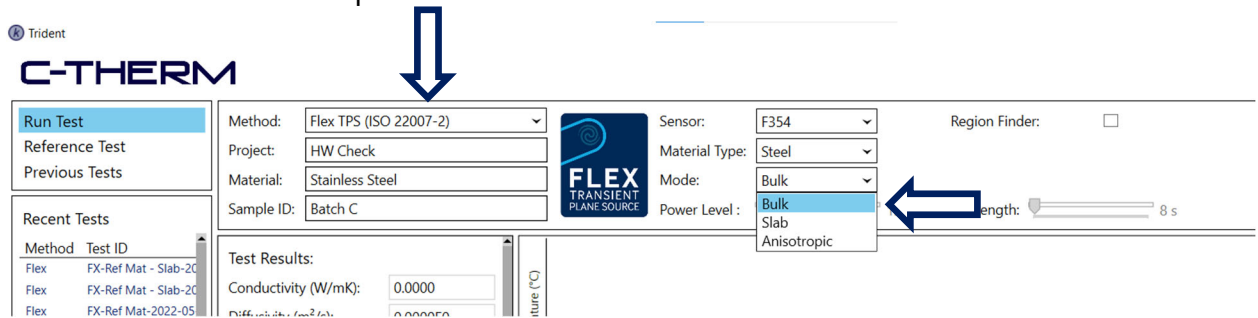
The screenshot shows the C-THERM software interface. The 'Method' dropdown is set to 'Flex TPS (ISO 22007-2)'. The 'Sensor' is 'F354', 'Material Type' is 'Metal Alloy', and 'Mode' is 'Bulk'. The 'Power Level' is 2.00 W and 'Test Length' is 5 s. The 'Start Test' button is visible in the top right corner.

Method	Test ID
Flex	FX-Ref Mat - Slab-20
Flex	FX-Ref Mat - Slab-20
Flex	FX-Ref Mat-2022-05
Flex	FX-Ref Mat-2022-05
MTPSREF	MTPS-Ref-Insulation
Flex	FX-Ref Mat-2022-05
MTPSREF	MTPS-Ref-Ceramics
MTPSREF	MTPS-Ref-Insulation
MTPSREF	MTPS-Ref-Insulation
Flex	FX-Ref Mat-2022-05
MTPSREF	MTPS-Ref-Aerogels
MTPSREF	MTPS-Ref-Ceramics
MTPSREF	MTPS-Ref-Polymers
MTPSREF	MTPS-Ref-Insulation
MTPSREF	MTPS-Ref-Low Meta
MTPS	MTPS-Insulation-202
MTPSREF	MTPS-Ref-Polymers
MTPS	MTPS-Polymers-202
MTPS	MTPS-Liquids & Pow
MTPS	MTPS-Insulation-202
MTPS	MTPS-Insulation-202
MTPS	MTPS-Insulation-202
Flex	FX-TR92-19-00983 T
Flex	FX-TR92-19-00983 T
Flex	FX-TR92-19-00983 T

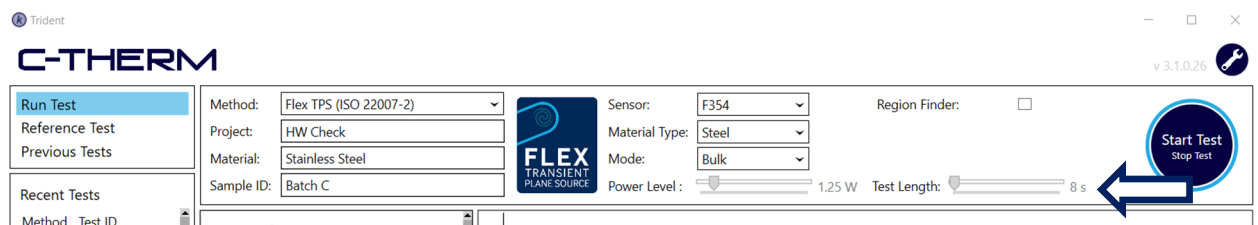
- Use the drop-down menu to select Material Type. The Material Type is not a calibration, but a recommended starting point in establishing the power and timing parameters for the type of material. These suggested starting parameters are based on the ISO document for the method, and it is advisable to additionally consult the standard.



- Enter test details such as Method, Project, Material and Sample ID. Select Mode. Bulk and Slab are available by default with the TPS module. Anisotropy, and Thin Films are additional optional modules available for purchase.

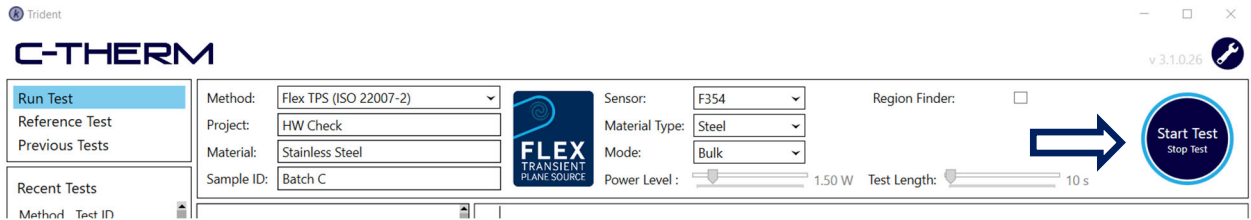


- Once Material and Mode is selected the initial power level and test time will be set for a scouting run. See Section 4.11.2 for further information on improving test parameters.

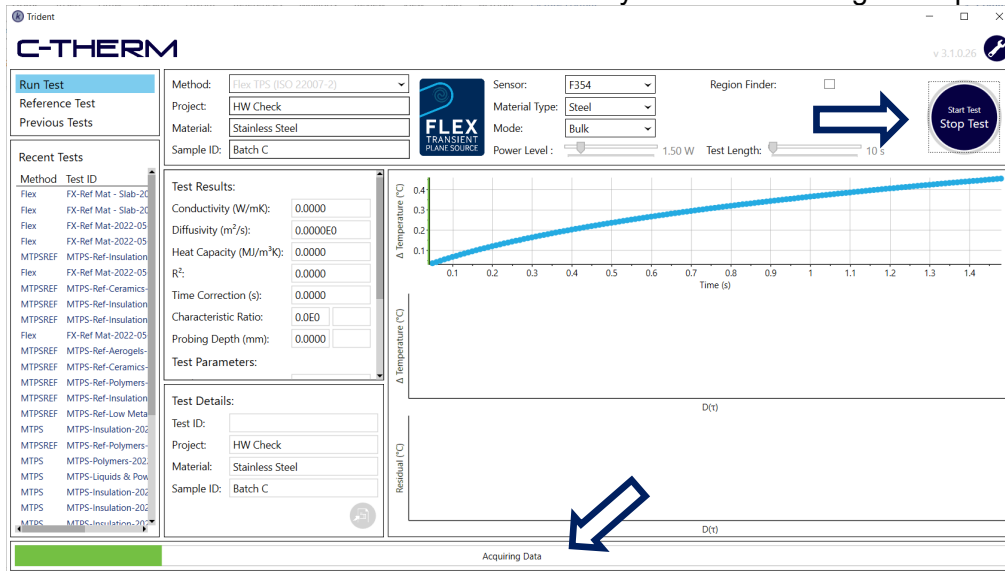




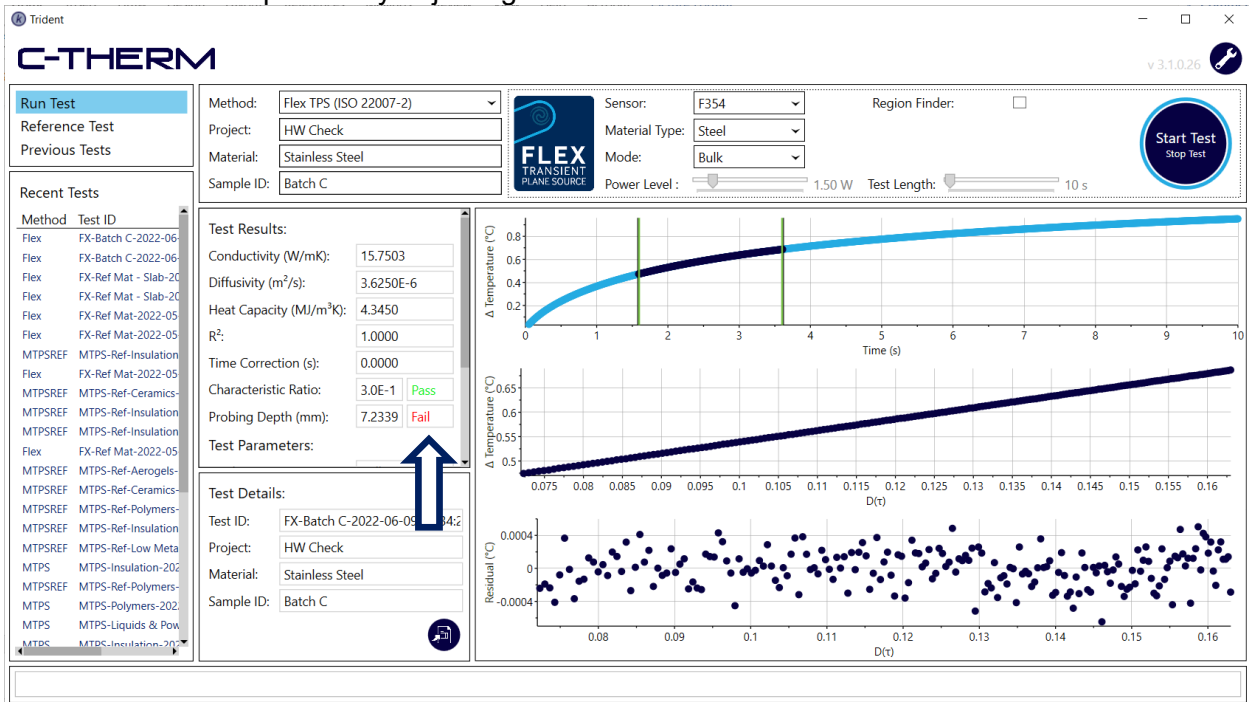
- Click Start Test. Note the measured thermal conductivity and diffusivity for further test optimization.



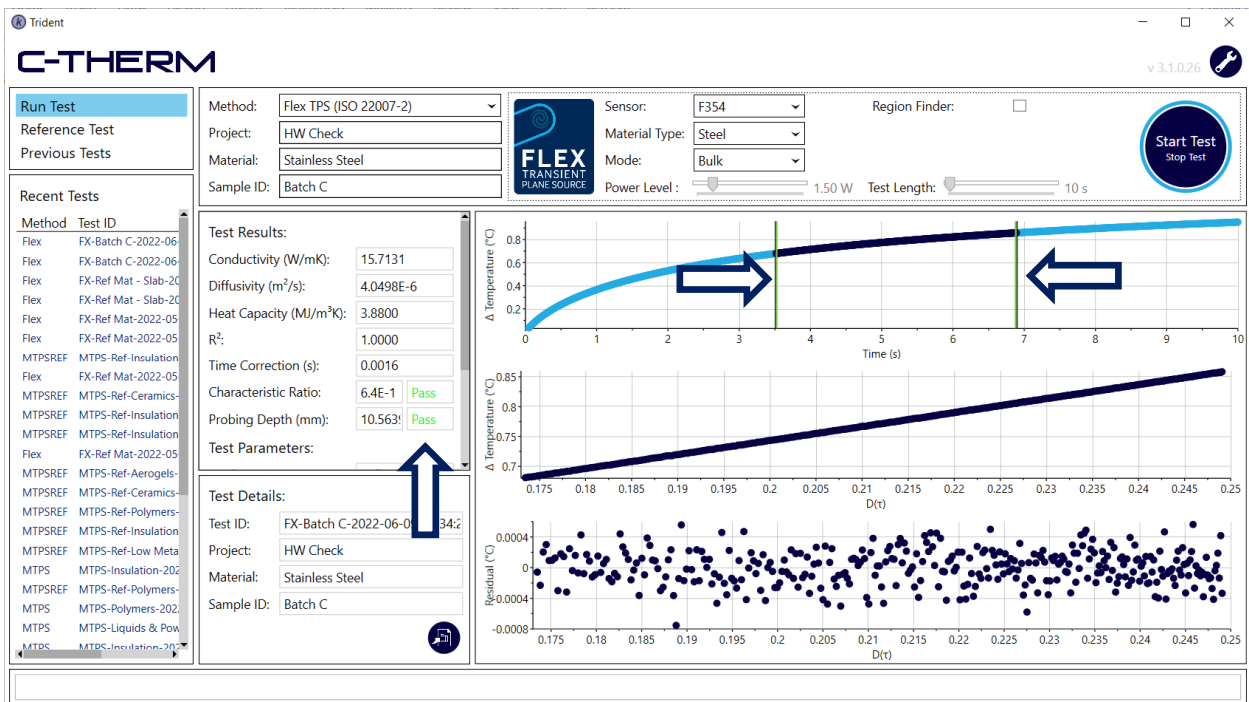
- The Status Bar at the bottom will indicate when the system is Stabilizing or Acquiring Data.



- Follow the testing optimization procedure detailed in 4.11.2 Test Parameters. Note that the characteristic ratio and probing depth tests are automated. They will be marked as “Pass” or “Fail” and can be improved by adjusting the start and end time bars.



- Restart test using optimized parameters for additional tests.





4.11.1 Cooling Time

If the sensor is not removed and the sample replaced before consecutive measurements, it is important to ensure that the heat of the stack is completely dissipated prior to running the next measurement. To determine the time required to cool the stack, it is suggested to adjust the time between measurements, starting at 0 with increments of 1 minute. Once the repeated measurement is within 2% of the initial measurement, the stack has completely cooled, and this should be used as the minimum cooling time.

Material Type	Estimated Cooling Time (min)
Metal	1 to 5
Ceramic	5 to 10
Polymers	10 to 30
Insulators	15 to 30

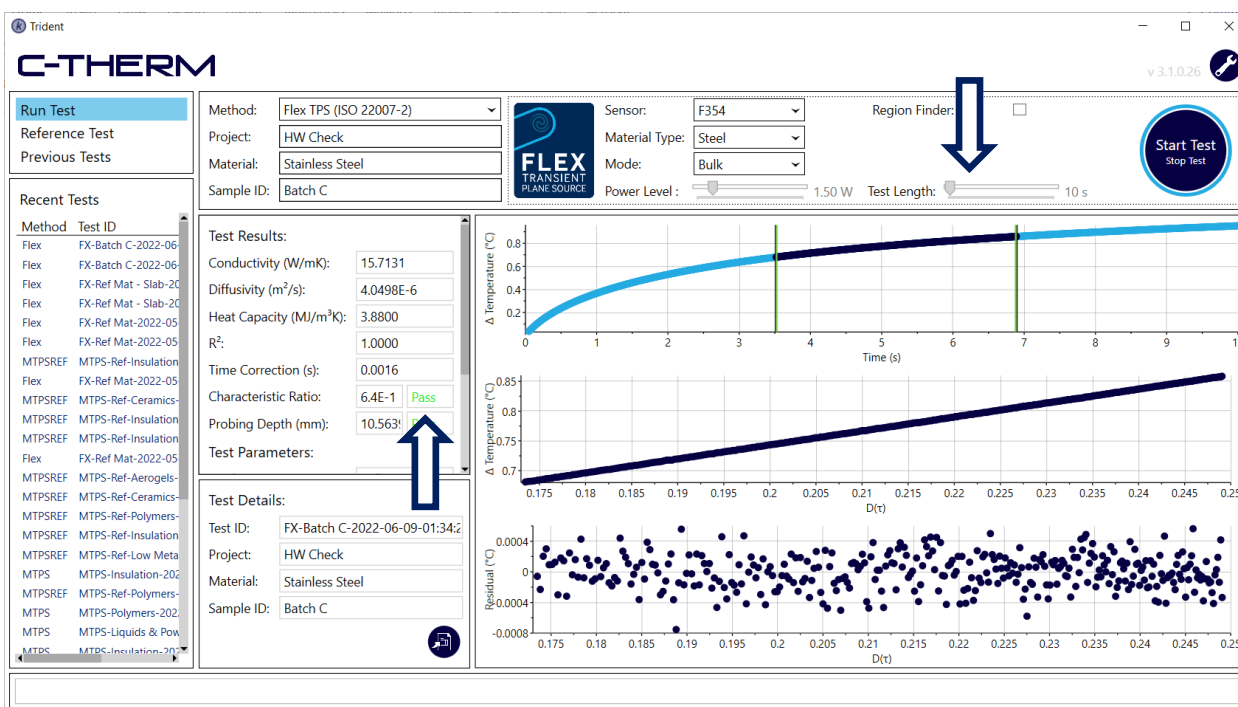
4.11.2 Test Parameters

To choose the optimal measured testing time, the following formula is recommended:

$$t_{max} = \frac{D^2}{4\alpha}$$

where D = diameter of the sensor and α = diffusivity of the sample measured in the scouting run.

1. Use the calculated t_{max} for the Test Length and re-test. It is also suggested that the lower boundary of the measurement be at least 1.5 seconds. The software will verify that the t_{max} is valid by indicating a Pass as the result for the Characteristic Ratio.



2. Obtain the new test result diffusivity and check that the following is satisfied:

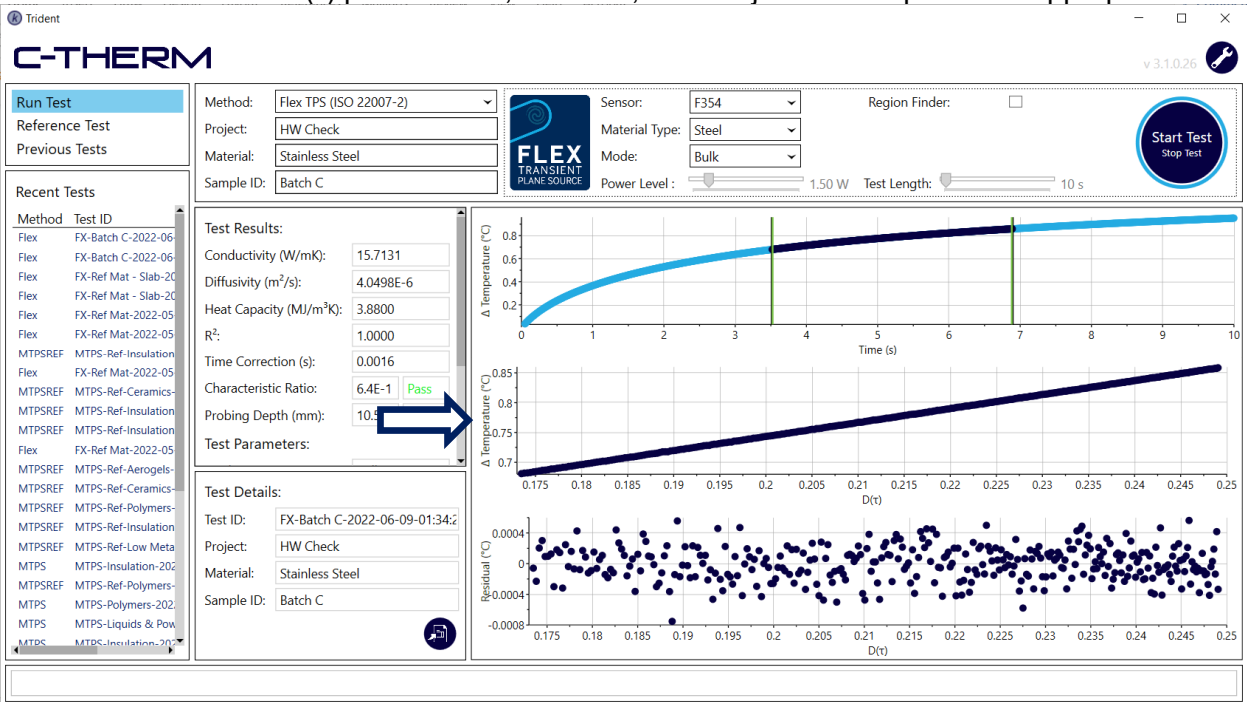
$$1.1r < \sqrt{4\alpha t} \leq 2.0r$$

where r = radius of the sensor, α = diffusivity of the sample and t = t_{max} used for re-test. If not satisfied return to (a). If satisfied, check if ΔT is $< 1.5^\circ\text{C}$. If it is, go to (d). If not, choose a lower power setting and return to (b).

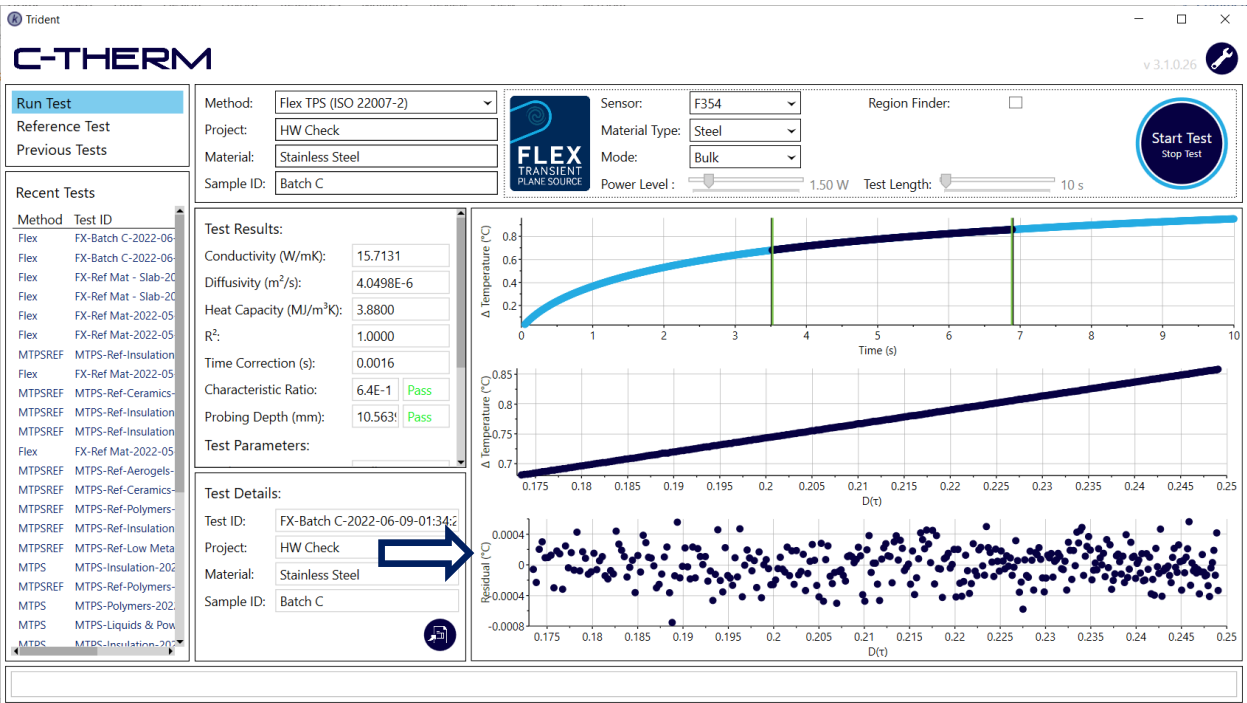


CAUTION! Always err on the side of too little power in initial testing. Overpowering the sensor may lead to damage to the sensor or the sample. Under no circumstances should the sensor be powered when not in contact with a sample as this may lead to destruction of the sensor and even risk of fire.

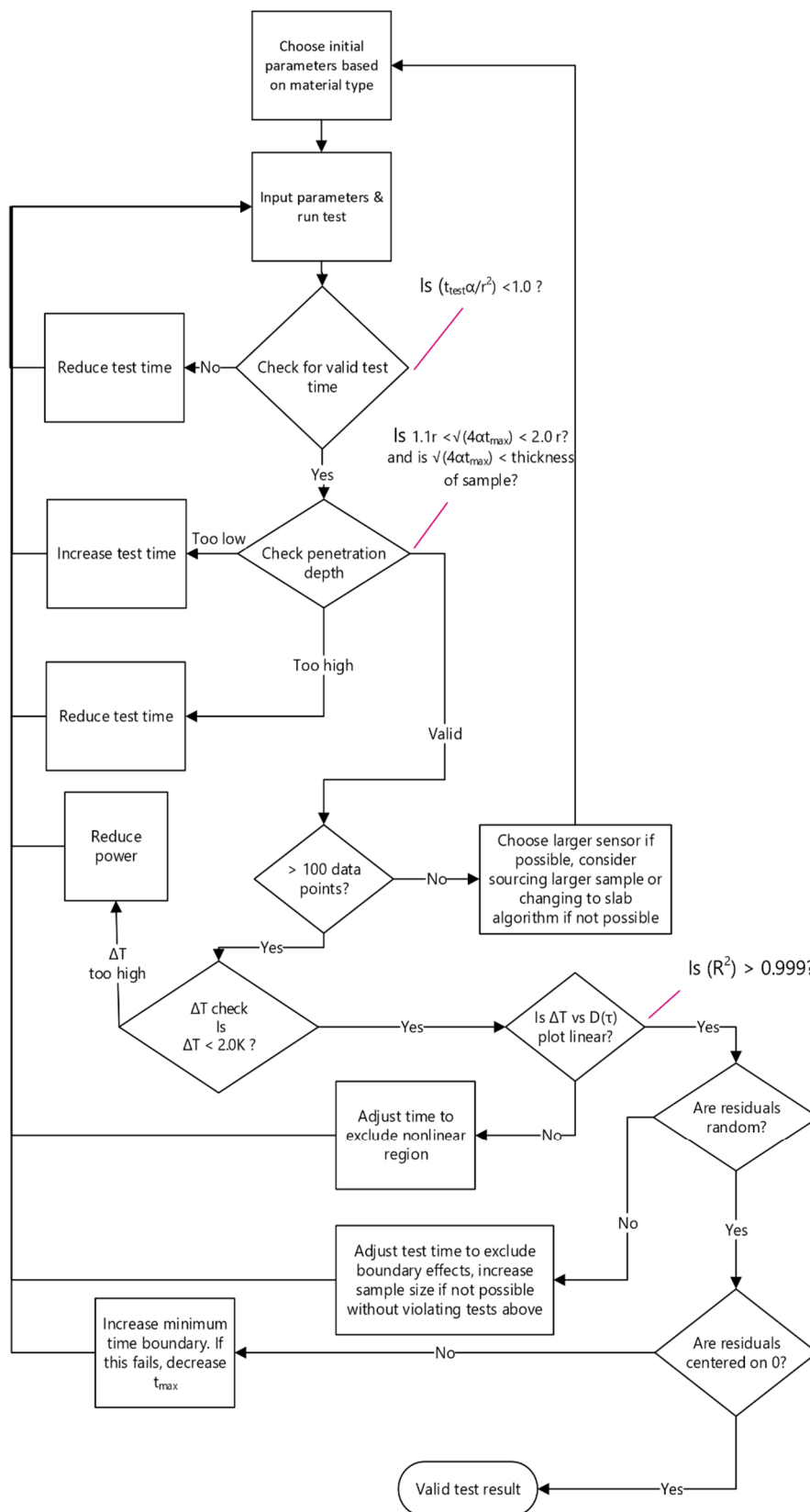
3. Examine the ΔT v. $D(t)$ plot. If linear, continue, if not adjust time or power as appropriate.



4. Examine the residual plot for the following three items:
- Randomness, if satisfied, continue. If not, adjust time boundaries and re-analyze.
 - Residuals centered on 0, if satisfied, continue. If not, adjust time boundaries and re-analyze.
 - Mean residuals are < 1 mK, if satisfied accept result. If not, adjust power or time boundaries and re-analyze.



The parameter optimization steps outlined above can be seen summarized in the figure below.



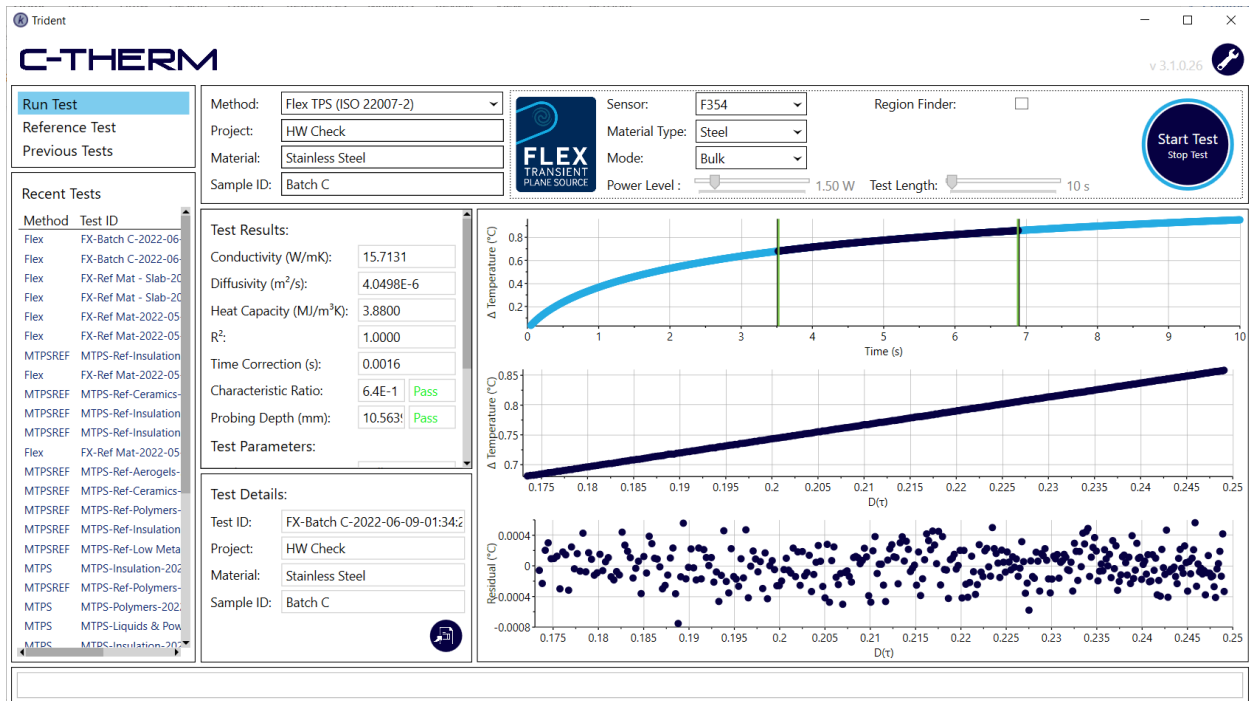
4.12 Data Analysis

4.12.1 Data Validation

The Trident software automates the penetration depth and valid test time checks. Verify that both the Characteristic Ratio and Probing Depth are listed as Pass. If they are not, adjust the upper time boundary to obtain passing results. If no passing results are available, reduce the test time.

Test Results:	
Conductivity (W/mK):	15.7131
Diffusivity (m ² /s):	4.0498E-6
Heat Capacity (MJ/m ³ K):	3.8800
R ² :	1.0000
Time Correction (s):	0.0016
Characteristic Ratio:	6.4E-1 Pass
Probing Depth (mm):	10.563 Pass
Test Parameters:	

The plot of ΔT vs time (upper plot) should be smooth with no irregularities. The plot of $D(\tau)$ (middle plot) vs T should be linear, and the residuals plot (bottom plot) should be randomly distributed. Finally, the checks outlined in 4.11.2 should be satisfied. If all conditions are met, the result may be accepted as valid. Note that adjusting time boundaries requires restarting the data validation process.



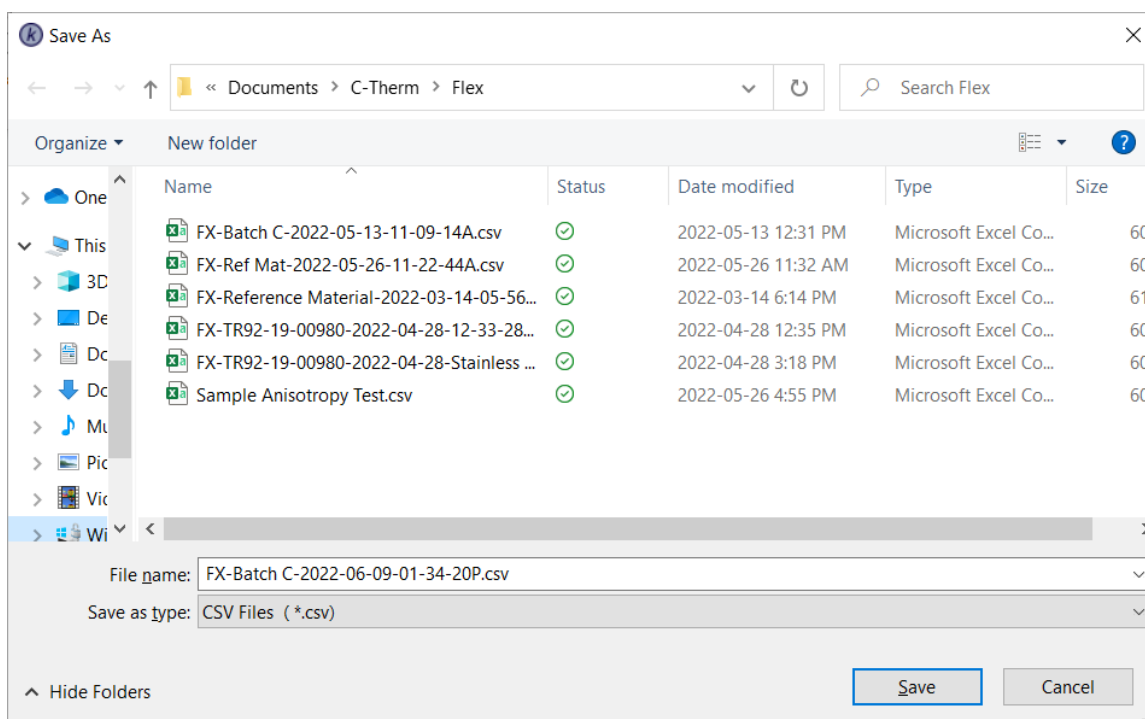
To verify the performance and condition of the TPS sensor, a reference test on the provided stainless steel samples should be performed. The stainless-steel samples should test within 7% of the provided thermal diffusivity value and 5% of the provided thermal conductivity value at room temperature for the system to be accepted as valid.

4.12.2 Exporting Data

Data can be exported for later analysis. Click the Export icon below the test details to save the file to CSV format.



Saved files are located in the “Documents\C-Therm\Flex\” folder. Below is an example of an automatically assigned file name. It is recommended that users rename tests with a naming convention which allows for easy identification of specific tests results in internal records.





An example of an exported CSV is shown.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	#Sensor Serial:	F354																
2	#Test ID:	FX-Batch C-2022-06-09-01:34:20P																
3	#Instrument:	C-Therm Trident																
4	#Project:	HW Check																
5	#Mode:	Bulk																
6	#Available Penetration Depth:	0.01 mm																
7	#Material Type:	Steel																
8	#Material:	Stainless Steel																
9	#Sample ID:	Batch C																
10	#Power Level:	1.5 W																
11	#Number of Rings:	15																
12	#Radius of Rings:	6.6 mm																
13																		
14																		
15	#Characteristic Ratio:	6.1E-1																
16	#Characteristic Ratio Status:	Pass																
17	#Probing Depth:	10.2726 mm																
18	#Probing Depth Status:	Pass																
19																		
20																		
21	Conductivity	Diffusivity	Volumetric Heat Capacity	R Squared	Time Correction	Measurement	Region Start	Region End	Number of Data Points in Calculation									
22	W/mK	m ² /s	MJ/m ³ K		seconds	seconds	seconds	seconds										
23	15.9108	3.96E-06	4.0161	1	0.0477	9.999	3.519	6.659	314									
24																		
25																		
26	Time	Delta Temperature	Sensor Current	Bridge Voltage														
27	s	degC	A	V														
28	0.049	0.03622	0.36828	0.43834														
29	0.059	0.04298	0.36827	0.43841														
30	0.069	0.04947	0.36827	0.43849														
31	0.079	0.05535	0.36826	0.43857														

4.12.3 Opening a Previous Test

Recent tests for each method are listed in the left sidebar.

The screenshot displays the C-THERM software interface. On the left, a sidebar lists 'Recent Tests' with columns for Method and Test ID. A blue arrow points to the 'Previous Tests' button in the top left navigation area. The main window shows test parameters: Method (Flex TPS (ISO 22007-2)), Project (HW Check), Material (Stainless Steel), Sample ID (Batch C), Sensor (F354), Material Type (Steel), Mode (Bulk), Power Level (1.50 W), and Test Length (10 s). A 'Start Test' button is visible in the top right. The central area displays 'Test Results' with values for Conductivity (15.7131 W/mK), Diffusivity (4.0498E-6 m²/s), Heat Capacity (3.8800 MJ/m³K), R² (1.0000), Time Correction (0.0016 s), Characteristic Ratio (6.4E-1, Pass), and Probing Depth (10.563 mm, Pass). Below this, 'Test Details' are shown for Test ID: FX-Batch C-2022-06-09-01:34:20P, Project: HW Check, Material: Stainless Steel, and Sample ID: Batch C. On the right, three graphs are displayed: a top graph of Δ Temperature (°C) vs Time (s) showing a curve; a middle graph of Δ Temperature (°C) vs D(t) showing a linear trend; and a bottom graph of Residual (°C) vs D(t) showing scattered data points around zero.

To open tests not displayed in the Recent Tests window, click Previous Tests and an additional list of tests is displayed. Material and test notes are displayed for each test in the list.

The screenshot shows the C-THERM software interface. On the left, there are three panels: 'Run Test' (Method: Flex TPS (ISO 22007)), 'Previous Tests' (listing various test IDs and materials like Stainless Steel Batch C), and 'Recent Tests' (listing more test IDs). The main area displays 'Test Results' for a specific test (FX-Batch C-2022-06-09-01:34:2) with parameters such as Conductivity (15.9108 W/mK), Diffusivity (3.9618E-6 m²/s), Heat Capacity (4.0161 MJ/m³K), and R² (1.0000). Below this, 'Test Parameters' and 'Test Details' are shown. On the right, three graphs are displayed: a plot of Δ Temperature (°C) vs Time (s) showing a curve, a plot of Δ Temperature (°C) vs D(t) showing a linear trend, and a Residual (°C) vs D(t) plot showing scattered data points around zero.

4.13 Testing at Elevated Temperatures – Notes and Consideration

4.13.1 Standard Versus High Temperature Sensors

Standard TPS sensors are rated to 80°C. Testing above this temperature range could prove detrimental to the sensor and result in permanent damage. For testing above 80°C it is recommended to use C-Therm’s high temperature TPS sensors, which are available with ratings of 300 °C (with high temperature polyimide encapsulant) and 500 °C (with mica encapsulant).

High temperature sensors experience more wear and tear on the sensor body and electrical connections owing to the thermal strain from cycling at elevated temperatures. It is expected that the lifespan of these sensors will be shorter than the standard sensors, although the exact service life depends on user operating profile, adherence to best practices (as previously outlined) and proper maintenance as outlined in the section 4.11, is important.

4.13.2 Equilibrium Consideration

For any non-ambient testing performed it is necessary to allow proper isothermal equilibration of the sensor and sample. Failure in doing so will result in invalid test results. To ensure proper equilibration, the temperature of the sample assembly should be monitored until the temperature drift is less than 0.1°C/min for test times of less than 1 minute and less than 0.01°C/min for test times of greater than 1 minute.

This document cannot anticipate all possible hazards associated with testing your samples and does not attempt to. It is necessary for you to conduct a full safety assessment of any testing you are considering, identify potential hazards, and take steps to mitigate these hazards. C-Therm will not be held liable for any damages caused by the user's failure to take appropriate steps to mitigate hazards associated with their samples and testing protocol or associated with the user's failure to heed the safety precautions identified herein.

4.14 Maintenance

4.14.1 Cleaning Instructions



CAUTION: Always remove any weight and the top sample prior to removing the sensor. Failure to do so may result in sensor damage.

Always ensure the controller has been turned off and the sensor unplugged prior to cleaning the sensor.



The yellow/brown part of the sensor may be wiped with a cloth dampened with soapy water, isopropanol or mineral oil.

The cable and plug may be cleaned with a soapy cloth only.

The controller may be wiped with a damp cloth.

Do not soak the sensor or immerse it in water.

Avoid the use of strong acids and bases.

4.14.2 Storage Instructions

Retain the packaging provided with the Trident system for storage or servicing at C-Therm Technologies. If the Trident system will be unused for any period, it may be stored safely in the original packaging.

Upon completion of testing and/or any cleaning it is strongly recommended to store the sensor in the case provided to avoid any unnecessary damage that may occur. It is also recommended to store the provided reference samples in the provided case to avoid loss or damage.

4.14.3 Replacement Criteria for Consumables

TPS sensors are consumables. The life expectancy is determined by the operating conditions and usage profile. It is the user's responsibility to ensure the materials to be tested will not damage the sensor(s) and appropriate care in handling of the sensor(s) is taken. Applying best practices and monitoring drift from the thermal conductivity value of the provided reference material are the best ways to ensure proper operation of the TPS sensors.

Signs of damage, which may indicate a need for replacement, to the TPS sensor include:

- Discolouration
- Delamination such as bubbling or separation of the plastic film
- Sharp creases
- Torn plastic film
- Wear at the cable connection points

For support & service, please contact support@ctherm.com

5. NEEDLE (TLS) OPERATING INSTRUCTIONS

The Transient Line Source (TLS) technique operates in accordance with ASTM D5334, D5930 and IEEE Std 442-1981. Commonly referred to as needle probes, the TLS sensors provide a robust and efficient solution for measuring the thermal conductivity of granular materials, powders, polymer melts, soils, slurries, gels, and pastes.



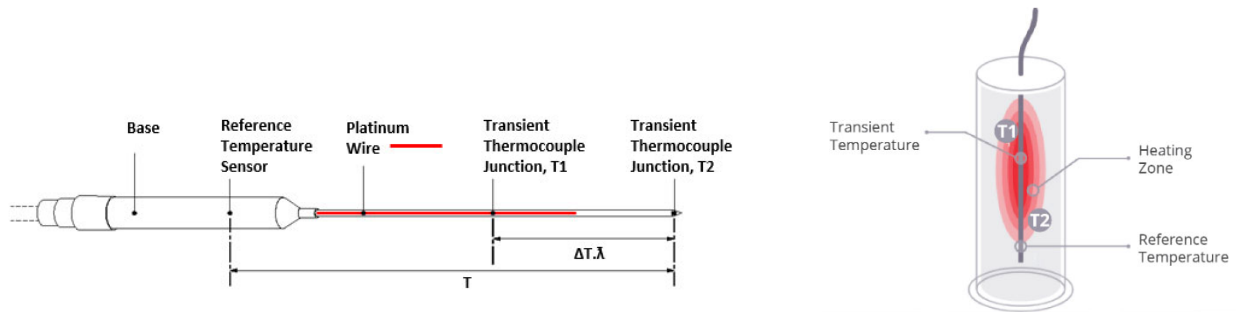
5.1 Principle of Operation

The TLS Method uses a needle probe. During a measurement, the needle is inserted into a sample material such as a soft soil (ASTM D5334), plastic (ASTM D5930), or liquid that is at a uniform and constant initial temperature. A typical needle probe consists of a 150 mm long stainless-steel hypodermic tube. Within the tube are the line heating source that provides a known amount of heat during the measurement and two thermocouple junctions positioned to measure the transient temperature rise (T_1) and reference temperatures (T_2) when the transient heat pulse is applied.

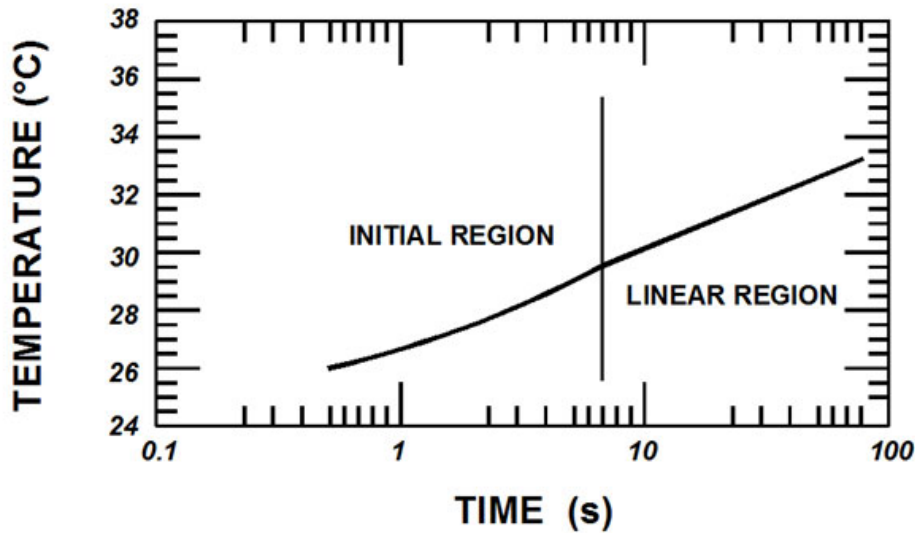
5.2 How It Works

A known amount of heat energy in the form of a heat pulse is applied to the line heating source (proportional to the known power supplied during the pulse) and this produces a heatwave that propagates radially away from the needle probe and into the sample. The thermocouple junction at T1 measures the rate of increase of the temperature in the middle of the heating and this is used to calculate the thermal conductivity of the sample.

Typical needle probe components:



The temperature rise in the line source varies linearly with the logarithm of time as shown below.



TRANSIENT LINE SOURCE TEMPERATURE VS. TIME RESPONSE

The initial non-linear portion of the curve is due to heatwave propagation through the walls of the tube and to thermal contact resistance when it is present. The relationship between the rate of temperature rise and time in the linear region can be used to calculate the thermal conductivity of the sample using the relationship:

$$k = \frac{CQ}{4\pi \cdot Slope}$$

where

$$Q = \text{Heat input per length of wire (W/m)} = I^2 \frac{R}{L} = \frac{VI}{L}$$

(*I* = Current, *R* = Wire Resistance, *V* = Voltage and *L* = Length of the heated wire)

and

$$Slope = \frac{T_2 - T_1}{\ln(t_2/t_1)}$$

where *T*₂ and *T*₁ are temperatures recorded at times *t*₂ and *t*₁, respectively, during the measurement. *C* is a calibration factor, ($C = \frac{k_{material}}{k_{measured}}$), determined by measurement of standard reference material. *k*_{material} is the known thermal conductivity of the reference material and *k*_{measured} is the thermal conductivity of the same material as measured by the method and apparatus being used.

As with TPS, it is important to maintain an awareness of the assumptions employed in TLS. The following assumptions are made in TLS measurements:

- Thermal contact resistance is negligible.
 - This is only valid when the sample is symmetrical about the sensor.
- The probe acts as a line source, with negligible heat capacity.
 - The sample volume must be much greater than the probe volume. For example, a 1mm diameter probe requires a 3cm sample diameter. The probe does not significantly contribute to the heat-transfer of the system.
- As the above conditions are not typically met, they must be addressed with the calibration of the sensor.
- The sample is in thermal equilibrium before the start of measurement.
- The probe (and heating wire inside) is exactly linear.
- Deviations from linear geometry may severely affect the measurement accuracy.
- Heat transfer occurs only through conduction.
 - TLS is inappropriate for measuring non-viscous fluids and other samples where convection or radiation may significantly contribute to the heat transfer.

- The sample is isotropic.
 - TLS is not recommended for anisotropic samples.
- Sample properties do not change during measurement, e.g., samples such as moist soils can lose moisture during the measurement.
- The sample behaves as an infinite medium.

Fortunately, the T vs. t plot for TLS measurements indicates when certain of these assumptions are invalid in a sample measurement. For this reason, it is important in TLS measurements to carefully inspect the T vs. t plot.

5.3 Specifications and Recommended Applications

Please see Appendix D for specifications and recommended applications.

5.4 Required Equipment

The necessary equipment for the operation of the TLS sensor is given below:



- Trident Controller
- USB Cable
- Power Cable
- TLS Needle Sensor
- Sample Holder - Body, Lid, Base, O-ring
- ½ inch PTFE Tape
- Bottle of Glycerin Reference Material (not pictured)

5.5 Optional Hardware and Accessories

Optional equipment for the operations of the TLS sensor includes:

- TLS HT300 High Temperature TLS Sensor for testing up to 300°C cell for high pressure testing.
- Furnace or dry block calibrator for use with the TLS HT300 configuration
- Controlled Temperature Bath (Sold Separately) for TLS – A Temperature Bath filled with an inert heat-transfer fluid is recommended for use if thermal conductivity is to be examined at above or below-ambient temperatures.

5.6 Verifying Condition of Sensor

Examine the sensor to ensure the needle is straight, free of bows, bend or kinks.



Examine the cable and confirm it is smooth, shiny, moderately stiff and free of discolouration or deformation. The connector should be rigid, clean, and free of discolouration or scorch marks. The pins in the connector should be straight, clean and free of visible corrosion or pitting. It must not be loose where it connects to the base of the sensor.

If any of these parts of the sensor show visible damage or are not operating within acceptable parameters, contact your C-Therm Representative or support@ctherm.com.

5.7 Recommended Handling Practices

A Separate SOP is available for the TLS HT300 configuration.

Handle the needle with care to avoid bending, breaking or scratching.

Connecting/Disconnecting Sensors - Do NOT connect or disconnect the sensors while the unit is powered on. Swapping sensors while power is on may cause damage to the system. Be sure to grip the connector to connect or disconnect. Do NOT pull on the cable.

Cables - The cable connecting the sensor to the controller can be damaged if not handled with care. Kinks are to be avoided. The minimum bend radius is 2.5 inches. The regions near the connectors are especially vulnerable to damage from excessive bending.



Caution: Appropriate personal protective equipment (PPE) should be worn when working with very hot or very cold apparatus. It is the user's responsibility to perform a safety assessment and select the appropriate PPE.



Caution: When inserting the sensor into a hot sample, take care that the fill level is not so high that the sample may over-flow from the vessel, as this could pose a burn hazard.



Caution: When testing high temperature liquids, ensure the hole in the side of the lid, designed to release vapor pressure, is not plugged or otherwise obstructed. If this hole is obstructed, pressure may build up in the vessel to a dangerous degree.

This document cannot anticipate all possible hazards associated with testing your samples and does not attempt to. It is necessary for you to conduct a full safety assessment of any testing you are considering, identify potential hazards, and take steps to mitigate these hazards. C-Therm will not be held liable for any damages caused by the user's failure to take appropriate steps to mitigate hazards associated with their samples and testing protocol or associated with the user's failure to heed the safety precautions identified herein.

5.8 Trident System Setup with TLS Sensor



TRIDENT WARNING: DO NOT CONNECT OR DISCONNECT ANY SENSOR WHILE THE CONTROLLER IS TURNED ON

Note: All sensors must be connected to the appropriate port as indicated by the label to the left of the port. Sensors connected to an incorrect port will not function.

1. Place the Trident controller on the countertop, with sensor connections on the side. Do not plug in or power the system.
2. Plug the power cable and USB cable into the Trident.



3. Connect the sensor to the sensor port on the back of the Trident controller, to the right of the NEEDLE label. Grip the end of the sensor cable by the connector and push into place until a click is heard. The white dot on the sensor should be facing up and will align with the mark on the port when correctly positioned.



4. Connect the communications USB cable to the PC.
5. Rotate the controller, carefully, so the front of the Trident controller is facing forward.
6. Verify that the power button is still off.
7. Plug the power cable into the outlet.
8. Turn the Trident controller on via the power button on the top of the controller.
9. Open the Trident software and perform reference material tests to verify the Trident system is operational.

5.9 Sample Preparation

5.9.1 Loading the Sample

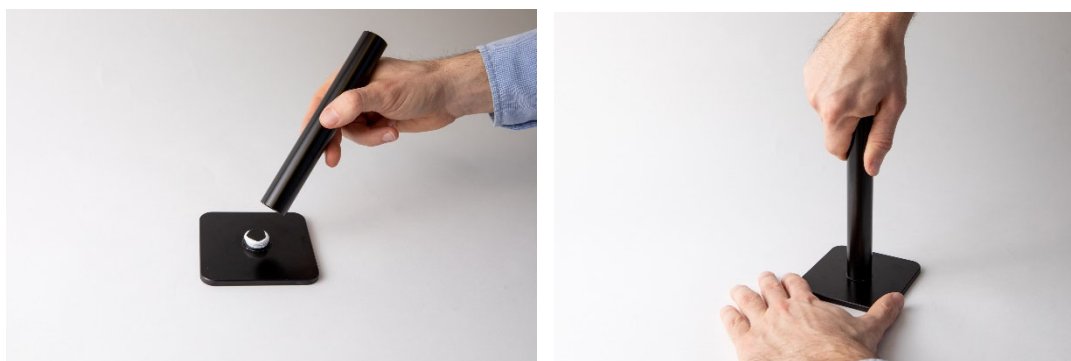
1. Remove the cap from the sensor.
2. Apply a thin layer of PTFE tape to the threading on the base of the sample holder. This is recommended if testing thin fluids such as glycerin and water under ambient conditions, or when testing in a fluid bath for temperature stability – but it is not necessary for powders or highly viscous liquids.



3. Apply an o-ring over the tape and secure to the bottom of the base.



4. Screw the base of the sample holder into the body of the sample containment vessel. If you are not using Teflon tape, finger-tighten the vessel base. If you are using Teflon tape, tighten the base so it is flush with the body of the sample holder, as seen below. For non-viscous liquid samples, it may be necessary to use a wrench to ensure the base is adequately sealed. Caution: Only use a wrench to tighten the base to the body if Teflon tape is to be employed as a thread lubricant and sealant. Use of a wrench without a thread lubricant risks damage to the vessel.



5. Fill the sample holder with the sample. Sufficient space should be left to allow for the lid to be placed on the sample, and for thermal expansion if expected. If testing with a new liquid: verify first that the liquid is compatible with stainless steel. Highly acidic, basic, or oxidizing samples may be inappropriate for testing.



6. Place the lid on the sample holder body. Push into place until it is level and flush with the body.



7. Optional: If testing a sample at a temperature outside ambient, the sample may be heated or cooled to the desired temperature range prior to insertion of the sensor, provided the sample will be liquid or powdered for the insertion of the sensor.
8. Feed the sensor through the hole in the sample holder, pushing down until the sensor will not go further. (Note: Firm but gentle pressure should be applied – great force is not necessary and may be harmful to the sensor).



9. When the sensor is fully inserted, the base of the needle should be inserted as far as possible into the cap of the holder, as shown. None of the needle should be visible.

5.9.1.1 Testing With Thermal Bath

NOTE: The thermal bath may not be used with any pressure application or with samples reactive in air.

A thermal bath can be used to regulate sensor temperature:

- Place the probe and sample holder in the bath, taking care that the bath level does not rise above the lip of the body of the vessel. The seal between the cap and the body of the sample holder is not liquid-tight, by design, to allow the cap to be displaced by the sample in the case of thermal expansion. It is important to ensure the bath level remains below this joint, to avoid contamination of the sample holder or the bath fluid.
- Ensure that the bottom of the sample holder has been properly sealed with Teflon tape, as described in Section 5.8.

5.9.1.2 Testing Liquids

Testing liquid samples successfully requires some special considerations, which differ from the testing of unconsolidated solids:

- Effort should be made to minimize convection. Use the provided sample holder wherever possible, as it has been designed to limit convection by limiting sample volume. Ensure the probe and liquid have settled from any disruption they may have encountered. Ensure as well that the liquid, sample holder and probe are all in thermal equilibrium before the onset of testing.
- For data to be valid, the sample and sensor must be protected from vibration or physical shock that can induce motion in the fluid. Care should be taken to avoid bumping the probe, the sample holder, or the surface on which they set during a measurement. Avoid the use of machinery which induce strong vibrations, such as vacuum pumps or centrifuges, on the same countertop as the TLS sensor.
- Due to the vulnerability of non-viscous fluids to convection, it may be necessary to employ a thickening agent (e.g., 0.4 weight % Agar) to obtain good data. See Appendix J for details on preparing an Agar solution for testing with water. Agar does not tend to significantly affect the thermal conductivity of samples at such a low concentration, and it is therefore recommended as a well-performing thickening agent. Please note that the long heating times required may make it inappropriate to use with samples containing volatile solutes.
- When testing liquids at high temperatures, it is necessary to allow sufficient space in the sample holder to accommodate the thermal expansion of the liquid. Liquids have coefficients of thermal expansion approximately 1-3 orders of magnitude larger than those typical of most solids, therefore substantial liquid thermal expansion may occur even with a relatively modest

temperature increase. It is advisable to intentionally under-fill the sample holder and top it off incrementally as needed after the contained liquid is heated, particularly if thermal expansion behavior of the sample is unknown.

5.9.1.3 Testing Powders

Powdered samples have some unique properties, which must be considered when testing them:

- The thermal conductivity measured by the transient line source of the powdered sample is the k_{eff} (effective thermal conductivity) of the powder material and the entrapped interstitial air – thus a powdered material will typically have a thermal conductivity orders of magnitude smaller than the thermal conductivity of the bulk material.
- The k_{eff} of a powder sample is directly related to the packing density of the powdered material. To obtain consistent data on samples, it is necessary to ensure they are packed consistently to ensure the powder density is consistent.
- In the case of highly inhomogeneous materials (e.g., aggregates for paving), a longer test time allows a greater volume of sample to be tested – and thus ensures that the data returned will be more reflective of the bulk behavior of the material. While short test times are entirely appropriate for highly homogenous materials like liquids, longer test times should be employed for the testing of inhomogeneous materials, to ensure the volume sampled is representative of the material. See Section 5.10.1 for details on the transient line guidance on the selection of test times.
- When testing natural samples likely to have substantial adsorbed water, it is necessary to weigh the advantage of a larger sample size given by a longer test time with the potential disadvantage of inducing local changes through evaporation of adsorbed water. Section 5.9.1 details guidance on the selection of appropriate test times. The applicable standards, ASTM D5334, D5930 and IEEE Std 442-1981, may be consulted for guidance in test time selection, as well.

5.9.1.4 Testing Powdered Samples Through a Melt

Testing powdered samples through a melt requires some special considerations:

- The user should be aware that the escape of entrapped air will result in a large volume contraction upon the onset of the melt.
- It is therefore recommended to heat the sample to the melt, then check the fill level in the sample vessel. If the vessel is not full enough to allow a good measurement, additional sample may be added until sufficient melt is in the vessel to give good data.

- If the melt is highly viscous and retains trapped air, sonication or vibration can be used to help mobilize the air bubbles to the surface and reduce voids.
- Exercise care when removing melt materials from the vessel, to avoid damage to the sensor caused by bending or breaking of the probe. Re-solidification of melts can cause very strong adhesion to the vessel walls by the melt.



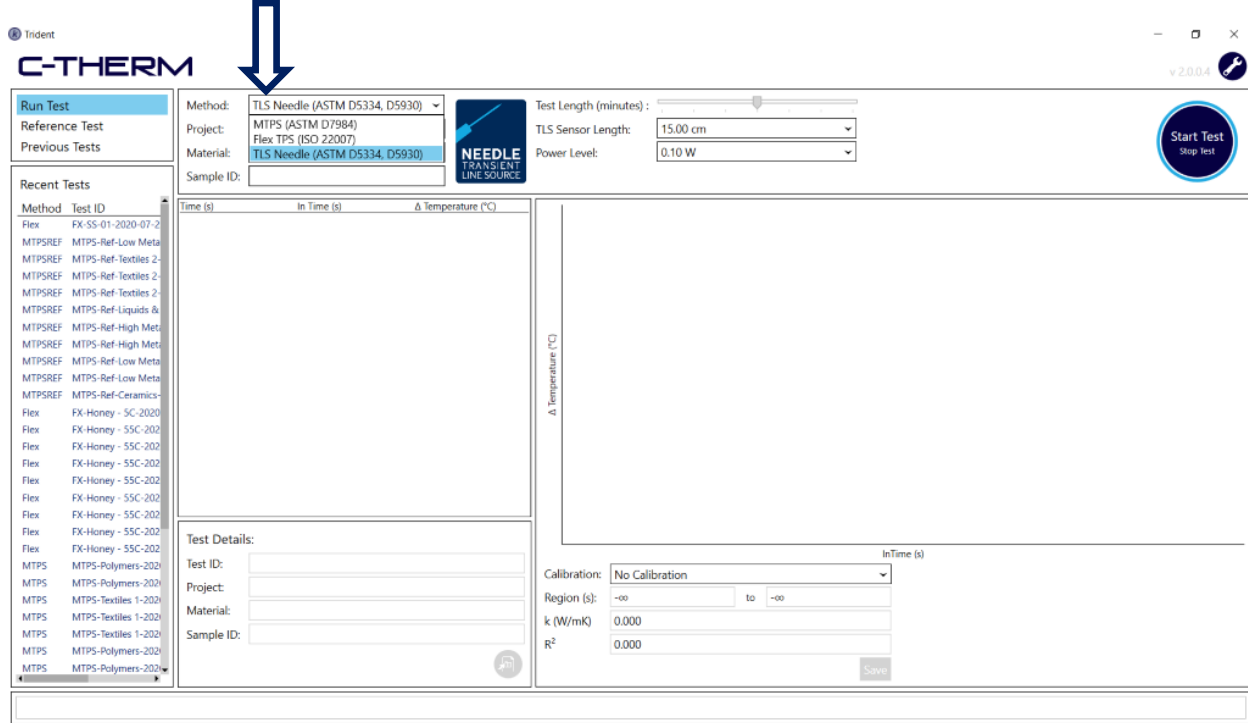
- Exercise care when handling a melt. **Be aware that the latent heat of phase change of a melt is typically several orders of magnitude larger than its contained sensible heat, and that melts often solidify on contact with cooler material making them difficult to remove without significant injury to underlying tissue. Severe burns may therefore occur if care is not exercised in handling melts.** It is the user's responsibility to ensure that sufficient safety precautions have been taken to mitigate or eliminate the burn hazard of a hot melt material and to ensure that sufficient first-responder training for hot-melt burns has been given to the laboratory's designated first aider in the event of a burn.



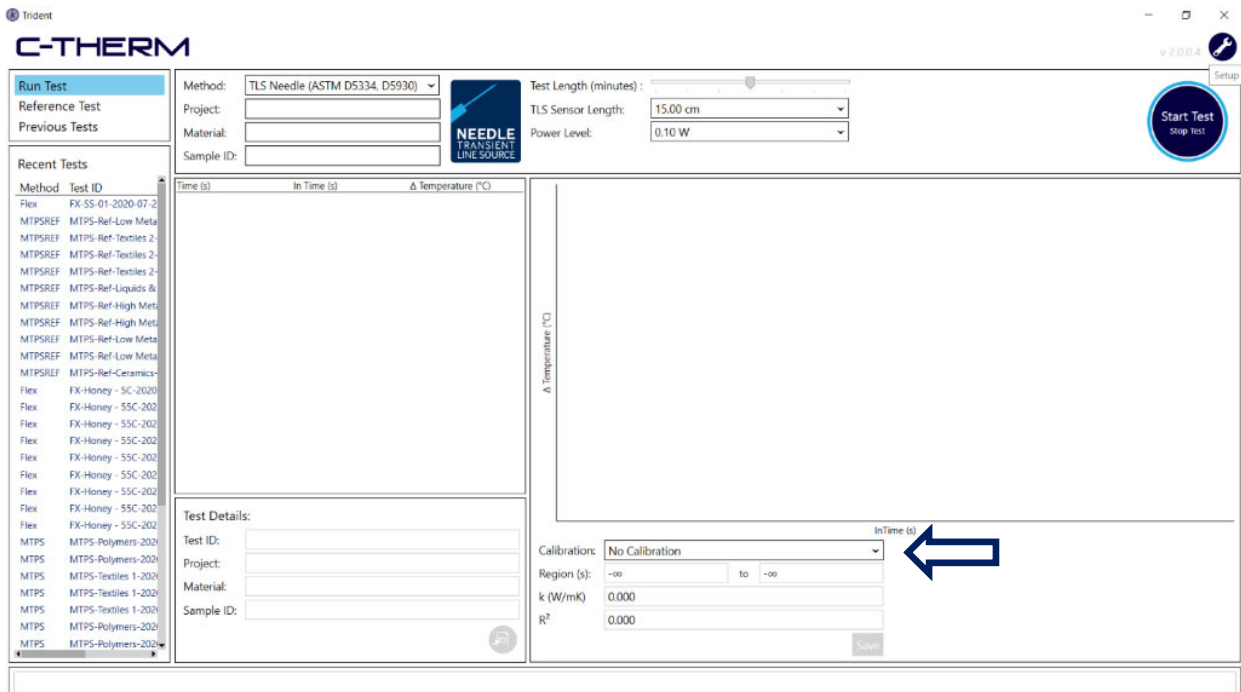
- **Caution: Samples will tend to adhere strongly to the sensor upon re-solidification from a melt. In the case of hard solids, this adhesion may be strong enough to make it very difficult to remove the sensor without risking damage to the sensor. It is therefore recommended to remove the sensor while the sample is molten. It may be necessary to re-melt the sample to achieve this.** In the case of thermoset samples, this may not be possible. In such a case, care should be exercised to avoid damage to the sensor in removing it from the sample. Use of a mold release agent to enable easy removal of the sample from the sample holder may be needed.

5.10 Running A Test

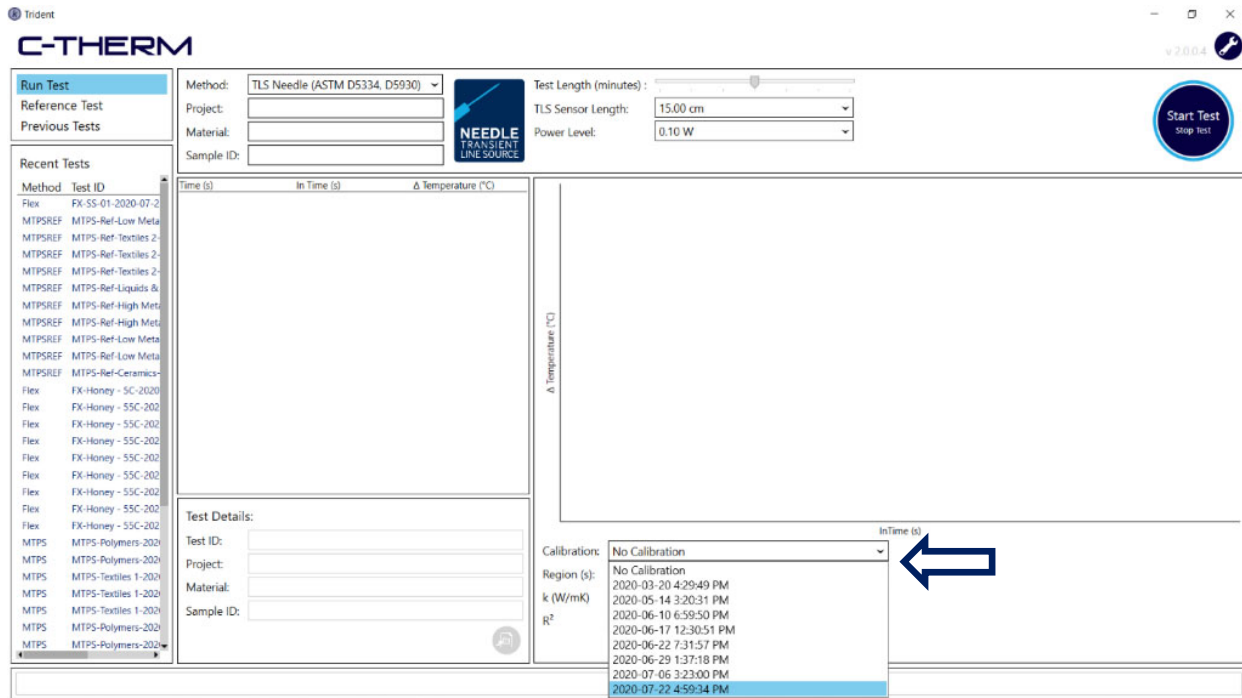
1. Launch the Trident software and select Run Test. Select the Method “TLS Needle”.



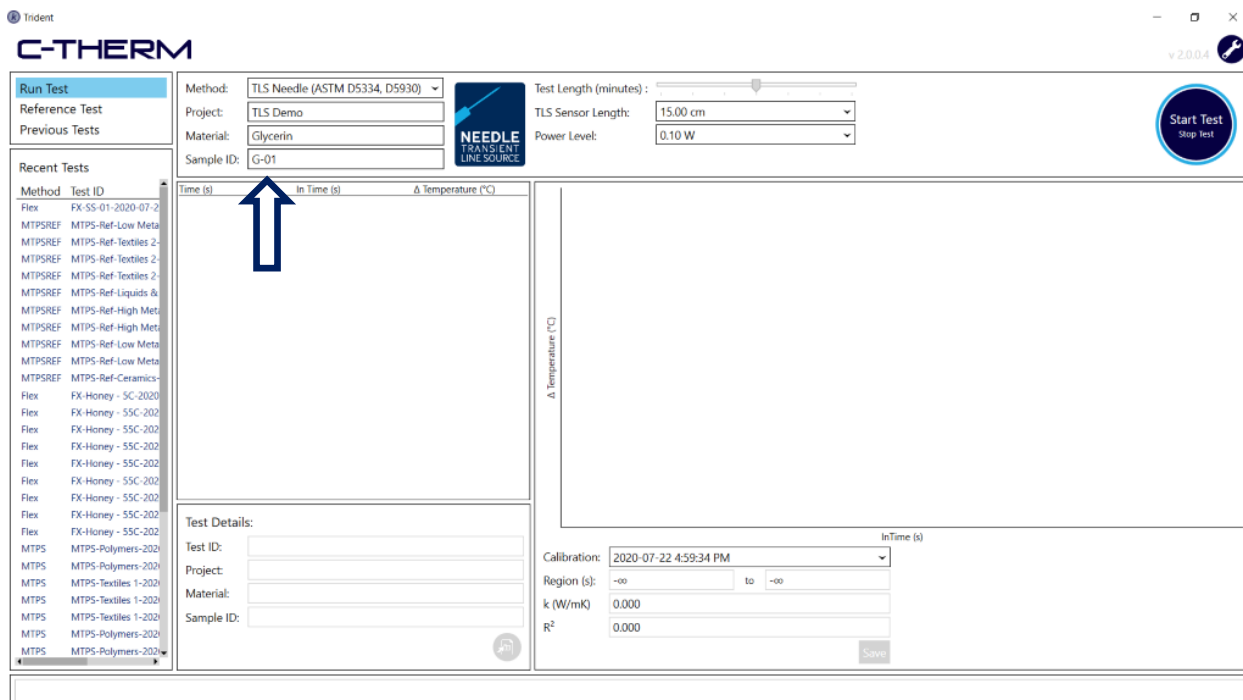
2. Please note, upon opening, the default Calibration is “No Calibration”. Calibration will need to be completed prior to running the first TLS test and repeated at least every 2 years. A monthly check of calibration validity is also recommended. Please see section 5.12 on Sensor Calibration.



3. Choose the most recent calibration from the Calibration dropdown. See Section 5.12 on Calibrating TLS Needle Sensor.

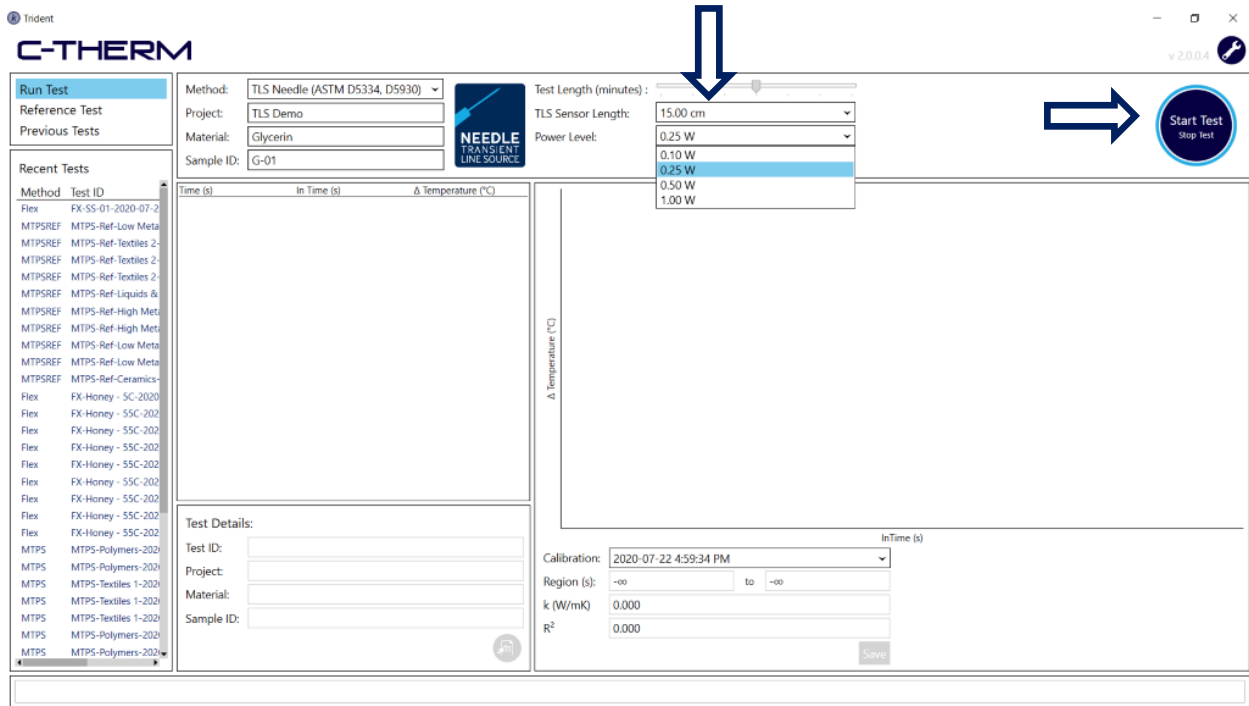


4. Fill in the Project, Material and Sample ID for your test.

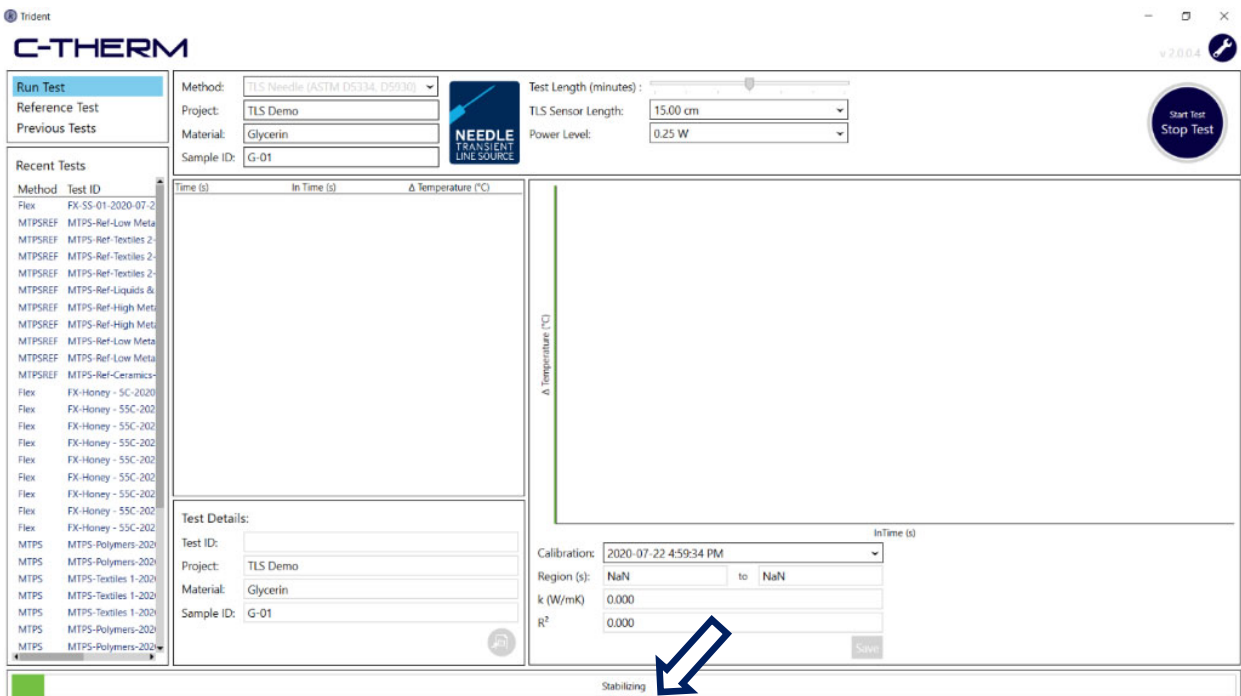




- The test parameters, Time Length and Power Level must be the same as the calibration. (i.e., 3 minutes, 0.25W) Refer to section 5.11.1 for guidance on selecting appropriate parameters for testing.



- Load the sample and click Start Test. The status bar on the bottom will first indicate the test is stabilizing, then acquiring data.



Indent

C-THERM

v 2.0.0.4

Run Test

Reference Test

Previous Tests

Method:

Project:

Material:

Sample ID:

Test Length (minutes):

TLS Sensor Length:

Power Level:

Start Test

Stop Test

Recent Tests

Method	Test ID
Flex	FX-SS-01-2020-07-2
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Liquids &
MTPSREF	MTPS-Ref-High Meta
MTPSREF	MTPS-Ref-High Meta
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Ceramics
Flex	FX-Honey - SC-2020
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
Flex	FX-Honey - SSC-202
MTPS	MTPS-Polymers-202
MTPS	MTPS-Polymers-202
MTPS	MTPS-Textiles 1-202
MTPS	MTPS-Textiles 1-202
MTPS	MTPS-Textiles 1-202
MTPS	MTPS-Polymers-202
MTPS	MTPS-Polymers-202

Test Details:

Test ID:

Project:

Material:

Sample ID:

Calibration:

Region (s): to

k (W/mK):

R²:

Acquiring Data

7. Once the test is complete a summary of the raw data will populate above Test Details and a plot of the data will populate to the right.

Indent

C-THERM

v 2.0.0.4

Run Test

Reference Test

Previous Tests

Method:

Project:

Material:

Sample ID:

Test Length (minutes):

TLS Sensor Length:

Power Level:

Start Test

Stop Test

Recent Tests

Method	Test ID	Time (s)	In Time (s)	Δ Temperature (°C)
TLS	TLS-G-01-2020-07-2	0.046	-3.079	-0.009
Flex	FX-SS-01-2020-07-2	0.092	-2.286	0.003
MTPSREF	MTPS-Ref-Low Meta	0.138	-1.981	0.005
MTPSREF	MTPS-Ref-Textiles 2	0.184	-1.693	0.018
MTPSREF	MTPS-Ref-Textiles 2	0.230	-1.470	0.036
MTPSREF	MTPS-Ref-Textiles 2	0.276	-1.287	0.050
MTPSREF	MTPS-Ref-Textiles 2	0.322	-1.133	0.091
MTPSREF	MTPS-Ref-Liquids &	0.368	-1.000	0.109
MTPSREF	MTPS-Ref-High Meta	0.414	-0.882	0.147
MTPSREF	MTPS-Ref-High Meta	0.460	-0.777	0.174
MTPSREF	MTPS-Ref-High Meta	0.506	-0.681	0.206
MTPSREF	MTPS-Ref-Low Meta	0.552	-0.594	0.244
MTPSREF	MTPS-Ref-Low Meta	0.598	-0.514	0.283
MTPSREF	MTPS-Ref-Low Meta	0.644	-0.440	0.316
MTPSREF	MTPS-Ref-Ceramics	0.690	-0.371	0.343
Flex	FX-Honey - SC-2020	0.736	-0.307	0.386
Flex	FX-Honey - SSC-202	0.782	-0.246	0.412
Flex	FX-Honey - SSC-202	0.828	-0.189	0.440
Flex	FX-Honey - SSC-202	0.874	-0.135	0.474
Flex	FX-Honey - SSC-202	0.920	-0.083	0.506
Flex	FX-Honey - SSC-202	0.966	-0.035	0.534
Flex	FX-Honey - SSC-202	1.012	0.012	0.551

Test Details:

Test ID:

Project:

Material:

Sample ID:

Calibration:

Region (s): to

k (W/mK):

R²:

- Adjust the boundaries of analysis, indicated with green lines, to exclude the initial and end portions where applicable. (R^2 ideally 0.999). See Section 5.1 on optimizing selection of the boundaries and other parameters.

It is important that for any valid measurement the sample, sensor and environment are isothermal. A settling time is programmed automatically into the software and is equal in length to the test time – thus if you program a 4-minute test, there will be a delay of 4 minutes prior to the onset of data collection. The delay serves two purposes: In the case of samples on which more than one test is to be performed, it gives sufficient time for the sample to stabilize in temperature prior to the next test starting, and in the case of single-test samples, it allows time for the sample to settle from any disruption caused by the insertion of the sensor. After the settling time has elapsed, the data will be plotted to a chart as it is collected, in real time.

5.10.1 Guidance on selecting the appropriate parameters for testing

Longer tests collect more data and sample more of the material, but in the case of liquid samples, they also make it more likely that the sample will exhibit convection. Convection will negatively affect the accuracy of the data and quality of the test result, so it is advisable to avoid it. See the table below for guidance on selection of test time.

In testing of thermal conductivity of homogeneous samples (e.g., liquids), a 2.5-minute test time has been found sufficient.

The screenshot shows the C-THERM software interface. On the left, there are navigation tabs: 'Run Test', 'Reference Test', and 'Previous Tests'. Below these is a 'Recent Tests' list with columns for Method, Test ID, Time (s), In Time (s), and Δ Temperature (°C). The main area contains test configuration fields: Method (TLS Needle ASTM D5334, D5930), Project (TLS Demo), Material (Glycerin), Sample ID (G-01), Test Length (minutes), TLS Sensor Length (15.00 cm), and Power Level (0.25 W). A 'Start Test' button is visible. Below the configuration is a 'Test Details' section with fields for Test ID, Project, Material, and Sample ID. To the right is a graph of Δ Temperature (°C) vs. InTime (s) showing a curve that starts at zero, remains flat for a short period, and then rises. Two vertical green lines indicate the selected region for analysis. Below the graph are calibration and region settings: Calibration (2020-07-22 4:59:34 PM), Region (s) (0.610 to 4.456), k (W/mK) (0.292), and R² (0.998). A 'Save' button is at the bottom right.

Method	Test ID	Time (s)	In Time (s)	Δ Temperature (°C)
TLS	TLS-G-01-2020-07-2	0.046	-3.079	-0.009
Flex	FX-SS-01-2020-07-2	0.092	-2.386	0.003
MTPSREF	MTPS-Ref-Low Meta	0.138	-1.981	0.005
MTPSREF	MTPS-Ref-Low Meta	0.184	-1.693	0.018
MTPSREF	MTPS-Ref-Textiles 2	0.230	-1.470	0.036
MTPSREF	MTPS-Ref-Textiles 2	0.276	-1.287	0.050
MTPSREF	MTPS-Ref-Textiles 2	0.322	-1.133	0.091
MTPSREF	MTPS-Ref-Textiles 2	0.368	-1.000	0.109
MTPSREF	MTPS-Ref-Liquids &	0.414	-0.882	0.147
MTPSREF	MTPS-Ref-High Met	0.460	-0.777	0.174
MTPSREF	MTPS-Ref-High Met	0.506	-0.681	0.206
MTPSREF	MTPS-Ref-Low Meta	0.552	-0.594	0.244
MTPSREF	MTPS-Ref-Low Meta	0.598	-0.514	0.283
MTPSREF	MTPS-Ref-Low Meta	0.644	-0.440	0.316
MTPSREF	MTPS-Ref-Ceramics	0.690	-0.371	0.343
Flex	FX-Honey - SC-2020	0.736	-0.307	0.386
Flex	FX-Honey - SSC-202	0.782	-0.246	0.412
Flex	FX-Honey - SSC-202	0.828	-0.189	0.440
Flex	FX-Honey - SSC-202	0.874	-0.135	0.474
Flex	FX-Honey - SSC-202	0.920	-0.083	0.506
Flex	FX-Honey - SSC-202	0.966	-0.035	0.534
Flex	FX-Honey - SSC-202	1.012	0.012	0.551

In testing of heterogeneous samples (e.g., soils), a longer test time may be needed. Be sure that the sensor has been calibrated for use with your desired test time.

The power level should be as low as possible to obtain good data. It is recommended that the user start at the lowest setting and increase the power only as necessary to obtain good data. Higher thermal conductivity materials will require higher power levels to generate a good plot – however, a higher power level can affect the material being tested, e.g., through the generation of convection or by causing local evaporation of water in the case of moist unconsolidated materials. Some trial and error may be necessary to determine the correct power level for a given unknown sample. Some guidance on selection of a power level and test time is given below.

Test Times	Power Levels			
	0.10	0.25	0.50	1.00
2-3 min	Non-viscous fluids	Viscous fluids, most inorganic powders	Conductive powders, most nanofluids	Exceptional Nanofluids
3-4 min	Many biological/organic powders (loam, compost, etc.)	Sands, some soils, most gels, many thermal greases, coarse powders	Polymer melts, some thermal greases	Thermally conductive polymer melts, exceptional thermal greases
5-6 min	Not typically recommended	Topsoil, geological samples	Not typically recommended	Not typically recommended
7+ min	Not typically recommended	Aggregates and other highly heterogeneous samples	Not typically recommended	Not typically recommended

5.11 Data Analysis

5.11.1 Data Validation

1. In the result window, a plot of temperature vs the natural logarithm of time will be displayed. These plots typically have a curved transient region followed by a period where conduction dominates the test results. If the test time is long or the sample is disturbed during the test, the linear region may be followed by a non-linear. Move the boundaries of analysis to be inside the same boundaries of the calibration, excluding the initial and end portions when applicable. Optimize the parameters region selected with a goal of establish the R^2 as close to 0.999 as possible.



2. Click and drag the green bars to select the linear region of the plot. The linear region should start after 1.5 ln s, and should be at least 0.5 ln s in length. Finally, if testing at room temperature, the R^2 value should be >0.998 , and if testing at another temperature, it should be >0.99 . The most accurate data is generally found by maximizing the R^2 . Region boundaries, R^2 , and k as seen above will update automatically. If you find it difficult to get an R^2 value close to 1, try to resolve any sources of sensor disturbance – and if that fails, try increasing the power level.

Caution: If running a calibrated test in compliance with ASTM D5334, it is necessary to select the same time boundaries as used in calibration of the probe.

5.11.2 Error Calculations

The absolute uncertainty of the TLS method is given by:

$$y = 0.03x + 0.02 \frac{W}{mK} \pm 0.02\%/K$$

Where y is the uncertainty of the measurement and x is the measured thermal conductivity. The temperature dependent error is the difference in temperature between the calibration temperature of 20°C and the testing temperature.

For example, if measuring a sample of 0.3 W/mK at 25°C, uncertainty can be calculated according to:

$$y = 0.03 * \left(0.3 \frac{W}{mK}\right) + 0.02 \frac{W}{mK} \pm (0.02\% * 5^{\circ}C)$$

$$y = 0.029 \frac{W}{mK} \pm 0.1\%$$

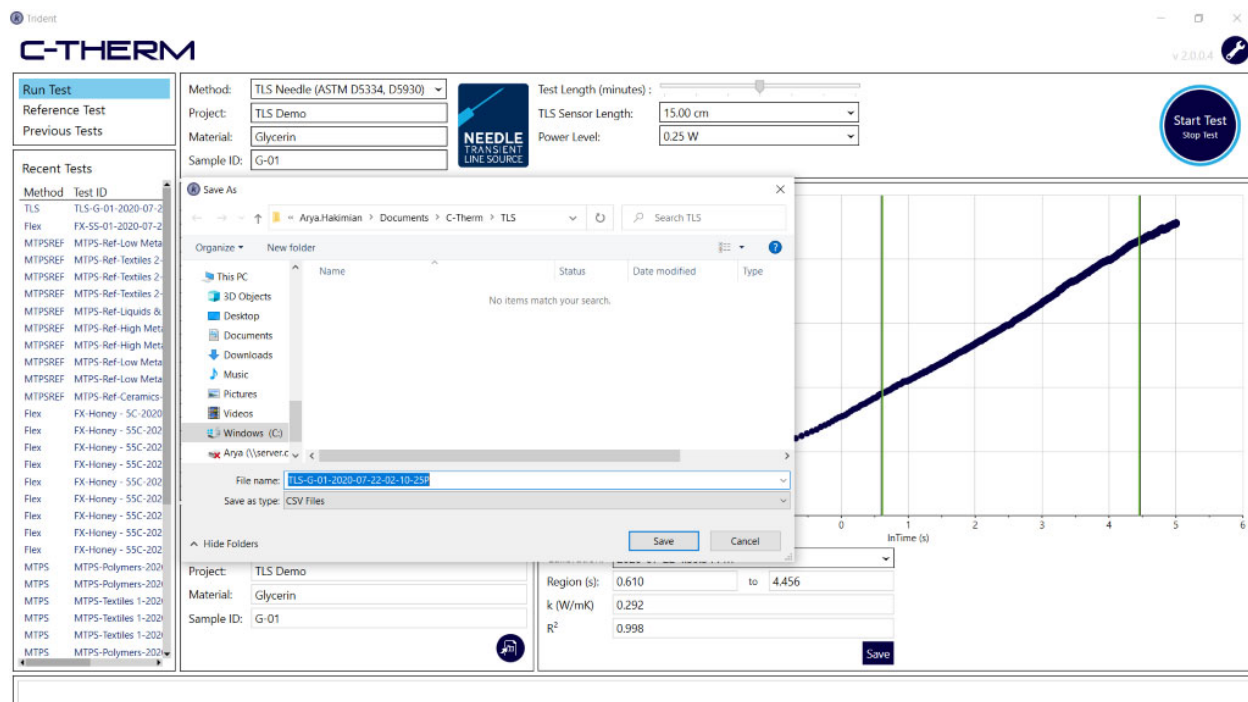
Relative uncertainty can then be determined by dividing the absolute uncertainty by the measured value. In this case, relative uncertainty is approximately 10% of the measured value. If we repeat the calculation for a material with a thermal conductivity of 1 W/mK, the same exercise finds a relative uncertainty of 5%.

5.11.3 Exporting Data

Data can be exported for later analysis. Click the Export icon below the test details to save the file to CSV format.

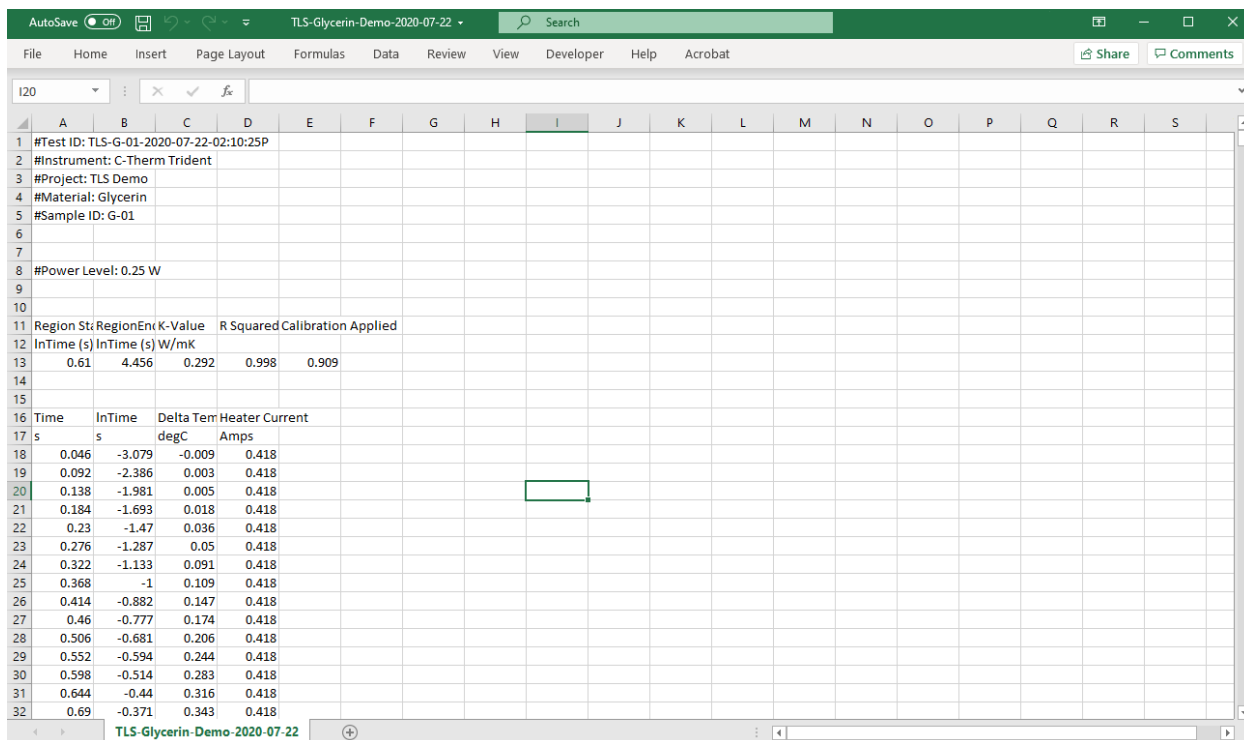


Saved files are located in the “Documents\C-Therm\TLS\” folder. Below is an example of an automatically assigned file name. It is recommended that users rename tests with a naming convention which allows for easy identification of specific tests results in internal records.



The screenshot displays the C-THERM software interface. On the left, there is a sidebar with 'Run Test', 'Reference Test', and 'Previous Tests' buttons, and a 'Recent Tests' list. The main area shows test parameters: Method (TLS Needle (ASTM D5334, D5930)), Project (TLS Demo), Material (Glycerin), Sample ID (G-01), Test Length (minutes) (slider), TLS Sensor Length (15.00 cm), and Power Level (0.25 W). A 'Start Test' button is visible in the top right. A graph on the right shows a curve of InTime (s) vs. InTime (s). A 'Save As' dialog box is open, showing the file path 'Arya.Hakimian > Documents > C-Therm > TLS' and the file name 'TLS-G-01-2020-07-22-02-10-25H'. The 'Save as type' is set to 'CSV Files'. Below the dialog, there are fields for Project (TLS Demo), Material (Glycerin), Sample ID (G-01), Region (s) (0.610 to 4.456), k (W/mK) (0.292), and R² (0.998).

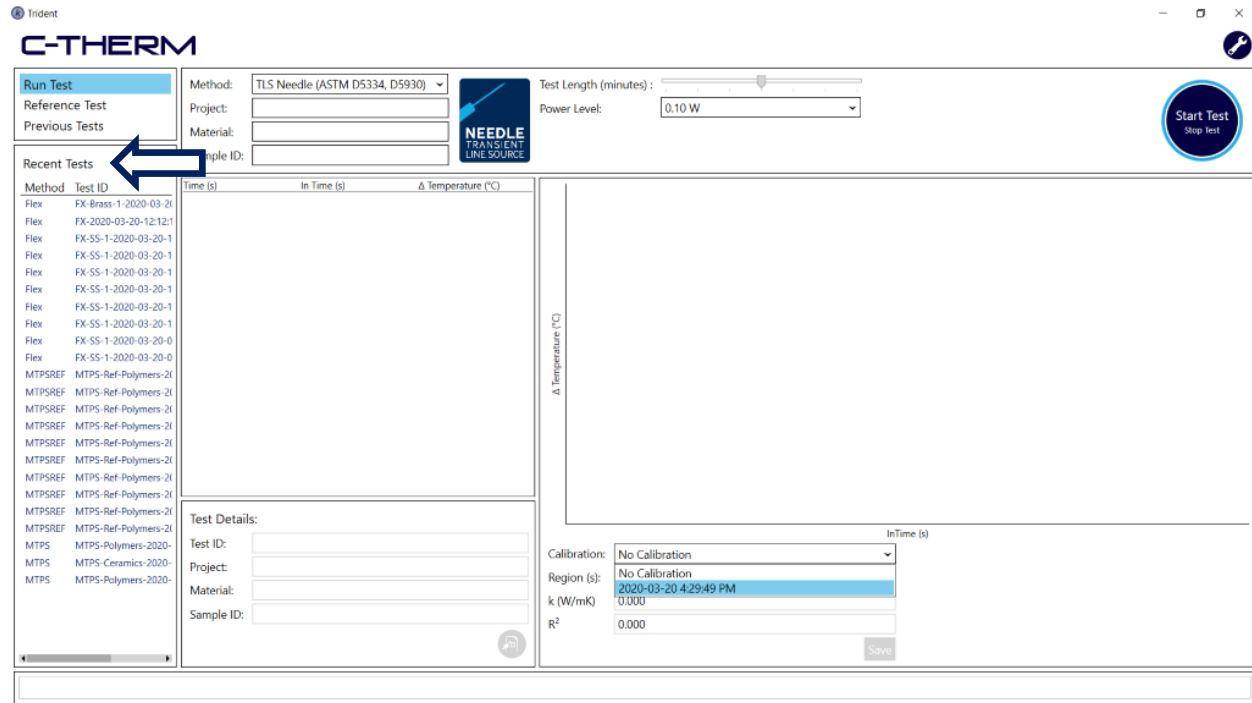
An example of an exported CSV is shown below.



Time	InTime	Delta Tem	Heater Current
s	s	degC	Amps
0.046	-3.079	-0.009	0.418
0.092	-2.386	0.003	0.418
0.138	-1.981	0.005	0.418
0.184	-1.693	0.018	0.418
0.23	-1.47	0.036	0.418
0.276	-1.287	0.05	0.418
0.322	-1.133	0.091	0.418
0.368	-1	0.109	0.418
0.414	-0.882	0.147	0.418
0.46	-0.777	0.174	0.418
0.506	-0.681	0.206	0.418
0.552	-0.594	0.244	0.418
0.598	-0.514	0.283	0.418
0.644	-0.44	0.316	0.418
0.69	-0.371	0.343	0.418

5.11.4 Opening A Previous Test

Recent tests for each method are listed in the sidebar. To open tests not listed, click Previous Tests and an additional list of tests is displayed. Material and test notes are displayed for each test in the list.



5.12 Calibration

For best results with the Transient Line Source method, a calibration is recommended in accordance with ASTM Standard Transient Line Source method. The calibration used for the transient line source is a simple single point calibration which corrects for the effect of the heat capacity and thermal conductivity of the sensor on the measurement. The calibration should be validated prior to use and at least once per month thereafter.

Set up a reference sample of known thermal conductivity. Glycerin is provided with the sensor, however, for tests expected to be longer than 4-5 minutes, it is recommended to instead calibrate with a more viscous reference material, such as 0.4 wt% agar gel or ultrahigh viscosity polydimethylsiloxane. Guidance on some appropriate reference materials is provided in Appendix J.

Ensure that the reference material, TLS sensor, and sample cell have sufficient time (4 to 6 hours) to equilibrate in the stable testing environment prior to beginning the calibration test.

Upon selecting the TLS method, no calibration is loaded. Click the Settings icon, top right, to open the Calibration Manager.

Trident

C-THERM

2.0.0.4

Method: TLS Needle (ASTM D5334, D5930) | Test Length (minutes): [Slider] | TLS Sensor Length: 15.00 cm | Power Level: 0.10 W

Project: [Field] | Material: [Field] | Sample ID: [Field]

Recent Tests

Method	Test ID
Flex	FX-SS-01-2020-07-2
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Textiles 2
MTPSREF	MTPS-Ref-Liquids &
MTPSREF	MTPS-Ref-High Meta
MTPSREF	MTPS-Ref-High Meta
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Low Meta
MTPSREF	MTPS-Ref-Ceramics
Flex	FX-Honey - 5C-2020
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
Flex	FX-Honey - 55C-202
MTPS	MTPS-Polymers-202
MTPS	MTPS-Polymers-202
MTPS	MTPS-Textiles 1-202
MTPS	MTPS-Textiles 1-202
MTPS	MTPS-Textiles 1-202
MTPS	MTPS-Polymers-202
MTPS	MTPS-Polymers-202

Time (s) | In Time (s) | Δ Temperature (°C)

Δ Temperature (°C)

Test ID: [Field] | Project: [Field] | Material: [Field] | Sample ID: [Field]

Calibration: No Calibration | Region (s): -∞ to -∞ | k (W/mK): 0.000 | R²: 0.000

Start Test (Stop Test)

1. Select the TLS Calibration tab.

Trident

C-THERM

v 2.0.0.4

Calibration Manager | **TLS Calibration**

Machine Code: qJ0gBd70FzWp | Copy to Clipboard

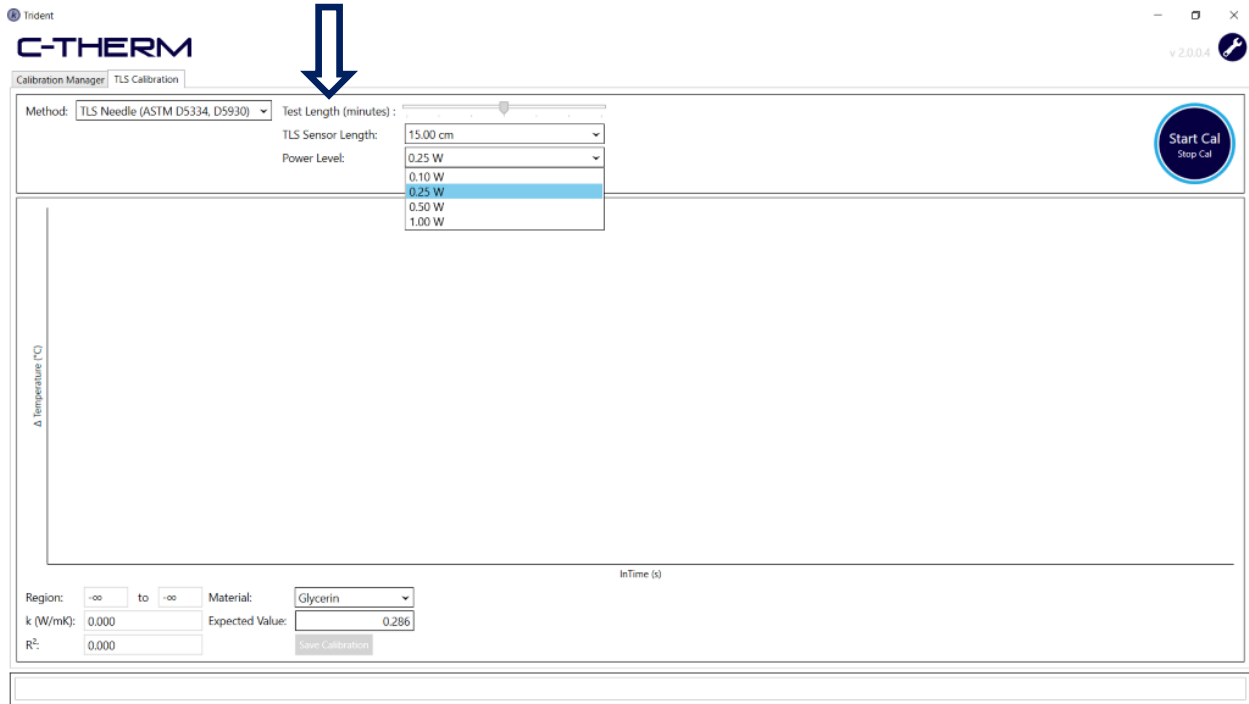
Import Calibration(s) from Clipboard | Import Calibration(s) from File

Customer Name: Demo 2

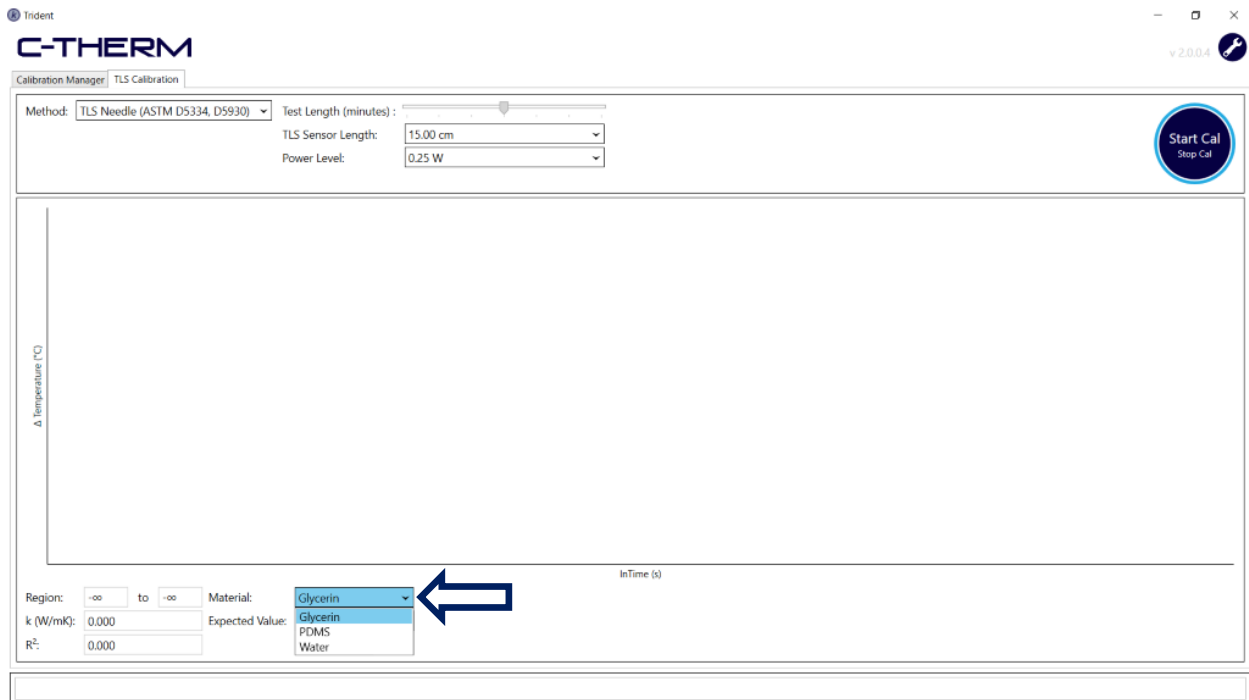
Calibration(s) loaded:

Sensor Type	Sensor Serial	Calibration Name	Calibration Date
TPS	F148	Default	7/17/2020
MTPS	H466	Aerogels	7/17/2020
MTPS	H466	Insulation	7/17/2020
MTPS	H466	Liquids & Powders	7/17/2020
MTPS	H466	Polymers	7/17/2020
MTPS	H466	Ceramics	7/17/2020
MTPS	H466	Low Metals	7/17/2020
MTPS	H466	High Metals	7/17/2020
MTPS	H466	Textiles 1	7/17/2020
MTPS	H466	Textiles 2	7/17/2020
TLS	NP412	Default	7/17/2020

- Select the Desired Parameters. Use the slider to select Test Length, and the dropdown menus to select TLS Sensor Length and Power Level.



- Select the desired reference material from the Material dropdown menu.



- The Expected Value will now be populated. Click Start Cal. The sensor will go through an initial period of stabilization as shown in the status bar at the bottom.

Method: TLS Needle (ASTM D5334, D5930) Test Length (minutes):

TLS Sensor Length: 15.00 cm

Power Level: 0.25 W

Start Cal Stop Cal

Region: NaN to NaN Material: Glycerin

k (W/mK): 0.000 Expected Value: 0.286

R²: 0.000 Save Calibration

Stabilizing

- The status bar will also indicate when the sensor is acquiring data.

Method: TLS Needle (ASTM D5334, D5930) Test Length (minutes):

TLS Sensor Length: 15.00 cm

Power Level: 0.25 W

Start Cal Stop Cal

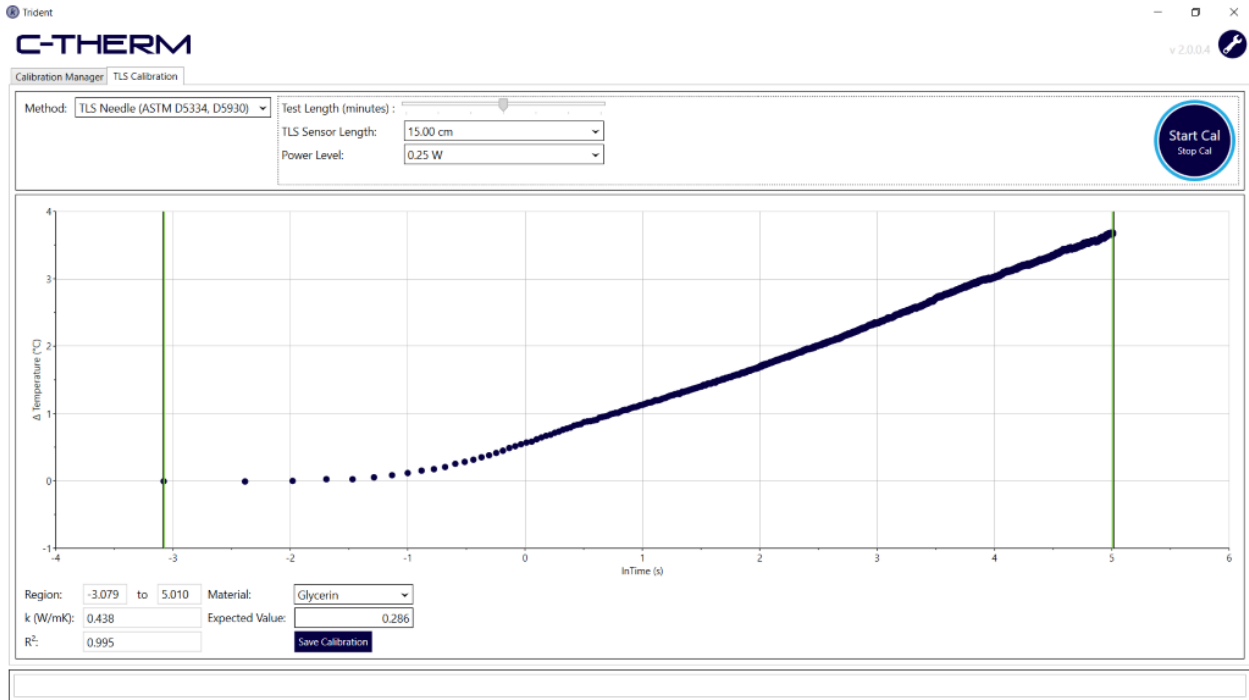
Region: NaN to NaN Material: Glycerin

k (W/mK): 0.000 Expected Value: 0.286

R²: 0.000 Save Calibration

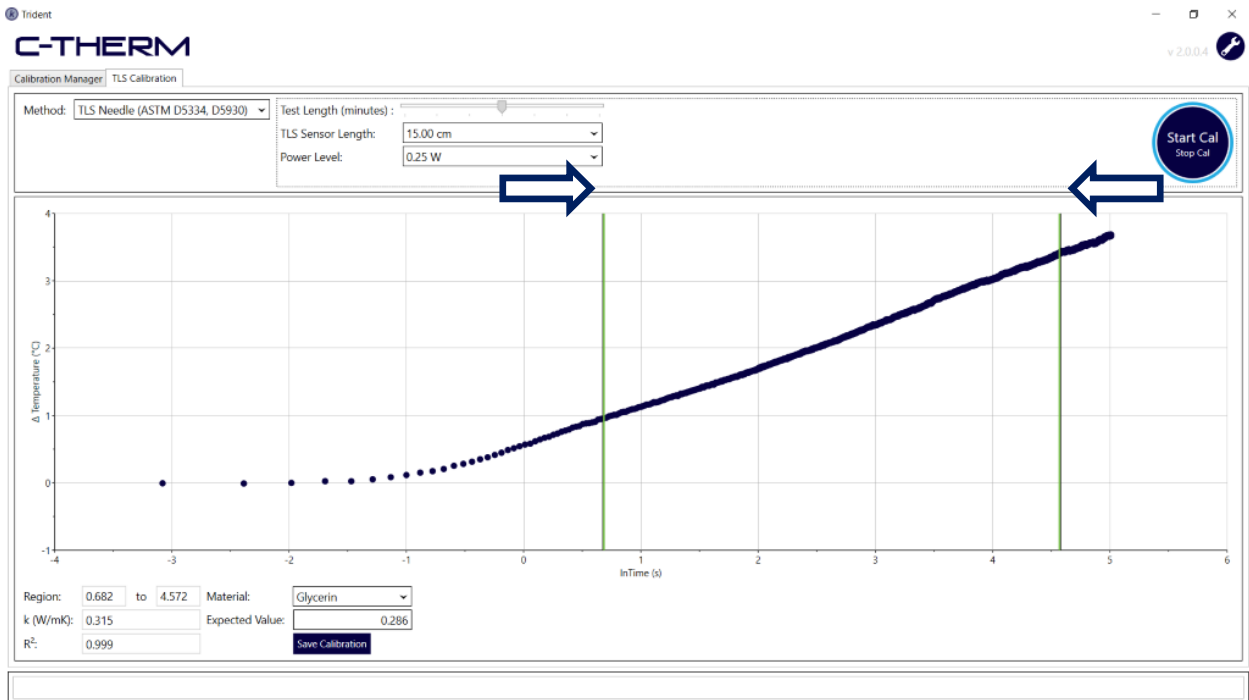
Acquiring Data

6. The data plot will populate as follows once the test is complete.

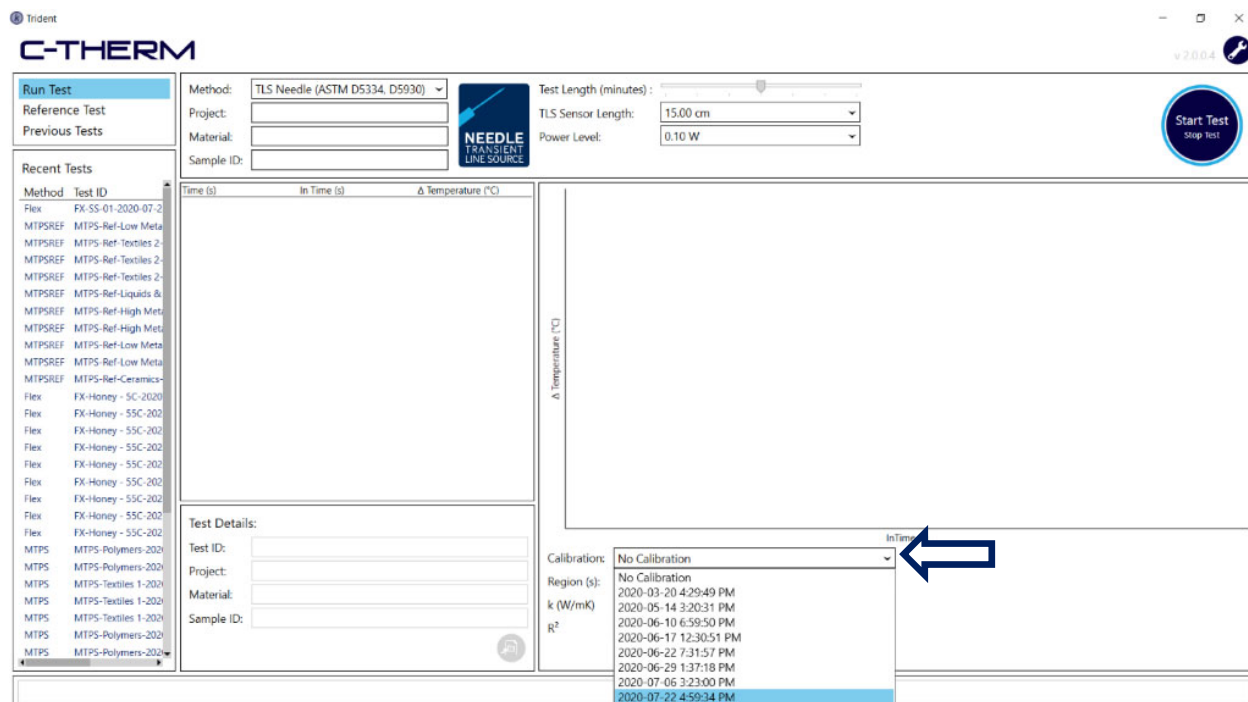


7. Select the linear section by sliding the vertical green bars and click Save Calibration.

Optimize the time boundaries selection iteratively with a goal of establish the R² as close to 0.999 as possible.



- The saved calibration will then be available for selection, along with any previous calibrations.



- Click the Settings icon, top right, to return to the test screen.

5.13 Maintenance

5.13.1 Cleaning Instructions

The sensor must be cleaned regularly and not stored in samples. Ensure that polymer melts are melted again prior to sensor removal to avoid damage. Use a soft cloth or lab wipes to remove residual sample.

The Trident case may be wiped down with a damp cloth but should not be fully immersed.

5.13.2 Storage Instructions

Retain the packaging provided with the Trident system for storage or servicing at C-Therm Technologies. If the Trident system will be unused for any period, it may be stored safely in the original packaging.

Upon completion of testing and/or any cleaning it is strongly recommended to store the sensor in the case provided to avoid any unnecessary damage that may occur. It is also recommended to store the provided reference samples in the provided case to avoid loss or damage.

5.13.3 Replacement Criteria for Consumables

TLS sensors are consumables. The life expectancy is determined by the operating conditions and usage profile. It is the user's responsibility to ensure the materials to be tested will not damage the sensor(s) and appropriate care in handling of the sensor(s) is taken. Applying best practices and monitoring drift from the thermal conductivity value of the provided reference material are the best ways to ensure proper operation of the TLS sensors.

Signs of damage, which may indicate a need for replacement, to the TLS sensor include:

- Bows, bends, or kinks in the needle
- Discolouration
- Torn plastic film
- Wear at the cable connection points
- Wear at the base of the needle

For support & service, please contact support@ctherm.com

APPENDIX A

TRIDENT CONTROLLER SPECIFICATIONS



APPENDIX A

Trident Controller Specifications

Actual range and specifications may be limited by the instrument's purchased modular configuration.

Input Power					
110 to 230 VAC			50 to 60 Hz		
Construction					
Manufactured in ISO 9001 compliant facility			Modular architecture		
Test Methods Available					
Modified Transient Plane Source (MTPS)			Transient Plane Source (TPS)		
Transient Line Source (TLS)			○ Bulk		
Transient Line Source High Temperature (TLS HT300)			○ Anisotropic		
			○ Slab		
Thin Films TPS (TPSTF)			○ High Temperature 300°C or 500°C		
Environmental - Operating					
Temperature: 15°C to 80°C			Relative Humidity: up to 95%, non-condensing		
For best results, power for 1 hour before initiating tests					
Environmental – Non-operating					
Temperature Shock: -50°C to +70°C			Storage: relative humidity up to 95%, non-condensing		
Mechanical Shock: typical transportation					
Standards					
FCC			CE		
CSA†			Calibrated to ISO 17025†		
Reliability					
MTBF ≥ 4000 hours for a typical operation profile			Warranted to be free of defects per terms & conditions		
Automatic initialization tests			Boards are factory calibrated and verified		
Customization					
Method	Available Co-Methods				
	MTPS	TPS	TPSTF	TLS	TLS HT300
MTPS		•	•	○	○
TPS	•		•	○	○
TPSTF	•	•		○	○
TLS	•	•			
TLS HT 300	•	•			

●: available

○: select only one

† special order



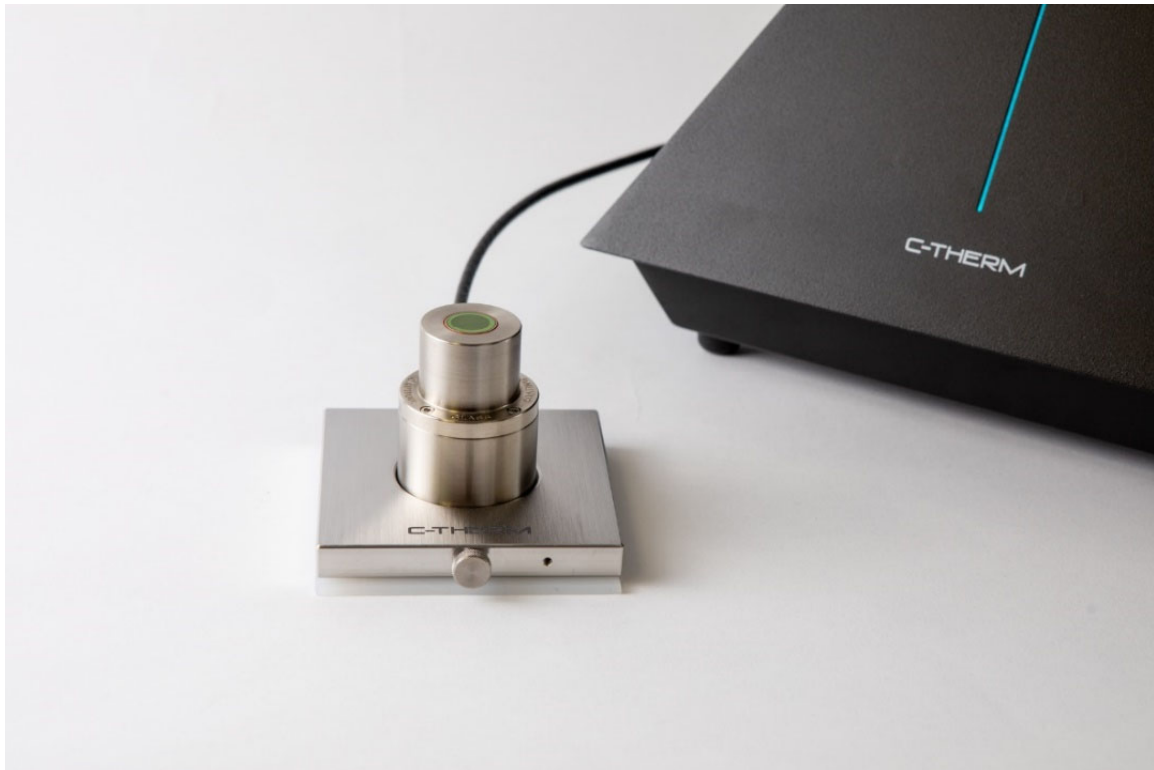
APPENDIX B

MTPS SENSOR SPECIFICATIONS & RECOMMENDED APPLICATIONS

Actual range and specifications may be limited by the instrument's purchased modular configuration.

Applications	
Aerogels	Nanomaterials
Automotive	Metal Hydrides
Batteries	Nuclear
Composites	Phase Change Materials (PCMs)
Insulation	Polymers
Explosives	Rubber
Geological	Thermal Interface Materials
Liquids	(TIMs)
Metals	Thermoelectrics

The ability to extend the sensor capabilities to niche areas of study is easily achieved through various accessories, such as the Air-Hoop®, MTPS Liquids and Powders Test Cell, and Compression Test Accessory.





MTPS Sensor Specifications and Recommended Applications

Sample Specifications	
Minimum Diameter: 18 mm	Maximum sample size: unlimited
Minimum sample thickness: sample dependent	Liquids testing minimum volume: 1.25 mL
Construction	
Stainless steel housing	Chip surface is alumina (96% aluminum oxide) with a thin glass sealing layer (Dupont 5415A)
Sealed against dust and liquids.	
Performance	
Thermal Conductivity: 0 to 500 Wm ⁻¹ K ⁻¹	Testing Time: less than 3 seconds
Thermal Effusivity: 5 to 40,000 Ws ^{1/2} m ⁻² K ⁻¹	Stabilization Time: less than 90 seconds
Precision: typically better than 1% RSD† for non metals, better than 2.5% RSD† for metals	Accuracy: typically better than 5%
Environmental - Operating	
Temperature*: -50°C to 500°C	External vacuum: up to 6 Atm (90 PSIG)
Relative Humidity: up to 95%, non-condensing	
Environmental – Non-operating	
Temperature Shock: -20°C to +30°C	Storage: temperature up to 70°C, relative humidity up to 95%, non-condensing
Mechanical Shock: typical transportation	
Certifications	
ASTM D7984	
Reliability	
MTBF ≥ 5000 hours for a typical operation profile	Warranted to be free of defects per terms & conditions
Safety and Failure Protection	
Surface temperature rise during a test does not exceed 10°C	Maximum voltage potential across sensor surface is 6.5 VDC
Cleaning and Compatibility	
Immune to cleaning agents such as detergents and isopropyl alcohol	Compatible with acidic liquids
Customization	
BC: standard blue sensor chip	WC: white sensor chip, withstands 500°C
RTV: standard sealant, compatible with blue chip	FRV: sealant recommended for fuels and solvents, compatible with blue or white chip
KRZ: high temperature sealant, up to 316°C, compatible with white chip	NSM: sealant-free, up to 500°C, compatible with white chip

* Actual performance depends on configuration purchased. Please contact a C-Therm representative for details.

† Precision is defined as the %RSD of a test of 10 consecutive measurements



APPENDIX C

TPS SENSOR SPECIFICATIONS & RECOMMENDED APPLICATIONS



TPS Sensor Specifications & Recommended Applications

Actual range and specifications may be limited by the instrument's purchased modular configuration.

Applications	
Cement	Polymers
Ceramics	Metals
Specialty utilities available for anisotropic materials, sheet/slab samples and thin films.	



The TPS method employs a double-sided hot disc sensor to simultaneously determine thermal conductivity, thermal diffusivity and specific heat capacity of materials from a single measurement. TPS provides the user the greatest flexibility and control over experimental parameters and avoids the use of any contact agents. Due to legacy reasons some industries are required to measure samples using the ISO 22007-2 method; this TPS sensor is designed to meet the needs of these standards compliant industries.

Unlike the MTPS sensor, the TPS sensor requires operator influence and is recommended for more experienced users. As the determination of the results is iterative, it is the responsibility of the operator to ensure proper procedures are followed. Due to convection effects, this sensor is not recommended for testing liquids.

Add-on modules allow for extended capabilities such as slab and thin film measurements; selection of the slab or thin film modules depends largely on the sample thickness.



TPS Sensor Specifications & Recommended Applications

Sample Specifications					
Requires two identical samples			Minimum sample diameter: 2.5x sensor diameter		
Maximum sample size: unlimited			Minimum sample thickness: sensor diameter		
Construction & Customization					
DU: Nickel encapsulated polyimide sensor, withstands 80°C					
KP: Nickel encapsulated polyimide sensor, withstands 300°C					
MC: Nickel encapsulated Mica sensor, Single use, 400°C to 500°C					
Performance					
Construction	Radius (mm)	Thermal Conductivity ($Wm^{-1}K^{-1}$)		Thermal Diffusivity (m^2s^{-1})	
		Min	Max	Min	Max
DU	6	0.1	20	7.0e-8	6.41e-6
	13	0.05	100	4e-8	2.49e-5
	30	0.005	2000	1.0e-8	1.20e-3
KP	13				
MC	20				
Maximum Heat Capacity: 5 MJ ³ K ⁻¹					
Environmental - Operating					
Temperature: -10°C to 500°C			Relative Humidity: up to 95%, non-condensing		
Standards					
ISO 22007-2			GB/T 32064		
Reliability					
Warranted to be free of defects per terms & conditions					
Safety and Failure Protection					
Maximum voltage potential across sensor surface is 24 VDC			Software-based emergency cut-off when sensor surface temperature increase exceeds 10°C		
Parameter Selection					
Test Power: 0.02 to 10 Watts			Test Time: 2 to 180 seconds		
Common test pre-sets available					
Cleaning and Compatibility					
Refer to materials of construction (above) to determine compatibility and best cleaning practices.					

† Precision is defined as the %RSD of a test of 10 consecutive measurements



APPENDIX D

TLS SENSOR SPECIFICATIONS & RECOMMENDED APPLICATIONS



TLS Sensor Specifications & Recommended Applications

Actual range and specifications may be limited by the instrument's purchased modular configuration.

Applications	
Polymer Melts	Soils
Gels	Semi-solids
Tars	Unconsolidated Solids

Sheathed in stainless steel, the TLS Needle sensor offers maximum robustness in thermal conductivity testing to characterize viscous and granular materials.

The Transient Line Source (TLS) technique operates in accordance with ASTM D5334, D5930 and IEEE Std 442-1981. Commonly referred to as needle probes, TLS sensors provide a robust and efficient solution for measuring the thermal conductivity of granular materials, powders, polymer melts, soils, slurries, gels, and pastes.

This technique involves placing an electrically heated needle into a material. The heat flows out radially from the needle into the sample. During heating, the temperature difference between a thermocouple positioned in the middle of the heating wire, and a second thermocouple located at the tip of the needle is measured. By plotting this temperature difference versus the logarithm of time, thermal conductivity can be calculated.

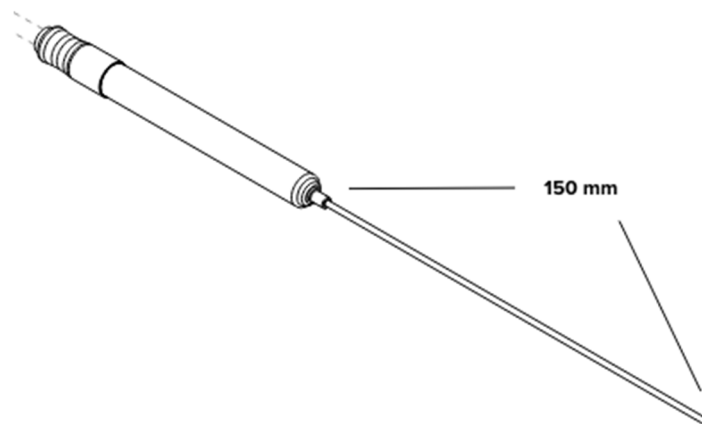





TLS Sensor Specifications & Recommended Applications

Sample Specifications	
Minimum sample volume: 80 mL	Suitable Media: granular materials (< 0.5 mm), powders, soils, gels, pasts, slurries, foodstuff or similar
Sample must be thermally stable during testing	
Construction	
Stainless steel needle and base	Needle and base are rated protection class IP68
Needle rated to 250 °C	Base and cable rated to 180 °C
Performance	
Thermal Conductivity: 0.1 to 6 Wm ⁻¹ K ⁻¹ Wm ⁻¹ K ⁻¹	Testing Time: approximately 2 to 10 minutes
Precision†: typically better than 3%	Accuracy: @20 °C is ±(3% + 0.02) Wm ⁻¹ K ⁻¹
Environmental - Operating	
Temperature: -55°C to 180°C	
Standards	
ASTM D5334-14	ASTM D5930-97
IEEE Std 442-1981	
Reliability	
Warranted to be free of defects per terms & conditions	
Safety and Failure Protection	
Complies with CE directives	
Cleaning and Compatibility	
Immune to cleaning agents such as detergents and isopropyl alcohol	

† Precision is defined as the %RSD of a test of 10 consecutive measurements





APPENDIX E

COMPUTER SPECIFICATIONS

APPENDIX E

Computer Specifications

Minimum Computer Specifications	
HP 255 G7 Notebook PC	
Processor	AMD A-4-9125 Radeon R3 2.30 GHz
Installed RAM	4 Gb RAM
System Type	64-bit Windows 10 OS
Hard Drive	500 GB HDD storage
Screen	15.6" diagonal HD display

Recommended Computer Specifications	
Lenovo V14-ARE 82DQ000PUS 14" Notebook	
Processor	AMD Ryzen 5 4500U Hexa-core (6 Core) 2.30 GHz
Installed RAM	8 Gb RAM
System Type	Windows 10 Pro
Storage Capacity	256 GB SSD
Screen	14" Full HD - 1920 x 1080
AMD Radeon Graphics	
Twisted nematic (TN)	
English Keyboard	



APPENDIX F
SAFETY DATA SHEETS (SDS)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Page 1/12

Printing date 12/13/2021

Reviewed on 12/13/2021

1 Identification

- **Product identifier**
- **Trade name: ArctiClean 1**
- **Relevant identified uses of the substance or mixture and uses advised against**
No further relevant information available
- **Product description** *Cleaning product*
- **Details of the supplier of the safety data sheet**
- **Manufacturer/Supplier:**
 - Arctic Silver Incorporated
 - 9826 West Legacy Ave.
 - Visalia, CA 93291 USA
 - Voice: 559.740.0912
 - Fax: 559.740.0913
 - infoas@arcticsilver.com*
 - www.arcticsilver.com*
- **Emergency telephone number:**
 - Rocky Mountain Poison Control
 - Toll Free: 877-740-5015
 - Alternate: 303-739-1110

2 Hazard(s) identification**Classification of the substance or mixture**

GHS07

- Skin Irrit. 2 H315 Causes skin irritation.*
- Eye Irrit. 2A H319 Causes serious eye irritation.*
- Skin Sens. 1 H317 May cause an allergic skin reaction.*
- STOT SE 3 H335 May cause respiratory irritation.*
- Flam. Liq. 4 H227 Combustible liquid.*

- **Label elements**
- **GHS label elements**
The product is classified and labeled according to the Globally Harmonized System (GHS).
- **Hazard pictograms**



GHS07

- **Signal word** *Warning*
- **Hazard-determining components of labeling:**
 - d-limonene*
 - Poly(oxy-1,2-ethanediyl), alpha-(4- 4 – 8% nonylphenyl)-omega-hydroxy-, branched*
- **Hazard statements**
 - Combustible liquid.*
 - Causes skin irritation.*
 - Causes serious eye irritation.*
 - May cause an allergic skin reaction.*
 - May cause respiratory irritation.*

(Contd. on page 2)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Reviewed on 12/13/2021

Trade name: ArctiClean 1

Precautionary statements

- Keep away from flames and hot surfaces. – No smoking.
- Avoid breathing dust/fume/gas/mist/vapors/spray
- Use only outdoors or in a well-ventilated area.
- Wear protective gloves / eye protection / face protection.
- Wear protective gloves.
- Wear eye protection / face protection.
- Wash thoroughly after handling.
- Contaminated work clothing must not be allowed out of the workplace.
- If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
- Specific treatment (see supplementary first aid instructions on this Safety Data Sheet).
- IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
- Call a poison center/doctor if you feel unwell.
- Wash contaminated clothing before reuse.
- If skin irritation or rash occurs: Get medical advice/attention.
- If eye irritation persists: Get medical advice/attention.
- In case of fire: Use for extinction: CO2, powder or water spray.
- If on skin: Wash with plenty of water.
- Take off contaminated clothing and wash it before reuse.
- Store locked up.
- Store in a well-ventilated place. Keep container tightly closed.
- Keep cool.
- Dispose of contents/container in accordance with local/regional/national/international regulations.

Unknown acute toxicity:

5 percent of the mixture consists of ingredient(s) of unknown toxicity.

Classification system:

NFPA ratings (scale 0 - 4)



HMIS-ratings (scale 0 - 4)



Hazard(s) not otherwise classified (HNOC): None known

3 Composition/information on ingredients

- Chemical characterization:** Mixtures
- Description:** Mixture of substances listed below with nonhazardous additions.

(Contd. on page 3)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: ArctiClean 1

· Dangerous Components:

CAS: 5989-27-5 RTECS: GW 6360000	d-limonene ⚠ Aquatic Acute 1, H400; Aquatic Chronic 1, H410; ⚠ Skin Irrit. 2, H315; Skin Sens. 1, H317; Flam. Liq. 4, H227	≥85%
CAS: 127087-87-0 RTECS: WZ4750000	Poly(oxy-1,2-ethanediyl), alpha-(4- 4 – 8% nonylphenyl)-omega-hydroxy-, branched ⚠ Eye Dam. 1, H318; ⚠ STOT SE 3, H335	5-10%
CAS: 67784-80-9	Methyl ester, soybean oil ⚠ Acute Tox. 4, H312; Skin Irrit. 2, H315; Eye Irrit. 2A, H319	2-12%

4 First-aid measures

· Description of first aid measures

· After inhalation:

Supply fresh air; consult doctor in case of complaints.
In case of unconsciousness, place patient securely on side position for transportation.

· After skin contact:

Immediately wash with water and soap and rinse thoroughly.
If skin irritation occurs, consult a doctor.

· After eye contact:

Rinse opened eye for at least 15 minutes under running water. If symptoms persist, consult a doctor.

· After swallowing: If swallowed and symptoms occur, consult a doctor.

· Information for doctor:

· Most important symptoms and effects, both acute and delayed

No further relevant information available.

· Indication of any immediate medical attention and special treatment needed

No further relevant information available.

5 Fire-fighting measures

· Extinguishing media

· Suitable extinguishing agents:

CO2, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.

· Special hazards arising from the substance or mixture

Combustible liquid. Vapors can travel to a source of ignition and flash back.
Explosive mixtures may occur at temperatures at or above flashpoint.

· Advice for firefighters

· Protective equipment:

As in any fire, wear self-contained breathing apparatus pressure-demand (NIOSH approved or equivalent), and full protective gear to prevent contact with skin and eyes.

6 Accidental release measures

· Personal precautions, protective equipment and emergency procedures Not required.

· Environmental precautions:

Inform respective authorities in case of seepage into water course or sewage system.

(Contd. on page 4)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: ArctiClean 1

Do not allow to enter sewers/ surface or ground water.

Methods and material for containment and cleaning up:

Absorb with liquid-binding material (ie. sand, diatomite, acid binders, universal binders, sawdust).

Ensure adequate ventilation.

Dispose of the collected material according to regulations.

Reference to other sections

See Section 7 for information on safe handling.

See Section 8 for information on personal protection equipment.

See Section 13 for disposal information.

7 Handling and storage

Handling:

Precautions for safe handling

Ensure good ventilation/exhaustion at the workplace.

Prevent formation of aerosols.

Information about protection against explosions and fires: *Protect from heat.*

Conditions for safe storage, including any incompatibilities

Storage:

Requirements to be met by storerooms and receptacles: *No special requirements.*

Information about storage in one common storage facility: *Not required.*

Further information about storage conditions:

Keep receptacle tightly sealed.

Protect from heat and direct sunlight.

Specific end use(s) *No further relevant information available.*

8 Exposure controls/personal protection

Additional information about design of technical systems: *No further data; see section 7.*

Control parameters

Components with occupational exposure limits:

5989-27-5 d-limonene

TWA Short-term value: 10 mg/m³

Additional information: *The lists that were valid during the creation of this SDS were used as basis.*

Exposure controls

Personal protective equipment:

General protective and hygienic measures:

The usual precautionary measures for handling chemicals should be followed.

Keep away from foodstuffs, beverages and feed.

Immediately remove all soiled and contaminated clothing and wash before reuse.

Wash hands before breaks and at the end of work.

Avoid contact with the eyes and skin.

Breathing equipment: *Not required.*

(Contd. on page 5)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Trade name: ArctiClean 1

· **Protection of hands:**



Protective gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation. Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.

Select glove material based on penetration times, rates of diffusion and degradation.

· **Material of gloves**

The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer. As the product is a preparation of several substances, the resistance of the glove material cannot be calculated in advance and has therefore to be checked prior to the application.

· **Penetration time of glove material**

The exact break-through time has to be determined and observed by the manufacturer of the protective gloves.

· **Eye protection:**



Tightly sealed goggles

9 Physical and chemical properties

· **Information on basic physical and chemical properties**

· **General Information**

· **Appearance:**

Form:

Liquid

Color:

Pale yellow

· **Odor:**

Citrus, reminding of orange peel

· **Odor threshold:**

Not determined.

· **pH-value:**

Not determined.

· **Change in condition**

Melting point/Melting range:

Not determined.

Boiling point/Boiling range:

173 °C (343 °F)

· **Flash point:**

91 °C (196 °F)

· **Flammability (solid, gaseous):**

Not applicable.

· **Ignition temperature:**

255 °C (491 °F)

· **Decomposition temperature:**

Not determined.

· **Auto igniting:**

Product is not self-igniting.

· **Danger of explosion:**

Not determined.

(Contd. on page 6)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Reviewed on 12/13/2021

Trade name: ArctiClean 1

<ul style="list-style-type: none"> · Explosion limits: <li style="padding-left: 20px;">Lower: 0.7 Vol % <li style="padding-left: 20px;">Upper: 6.1 Vol %
<ul style="list-style-type: none"> · Vapor pressure @ 20 °C (68 °F): 2.3 hPa (2 mm Hg)
<ul style="list-style-type: none"> · Density @ 20 °C (68 °F): 0.85 g/cm³ (7.093 lbs/gal) · Relative density Not determined. · Vapor density Not determined. · Evaporation rate Not determined.
<ul style="list-style-type: none"> · Solubility in / Miscibility with Water: Not miscible or difficult to mix.
<ul style="list-style-type: none"> · Partition coefficient (n-octanol/water): Not determined.
<ul style="list-style-type: none"> · Viscosity: <li style="padding-left: 20px;">Dynamic: Not determined. <li style="padding-left: 20px;">Kinematic: Not determined.
<ul style="list-style-type: none"> · Solvent content: <li style="padding-left: 20px;">Organic solvents: 85.0 % <li style="padding-left: 20px;">VOC content: 85.0 % <li style="padding-left: 40px;">722.5 g/l / 6.03 lb/gl · Other information No further relevant information available.

10 Stability and reactivity

- **Reactivity** No further relevant information available.
- **Chemical stability** Stable under normal conditions.
- **Thermal decomposition / conditions to be avoided:** No decomposition if used according to specifications.
- **Possibility of hazardous reactions** No dangerous reactions known.
- **Conditions to avoid** No further relevant information available.
- **Incompatible materials:** Strong oxidizing agents.
- **Hazardous decomposition products:** No dangerous decomposition products known.

11 Toxicological information

- **Information on toxicological effects**
- **Acute toxicity:**

· **LD/LC50 values that are relevant for classification:**

5989-27-5 d-limonene

Oral	LD50	4400 mg/kg (rat) Remarks: Behavioral: Change in motor activity (specific assay). Respiratory disorder Skin and Appendages: Other: Hair
Dermal	LD50	>5000 mg/kg (rabbit)

(Contd. on page 7)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Reviewed on 12/13/2021

Trade name: ArctiClean 1

Inhalative	LC50/96 hours	0.72 mg/l (Pimephales) (OECD Test Guideline 203)
127087-87-0 Poly(oxy-1,2-ethanediyl), alpha-(4- 4 – 8% nonylphenyl)-omega-hydroxy-, branched		
Oral	LD50	16000 mg/kg (rat)
Dermal	LD50	4490 mg/kg (rabbit) (24 hr occluded contact)

- **Primary irritant effect:**
- **on the skin:**
Irritant to skin and mucous membranes.
May cause an allergic skin reaction.
- **on the eye:**
Irritating effect.
Causes serious eye irritation.
- **Sensitization:** Sensitization possible through skin contact.
- **Additional toxicological information:**
The product shows the following dangers according to internally approved calculation methods for preparations:
Irritant
- **Carcinogenic categories**
- **IARC (International Agency for Research on Cancer)**
Group 1 - Carcinogenic to humans
Group 2A - Probably carcinogenic to humans
Group 2B - Possibly carcinogenic to humans
Group 3 - Not classifiable as to its carcinogenicity to humans
Group 4 - Probably not carcinogenic to humans

5989-27-5	d-limonene	3
• NTP (National Toxicology Program)		
None of the ingredients are listed.		
• OSHA-Ca (Occupational Safety & Health Administration)		
None of the ingredients are listed.		

12 Ecological information

- **Toxicity**
- **Aquatic toxicity:**
Avoid release into the environment. Runoff from fire control or dilution water may cause pollution.

5989-27-5 d-limonene	
EC50	0.36 mg/l (daphnia) (OECD Test Guideline 202)

- **Persistence and degradability** No further relevant information available.
- **Behavior in environmental systems:**
- **Bioaccumulative potential** No further relevant information available.
- **Mobility in soil** No further relevant information available.
- **Ecotoxicological effects:**
- **Remark:** Very toxic for fish
- **Additional ecological information:**
- **General notes:**
Do not allow product to reach ground water, water course or sewage system.

(Contd. on page 8)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Trade name: ArctiClean 1

- Danger to drinking water if even small quantities leak into the ground.*
- Also poisonous for fish and plankton in water bodies.*
- Very toxic for aquatic organisms*
- **Results of PBT and vPvB assessment**
- **PBT:** Not applicable.
- **vPvB:** Not applicable.
- **Other adverse effects** No further relevant information available.

13 Disposal considerations

- **Waste treatment methods**
- **Recommendation:**
Must not be disposed of together with household garbage. Do not allow product to reach sewage system.
- **Uncleaned packagings:**
- **Recommendation:** *Disposal must be made according to official regulations.*

14 Transport information

- **UN-Number**
- **DOT, ADR, IMDG, IATA** UN2052
- **UN proper shipping name**
- **DOT** *Dipentene*
- **ADR** *UN2052 Dipentene, ENVIRONMENTALLY HAZARDOUS*
- **IMDG** *DIPENTENE, MARINE POLLUTANT*
- **IATA** *DIPENTENE*
- **Transport hazard class(es)**
- **DOT**
- 
- **Class** *3 Flammable liquids*
- **Label** *3*
- **ADR, IATA**
- 
- **Class** *3 Flammable liquids*

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Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: ArctiClean 1

· Label	3
· IMDG	
	
· Class	3 Flammable liquids
· Label	3
· Packing group	
· DOT, ADR, IMDG, IATA	III
· Environmental hazards:	Not applicable.
· Special precautions for user	Warning: Flammable liquids
· EMS Number:	F-E,S-E
· Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code	Not applicable.
· Transport/Additional information:	
· DOT	
· Quantity limitations	On passenger aircraft/rail: On cargo aircraft only:
· Remarks:	ERG Number: 127
· ADR	
· Excepted quantities (EQ)	Code: E1
· UN "Model Regulation":	UN2052, Dipentene, ENVIRONMENTALLY HAZARDOUS, 3, III

15 Regulatory information

· **Safety, health and environmental regulations/legislation specific for the substance or mixture**
· **Sara**

· **Section 355 (extremely hazardous substances):**

None of the ingredients are listed.

· **Section 313 (Specific toxic chemical listings):**

None of the ingredients are listed.

· **TSCA (Toxic Substances Control Act):**

All ingredients are listed.

· **Proposition 65**

· **Chemicals known to cause cancer:**

None of the ingredients are listed.

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Safety Data Sheet (SDS)

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Trade name: ArctiClean 1

· **Chemicals known to cause reproductive toxicity for females:**

None of the ingredients are listed.

· **Chemicals known to cause reproductive toxicity for males:**

None of the ingredients are listed.

· **Chemicals known to cause developmental toxicity:**

None of the ingredients are listed.

· **Carcinogenic categories**

· **EPA (Environmental Protection Agency)**

None of the ingredients are listed.

· **TLV (Threshold Limit Value established by ACGIH)**

None of the ingredients are listed.

· **NIOSH-Ca (National Institute for Occupational Safety and Health)**

None of the ingredients are listed.

· **GHS label elements**

The product is classified and labeled according to the Globally Harmonized System (GHS).

· **Hazard pictograms**



GHS07

· **Signal word** Warning

· **Hazard-determining components of labeling:**

d-limonene

Poly(oxy-1,2-ethanediyl), alpha-(4- 4 – 8% nonylphenyl)-omega-hydroxy-, branched

· **Hazard statements**

Combustible liquid.

Causes skin irritation.

Causes serious eye irritation.

May cause an allergic skin reaction.

May cause respiratory irritation.

· **Precautionary statements**

Keep away from flames and hot surfaces. – No smoking.

Avoid breathing dust/fume/gas/mist/vapors/spray

Use only outdoors or in a well-ventilated area.

Wear protective gloves / eye protection / face protection.

Wear protective gloves.

Wear eye protection / face protection.

Wash thoroughly after handling.

Contaminated work clothing must not be allowed out of the workplace.

If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

Specific treatment (see supplementary first aid instructions on this Safety Data Sheet).

IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.

Call a poison center/doctor if you feel unwell.

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Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Reviewed on 12/13/2021

Trade name: ArctiClean 1*Wash contaminated clothing before reuse.**If skin irritation or rash occurs: Get medical advice/attention.**If eye irritation persists: Get medical advice/attention.**In case of fire: Use for extinction: CO2, powder or water spray.**If on skin: Wash with plenty of water.**Take off contaminated clothing and wash it before reuse.**Store locked up.**Store in a well-ventilated place. Keep container tightly closed.**Keep cool.**Dispose of contents/container in accordance with local/regional/national/international regulations.***• National regulations:***The product is subject to be labeled according with the prevailing version of the regulations on hazardous substances.***• State Right to Know**

CAS: 5989-27-5 RTECS: GW 6360000	d-limonene ⚠ Aquatic Acute 1, H400; Aquatic Chronic 1, H410; ⚠ Skin Irrit. 2, H315; Skin Sens. 1, H317; Flam. Liq. 4, H227	≥85%
CAS: 127087-87-0 RTECS: WZ4750000	Poly(oxy-1,2-ethanediyl), alpha-(4- 4 – 8% nonylphenyl)-omega-hydroxy-, branched ⚠ Eye Dam. 1, H318; ⚠ STOT SE 3, H335	5-10%
CAS: 67784-80-9	Methyl ester, soybean oil ⚠ Acute Tox. 4, H312; Skin Irrit. 2, H315; Eye Irrit. 2A, H319	2-12%

All ingredients are listed.

• Chemical safety assessment: A Chemical Safety Assessment has not been carried out.**16 Other information**

The information and recommendations in this safety data sheet are, to the best of our knowledge, accurate as of the date of issue. Nothing herein shall be deemed to create warranty, expressed or implied and shall not establish a legally valid contractual relationship. It is the responsibility of the user to determine applicability of this information and the suitability of the material or product for any particular purpose.

• Date of preparation / last revision 12/13/2021 / 2**• Abbreviations and acronyms:**

ADR: The European Agreement concerning the International Carriage of Dangerous Goods by Road

ADN: The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways

IMDG: International Maritime Code for Dangerous Goods

DOT: US Department of Transportation

IATA: International Air Transport Association

ACGIH: American Conference of Governmental Industrial Hygienists

EINECS: European Inventory of Existing Commercial Chemical Substances

ELINCS: European List of Notified Chemical Substances

CAS: Chemical Abstracts Service (division of the American Chemical Society)

NFPA: National Fire Protection Association (USA)

HMIS: Hazardous Materials Identification System (USA)

VOC: Volatile Organic Compounds (USA, EU)

LC50: Lethal concentration, 50 percent

LD50: Lethal dose, 50 percent

Flam. Liq. 4: Flammable liquids, Hazard Category 4

Acute Tox. 4: Acute toxicity, Hazard Category 4

Skin Irrit. 2: Skin corrosion/irritation, Hazard Category 2

Eye Dam. 1: Serious eye damage/eye irritation, Hazard Category 1

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Reviewed on 12/13/2021

Trade name: ArctiClean 1

Eye Irrit. 2A: Serious eye damage/eye irritation, Hazard Category 2A
Skin Sens. 1: Sensitization - Skin, Hazard Category 1
STOT SE 3: Specific target organ toxicity - Single exposure, Hazard Category 3 Aquatic
Acute 1: Hazardous to the aquatic environment - Acute Hazard, Category 1 Aquatic
Chronic 1: Hazardous to the aquatic environment - Chronic Hazard, Category 1
• *** Data compared to the previous version altered.**

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Page 1/9

Printing date 12/13/2021

Reviewed on 12/13/2021

1 Identification

- **Product identifier**
- **Trade name:** ArctiClean 2
- **Relevant identified uses of the substance or mixture and uses advised against**
Product description: Surface cleaner-purifier
- **Details of the supplier of the safety data sheet**
- **Manufacturer/Supplier:**
- **Arctic Silver Incorporated**
9826 West Legacy Ave.
Visalia, CA 93291 USA
Voice: 559.740.0912 Fax: 559.740.0913
infoas@arcticsilver.com
www.arcticsilver.com
- **Emergency telephone number:**
Rocky Mountain Poison Control
Toll Free: 877-740-5015
Alternate: 303-739-1110

2 Hazard(s) identification

- **Classification of the substance or mixture**



Skin Irrit. 2 H315 Causes skin irritation.

Eye Irrit. 2B H320 Causes eye irritation.

- **Label elements**
- **GHS label elements**
The product is classified and labeled according to the Globally Harmonized System (GHS).
- **Hazard pictograms**



- **Signal word** Warning
- **Hazard statements**
Causes skin and eye irritation.
- **Precautionary statements**
Wear protective gloves.
Wash thoroughly after handling.
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Specific treatment (see supplementary first aid instructions on this Safety Data Sheet).
If skin irritation occurs: Get medical advice/attention.
If eye irritation persists: Get medical advice/attention.
If on skin: Wash with plenty of water.
Take off contaminated clothing and wash it before reuse.
- **Unknown acute toxicity:**
10 percent of the mixture consists of ingredient(s) of unknown toxicity.
- **Classification system:** NFPA/HMIS Definitions: 0-Least, 1-Slight, 2-Moderate, 3-High, 4-Extreme
(Contd. on page 2)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

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Reviewed on 12/13/2021

Trade name: Arctic Clean 2

· **NFPA ratings (scale 0 - 4)**



Health = 1
Fire = 0
Reactivity = 0

· **HMIS-ratings (scale 0 - 4)**



Health = 1
Fire = 0
Reactivity = 0

· **Hazard(s) not otherwise classified (HNOC):** None known

3 Composition/information on ingredients

CAS: 7732-18-5 RTECS: ZC 0110000	Water, de-ionized	94-97%
-------------------------------------	-------------------	--------

· **Chemical characterization: Mixtures**

· **Description:** Mixture of substances listed below with nonhazardous additions.

· **Dangerous Components:**

CAS: 9016-45-9	Nonylphenoxy poly(ethyleneoxy)ethanol ⚠ Acute Tox. 4, H302; Skin Irrit. 2, H315; STOT SE 3, H335; Eye Irrit. 2B, H320	1-3%
CAS: 34590-94-8 RTECS: JM 1575000	(2-methoxymethylethoxy)propanol Flam. Liq. 4, H227	1-3%

4 First-aid measures

· **Description of first aid measures**

· **General information:**

Symptoms of poisoning may even occur after several hours; therefore medical observation for at least 48 hours after the accident.

· **After inhalation:**

Consult a doctor for complaints.

In case of unconsciousness, place patient securely on side position for transportation.

· **After skin contact:**

Immediately wash with water and soap and rinse thoroughly.

If skin irritation occurs, consult a doctor.

· **After eye contact:**

Rinse opened eye for several minutes under running water. If symptoms persist, consult a doctor.

· **After swallowing:** Immediately call a doctor.

· **Information for doctor:**

· **Most important symptoms and effects, both acute and delayed**

No further relevant information available.

(Contd. on page 3)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

· **Indication of any immediate medical attention and special treatment needed**

No further relevant information available.

5 Fire-fighting measures

- **Extinguishing media**
- **Suitable extinguishing agents:**
CO₂, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
- **Special hazards arising from the substance or mixture** No further relevant information available.
- **Advice for firefighters**
- **Protective equipment:** No special measures required.

6 Accidental release measures

- **Personal precautions, protective equipment and emergency procedures** Not required.
- **Environmental precautions:**
Do not allow product to reach sewage system or any water course.
Inform respective authorities in case of seepage into water course or sewage system.
Dilute with plenty of water.
Do not allow to enter sewers/ surface or ground water.
- **Methods and material for containment and cleaning up:**
Absorb with liquid-binding material (ie. sand, diatomite, acid binders, universal binders, sawdust).
Dispose contaminated material as waste according to section 13.
Ensure adequate ventilation.
- **Reference to other sections**
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.

7 Handling and storage

- **Handling:**
- **Precautions for safe handling**
Ensure good ventilation/exhaustion at the workplace.
Prevent formation of aerosols.
- **Information about protection against explosions and fires:** No special measures required.
- **Conditions for safe storage, including any incompatibilities**
- **Storage:**
- **Requirements to be met by storerooms and receptacles:** No special requirements.
- **Information about storage in one common storage facility:** Not required.
- **Further information about storage conditions:** Keep receptacle tightly sealed.
- **Specific end use(s)** No further relevant information available.

8 Exposure controls/personal protection

- **Additional information about design of technical systems:** No further data; see section 7.

(Contd. on page 4)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

• **Control parameters**

• **Components with occupational exposure limits:**

34590-94-8 (2-methoxymethylethoxy)propanol

PEL Long-term value: 600 mg/m³, 100 ppm
Skin

REL Short-term value: 900 mg/m³, 150 ppm
Long-term value: 600 mg/m³, 100 ppm
Skin

TLV Short-term value: 909 mg/m³, 150 ppm
Long-term value: 606 mg/m³, 100 ppm
Skin

• **Additional information:** The lists that were valid during the creation of this SDS were used as basis.

• **Exposure controls**

• **Personal protective equipment:**

• **General protective and hygienic measures:**

Keep away from foodstuffs, beverages and feed.

Immediately remove all soiled and contaminated clothing and wash before reuse.

Wash hands before breaks and at the end of work.

Avoid contact with the eyes and skin.

• **Breathing equipment:** Not required.

• **Protection of hands:**



Protective gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation. Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.

Select glove material based on penetration times, rates of diffusion and degradation.

• **Material of gloves**

The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer. As the product is a preparation of several substances, the resistance of the glove material cannot be calculated in advance and has therefore to be checked prior to the application.

• **Penetration time of glove material**

The exact break-through time has to be determined and observed by the manufacturer of the protective gloves.

• **Eye protection:**



Tightly sealed goggles

(Contd. on page 5)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

9 Physical and chemical properties

· **Information on basic physical and chemical properties**

· **General Information**

· **Appearance:**

Form: Liquid
Color: Colorless

· **Odor:** Mild

· **Odor threshold:** Not determined.

· **pH-value @ 20 °C (68 °F):** 7.5

· **Change in condition**

Melting point/Melting range: --

Boiling point/Boiling range: > 34 °C (> 93 °F)

· **Flash point:** Not applicable.

· **Flammability (solid, gaseous):** Not applicable.

· **Ignition temperature:** 270 °C (518 °F)

· **Decomposition temperature:** Not determined.

· **Auto igniting:** Product is not self-igniting.

· **Danger of explosion:** Product does not present an explosion hazard.

· **Explosion limits:**

Lower: 0.0 Vol %

Upper: 0.0 Vol %

· **Vapor pressure @ 20 °C (68 °F):** 23 hPa (17 mm Hg)

· **Density @ 20 °C (68 °F):** 1.01 g/cm³ (8.21 lbs/gal)

· **Relative density** Not determined.

· **Vapor density** Not determined.

· **Evaporation rate** Not determined.

· **Solubility in / Miscibility with**

Water: Fully miscible.

· **Partition coefficient (n-octanol/water):** Not determined.

· **Viscosity:**

Dynamic @ 20 °C (68 °F): 1 mPas

Kinematic: Not determined.

· **Solvent content:**

Organic solvents: 2-5 %

Water: 94-97 %

VOC content: <2 %

· **Solids content:** <1 %

· **Other information** No further relevant information available.

(Contd. on page 6)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

10 Stability and reactivity

- **Reactivity** No further relevant information available.
- **Chemical stability**
- **Thermal decomposition / conditions to be avoided:**
No decomposition if used according to specifications.
- **Possibility of hazardous reactions** No dangerous reactions known.
- **Conditions to avoid** No further relevant information available.
- **Incompatible materials:** No further relevant information available.
- **Hazardous decomposition products:** No dangerous decomposition products known.

11 Toxicological information

- **Information on toxicological effects**
- **Acute toxicity:**
- **Primary irritant effect:**
- **on the skin:** Irritant to skin and mucous membranes.
- **on the eye:** Irritating effect.
- **Additional toxicological information:**
The product shows the following dangers according to internally approved calculation methods for preparations:
Harmful
Irritant

- **Carcinogenic categories**

- **IARC (International Agency for Research on Cancer)**

Substance is not listed.

- **NTP (National Toxicology Program)**

None of the ingredients are listed.

- **OSHA-Ca (Occupational Safety & Health Administration)**

None of the ingredients are listed.

12 Ecological information

- **Toxicity**

- **Aquatic toxicity:**

9016-45-9 Nonylphenoxypoly(ethyleneoxy)ethanol

EC50 12.2 mg/kg (daphnia) (48 hours)

- **Persistence and degradability** No further relevant information available.
- **Behavior in environmental systems:**
- **Bioaccumulative potential** No further relevant information available.
- **Mobility in soil** No further relevant information available.
- **Ecotoxicological effects:**
- **Remark:** Harmful to fish

(Contd. on page 7)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

- **Additional ecological information:**
- **General notes:**
Do not allow undiluted product or product that has not been neutralized to reach ground water, water course or sewage system.
Harmful to aquatic organisms
- **Results of PBT and vPvB assessment**
- **PBT:** Not applicable.
- **vPvB:** Not applicable.
- **Other adverse effects** No further relevant information available.

13 Disposal considerations

- **Waste treatment methods**
- **Recommendation:**
Must not be disposed of together with household garbage. Do not allow product to reach sewage system.
- **Uncleaned packagings:**
- **Recommendation:** Disposal must be made according to official regulations.
- **Recommended cleansing agent:** Water, if necessary with cleansing agents.

14 Transport information

- | | |
|---|--|
| · UN-Number
· DOT, ADR, ADN, IMDG, IATA | Non-Regulated Material |
| · UN proper shipping name
· DOT, ADR, ADN, IMDG, IATA | Not Regulated for Transportation
Non-Regulated Material |
| · Transport hazard class(es)
· DOT, ADR, ADN, IMDG, IATA
· Class | Non-Regulated Material |
| · Packing group
· DOT, ADR, IMDG, IATA | Non-Regulated Material |
| · Environmental hazards: | Not applicable. |
| · Special precautions for user | Not applicable. |
| · Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code | Not applicable. |
| · UN "Model Regulation": | - |

(Contd. on page 8)

Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

15 Regulatory information

- **Safety, health and environmental regulations/legislation specific for the substance or mixture**
- **Sara**

- **Section 355 (extremely hazardous substances):**

None of the ingredients are listed.

- **Section 313 (Specific toxic chemical listings):**

None of the ingredients are listed.

- **TSCA (Toxic Substances Control Act):**

All ingredients are listed.

- **Proposition 65**

- **Chemicals known to cause cancer:**

None of the ingredients are listed.

- **Chemicals known to cause reproductive toxicity for females:**

None of the ingredients are listed.

- **Chemicals known to cause reproductive toxicity for males:**

None of the ingredients are listed.

- **Chemicals known to cause developmental toxicity:**

None of the ingredients are listed.

- **Carcinogenic categories**

- **EPA (Environmental Protection Agency)**

None of the ingredients are listed.

- **TLV (Threshold Limit Value established by ACGIH)**

None of the ingredients are listed.

- **NIOSH-Ca (National Institute for Occupational Safety and Health)**

None of the ingredients are listed.

- **GHS label elements**

The product is classified and labeled according to the Globally Harmonized System (GHS).

- **Hazard pictograms**



GHS07

- **Signal word** Warning

- **Hazard statements**

Causes skin and eye irritation.

- **Precautionary statements**

Wear protective gloves.

Wash thoroughly after handling.

If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

Specific treatment (see supplementary first aid instructions on this Safety Data Sheet).

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Safety Data Sheet (SDS)

OSHA HazCom Standard 29 CFR 1910.1200(g) and GHS Rev 03.

Printing date 12/13/2021

Reviewed on 12/13/2021

Trade name: Arctic Clean 2

If skin irritation occurs: Get medical advice/attention.
 If eye irritation persists: Get medical advice/attention.
 If on skin: Wash with plenty of water.
 Take off contaminated clothing and wash it before reuse.

• National regulations:

The product is subject to be labeled according with the prevailing version of the regulations on hazardous substances.

• State Right to Know

CAS: 9016-45-9	Nonylphenoxypoly(ethyleneoxy)ethanol ⚠ Acute Tox. 4, H302; Skin Irrit. 2, H315; STOT SE 3, H335; Eye Irrit. 2B, H320	1-3%
CAS: 34590-94-8 RTECS: JM 1575000	(2-methoxymethylethoxy)propanol Flam. Liq. 4, H227	1-3%
CAS: 7732-18-5 RTECS: ZC 0110000	Water, de-ionized	94-97%

All ingredients are listed.

• **Chemical safety assessment:** A Chemical Safety Assessment has not been carried out.

16 Other information

The information and recommendations in this safety data sheet are, to the best of our knowledge, accurate as of the date of issue. Nothing herein shall be deemed to create warranty, expressed or implied and shall not establish a legally valid contractual relationship. It is the responsibility of the user to determine applicability of this information and the suitability of the material or product for any particular purpose.

• **Date of preparation / last revision** 12/13/2021 / 6

• Abbreviations and acronyms:

ADR: The European Agreement concerning the International Carriage of Dangerous Goods by Road
 ADN: The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
 IMDG: International Maritime Code for Dangerous Goods
 DOT: US Department of Transportation
 IATA: International Air Transport Association
 ACGIH: American Conference of Governmental Industrial Hygienists
 EINECS: European Inventory of Existing Commercial Chemical Substances
 ELINCS: European List of Notified Chemical Substances
 CAS: Chemical Abstracts Service (division of the American Chemical Society)
 NFPA: National Fire Protection Association (USA)
 HMIS: Hazardous Materials Identification System (USA)
 VOC: Volatile Organic Compounds (USA, EU)
 Flam. Liq. 4: Flammable liquids, Hazard Category 4
 Acute Tox. 4: Acute toxicity, Hazard Category 4
 Skin Irrit. 2: Skin corrosion/irritation, Hazard Category 2
 Eye Irrit. 2B: Serious eye damage/eye irritation, Hazard Category 2B
 STOT SE 3: Specific target organ toxicity - Single exposure, Hazard Category 3

* **Data compared to the previous version altered.**

SAFETY DATA SHEET: DOWTHERM® SR-1

1. IDENTIFICATION

Product Name: DOWTHERM® SR-1
Synonyms: (Dowtherm® is a registered trademark of the DOW Chemical Company)
Formula and Formula Weight: Mixture NA
Integra numbers beginning with: D918.50
Recommended Use: Commercial/industrial use
Restrictions on Use: No information available

INTEGRA Chemical Company **24 Hour Emergency Response: CHEMTREC 800-424-9300 (Outside USA 703-527-3887)**

1216 6th Ave N
Kent WA 98032
Phone: 253-479-7000

2. HAZARDS IDENTIFICATION

<u>OSHA Classification:</u>	<u>Hazard Category:</u>	<u>Hazard Statement:</u>
Acute Toxicity - Oral	4	Harmful if swallowed.
Eye Damage/Irritation	2A	Causes serious eye irritation.
Toxic to Reproduction	2	Suspected of damaging fertility or the unborn child.
Specific Target Organ Toxicity (single exposure)	1	Causes damage to organs if swallowed.

Signal Word: DANGER



Precautionary Statements

Prevention:

Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
Do not breathe dust, fume, gas, mist, vapors, spray.
Wash thoroughly after handling.
Do not eat, drink or smoke when using this product.
Wear protective gloves, protective clothing, eye protection, face protection.

Response

If swallowed: Call a poison center, doctor if you feel unwell.
If in eyes: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
If exposed: Call a poison center, doctor.
Specific treatment (see first aid section on this label)
Rinse mouth.
If eye irritation persists: Get medical advice, attention.

Storage

Store locked up.

Disposal

Dispose of contents, container in accordance with all governmental regulations.

Hazards Not Otherwise Classified: No information available

3. COMPOSITION/INFORMATION ON INGREDIENTS

<u>Component</u>	<u>Synonyms</u>	<u>CAS #</u>	<u>% Weight</u>
Ethylene glycol	1,2-Ethenediol	00107-21-1	>95
Water		07732-18-5	<3
Potassium phosphate dibasic	Dipotassium hydrogen phosphate; Dipotassium phosphate; DKP; Potassium monophosphate	07758-11-4	<3

4. FIRST AID MEASURES

Inhalation: Remove person to fresh air.
Eye Contact: Flush eyes with plenty of water. Remove contact lenses, if present and easy to do. If irritation persists, seek medical attention.
Skin Contact: Wash with soap and water. Seek medical attention if irritation develops.
Ingestion: Rinse mouth and give victim large quantities of water. Never give anything by mouth to an unconscious person. Seek immediate medical attention.
Additional notes: Symptoms and effects include skin, eye, respiratory irritation, temporary corneal damage; central nervous system effects,

cardiopulmonary effects, kidney failure; nausea, vomiting, abdominal pain, weakness, exhaustion; dizziness, stupor, convulsions skin sensitization.

5. FIRE-FIGHTING MEASURES

Extinguishing Media: Water fog, carbon dioxide, dry chemical, foam.
Special Equipment and Precautions: Use water to cool nearby containers and structures. Wear full protective equipment, including suitable respiratory protection.
Specific Hazards: Fire conditions may liberate toxic and noxious fumes.
Hazardous combustion products: Oxides of carbon.

6. ACCIDENTAL RELEASE MEASURES

Spill Procedures: Prevent spread of spill. Absorb with sand or inert material. Sweep or scoop into a disposal container. Flush spill area with water. Contain runoff. Do not flush to sewer or storm drain.

7. HANDLING AND STORAGE

Incompatible Materials: Incompatible with strong acids, strong bases, strong oxidizers. Silver compounds, oleum.
Storage and Handling: Store locked up in a cool, dry, well-ventilated area away from incompatible materials. Keep containers tightly closed and protect them from physical damage.
Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
Do not breathe dust, fume, gas, mist, vapors, spray.
Wash thoroughly after handling.
Do not eat, drink or smoke when using this product.
Wear protective gloves, protective clothing, eye protection, face protection.

8. EXPOSURE CONTROLS AND PERSONAL PROTECTION

OSHA & ACGIH Exposure Limits:

Ethylene glycol	ACGIH Ceiling: 100 mg/m ³ (aerosol only)
Water	None identified
Potassium phosphate dibasic	None identified

Engineering Controls: Use general or local exhaust ventilation to meet TLV and PEL requirements.

Respiratory Protection: Respiratory protection required if airborne concentrations exceed PEL or TLV. Use a NIOSH approved chemical cartridge respirator with an organic vapor cartridge and an oil-proof particulate filter.

Skin/Eye Protective Equipment: Safety goggles, protective clothing and gloves appropriate for the risk of exposure.
Facilities storing or utilizing this material should have readily accessible eyewash stations and safety showers.
Select respirators and other safety equipment in accordance with regulations and based upon the particular conditions of use and risk of exposure. Always use safe chemical-handling and good industrial hygiene practices.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	Clear, red to pink viscous liquid
Odor:	Not available
Odor Threshold:	Not available
pH:	Not available
Melting/Freezing Point:	Not available
Initial Boiling Point and Boiling Range:	163 °C
Flash Point:	232 °F
Evaporation Rate:	Not available
Flammability:	Not available
Flammable or Explosive	Upper: Not available
Limits (% by volume in air)	Lower: 3.2
Vapor Pressure:	2.2 mm Hg @20°C
Vapor Density:	Not available
Relative Density:	1.13 Water=1
Solubility:	Miscible with water
Partition Coefficient: n-octanol/water	Not available
Auto-Ignition Temperature:	748 °F
Decomposition Temperature:	Not available
Viscosity:	Not available

10. STABILITY AND REACTIVITY

Reactivity: No information available
Stability: Stable
Possibility of Hazardous Reactions: Hazardous polymerization will not occur
Conditions to Avoid: Excessive heat.
Incompatibles: Incompatible with strong acids, strong bases, strong oxidizers. Silver compounds, oleum.
Decomposition Products: Oxides of carbon.

11. TOXICOLOGICAL INFORMATION

Effects of Over Exposure:

Inhalation: Inhalation may irritate the nose, throat and upper respiratory tract. May cause dizziness, stupor, convulsions.
Skin Contact: Essentially non-irritating to skin. Prolonged or repeated exposure to large quantities may result in absorption of harmful amounts. May cause defatting, drying, and cracking of skin, sensitization.
Eye Contact: Contact is irritating to the eyes and may cause temporary corneal damage.
Ingestion: Harmful or fatal if swallowed. May cause nausea, vomiting, abdominal pain, weakness, exhaustion, central nervous system effects, cardiopulmonary effects and kidney failure.
Chronic Effects: Prolonged or repeated overexposure may result in delayed liver and/or kidney damage.
Target Organs: Eyes, skin, respiratory system, liver, kidneys, central nervous system.
Additional Effects: None identified
Reproductive Effects: May damage fertility or the unborn child.
Carcinogenicity: None identified

Toxicity Data:

Ethylene glycol	LD50 (skin, rabbit)	9530 mg/kg
Water	No information available	
Potassium phosphate dibasic	No information available	

12. ECOLOGICAL INFORMATION

	<u>Aquatic Toxicity Data:</u>	<u>Terrestrial Toxicity Data:</u>
Ethylene glycol	LC50 Bluegill: 27,540 mg/L - 96h; LC50 D	No information available
Water	No information available	No information available
Potassium phosphate dibasic	No information available	No information available

Persistence and degradability: Expected to be biodegradable
Bioaccumulative potential: No information available
Mobility in soil: No information available
Other adverse effects: No information available

13. DISPOSAL CONSIDERATIONS

Disposal Procedures: Dispose of material and containers in accordance with all local, state and federal regulations.

14. TRANSPORTATION INFORMATION

This product is not a regulated material for domestic ground transportation.

Environmental hazards: No information available
Special precautions: No information available
Bulk transport: No information available

15. REGULATORY INFORMATION

Ethylene glycol is listed in the TSCA inventory and in SARA 313.
Potassium phosphate dibasic is listed in the TSCA inventory.

16. OTHER INFORMATION

OSHA SDS #: 25582 rev 101 3/27/2015

NE = Not established, NA = Not applicable or Not available

The information presented above is offered for informational purposes only. This SDS, and the associated product, is intended for use only by technically qualified persons, and at their own discretion and risk. Since conditions and manner of use are outside the control of Integra Chemical Company, we make no warranties, either expressed or implied, and assume no liability in connection with any use of this information.

***** END OF SDS *****



DOWTHERM™ SR-1 Fluid

Product Type Inhibited Ethylene Glycol-based heat transfer fluid

- Applications**
- Closed-loop, water-based HVAC
 - Process heating and cooling
 - Food industry applications within temperature range

Recommended Use Temperature Range -50°C (-60°F) to 120°C (250°F)

Description DOWTHERM SR-1 heat transfer fluid is a formulation of 95.5 weight percent ethylene glycol and a specially designed package of industrial corrosion inhibitors. The fluid is dyed fluorescent pink for leak detection purposes. Solutions in water provide freeze protection to below -50°C (-60°F) and burst protection to below -73°C (-100°F).

Typical Properties†

Composition (% by weight)	
Ethylene Glycol	95.5
Performance Additives	4.5
Color	Fluorescent pink
Specific Gravity 25/25°C (77/77°F)	1.1250-1.1350
pH of Solution (50% glycol)	9.0-10.5
Reserve Alkalinity (min.)	12.0 ml

†Typical properties, not to be construed as specifications. Complete sales specifications are available on request.

Typical Concentrations of DOWTHERM SR-1 Fluid Required to Provide Freeze and Burst Protection at Various Temperatures

Temperature		Percent DOWTHERM SR-1 Fluid Concentration Required	
°C	(°F)	For Freeze Protection Volume %	For Burst Protection Volume %
-7	(20)	16.8	11.5
-12	(10)	26.2	17.8
-18	(0)	34.6	23.1
-23	(-10)	40.9	27.3
-29	(-20)	46.1	31.4
-34	(-30)	50.3	31.4
-40	(-40)	54.5	31.4
-46	(-50)	58.7	31.4
-51	(-60)	62.9	31.4

Note: These figures are examples only and may not be appropriate to your situation. Generally, for an extended margin of protection, you should select a temperature in this table that is at least 3°C (5°F) lower than the expected lowest ambient temperature. Inhibitor levels should be adjusted for solutions of less than 30% glycol. Contact Dow for information on specific cases or further assistance.

Attention: These are typical numbers only and are not to be regarded as specifications. As use conditions are not within its control, Dow does not guarantee results from use of the information or products herein; and gives no warranty, express or implied.

Typical Freezing and Boiling Points of DOWTHERM SR-1 Fluid†

Wt. % Ethylene Glycol	Vol. % Ethylene Glycol	Wt. % DOWTHERM SR-1	Vol. % DOWTHERM SR-1	Freezing Point		Boiling Point °C @ 101 kPa (°F @ 760 mmHG)		Degree Brix††	Refractive Index 22°C (72°F)
				°C	(°F)	°C	(°F)		
0.0	0.0	0.0	0.0	0	(32.0)	100.0	(212)	0.0	1.3328
5.0	4.4	5.2	4.6	-1.4	(29.4)	100.6	(213)	3.8	1.3378
10.0	8.9	10.5	9.3	-3.2	(26.2)	101.1	(214)	6.8	1.3428
15.0	13.6	15.7	14.2	-5.4	(22.2)	101.7	(215)	9.9	1.3478
20.0	18.1	20.9	19.0	-7.8	(17.9)	102.2	(216)	13.0	1.3530
25.0	22.9	26.2	24.0	-10.7	(12.7)	103.3	(218)	16.1	1.3582
30.0	27.7	31.4	29.0	-14.1	(6.7)	104.4	(220)	19.2	1.3635
35.0	32.6	36.6	34.1	-17.9	(-0.2)	105.0	(221)	22.3	1.3688
40.0	37.5	41.9	39.3	-22.3	(-8.1)	105.6	(222)	25.3	1.3741
45.0	42.5	47.1	44.5	-27.5	(-17.5)	106.7	(224)	28.3	1.3796
50.0	47.6	52.4	49.8	-33.8	(-28.9)	107.2	(225)	31.2	1.3849
55.0	52.7	57.6	55.2	-41.1	(-42.0)	108.3	(227)	33.9	1.3900
60.0	57.8	62.8	60.5	-48.3	(-54.9)	110.0	(230)	36.6	1.3952
65.0	62.8	68.0	65.8	a	a	112.8	(235)	39.1	1.4003
70.0	68.3	73.3	71.5	a	a	116.7	(242)	41.7	1.4055
75.0	73.6	78.5	77.1	a	a	120.0	(248)	44.2	1.4107
80.0	78.9	83.8	82.6	-46.8	(-52.2)	123.9	(255)	46.6	1.4159
85.0	84.3	89.0	88.3	-36.9	(-34.5)	133.9	(273)	49.0	1.4208
90.0	89.7	94.2	93.9	-29.8	(-21.6)	140.6	(285)	51.2	1.4255
95.0	95.0	99.5	99.5	-19.4	(-3.0)	158.3	(317)	53.2	1.4300

†Typical properties, not to be construed as specifications.

††Degree Brix is a measure of the sugar concentration in a fluid and is important in fermentation and syrups applications. Although there is no sugar present in DOWTHERM heat transfer fluids, the glycol affects the refractive index of the fluid in a similar fashion.

‡Freezing points are below -50°C (-60°F).

NOTE: Generally for an extended margin of protection, you should select a temperature in this table that is at least 3°C (5°F) lower than the expected lowest ambient temperature. Inhibitor levels should be adjusted for solutions of less than 30% glycol. Contact Dow for information on specific cases or further assistance.

Saturation Properties of DOWTHERM SR-1 Fluid at 30% Ethylene Glycol Concentration by Volume

Temperature °C	(°F)	Specific Heat		Density kg/m ³ (lb./ft. ³)	Therm. Cond. W/mK [Btu/hr. ft. ² (°F/ft.)]		Viscosity mPa·s (cps)		
		kJ/(kg)(K)	(Btu/lb. °F)		(0.851)	(0.865)	(0.2400)	(0.2554)	(6.18)
-10	(14)	3.562	(0.851)	1055.47	(65.89)	0.4154	(0.2400)	6.1788	(6.18)
10	(50)	3.619	(0.865)	1049.91	(65.54)	0.4420	(0.2554)	2.9482	(2.95)
40	(104)	3.704	(0.885)	1037.92	(64.80)	0.4731	(0.2733)	1.3398	(1.34)
65	(149)	3.775	(0.902)	1024.59	(63.96)	0.4909	(0.2836)	0.8246	(0.82)
90	(194)	3.846	(0.919)	1008.20	(62.94)	0.5015	(0.2897)	0.5599	(0.56)
120	(248)	3.931	(0.939)	984.53	(61.46)	0.5044	(0.2915)	0.5044	(0.38)

Saturation Properties of DOWTHERM SR-1 Fluid at 40% Ethylene Glycol Concentration by Volume

Temperature °C	(°F)	Specific Heat		Density kg/m ³ (lb./ft. ³)	Therm. Cond. W/mK [Btu/hr. ft. ² (°F/ft.)]		Viscosity mPa·s (cps)		
		kJ/(kg)(K)	(Btu/lb. °F)		(0.797)	(0.821)	(0.2142)	(0.2342)	(15.7533)
-20	(-4)	3.336	(0.797)	1073.23	(67.00)	0.3707	(0.2142)	15.7533	(15.75)
10	(50)	3.436	(0.821)	1064.73	(66.47)	0.4053	(0.2342)	4.0451	(4.05)
40	(104)	3.537	(0.845)	1051.85	(65.66)	0.4312	(0.2491)	1.7731	(1.77)
65	(149)	3.621	(0.865)	1037.76	(64.79)	0.4462	(0.2578)	1.0646	(1.06)
90	(194)	3.705	(0.885)	1020.63	(63.72)	0.4552	(0.2630)	0.7013	(0.70)
120	(248)	3.805	(0.909)	996.06	(62.18)	0.4582	(0.2647)	0.4614	(0.46)

Saturation Properties of DOWTHERM SR-1 Fluid at 50% Ethylene Glycol Concentration by Volume

Temperature		Specific Heat		Density		Therm. Cond.		Viscosity	
°C	(°F)	kJ/(kg)(K)		kg/m ³		W/mK		mPa·s	
		(Btu/lb. °F)		(lb./ft. ³)		[Btu/hr. ft. ² (°F/ft.)]		(cps)	
-30	(-22)	3.090	(0.739)	1090.31	(68.07)	0.3333	(0.1926)	43.9970	(44.0)
-20	(-4)	3.129	(0.748)	1088.15	(67.93)	0.3442	(0.1989)	22.0816	(22.08)
10	(50)	3.245	(0.776)	1078.72	(67.34)	0.3724	(0.2152)	5.5071	(5.51)
40	(104)	3.361	(0.803)	1064.91	(66.48)	0.3937	(0.2275)	2.2567	(2.26)
65	(149)	3.457	(0.826)	1050.05	(65.55)	0.4062	(0.2347)	1.2936	(1.29)
90	(194)	3.554	(0.849)	1032.15	(64.44)	0.4139	(0.2391)	0.8227	(0.82)
120	(248)	3.670	(0.877)	1006.66	(62.84)	0.4168	(0.2408)	0.5252	(0.53)

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APPENDIX G

MATERIALS OF CONSTRUCTION CHEMICAL RESISTANCE CHART AND TESTING

Materials of Construction and Chemical Resistance Chart

Chemical Resistance Guidelines

RTV	FRV	Kalrez
Room Temperature Vulcanizing Silicone	Fluorosilicone Fuel-Resistant Room Temperature Vulcanizing Silicone	Perfluoroelastomer FFKM O-Ring
RTV116 is the standard silicone seal used with MTPS sensor. It is considered viable for use with acetone and isopropanol.	FRV1106 silicone performs well with most solvents, with the exception of Acetone and Dichloromethane, and is recommended for testing of fuels.	Kalrez 4079 O-Ring is recommended for use in high temperature (up to 316 °C) and aggressive material testing in a liquid cell.
*Test tabs for RTV and FRV are required for sensor compatibility tests.		
Please Note: It is the client’s responsibility to ensure compatibility of all materials under test with the sensor prior to the onset of testing.		

Materials of Construction and Chemical Resistance Chart

Chemical Resistance Data - RTV

The sensor is constructed from passivated 316 stainless steel, RTV (silicone), green glass, and silicon.

If there is uncertainty as to the safety of using a chemical with an RTV sealed sensor, test the chemical with a tab of RTV before using it with the sensor.

The following chemicals are safe to use with RTV sensors:

Acetaldehyde	Brine	Ethyl Acetate
Acetamide	Butanol (Butyl Alcohol)	Ethylene Diamine
Acetic Acid, 30%	Butter	Epsom Salts (Magnesium Sulfate)
Acetic Acid, 80%	Buttermilk	Ethanol
Acetic Acid, Glacial	Butyl Amine	Ethylene Glycol
Acetone	Butyl Phthalate	Ferric Sulfate
Acetylene	Calcium Bisulfite	Formaldehyde 100%
Alconox	Calcium Carbonate	Formic Acid
Aluminum Chloride	Calcium Chloride	Gelatin
Aluminum Nitrate	Calcium Hydroxide	Glucose
Aluminum Potassium Sulfate, 10%	Calcium Hypochlorite	Glue, P.V.A.
Aluminum Potassium Sulfate, 100%	Calcium Nitrate	Glycerin
Aluminum Sulfate	Calcium Oxide	Glycolic Acid
Alums	Calgon	Grape Juice
Amines	Carbon Monoxide	Hair Mousse
Ammonia, 10%	Carbon Dioxide (dry)	Hexanol
Ammonia Nitrate (RT)	Carbon Dioxide (wet)	Honey
Ammonium Hydroxide	Carbonated Water	Hydraulic Oil (Petro)
Ammonium Nitrate	Carbonic Acid	Hydraulic Oil (Synthetic)
Ammonium Phosphate, Monobasic	Castor Oil	Hydrazine
Ammonium Sulfate	Cider	Hydrogen Peroxide, 10%
Aniline	Citric Acid	Hydrogen Peroxide, 30%
Antifreeze	Clorox (Bleach)	Hydrogen Peroxide 50%
Arochlor 1248	Coconut Oil	Hydrogen Peroxide 100%
Arsenic Acid	Cod Liver Oil	Isopropanol
Asphalt	Coffee	Lactic Acid
Avicel Microcrystalline	Cold Cream	Lard
Cellulose	Copper Cyanide	Latex
Barium Chloride	Copper Sulfate 5%	Lead Acetate
Barium Hydroxide	Copper Sulfate >5%	Lead Nitrate
Barium Nitrate	Corn Oil	Liquinox
Barium Sulfate	Cottonseed Oil	Linoleic Acid
Barium Sulfide	Cough Syrup	Linseed Oil
Beer	Cream	Lithium Chloride
Beet Sugar Liquids	Cupric Acid	Lye: Sodium Hydroxide
Benzoic Acid	Cyanic Acid	Lye: Calcium Hydroxide
Bleach	Detergents	Magnesium Hydroxide
Body Wash	Detergents, Laundry	Magnesium Sulfate (Epsom salts)
Borax	Diethylamine	Malic Acid
Boric Acid	Diethylene Glycol	Manganese Sulfate
	Dow 200	Methanol (Methyl Alcohol)
	Dowtherm SR-1	
	Ethanolamine	

APPENDIX G

Materials of Construction and Chemical Resistance Chart

Methyl Alcohol, 10%	Sea Water	Sugar
Milk	Shampoo	Sugar (liquids)
Mineral Oils	Shampoo, Dandruff	Sulphate (liquors)
Monoethanolamine	Shaving Cream	Sulfur
Mustard	Silica Gel	Sulphur Dioxide
Natural Gas	Silicone	Sulphur Dioxide (dry)
Nickel Sulfate	Silicone Oil	Sulphur Trioxide (dry)
Octanol	Silicone Grease	Tanic Acid
Oxalic Acid (cold)	Silver Nitrate	Tanning Liquors
Ozone	Soap Solutions	Toothpaste
Oil, Engine	Sodium Bicarbonate	Transformer Oil
Peanut Oils	Sodium Bisulfite	Trisodium Phosphate
Photographic Developer	Sodium Borate (Borax)	Urea
Phthalic Acid	Sodium Carbonate (Soda Ash)	Vegetable Juice
Polydimethylsiloxane	Sodium Chloride	Vinegar
Potassium Bicarbonate	Sodium Cyanide	Wakefield Type 120 Thermal Grease
Potassium Bromide	Sodium Hydroxide, 10%	Water, Acid, Mine
Potassium Chlorate	Sodium Metaphosphate	Water, Distilled
Potassium Chloride	Sodium Perborate	Water, Fresh
Potassium Cyanide Solutions	Sodium Silicate	Water, Salt
Potassium Dichromate	Sodium Sulfate	Weed Killers
Potassium Nitrate	Sodium Sulfite	Whiskey and Wines
Potassium Sulfate	Sodium Tetraborate	White Liquor (Pulp Mill)
Potassium Sulfide	Sodium Thiosulfate (hyppo)	Zinc Chloride
Propanol	Soybean Oil	Zinc Sulfate
Propylene Glycol	Stannous Chloride	
Rosins	Starch	
Rum	Stearic Acid	
Salt Brine (NaCl saturated)		

The following chemicals are **not** safe to use with RTV Sensors (Chemicals considered unsafe due to lack of information on one or more components are marked with *):

Acetate Solvent	Amyl Chloride	Benzene
Acetic Acid	Anderol L-774	Benzene Sulfonic Acid
Acetic Anhydride	Aniline Oil	Benzine
Acetophenone	Aniline Hydrochloride	Benzol
Acetyl Chloride (dry)	Ansul Ether	Benzophenone
Acrylonitrile	Antimony Trichloride	Brake Fluid
Aluminum Chloride, 20%	Aqua Regia (80% HCl, 20% HNO ₃)	(Nonpetroleum)*
Aluminum Fluoride	Aromatic Hydrocarbons	Bromine
Aluminum Hydroxide	Askarel	Bromobenzene
Ammonia, Anhydrous	ASTM #1*	Bunker Oil
Ammonia, Liquid*	ASTM #3	Butadiene
Ammonium Carbonate	ASTM Fuel A	Butane
Ammonium Chloride	ASTM Fuel B	Butyl Carbitol
Ammonium Persulfate	ASTM Fuel C	Butyl Ether
Ammonium Phosphate, Dibasic	ASTM Fuel D	Butylacetate
Ammonium Phosphate, Tribasic	Auto Transmission Fluid	Butylaldehyde
Amyl Acetate	Barium Carbonate*	Butylene
Amyl Alcohol	Barium Cyanide*	Butyric acid
	Benzaldehyde	Calcium Bisulfate
		Calcium Bisulfide

APPENDIX G

Materials of Construction and Chemical Resistance Chart

Calcium Sulfate*	Diphenyl	Hydrocyanic Acid
Carbitol*	Diphenyl Oxide	Hydrocyanic Acid (Gas 10%)
Carbitol Acetate	Dow Corning 550*	Hydrofluoric Acid 20%
Carbolic Acid (Phenol)	Dow Gard*	Hydrofluoric Acid 50%
Carbon Bisulfide*	Dowtherm A & E	Hydrofluoric Acid 75%
Carbon Disulfide	Elco 28*	Hydrofluoric Acid 100%
Carbon Tetrachloride	Ethane	Hydrofluosilicic Acid 20%
Cellosolve	Ether	Hydrofluosilicic Acid 100%
Chassis Grease	Ethyl Benzene	Hydrogen Gas
Chlordane	Ethyl Benzoate	Hydrogen Sulfide (aqua)
Chlorine Water	Ethyl Cellulose*	Hydrogen Sulfide (dry)
Chlorine, Anhydrous Liquid	Ethyl Chloride	Hypoid Gear Lube
Chlorine (dry)	Ethyl Ether	Ink
Chloroacetic Acid	Ethyl Merlaptan	Iodine
Chloroacetone	Ethylene Bromide	Isooctane
Chlorobenzene (Mono)	Ethylene Chloride	Iso Phorone
Chlorobenzol	Ethylene Chlorohydrin	Isopar
Chlorobromomethane	Ethylene Dichloride	Isopropyl Acetate
Chloroform	Ethylene Oxide	Isopropyl Ether
Chlorosulfonic Acid	Fatty Acids	Jet Fuel (JP3, JP4, JP5)
Chrome Plating Solution*	Ferric Chloride	Kerosene
Chromic Acid 55	Ferric Nitrate	Ketones
Chromic Acid 10%	Ferrous Chloride	Lacquer Thinner
Chromic Acid 30%	Ferrous Sulfate*	Lacquer
Chromic Acid 50%	Fluoboric Acid*	Lead Sulfamate
Copper Chloride	Fluorine	Ligroin
Copper Nitrate*	Fluosilicic Acid*	Lime*
Creosote	Formaldehyde 40%	Lubricants
Creosote Oil	Freon® 11	Lye: Potassium Hydroxide
Cresols	Freon 12	Magnesium Carbonate*
Cresylic Acid	Freon 22	Magnesium Chloride
Crude Oil	Freon 113	Magnesium Nitrate*
Cyclohexane	Freon TF	Malathion
Cyclohexanol	Fuel Oils	Maleic Acid*
Cyclohexanone	Furan resin	Melamine
Decalin	Furfural	Mercuric Chloride (dilute)
Denatured Alcohol*	Furfuryl Alcohol	Mercuric Cyanide
Diacetone	Fyrquel*	Mercury*
Diacetone Alcohol	Gallic Acid	Meter-Cresol
Dibutyl Amine	Gasoline (high Aromatic) Gasoline, leaded, ref.	Methacrylic Acid
Dichloro Aniline	Gasoline, unleaded	Methane
Dichlorobenzene	Grease	Methyl Acetate
Dichloro Butane Dichloroethane*	Heptane	Methyl Acetone*
Diethyl Ether	Hexaldehyde*	Methyl Acrylate
Diesel Fuel	Hexane	Methyl Bromide*
Dimethyl aniline	Home Heating Oil*	Methyl Butyl Ketone
Dimethyl Ether	Hydrobromic Acid 20%	Methyl Cellosolve
Dimethyl Formaldehyde	Hydrobromic Acid 100%	Methyl Chloride
Dimethyl Formamide	Hydrochloric Acid 20%	Methyl Ethyl Ketone
Dimethyl Terephthalate	Hydrochloric Acid 37%	Methyl Ethyl Ketone Peroxide*
Diocetyl Phthalate	Hydrochloric Acid 100%	Methyl Isobutyl Ketone
Dioxane	Hydrochloric Acid, Dry Gas*	

APPENDIX G

Materials of Construction and Chemical Resistance Chart

Methyl Isopropyl Ketone	Propyl Acetate	Toluene (Toluol)
Methyl Methacrylate	Propylene	Tomato Juice*
Methylamine*	Pydraul	Trichloroacetic Acid
Methylene Chloride	Pyranol	Trichloroethane
Mineral Spirits	Pyridine	Trichloroethylene
Molasses*	Pyrogallic Acid*	Tricresylphosphate
Monovinyl Acetylene*	Rapeseed Oil	Triethylamine*
Naphtha	SAE10W30*	Turbine Oil
Naphthalene	Salad Dressings*	Turpentine
Naphthenic Acid	Salt (Sodium Chloride)	UCDN 50HB280X*
Neatsfoot Oil*	Shellac (Bleached)*	Univis J-43
Nickel Chloride	Shellac (Orange)*	Urine*
Nitrating Acid <15%	Skydrol	Varnish
Nitric Acid 5-10%	Skydrol 500	Vinyl Acetate
Nitric Acid 20%	Sodium Acetate	Wheat Germ Oil*
Nitric Acid 50%	Sodium Bisulfate	White water (Paper Mill)*
Nitric Acid Concentrated	Sodium Chlorate	Wood Oil
Nitrobenzene	Sodium Chromate*	Xylene
Nitromethane	Sodium Fluoride	Zinc Hydrosulfite*
Nitropropane	Sodium Hydrosulfite	
Nitrous Acid*	Sodium Hydroxide 50%	
Octane	Sodium Hydroxide 80%	
Oleic Acid	Sodium Hypochlorite <20%	
Oleum 25%	Sodium Hypochlorite 100%	
Oleum 100%	Sodium Metasilicate*	
Olive Oils	Sodium Nitrate	
Orange Oils	Sodium Peroxide	
Oronite 8200	Sodium Polyphosphate	
Palmitic Acid	Sodium Sulfide	
Paraffin*	Sorghum*	
Pentane	Sovasol	
Perchloric Acid	Stannic Chloride	
Perchloroethylene	Stoddard Solvent	
Petrolatum	Styrene	
Petroleum	Sulfur Chloride	
Petroleum Ether	Sulfur Hexafluoride*	
Phenol 10%	Sulfur Trioxide	
Phenol (Carbolic Acid)	Sulfuric Acid <10%	
Phosphoric Acid (crude)	Sulfuric Acid 10-75%	
Phosphoric Acid >40%	Sulfuric Acid 75-100%	
Phosphoric Acid <40%	Sulfuric Acid (cold Concentrated)	
Photographic Solutions*	Sulfuric Acid (hot Concentrated)	
Phthalic Anhydride*	Sulfurous Acid	
Picric Acid	Tar*	
Pine Oil	Tartaric Acid	
Potash (Potassium Carbonate)*	Tetrachloroethane	
Potassium Chromate*	Tetrachloroethylene	
Potassium Ferrocyanide*	Tetrahydrofuran	
Potassium Hydroxide	Tetralin	
(Caustic Potash)	Tidewater Oil*	
Potassium Permanganate*	Tin Salts	
Propane (liquefied)		

Materials of Construction and Chemical Resistance Chart

Chemical Resistance Data - FRV

FRV1106 is designed for use in fuel, solvent and chemical environments. It is not compatible with acetone and dichloromethane.

The following chemicals are safe to use with FRV Sensors:

Sodium Chlorate	Isooctane
Acetate Solvent	Isopropyl Acetate
Acetic Acid	Kerosene
Acrylonitrile	Ketones
Ammonia, anhydrous	Lime
Ammonia, liquid	Lye: Potassium Hydroxide
Ammonium Carbonate	Mercury
Ammonium Chloride	Methyl Isobutyl Ketone
Ammonium Persulfate	Molasses
Amyl Acetate	Naphtha
Amyl Alcohol	Naphthalene
Amyl Chloride	Nitric Acid (5-10%)
Aniline Oil	Olive Oils
Asphalt	Palmitic Acid
Benzaldehyde	Paraffin
Butyl Ether	Phenol (Carbolic Acid)
Butylene	Picric Acid
Butyric Acid	Potash (Potassium Carbonate)
Calcium Bisulfate	Potassium Chromate
Calcium Bisulfide	Propane (liquefied)
Calcium Sulfate	Sodium Nitrate
Carbolic Acid (Phenol)	Sodium Peroxide
Chromic Acid 10%	Sulfuric Acid <10%
Copper Nitrate	Sulfurous Acid
Diacetone Alcohol	Tricresylphosphate
Dimethyl Formamide	Urine
Diethyl Phthalate	Water, Salt
Diphenyl Oxide	
Ethane	
Fatty Acids	
Fluosilicic Acid	
Formaldehyde 40%	
Gallic Acid	
Hydrofluosilicic Acid 20%	
Hydrogen Gas	
Hydrogen Sulfide (dry)	

Materials of Construction and Chemical Resistance Chart

Chemical Resistance Data - Kalrez

The following chemicals are safe to use with Kalrez O-Rings in a liquid cell:

- Acetic Acid
- Acetone
- Ammonia
- Ammonium Hydroxide
- Animal Oils
- Bases
- Benzene
- Boric Acid
- Brake Fluids
- Butyl Alcohol
- Calcium Hydroxide
- Citric Acid
- Diluted Salt Solutions
- Ethanol
- Ethylene Glycol
- Glycerin
- Grease
- Hydraulic Oils
- Isopropyl Alcohol
- Methanol
- Methyl Ethyl Ketone (MEK)
- Mineral Oils
- Motor Oil
- Nitric Acid
- Petroleum Fluids
- Phosphoric Acid
- Potassium Hydroxide
- Sodium Bicarbonate
- Solvents
- Sulfonic Acid
- Transmission Fluid
- Vegetable Oils

Purpose:

The purpose of this project was to assist C-Therm Technologies in identifying and testing an RTV silicone sealant with enhanced chemical resistance.

Methodology:

Silicones: RTV116 (currently used in C-Therm sensors) and FRV1106 (a newly selected gasoline resistant silicone) were chosen for evaluation.

Solvents: Four organic solvents (Acetone, Isopropanol, Toluene and Dichloromethane) were selected for evaluation.

Fuel oils: Six fuel oils were supplied by Southwest Research (AL27233-F, AL27915, AL28126, AL27119, AL27741-F and CL08 0015) for evaluation.

Test Patches: Round test patches (28-29 mm diameter) of each silicone were formed on individual stainless steel coupons and allowed to cure.

Room temperature trial: Ten clear glass jars were labelled with the silicone "RTV" and the name of the solvent or fuel to be tested. Similarly another ten jars were labelled with "FRV" and the appropriate solvent or fuel to be tested. A test patch (adhered to the steel coupon) of the appropriate silicone was placed into each of the jars. A measured portion of the appropriate solvent was then added to each jar, immersing the test patch, and the jars were capped and left in the fumehood for 48 hours. The test patches were then removed from the solvent, and observations were recorded.

Elevated temperature trial: The elevated temperature trials were completed using only the fuel oils supplied by Southwest Research and the FRV silicone. As above, glass jars were labelled appropriately, test patches added, and a measured volume of fuel oil was added to each vial, immersing the test patch. The samples were heated on a hot plate and maintained at a temperature of 140 ± 15 °C for four hours. During the four hour trial, several of the fuel oils needed to be topped up in order to keep the test patch immersed. At the end of the four hours the jars were removed from the hot plate, the test patches removed from the jars, and observations were recorded.

Results:

Observational data is included in Tables 1 (room temperature solvents), 2 (room temperature fuel oils), and 3 (elevated temperature fuel oils) below. For the purposes of this evaluation, silicones exhibiting minimal swell while maintaining adhesion to the steel coupon after immersion in a particular solvent are considered potentially viable for use with that solvent.

Room temperature trial:

RTV116: The RTV silicone performed well in Acetone and Isopropanol, exhibiting minimal swell and maintaining adhesion. Moderate performance was also obtained in the immersion in Fuel AL27119; The test patch swelled only slightly and maintained adhesion.

In all of the other solvents and fuels tested, the test patch either exhibited considerable swelling and/or loss of adhesion, and would not make a reliable sealant when in contact with these solvents.

FRV1106: The FRV silicone performed well in all solvents and fuels tested, with the exception of Acetone and Dichloromethane. Both of these solvents caused swelling of the silicone as well as loss of adhesion.

Elevated temperature trial:

FRV1106: The FRV silicone performed well in all six fuel oils tested. There was no discernable swell detected and all test patches maintained adhesion to the steel coupon.

Room Temperature Trials:

Table 1: Solvents

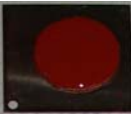






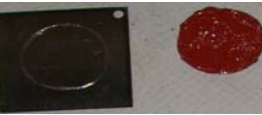









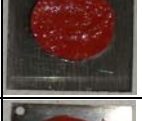




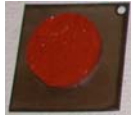
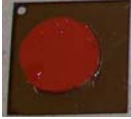


	Silicone	Swelling	Diameter (mm)	Adhesion	Post trial picture
Acetone	RTV	No	30	Yes	
	FRV	Yes	40	No	
Isopropanol	RTV	No	29	Yes	
	FRV	No	28	Yes	
Toluene	RTV	Yes	43	No	
	FRV	No	29	Yes	
Dichloromethane	RTV	Yes	40	No	
	FRV	Yes	33	No	

Table 2: Fuels

	Silicone	Swelling	Diameter (mm)	Adhesion	Post trial picture
AL27233-F	RTV	Yes	40	No	
	FRV	No	29	Yes	
AL27915	RTV	Yes	40	No	
	FRV	No	29	Yes	
AL28126	RTV	Yes	44	No	
	FRV	No	29	Yes	
AL27119	RTV	Slight	30	Yes	
	FRV	No	29	Yes	
AL27741-F	RTV	Yes	33	Yes	
	FRV	No	29	Yes	
CL08	RTV	Yes	33	Yes	
	FRV	No	29	Yes	

Elevated Temperature Trials:

Table 3: Fuels	Silicone	Swelling	Diameter (mm)	Adhesion	Post trial picture
AL27233	FRV	No	28	Yes	
AL27915	FRV	No	28	Yes	
AL28126	FRV	No	29	Yes	
AL27119	FRV	No	28	Yes	
AL27741-F	FRV	No	28	Yes	
CL08	FRV	No	28	Yes	

Note 1: The FRV silicone was much more viscous than the RTV, and had to be manually "squeegied" into the form. The rough surface texture of the FRV test patches pictured above is due to this preparation procedure, and not degradation by the solvent.


Note 2: The photographs for the room temperature trials were taken two days after they were removed from the solvents, so do not appear as swollen as diameter data indicates.

Conclusion:

RTV116: This silicone is considered potentially viable for use in Acetone and Isopropanol.

FRV1106: This silicone is considered potentially viable for use in all solvents and fuels tested with the exception of Acetone and Dichloromethane.

Dichloromethane was the only solvent tested in which neither silicone (RTV or FRV) performed satisfactorily.


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Operation Procedure For Chemical Testing with RTV Tabs
Document No: TH030280-OP

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APPENDIX G

Chemical Testing RTV

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1. Scope

This document provides instructions for testing chemicals using the RTV chemical testing tabs (PN: TH030280) or FRV chemical testing tabs to test the compatibility of a pure chemical or commercial product with the C-Therm MTPS sensor. Of all the materials which are used for constructing these sensors, the sealant is considered the most susceptible to chemical aggression (refer to your operating manual for details on materials of construction and chemical aggression charts).

For this reason, C-Therm offers cured RTV and FRV test tabs to help prevent shortened sensor life by allowing tests for compatibility to be performed before testing on the MTPS sensor itself. In this way, compatibility can be verified without risking the sensor integrity by exposure to a material of unknown compatibility.

2. Test equipment required

- Beakers
- RTV or FRV Test Tabs
- Chemicals under test
- Scissors
- Paraffin Film / other cover for beakers (optional)
- Fume Hood (optional)
- Thermal Chamber (optional)

3. Introduction

The RTV sealant around the MTPS sensor chip (orange) is the sensor component most vulnerable to damage from aggressive chemicals. RTV tabs are provided to allow potentially damaging chemicals to be tested prior to use with the sensor, resulting in extended sensor life. See Appendix G for a complete list of chemicals already tested.

FRV tabs are provided with FRV sensors. The FRV seal is used for testing fuels, which damage the RTV seals on standard sensors. As with RTV test tabs, FRV test tabs should be used to test potentially damaging chemicals prior to use with the sensor. **Although FRV is a more resistant material to organic solvents, phase change materials, etc. than RTV, it is not guaranteed that it is compatible with all organic materials.** C-Therm is not responsible if damage to a sensor occurs following use with an untested or known to be damaging chemical. Furthermore, damage resulting from use with untested or known to be damaging chemicals is not a manufacturer's defect and as such will not be covered under warranty. It is the client's responsibility to ensure compatibility of all materials under test with the sensor prior to the onset of testing.

Note 1: Use of a thermal chamber is required for testing at a specific temperature, representative to the process conditions for the sensor. The chemical shall be tested under the same conditions, for the same duration, as will be used with the MTPS sensor. In the case or prolonged testing to be done repeatedly under severe conditions, repeated testing on the same tab should be conducted to determine the sealant life time upon repeated, prolonged exposure under severe conditions to a potentially aggressive chemical, as such prolonged use may damage the sealant even if the material passes a single-test compatibility screening.

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Note 2: Where chemical testing is to be done, it is expected that the user is familiar with current best safety practices. Such procedures will not be described in this document and is the responsibility of the experimenter. Review all SDSs and conduct a task hazard analysis according to existing procedures prior to testing.

Note 3: Where chemical testing is to be done, it is expected that the user is familiar with local and federal legislation and regulations governing the disposal of hazardous materials. Such procedures will not be described in this document, and it is the responsibility of the experimenter to ensure that all chemicals have been appropriately disposed of after use.

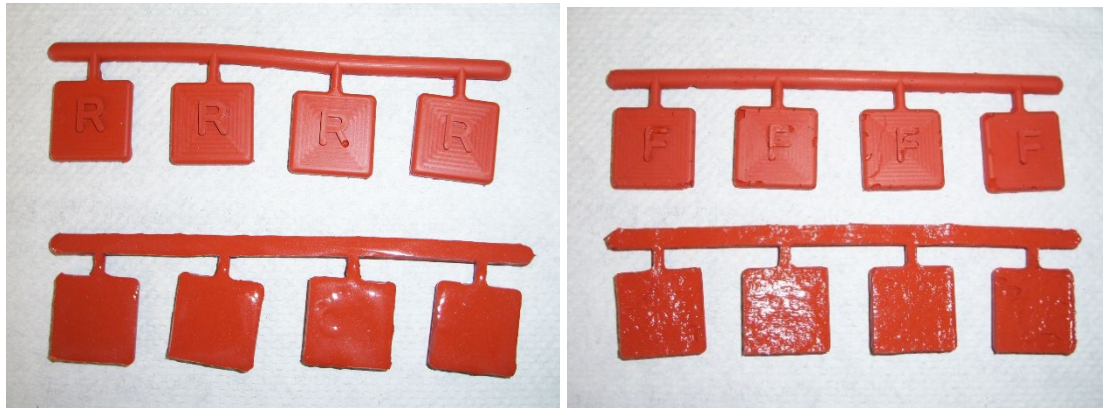
4. Test Procedure

Step 1 – Set the temperature of the thermal chamber if applicable.

Leave the thermal chamber closed for two hours for it to come to equilibrium.

Step 2 – Examine each tab for flaws, including pitting and air bubbles, prior to use, and record the initial condition and properties of the tab.

For your convenience, the test tabs come labelled with an R for RTV test tab material and an F for FRV. Ensure that the letters are legible and that the labelled material is consistent with the material of your sensor – unless an FRV sensor was specifically ordered, you have an RTV sensor. As FRV and RTV have significantly different chemical resistance profiles, testing RTV tabs for an FRV sensor or vice versa could yield erroneous results. Mass, tab dimensions, and tab color should all be recorded.



RTV (left) and FRV (right) test tabs

Some flaws are natural due to the curing and application process. RTV should appear smooth and highly consistent. FRV sealant is more prone to such flaws as an inherent consequence of its viscosity. If testing with FRV tabs, flaws should be documented photographically with a ruled straight edge or T-square for scale to prevent confusion of a natural flaw with one induced by the chemical or vice versa.

Step 3 – Label each beaker with the chemical to be tested.

Ensure that beaker labels are consistent with the chemicals to be tested, and that they are labelled in such a way that the table will not be ruined should the chemical spill.

Step 4 – Seal each beaker with paraffin film or cover.

Chemical Testing RTV

This step may be omitted at temperatures higher than 60°C depending on chemical under test or if the chemicals are aggressive towards paraffin.

Step 5 – Place the beakers to be tested in the thermal chamber or fume hood if applicable.
Leave the samples in the thermal chamber or fume hood for an appropriate time period – 60 minutes for general testing.

Step 6 – Remove the samples individually from the thermal chamber.
Remove the sample piece from the beaker, using tweezers if necessary. Wipe the tab clean with a laboratory wipe and rinse it with a small quantity of water if necessary, then pat dry.

Step 7 – Examine the test tab.
Examine the sample and note observations in the table. Record mass, dimensions, and color as compared with an untested tab of the same material, and mechanical properties such as stiffness and elasticity (these may be compared with an unused tab). In the case of FRV tabs, it is strongly recommended that the client take a photograph with consistent lighting and scale compared with the photo at the onset of testing for comparison of the flaws prior to and post exposure to the chemical under testing.

Step 8 – Replace the sample in the beaker.
Add a small additional amount of chemical if necessary (note uptake or evidence of absorbing which should also be evident by the tab gaining mass, swelling, or taking on a puffy appearance, depending on the chemical under test).

Step 9 – Replace the sample in the thermal chamber.

Step 10 – Repeat steps 5 to 9 for each sample at 120, 180, and 240 minutes and at 24 hours or as required.

As stated previously, all potentially chemicals should be tested for similar durations to the full lifetime exposure expected of the sensor material. Therefore, test times much longer than the 24 hours described may be required, in the case of very severe applications.

Step 11 – Dispose of the chemical as per its SDS and local and national legislation and regulations.

Nations, states, provinces and municipalities may have requirements which differ greatly from the disposal procedure specified in the SDS. It is recommended the client research their local regulations and disposal requirements.

Step 12 – Clean the beakers.

Step 13 – Evaluate the results.

Section 5 has detailed instructions on post-test inspection and section 6 has detailed instructions on evaluation of results.

5. Inspection

Test tabs should be visually inspected for color, texture, obvious size, and luster changes of the material, as well as less common effects such as material 'sweating' (slow desorption of absorbed liquid) or warping. Any such changes should be recorded.

Chemical Testing RTV

The tabs should be manually inspected for changes in pliability, elasticity and malleability, by comparison with a fresh, untreated tab. Observations should be recorded.

RTV test tabs should be weighed and measured for length, width, and height. Any changes of significance should be recorded. FRV test tabs should be photographed with a ruled straight edge or T square for scale and should be weighed to observe mass change. Any changes of significance should be noted.

6. Evaluation of Results

A chemical is to be designated as safe to be used with the C-Therm MTPS sensors if it has no effect on the test tab (effect A as noted below). The tab should be evaluated as “not safe” ***if any of the following is observed***: significant change in tab mass; pitting, cracking or other visible signs of tab corrosion; tab discoloration; film formation following tab cleaning on the tab surface; growth of crystalline material or oozing of liquid material from the tab surface following tab cleaning (note that this may occur as a delayed effect, several minutes to several hours following exposure), significant tab dimensional change (either swelling or shrinkage); erosion of the tab (most likely visible at the letter label, which has a high surface area-to-volume ratio); change in tab mechanical properties including but not limited to strength, flexibility, and elasticity (determined by comparison to the properties of an untested tab); and any other change in the consistency, texture, color, or other properties of the tab material.

FRV tabs should be evaluated on the physical appearance and dimension basis by comparison of the scaled photographs before and after testing, which should be taken under the same lighting, with the same camera. This is owing to the inherent variability in surface of the FRV tab which can significantly confound dimensional analysis by more precise methods, e.g. by calipers. Additionally, comparison of the scaled photographs prevents confusion of a natural flaw for one induced by the testing process.

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After all of the test results have been recorded and analyzed, a chemical is deemed “safe” *if and only if* there is no observable effect on the test tab. ***It is strongly recommended that thermal conductivity or effusivity testing only be performed on those chemicals which have been deemed “safe” as a result of chemical compatibility testing described herein, and C-Therm Technologies, Inc shall not be liable for any damage that results, or may result, from testing on the basis of chemical compatibility testing not performed or improperly performed.***

In the event of a chemical showing marginal compatibility testing results (i.e., negative effects on the test tab observable only after an aggressive period of exposure - >12 hours, for example) it is possible to test the chemical for brief periods of time. In such a case, the user must bear in mind that each such test is likely to shorten the lifespan of the sensor and that if extensive testing is to be done with this chemical, the sensor will eventually fail. It is recommended instead that the client contact C-Therm.

APPENDIX G

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Table 1: Chemical Compatibility Data for RTV

Chemical	Temp	1 Hr	2 Hrs	3 Hrs	4 Hrs	24 Hrs	Safe/Not Safe
Example 1234	40 °C	A	B	C		F	Not Safe

Legend of Effects:

A – No Effect

B – Some warping, puffiness, or mass gain

C – Some pitting, discoloration, or mass loss

D – Severe damage, including bleaching, loss of flexibility, substantial (>7.5%) mass loss or gain and/or cracking

E – Delayed effects including desorption of adsorbed material, loss of flexibility or cracking

F – Dissolved

APPENDIX G

Chemical Testing RTV

APPENDIX H

GUIDELINES FOR TESTING MTPS IN THERMAL CHAMBER OR FURNACE





Note: Users are advised that when operating the MTPS sensor in a thermal chamber, furnace, or other metal surface, it is possible for some electrical leakage to pass from the metal surfaces, such as the thermal chamber floor, through to the sensor. This has the potential to adversely impact the accuracy of testing results and can **damage the sensor** if operated at elevated temperatures over extended periods of time.

It is always recommended to employ an insulative layer below the MTPS sensor baseplate; a silicone rubber matt being provided with the Trident system for this purpose (for temperatures of -50 to 200°C).



Pictured: Recommended Tenney Jr. Thermal Chamber (3rd Party OEM: TPS Tenney Environmental)

RECOMMENDED THERMAL CHAMBER / FURNACE SPECIFICATIONS

MAXIMUM RAMP RATE	1 °C / min
CONTROL	+/-1.0°C
TEMPERATURE RANGE	Sensor Dependent
MINIMUM INTERIOR DIMENSIONS	30cm x 30cm x 30cm
CABLE PORT	One

APPENDIX I

CE CERTIFICATION



APPENDIX J

AGAR SOLUTION - PREPARATION PROCEDURE



APPENDIX J

Agar Solution – Preparation Procedure

Preparation of 0.4 wt % Agar Solution

Agar gel is an ideal thermal conductivity reference material and calibration material for the needle probe. Agar is optimal as it is a non-toxic, water-based gel, the ingredients of which are widely available. The agar itself does not significantly influence the thermal properties of water but eliminates the effects of convection.

The properties of agar gel at 0.4 weight % (wt %) closely resemble those of water and are given by the following equation:

$$\lambda_g \text{ (W/m)} = 0.57 + 0.0015 T$$

This equation is valid from 5°C to 80°C, and T is temperature in °C. Agar may be used from 5°C to 80°C as a reference or calibration material. The thermal diffusivity of the agar solution is $0.14 \times 10^{-6} \text{ m}^2/\text{s}$.

Preparation of the agar gel is achieved by weighing appropriate amounts of water and agar to achieve 0.4 wt %, then boiling the solution for 20 minutes to ensure full dissolution and denaturation. The agar should then be placed in the sample containment vessel and allowed to cool down and solidify overnight.

APPENDIX K

UNITS AND CONVERSIONS



APPENDIX K

Units and Conversions

Basic symbols and dimensions:

	MKS (SI)	CGS	Imperial
Thermal Conductivity	k (W/mK)	k (cal/s°C)	k (Btu/hr/ft/°F) or (Btu*in/hr/ft2°F)
Thermal Diffusivity	α (m2/s)	α (cm2/s)	α (-)
Heat Capacity	Cp (J/kg/K)	Cp (cal/g/°C)	Cp (Btu/lb/°F)
Density	ρ (kg/m3)	ρ (g/cm3)	ρ (lb/ft3)
Energy	J (Joules)	J (Joules)	Btu (British Thermal Units)
Energy Rate (Watts)	W = J/s (Watts)	W	Btu/min
Change in absolute Temperature	K (Kelvin)	°C	°F
Time	s (seconds)	s(seconds)	hr, min
Effusivity	e (W· s1/2/m2/K)	e (cal· s1/2/cm2/K)	e (Btu/hr1/2/ft2/°F)
Thickness	l(m)	l(cm)	l(ft)
Depth of Penetration	d(m)	d(cm)	d(ft)

Conversions

Thermal conductivity: $1 \text{ W/mK} = 0.002389 \text{ cal/s}^\circ\text{C}$
 $= 0.5782 \text{ Btu/hr/ft/}^\circ\text{F}$
 $= 6.938 \text{ Btu-in/hr/ft}^2/^\circ\text{F}$

Thermal Diffusivity: $1 \text{ m}^2/\text{s} = 1000000 \text{ mm}^2/\text{s}$
 $= 10000 \text{ cm}^2/\text{s}$

Heat Capacity: $1 \text{ J/kg/K} = 2.388 \times 10^{-4} \text{ cal/g/}^\circ\text{C}$
 $= 2.391 \times 10^{-4} \text{ Btu/lb/}^\circ\text{F}$

Density: $1 \text{ kg/m}^3 = 0.001 \text{ g/cm}^3$
 $= 0.06243 \text{ lb/ft}^3$

Energy: $1 \text{ J} = 0.23885 \text{ cal}$
 $= 9.4782 \times 10^{-4} \text{ Btu}$

APPENDIX K

Units and Conversions

$$e = \sqrt{k\rho C_p}$$

$$e^2 = k\rho C_p$$

$$C_p = \frac{e^2}{k\rho}$$

$$C_p = \frac{(W \cdot s^{1/2} / m^2 / K)^2}{W / mK \cdot kg / m^3} = \frac{(J^2 / s^2) \cdot s / m^4 / K^2}{(J / s) / mK \cdot kg / m^3} = \frac{(J / s) \cdot s / m^4 / s}{K \cdot kg / m^4} = \frac{J}{kgK}$$

User must enter the density for this calculation

Calculation of R-value (RSI):

$$R = \frac{l}{k}$$

$$R = \frac{m}{W / mK} = \frac{K \cdot m^2}{W}$$

The user must enter the thickness of material for this calculation

Depth of Penetration:

$$d = (4\alpha t)^{1/2}$$

$$d = \left(\frac{m^2}{s} s \right)^{1/2} = m$$

Where: t is the test time.

APPENDIX L
COMPRESSION TEST ACCESSORY - SOP



Please reach out to support@ctherm.com to request this Appendix.

APPENDIX M

LIQUIDS AND POWDERS TEST CELL - SOP



Standard Operation Procedure (SOP) For MTPS Liquids & Powders Test Cell Accessory

Document No: SOP-MTPSLiquidsCell



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APPENDIX M

Small Volume Test Kit - SOP

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Reviewed By: Patrick Scanlan	Date: August 25, 2020
Approved By: Jarett Nickerson	Date: August 25, 2020

APPENDIX M

Small Volume Test Kit - SOP

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3.2 Liquid sample preparation	6
3.3 Powder Sample Preparation	7
4 Cleaning Procedure	8

1 Scope

The scope of this document is to inform the user on the proper technique in using the MTPS Liquids & Powders Test Cell accessory for measuring liquids, pastes, and powders using the Trident MTPS sensor.

This document does not provide instructions on the safe handling of the samples under test, as required safety precautions will vary sample-to-sample depending on the materials in question. It is the Client's responsibility to be familiar with local and national occupational health and safety laws and regulations, to be familiar with the hazard profiles of the samples under test, and to take appropriate safety precautions. C-Therm is not responsible for any damage to the sensor or to personnel resulting from use of incompatible materials on the sensor or from the improper handling of hazardous materials.

2 Test Equipment



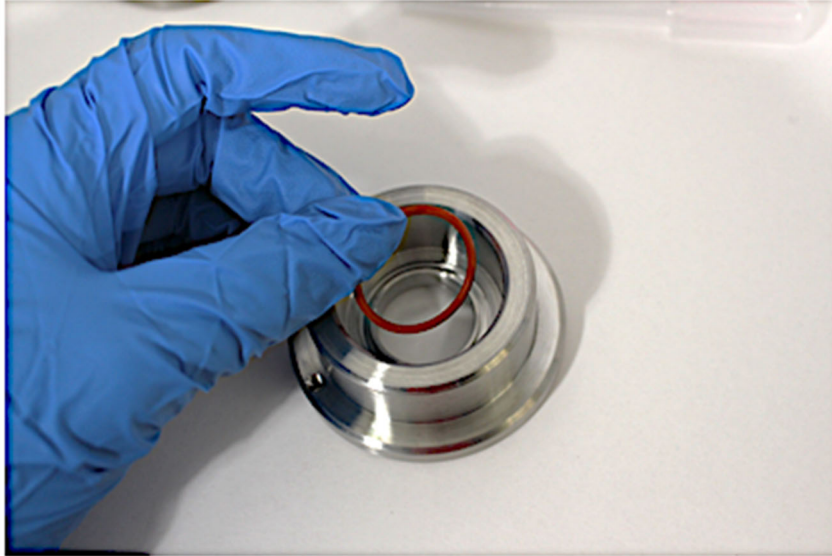
Trident MTPS Sensor with a Trident system (above) and software

1. MTPS Liquids & Powders Test Cell accessory: P/N: 20-006555-REV-A-Cap
2. RTV O-ring, 1" in diameter.
3. Liquids cell cap, P/N: 20-006569
4. Powder Weight P/N: 20-006568

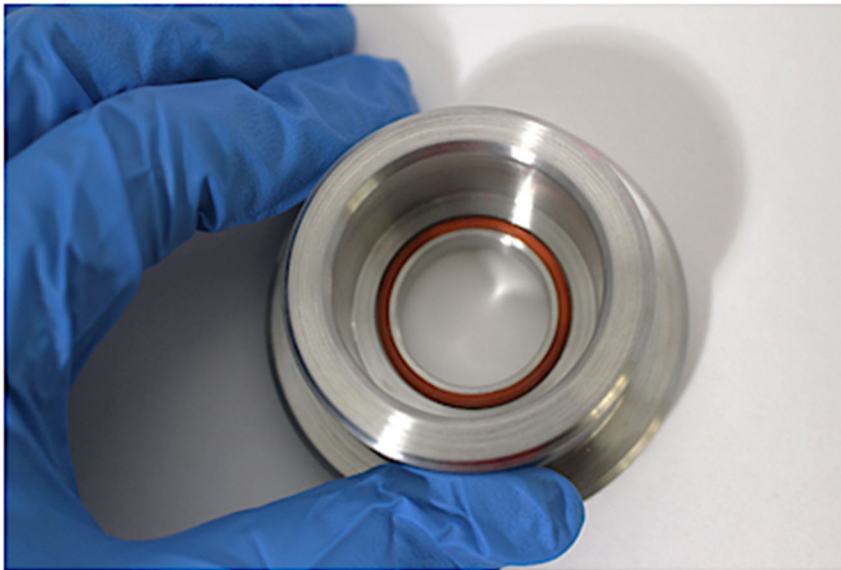
3 Test Procedure

3.1 Cell Setup

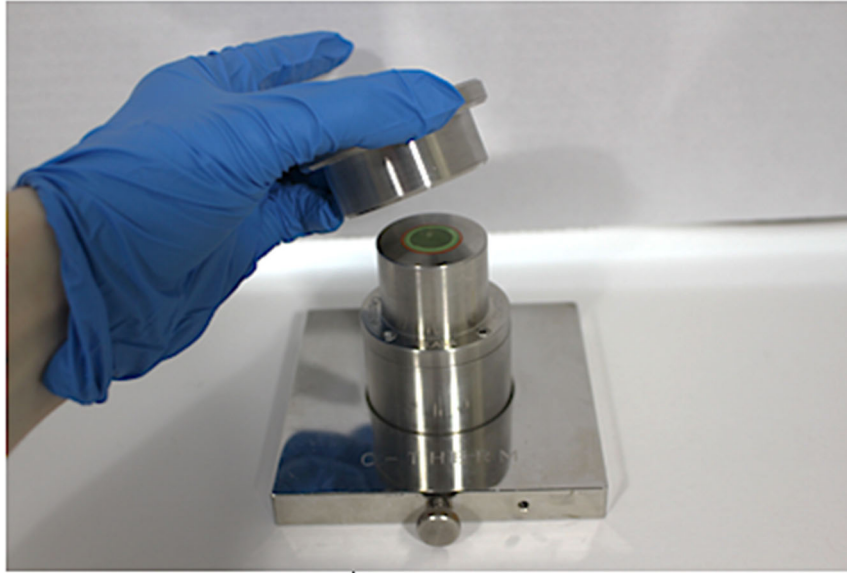
1. Ensure the MTPS Liquids & Powders Test Cell accessory, O-ring and MTPS sensor housing are dry. Wipe with a clean, dry laboratory wipe until the wipe comes free with no liquid residue.



2. Place O-ring seal inside of the groove on the underside of MTPS Liquids & Powders Test Cell accessory.



3. Ensure that the O-ring is fitted securely into the groove.



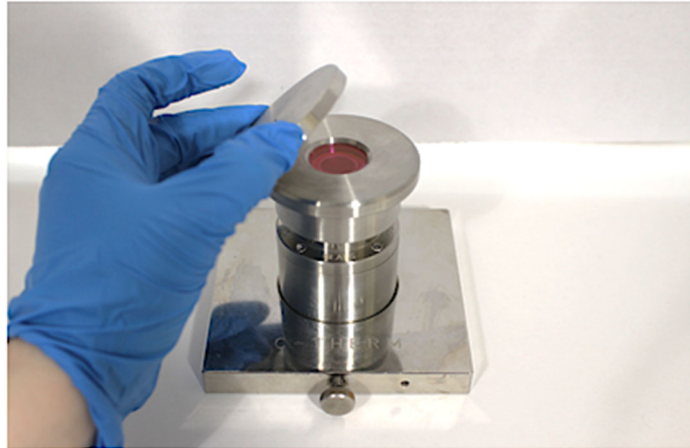
4. Place MTPS Liquids & Powders Test Cell accessory on top of the MTPS sensor. Press down firmly and evenly to ensure a good seal is formed between the O-ring and the MTPS sensor housing.
5. The MTPS Liquids & Powders Test Cell is now ready for use.

3.2 Liquid sample preparation

1. Setup the MTPS Liquids & Powders Test Cell as in 3.1.



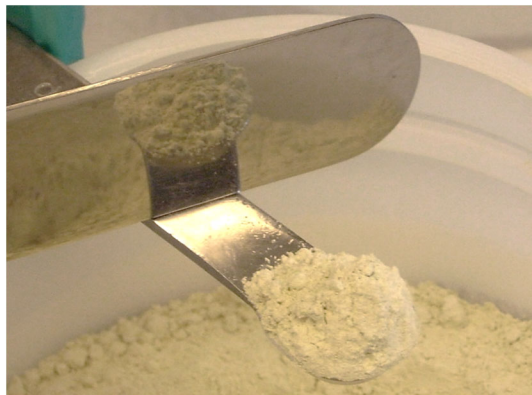
2. Measure a minimum of 1.25 ml of liquid specimen using a dropper and transfer this volume directly to the MTPS Liquids & Powders Test Cell.



3. Optional: Place the cap on the MTPS Liquids & Powders Test Cell. Use of the Liquids Cap is highly recommended for volatile liquids to prevent excessive evaporation from the cell and the confounding effect of the resulting evaporative cooling. Ensure the Liquids Cap is centered on the MTPS Liquids & Powders Test Cell.
4. Begin testing with the Trident software.
5. After testing, clean the MTPS Liquids & Powders Test Cell as described in section 4.

3.3 Powder Sample Preparation

1. Set up the MTPS Liquids & Powders Test Cell as in 3.1.
2. Fill the 1/8 tsp measuring spoon (0.63 ml) with the powder to be investigated.

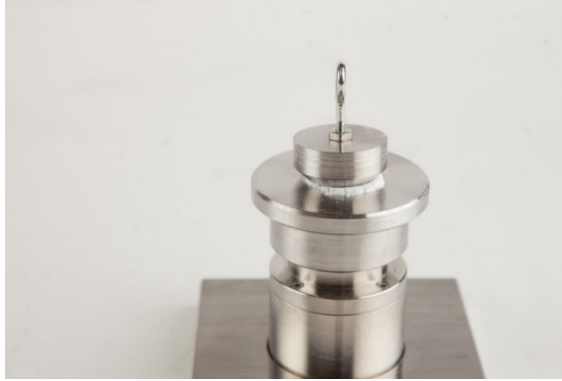


3. Level off the excess powder by scraping off the excess with a spatula by making a horizontal movement. The spatula should be applied on the side of handle and moved across to the opposite side of the measuring spoon to scrape off the excess powder.
4. Empty the measuring spoon into the MTPS Liquids & Powders Test Cell.

APPENDIX M

Small Volume Test Kit - SOP

- Repeat steps 2-4 two times (3X total) for a total volume of specimen of approximately 3/8 (tsp) or 1.8 ml. Ensure the blue or green active area of the MTPS sensor is fully covered by the powder.



- Place the Powders Weight onto the sample so that it seats on the rim of the MTPS Liquids & Powders Test Cell. No extra force is required.
- Start the test in the Trident software
- Clean the MTPS Liquids & Powders Test Cell as described in Section 4.

4 Cleaning Procedure

Clean the MTPS sensor and MTPS Liquids & Powders Test Cell between each sample to avoid cross-contamination of samples. If samples get cross-contaminated, test results may be affected.

To clean the MTPS Liquids & Powders Test Cell:

- Pour the contents of the MTPS Liquids & Powders Test Cell into a suitable waste container.
- Remove The MTPS Liquids & Powders Test Cell and thoroughly clean the MTPS sensor surface and MTPS Liquids & Powders Test Cell using C-Therm's approved cleansers outlined in the user manual.
- Using laboratory wipes, thoroughly dry the MTPS sensor housing, the MTPS Liquids & Powders Test Cell body and the O-ring. Regardless of whether the MTPS Liquids & Powders Test Cell will be put away or re-used, it is important to ensure the cell is thoroughly dried following cleaning.

To test again, simply replace the O-ring, then place the MTPS Liquids & Powders Test Cell back on the sensor.

APPENDIX N

TRIDENT THERMAL CONDUCTIVITY TECH TIP: MEASURING ANISOTROPIC SAMPLES USING FLEX TPS SENSOR



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APPENDIX O

TRIDENT THERMAL CONDUCTIVITY TECH TIP: TESTING HIGH THERMAL CONDUCTIVITY MATERIAL USING FLEX TPS



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APPENDIX P

TRIDENT THERMAL CONDUCTIVITY TECH TIP: TPS SLAB UTILITY



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APPENDIX Q

TRIDENT THERMAL CONDUCTIVITY APPLICATION HIGHLIGHT: MEASURING THIN FILMS USING FLEX TPS SENSOR

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APPENDIX R

TESTING THIN FILMS USING FLEX TPS SENSOR



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APPENDIX S

TESTING WITH MTPS HIGH PRESSURE CELL



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APPENDIX T

TESTING WITH MTPS HIGH TEMPERATURE CELL

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APPENDIX U

TRIDENT THERMAL CONDUCTIVITY TECH TIP: TLS HT300



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APPENDIX V
DISCLAIMER



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The data and results set forth herein are based on laboratory work and do not necessarily indicate results that the buyer or User will attain. Full-scale testing and product performance is the responsibility of the buyer and User.

Any discrepancy between this disclaimer and the warranty through the distributor of this product, the warranty shall prevail.