C-Therm TCi™ Thermal Conductivity Analyzer

Introduction to the Modified Transient Plane Source (MTPS)Technique

Agenda

- **Who we are?**
- **What we do?**

  Thermal Conductivity (k)
  - ✓ Introducing to the TCi™
  - ✓ Principles of Operation
  - ✓ Capabilities
- **Applications**
  - ✓ Metal Hydrides
  - ✓ Explosives
  - ✓ Polymers & Nanomaterials
    - ✓ Electronic Adhesives
    - ✓ Carbon Nanotubes (CNTs)
  - ✓ Asphalt / Concrete
- **Comparison of Methods**
- **Q&A**


C-THERM TECHNOLOGIES Ltd.

WHO WE ARE?

Who is C-Therm?

C-THERM TECHNOLOGIES Ltd.

(Formerly Mathis Instruments Ltd.)

Non-destructive thermal sensor technology solutions for R&D, production, and QC applications, delivering fast, accurate measurement of **thermal conductivity** and **effusivity i**n seconds with virtually unlimited sample size.

R&D 100 WINNER

Manning Innovation Awards Prix d'innovation Manning




C-THERM
TECHNOLOGIES Ltd.

WHAT WE DO

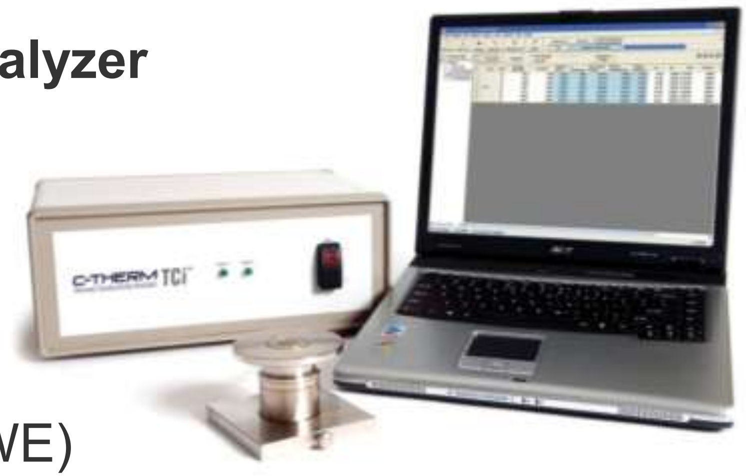
C-Therm Product Lines

THERMAL CHARACTERIZATION

C-Therm TCi™ Thermal Conductivity Analyzer

Clients include:

- NRC
- US Army
- Kodak
- P&G
- Dupont
- Philip Morris
- US Navy
- Texas Tech University
- Henkel Technologies
- Atomic Weapons Est. (AWE)



PHARMACEUTICAL APPLICATIONS

C-Therm ESP™ Effusivity Sensor Package

Process Analytical Technology (PAT)

Clients include:

- Patheon
- Wyeth
- BMS
- Astra Zeneca
- Biovail
- USP

Overview of TCi™

Fast
0 to 100 W/mK in 5 seconds

Wide Temperature Range
-50˚ to 200˚C

Easy-to-Use
No calibration required

No Sample Preparation
Unlimited sample sizes

Non-Destructive
Leaves sample intact

Versatile
Tests solids, liquids, powders & pastes

Highly Flexible
Designed for lab, QC & at-line testing

Accurate
Better than 5%

Precision
Better than 1%

What does it Measure?

The C-Therm TCi measures two thermal properties primarily:

$$\text{Thermal Conductivity} = (W/m \cdot K)$$

and

$$\text{Effusivity} = \sqrt{k\rho c_p}$$

Where :

k = Thermal Conductivity (W/m • K)

ρ = Density (kg/m³)

c_p = Heat Capacity (J/kg • K)

It also indirectly measures (calculated) Thermal Diffusivity and Heat Capacity and has user input capabilities to determine Density

How the sensors work?

Heat always flows from a hot object to a cold object.

Wood is not a good conductor of heat, so it is **slow** to absorb the heat.

Metal has higher **“thermal conductivity”** so the heat from your hand flows into the metal **quickly** - creating the sensation of it being cold.

C-Therm sensors work like your hand, by **rapidly** determining the **rate** of heat flow from one material to another. Like your hands, our sensors **supply** the heat source *and* **detect** the heat flow. They also have no **sample size** issues, and do not destroy the sample being tested.

How the Technology Works

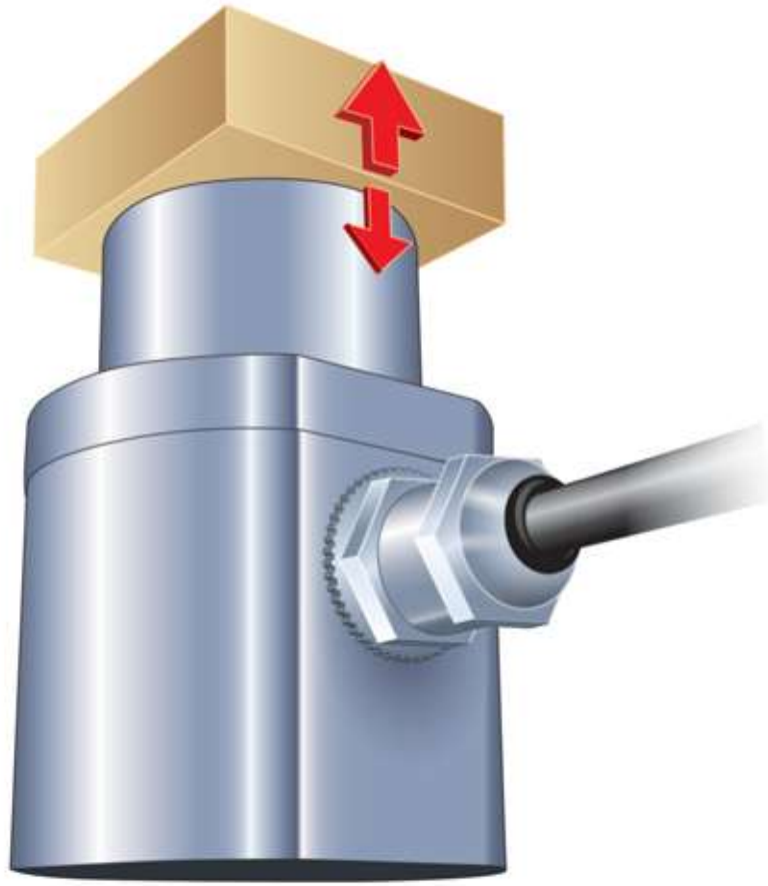
Sample material can be solid, liquid, powder or paste.

A known current is applied to the sensor's heating element, providing a small amount of heat.

The heat provided results in a rise in temperature at the interface between the sensor and the sample – typically less than 2˚C.

This temperature rise at the interface induces a change in the voltage drop of the sensor element.

The rate of increase in the sensor voltage is used to determine the thermo-physical properties of the sample material.

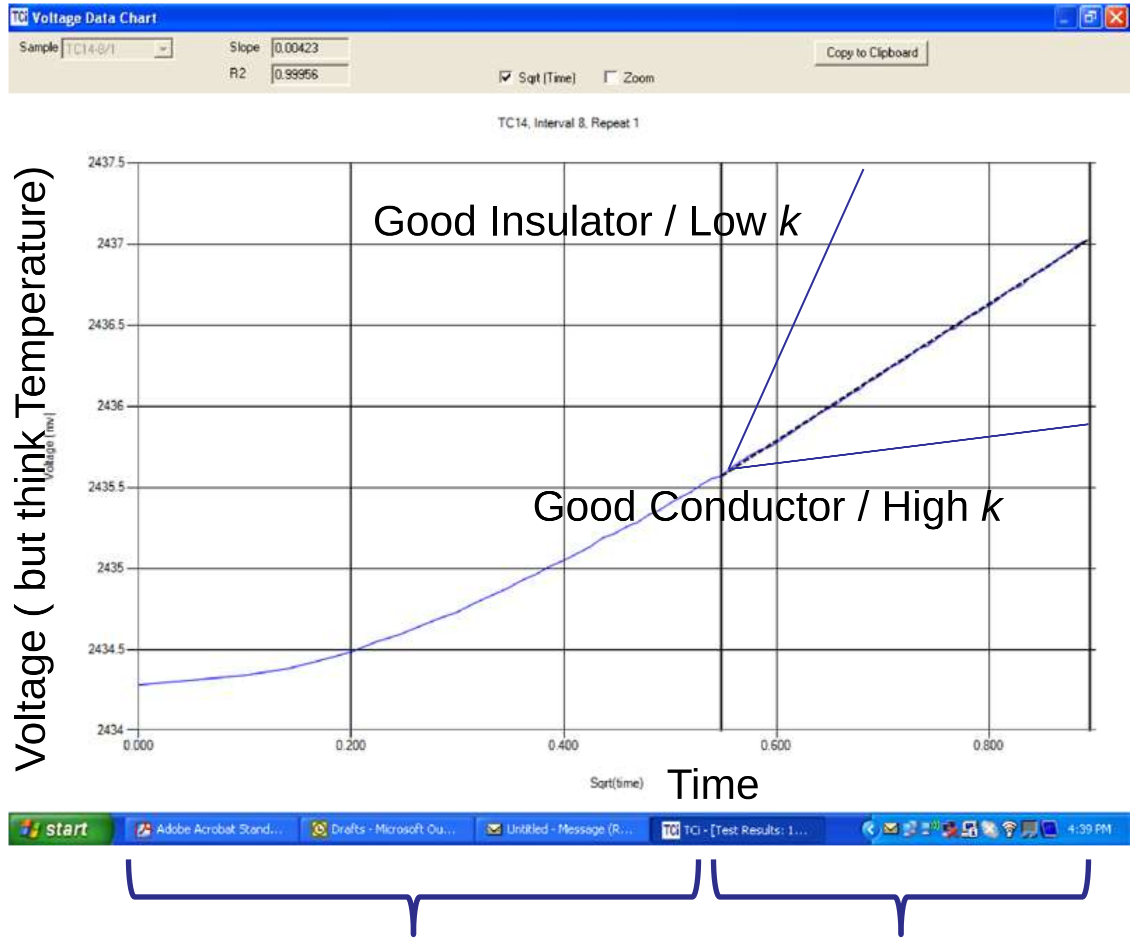


How the sensors work?

The thermal conductivity of the sample material is inversely proportional to the rate of increase in sensor voltage. The change in voltage drop correlates with an increase in temperature at the sensor interface.

The more thermally insulative the material is – the steeper the voltage rise.

Results are displayed on the system's laptop computer in real time.

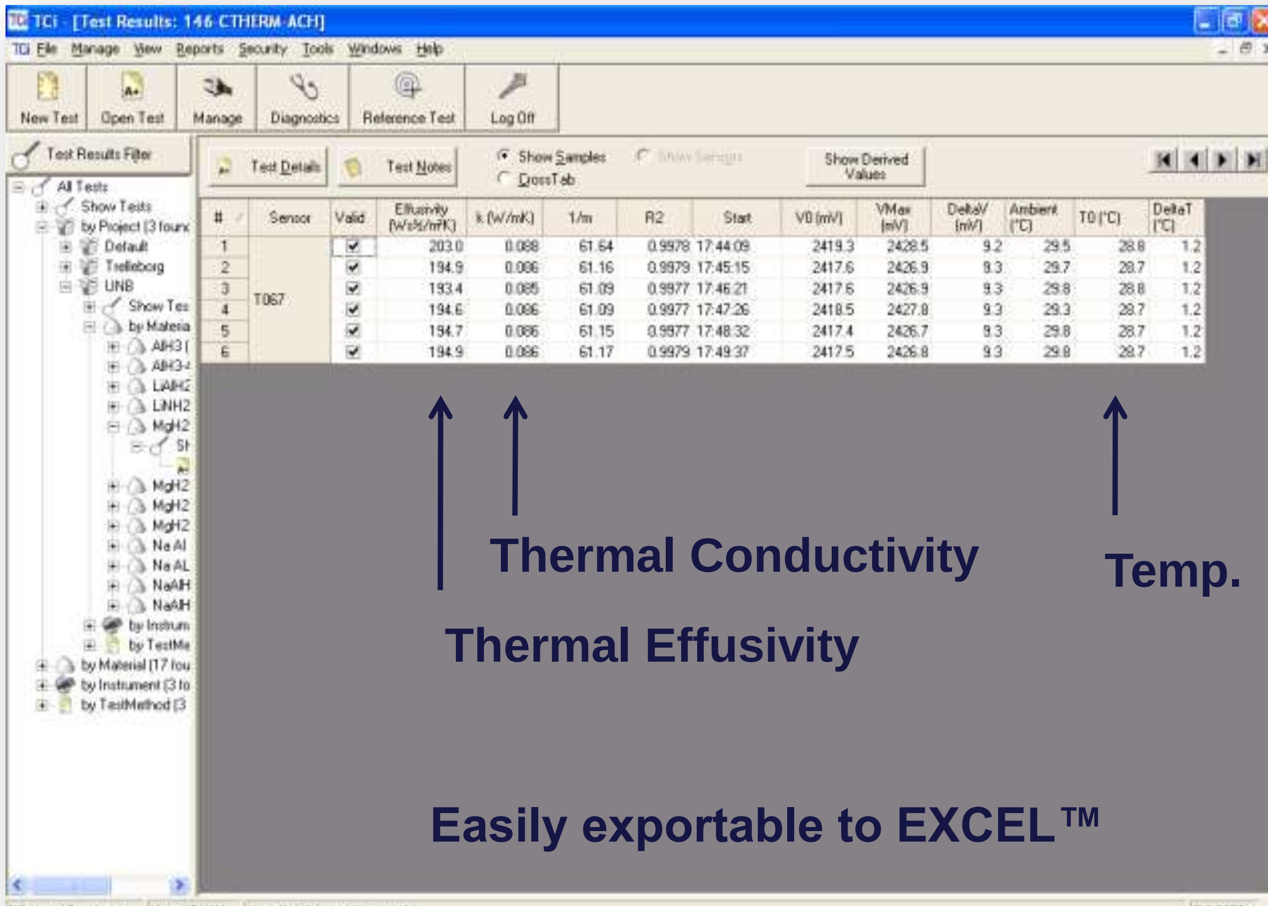


First 0.3 Seconds: Addressing Contact Resistance, Non-Linear

0.3 – 0.8 Seconds: Within Sample, Linear

No Interpretation Required

Results are presented in tabular format displaying:



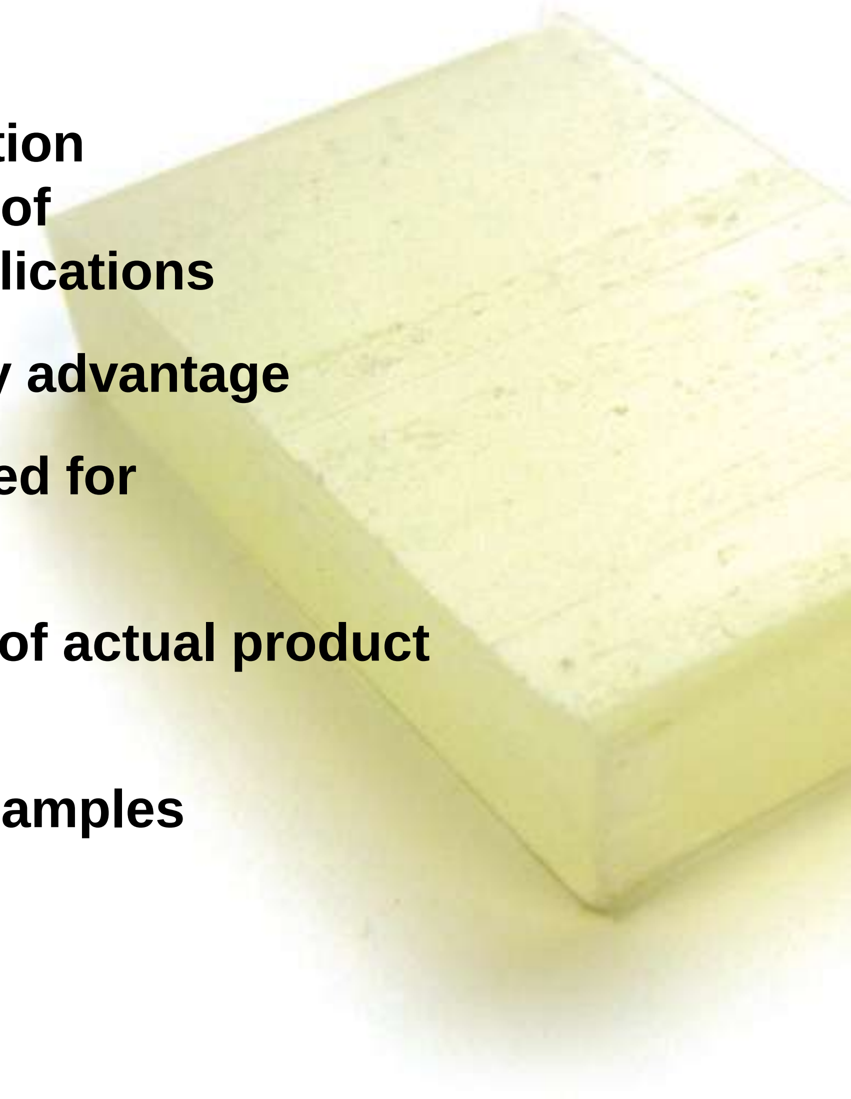
Fast

- No Calibration or Sample Preparation
- Instrument comes fully calibrated from the factory
- No sample preparation required for testing
- Rapid Testing
- 0 - 100 W/mK in only 0.8 to 5 seconds
- Accelerates your research or QC processes dramatically
- Highly accurate, repeatable testing
- Add a Second Sensor, theTCi can be equipped with two sensors to double your throughput

Flexible

Testing Solids

- **Breakthrough in the characterization of critical performance attributes of ceramics used for aerospace applications**
- **Simplicity of sample format is key advantage**
- **Eliminates technician time required for sample preparation**
- **Sample size flexibility evaluation of actual product formats**
- **Eliminates the need to mock-up samples**



Flexible

Testing Liquids

- **Helping manufacturers improve heat transfer properties of advanced nano-filled liquids**
- **Allows wide range of operating temperatures for the testing of engineered liquids**
- **Low amount of heat introduced during testing minimizes convective errors typical of liquid testing**
- **Can measure liquids through a bag – or directly**

Flexible

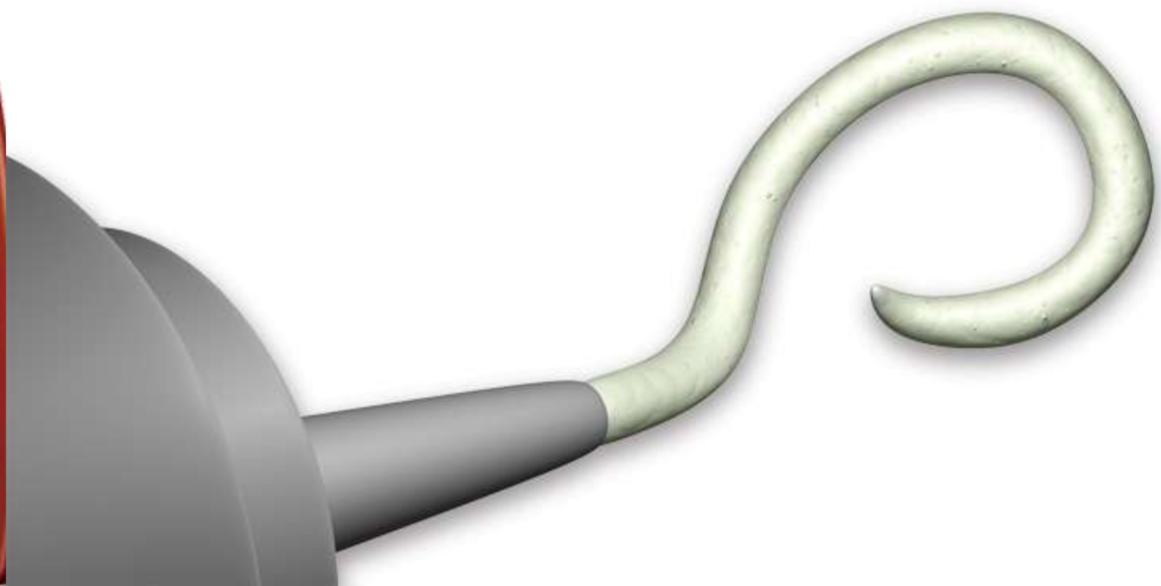
Testing Powders

- **Only instrument engineered for evaluating the thermal conductivity of powders**
- **Used to safely test the stability, degradation, and shelf life of explosives**
- **Sample volumes can be as small as 3/8 tsp**
- **Minimal samples are critical to pharma customers, where active ingredients are expensive and available in low quantities**
- **Migratable to manufacturing as a cost-effective way to monitor powder processes**

Flexible

Testing Pastes

- **Providing insights into all materials that contribute to the overall thermal budget for microprocessors**
- **Thermal interface pastes are a prime application for the TCi**
- **Testing allows different amount of heat penetration – resulting in a variable scale of scrutiny to ensure homogenous distribution of vital filler components**



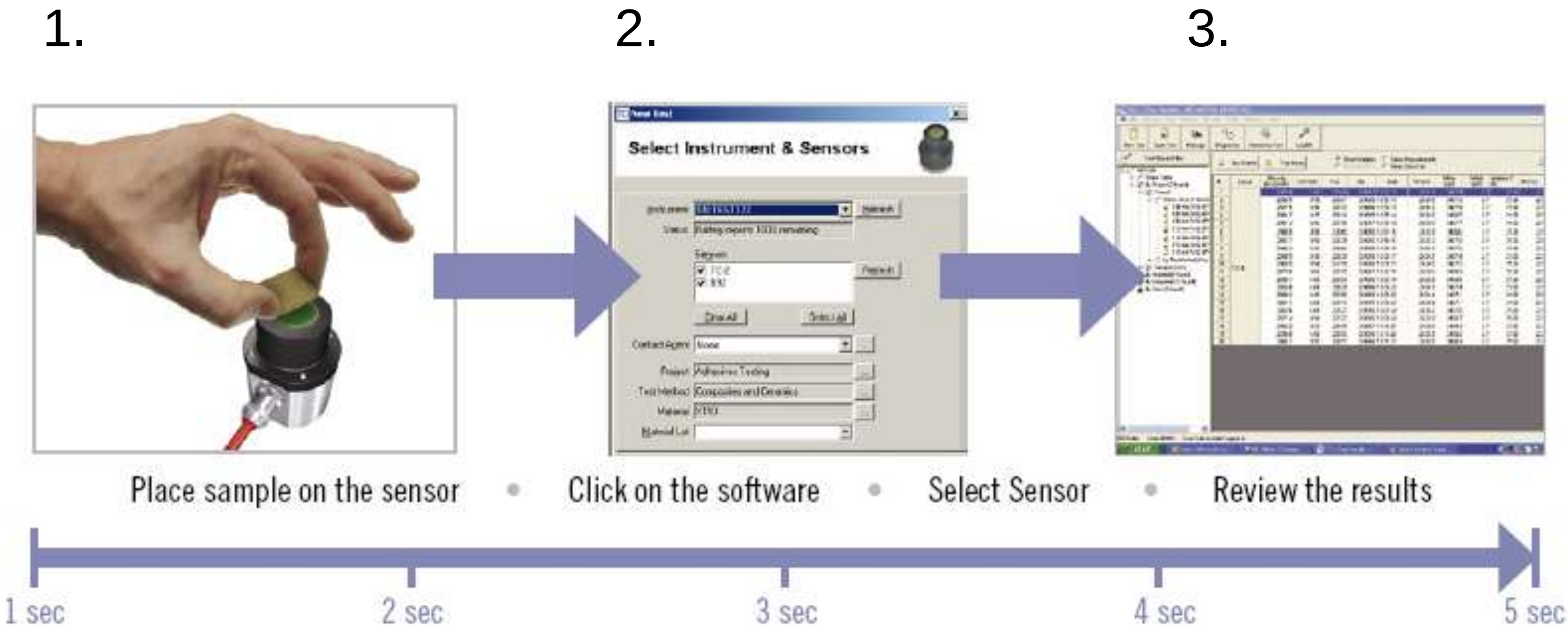
Flexible

Operate the TCi sensor in various environmental enclosures:

Thermal Chambers

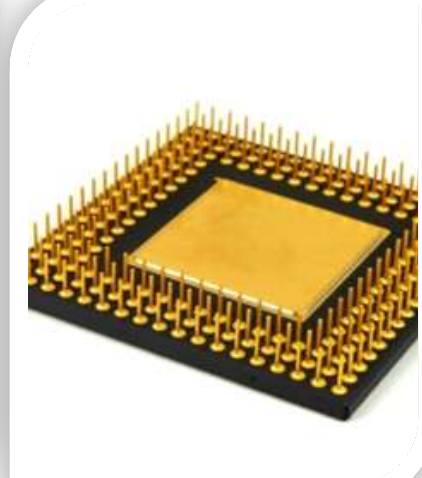
Glove Boxes

Easy



There isn’t a faster, easier way to generate thermal conductivity results on your sample materials!!!!

Step 1. Place sample on sensor.
Step 2. Press Start.
Step 3. Wait lest than 5 seconds for your first result.



C-THERM TCi™

Thermal Conductivity Analyzer

APPLICATIONS

Applications

IMPORTANT NOTE: with applicability in a wide and diverse range of industries, the following section touches only on a select few highlighted applications.

For more information on the comprehensive range of applications for the TCi please visit **www.ctherm.com** and refer to our vast technical library.

Application: Fuel Cell (Hydrogen Storage)

Background

Pic: Dr. Shane Beattie of the University of New Brunswick working with the TCi

In the development and characterization of metal hydrides for hydrogen absorption, the **thermal conductivity** of the material is an important material performance property. The thermal conductivity of the solid material is **important to know how long it will take to get the pellets to an equilibrium temperature to understand when they will begin releasing hydrogen**. Furthermore, it is important to know the thermal conductivity of these pressed powders while **engineering a storage device to use the powders commercially.**

The thermal conductivity of the material changes substantially from a powder to a compressed solid necessitating the direct measurement of both material formats.

Application: Hydrogen Storage

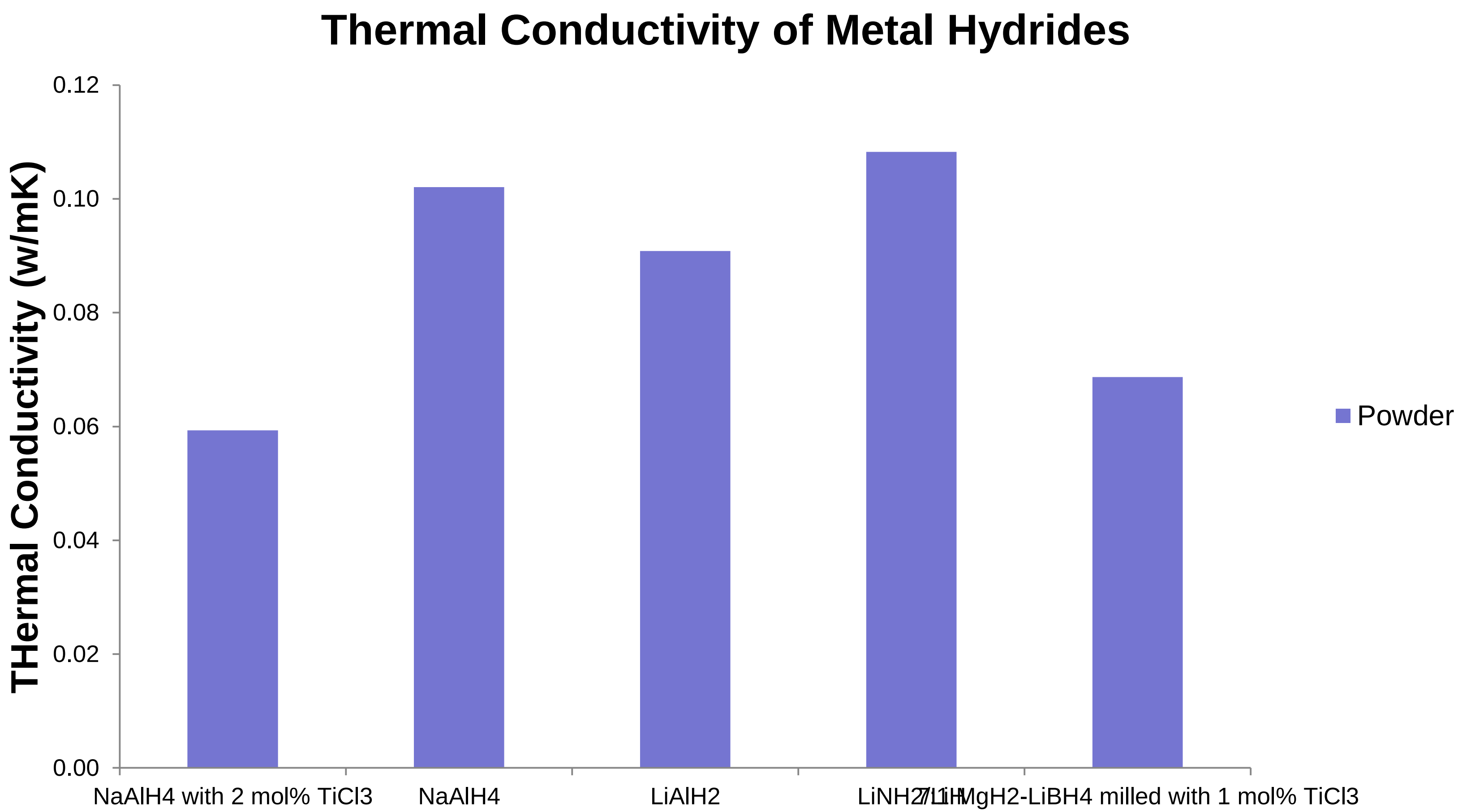
Special Setup

Due to the highly reactive nature of the materials the sample are tested in an argon or nitrogen purged glove box.

The TCi sensor cable is fed through one of the sealed ports – enabling the sensor to test both the powder and solid pressed pellets inside of the glove box.

Application: Hydrogen Storage

Results



Application: Explosives & Energetics

Application

Safety constraints have traditionally presented researchers with challenges in testing the thermal conductivity of energetic powdered materials. Minimal volumes of energetic powders can now be tested with the TCi in employing the modified transient plane source techique.

Profile Clients

- ✓ US Army & Navy (2X Each)
- ✓ NRC (Natural Resources Canada)
- ✓ Australian Defense Department

Tools & References

- ✓ Harris & Sorensen. *Testing Minimal Volumes of Energetic Powders*
- ✓ *Singh (et al). Physical Characterization, Accelerating Rate Calorimetry and Thermal Conductivity of Ammonium Nitrate Emulsion*
- ✓ *NEW: Archived Webinar Recorded by NRC*

Frank Kamenetskii Equation

$$T_c = \left[\frac{R}{E} \ln\left(\frac{d^2 \rho HZE}{T_c^2 \lambda \delta R} \right) \right]^{-1}$$

Where,

- d - diameter
- H,Z,E - kinetic parameters
- δ- shape factor
- **λ - thermal conductivity**
- R - gas constant
- ρ - density

Background

- **Critical Temperature using the Frank-Kamenetskii equation**
  - ✓ Kinetics of decomposition, heat capacity and thermal conductivity
- **Thermal conductivity via MDSC is not possible for powders/liquids**
- **Need for rapid, safe measurement**
  - ✓ Minimize volume requirement
  - ✓ Eliminate ESD potential
  - ✓ Limit opportunities for powder ingression

Accuracy

Table A1: Accuracy Test Results vs. Certified Values

Sample	Measured k (W/mK)	Avg. of the Measured k (W/mK)	RSD (%)	Real k (W/mK)	Accuracy (%)
PDMS	0.162194	0.162865	0.24%	0.159	2.43%
	0.162951				
	0.162945				
	0.163008				
	0.163226				

Reference Material: PDMS (DiMethyl PolySiloxane Silicone Fluid)

Sample Material

Ammonium perchlorate (NH_4ClO_4.) was measured with a bulk particle size of 200µ

Ammonium perchlorate: used commonly as an oxidizer in solid rockets.

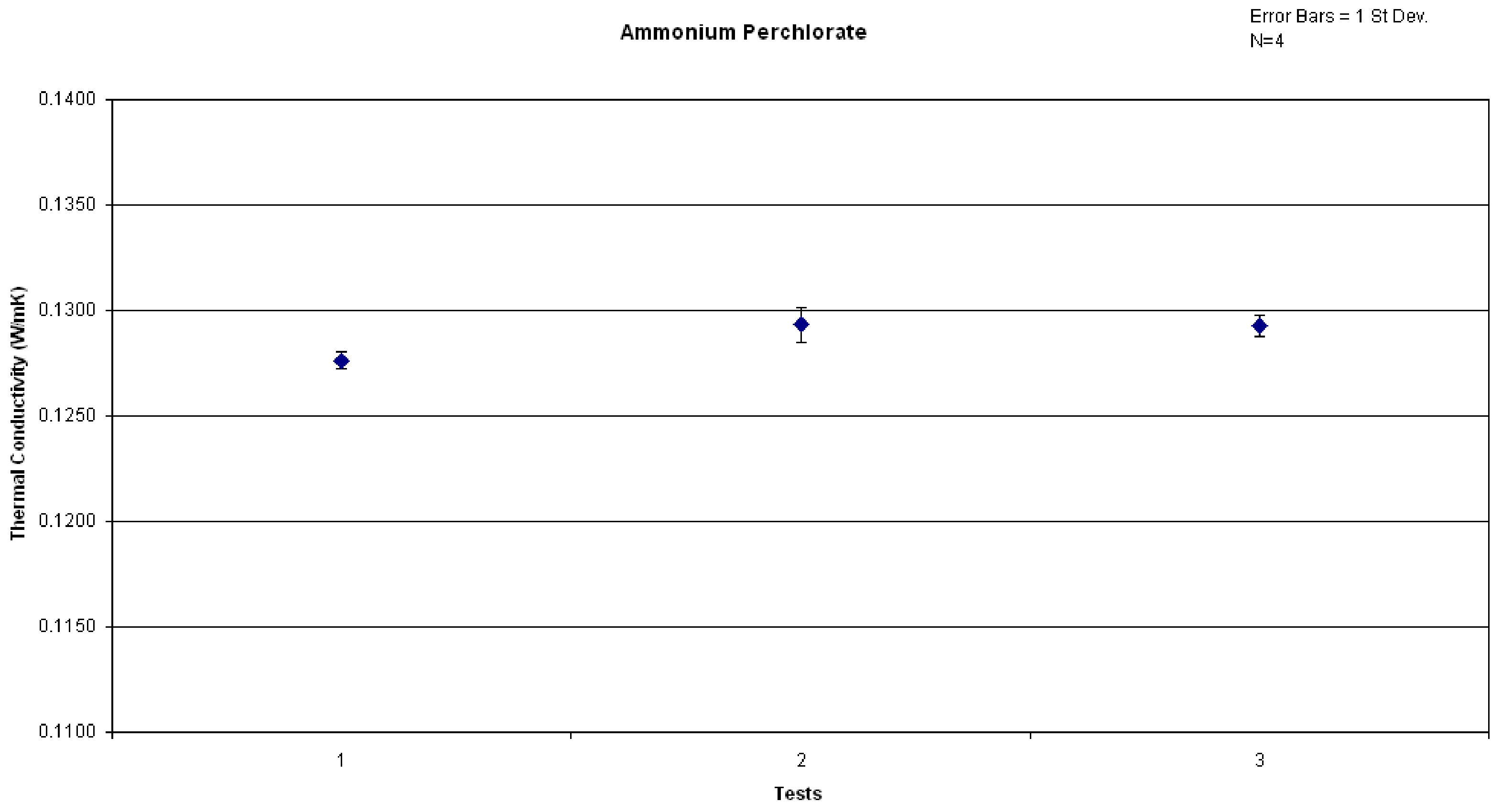
Testing Method

Pictures are example only and do not show ground wires.

Results

Test	Thermal Conductivity (W/m·k)	Average (W/m·k), N=4	RSD[1] (%), N=4	Average (W/m·k), N=3	RSD (%), N=3
1	0.127086	0.1276	0.31%	0.1288	0.75%
	0.127641				
	0.127866				
	0.127969				
2	0.130499	0.1293	0.64%		
	0.128595				
	0.128970				
	0.129272				
3	0.129295	0.1293	0.38%		
	0.129967				
	0.128839				
	0.129063				

Results


Ammonium Perchlorate
Error Bars = 1 St Dev.
N=4
Thermal Conductivity (W/mK)
0.1400
0.1350
0.1300
0.1250
0.1200
0.1150
0.1100
1
2
3
Tests

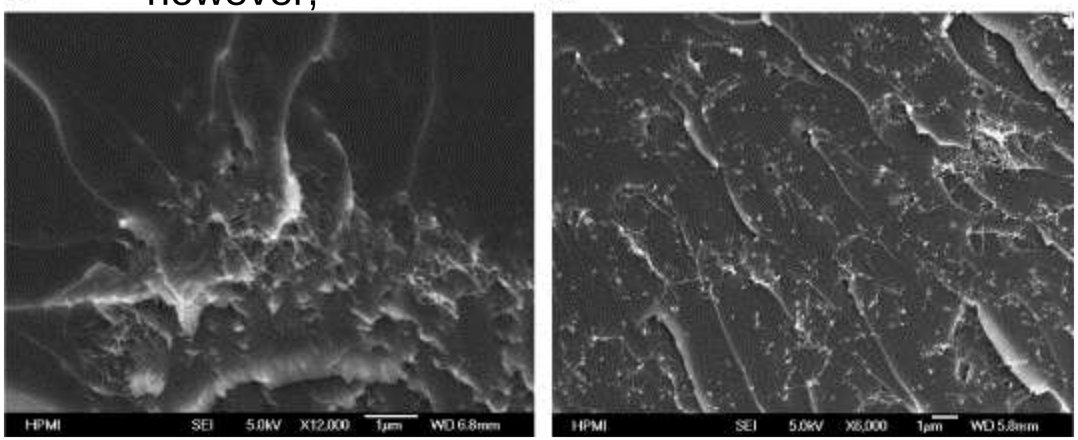
Conclusion

- The thermal conductivity of a volume of approximately 3/8 teaspoon of ammonium perchlorate was measured with an accuracy of better than 2.5%.
- Further studies are recommended to investigate the relationship between particle size, moisture content, and packing density on the thermal conductivity.

Application: Carbon NanoTubes (CNTs)

Background

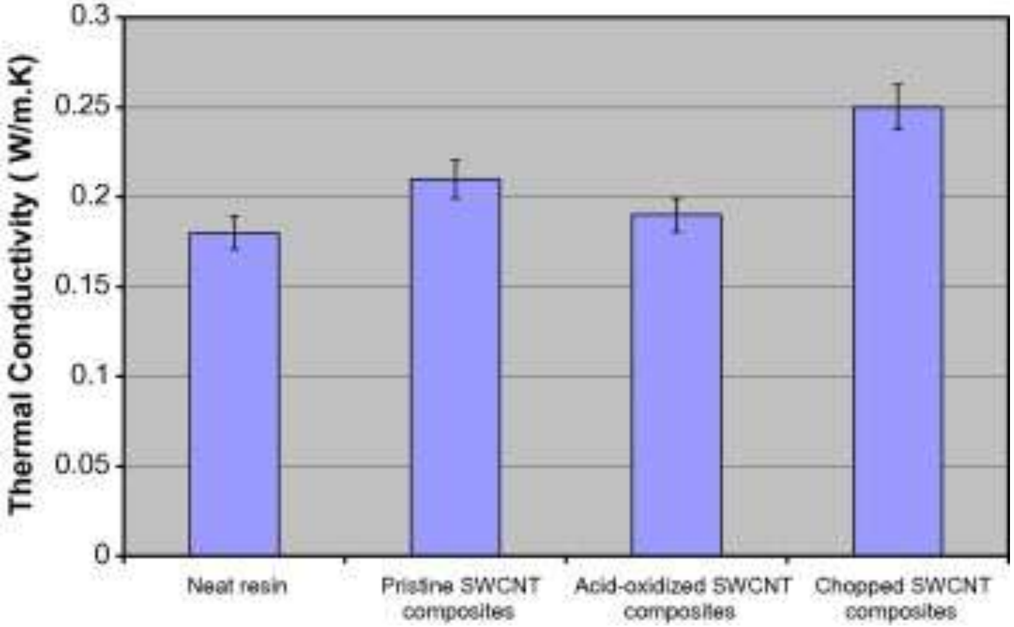
Carbon NanoTubes (CNTs) have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science, as well as potential uses in architectural fields. **They exhibit extraordinary strength and unique electrical properties, and are extremely efficient conductors of heat.** CNTs tend to aggregate and cluster however, resulting in poor dispersion and inferior properties. **Thermal conductivity is an important peformance attribute** as researchers assess the impact of mechanically altering the single walled carbon nanotubes (SWCNTs) to produce short and open-ended fullerene pipes for better dispersion used in polymer composites.



SEM images of pristine SWCNT/epoxy and shortened SWCNT/epoxy composites. (a) Dispersion of pristine SWCNTs in epoxy resin. (b) Dispersion of shortened SWCNTs in epoxy resin.

Application: Carbon NanoTubes (CNTs)

Results



The Univesity of Texas Tech found with their TCi that shortening the CNTs did not adversely impact the thermal conductivity. This was important as shortening the CNTs considerably improved the dispersion in the composites.

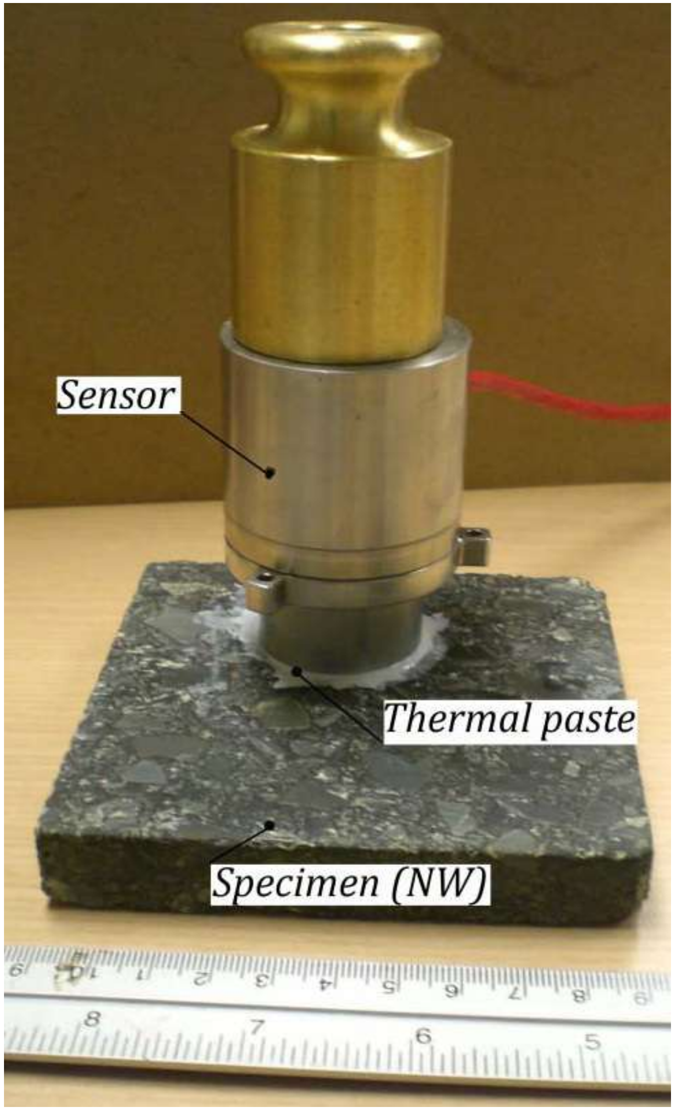
Application: Carbon NanoTubes (CNTs)

- **Profile Clients**
  - ✓ Texas Tech University
- **Tools & References**
  - ✓ Wang, Liang, Wang & Zhang. *Dispersion and thermal conductivity of carbon nanotube composites*
    - LINK: http://dx.doi.org/10.1016/j.carbon.2008.08.024

Application: Asphalt and Concrete

Application: Asphalt and Concrete

Sample



Application: Asphalt and Concrete

Specimen	Bulk density, kg/m^3	C-Therm TCi Modified Transient Plane Source (MTPS)		Guarded Hot Plate (GHP)		Traditional Transient Plane Source (TPS)	
		k, W/m·K	RSD*, %	k, W/m·K	RSD, %	k, W/m·K	RSD**, %
LW1	1686	0.841	2.62	0.845	n/a	-	-
LW2	1587	0.786	3.24	0.785	n/a	-	-
NW1	2585	2.124	3.12	-	-	2.008	1.12
NW2	2459	2.206	2.07	-	-	2.187	1.16

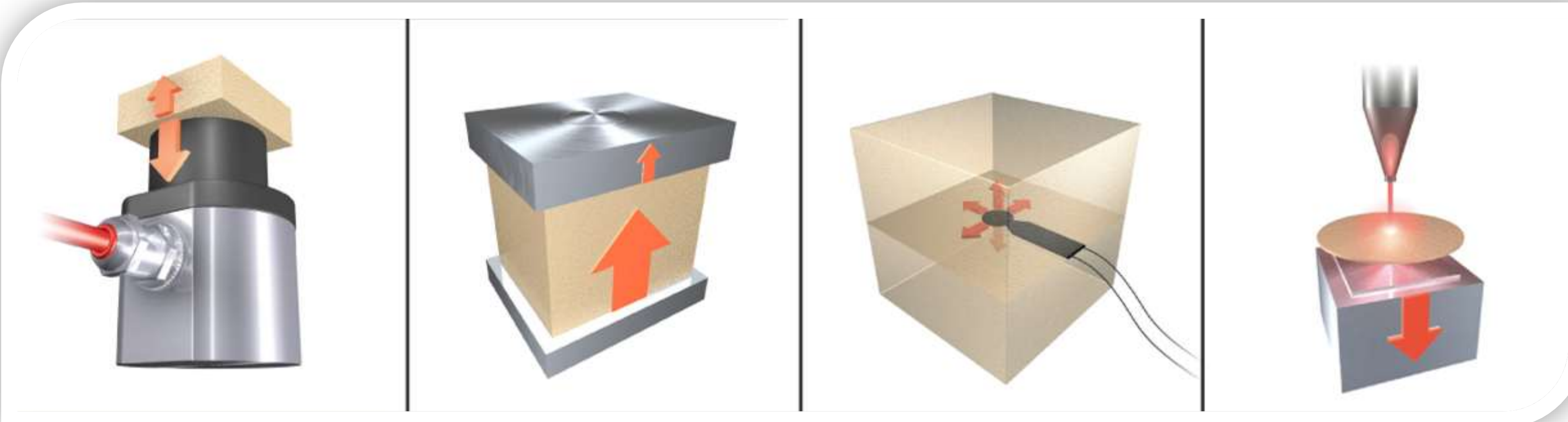
*RSD of five measurements across six different locations.

**RSD of five measurements at the same location.

Application: Food Products

Conclusion:

- Results show a good correlation
- Sample results for the light weight asphalt (LW1 and LW2) and the normal weight (NW2) provide a better than 1% agreement.
- Sample results for NW1 differed by approximately 6% which is likely due to positional bias of where the TPS sensor was located in relation to the multiple sample locations tested with the MTPS sensor.
- Advantage to the TCi is the ability to look at the relative homogeneity of the sample in understanding how this impacts the localized thermal conductivity performance.

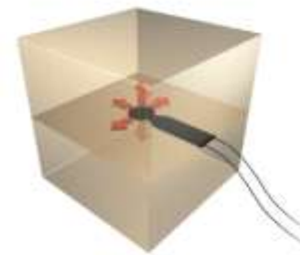


C-THERM TCi™
Thermal Conductivity Analyzer

HOW DO WE COMPARE

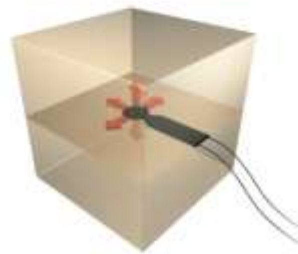
Competitive Positioning

Superior to Other Test Methods[1]:

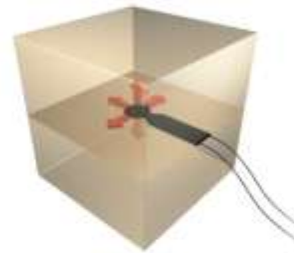
	 Mathis TCi (Modified Transient Plane Source)	 Traditional Guarded Hot Plate	 Transient Plane Source	 LaserFlash Diffusivity
Sample Configuration				
Minimum	0.67" diameter (17mm)	6" x 6" (150 x 150mm)	Two Identical Samples 1" x 1" (25 x 25mm)	0.5" diameter (12.4mm) 0.004" thick (1mm)
Maximum	Unlimited	24" x 24" (600 x 600mm)	Two Identical Samples Unlimited	0.5" diameter (12.4mm) 0.004" thick (1mm)
Material Testing Capabilities	Solids, Liquids, Powders, Pastes	Solids	Solids, Liquids	Solids

Competitive Positioning

Superior to Other Test Methods[1]:

	 Mathis TCi (Modified Transient Plane Source)	 Traditional Guarded Hot Plate	 Transient Plane Source	 LaserFlash Diffusivity
Speed & Flexibility				
Sample Preparation	None Required	Extensive	Some	Extensive
Testing Time	Seconds	Hours	Minutes	Seconds*
Training Time	Minimal	Moderate	Significant	Extensive
Non-Destructive	Yes	No	No	No
Integrated, Downloadable Test Results Database	Yes	No	No	No

Competitive Positioning

Superior to Other Test Methods[1]:				
	 **Mathis TCi** (Modified Transient Plane Source)	 **Traditional Guarded Hot Plate**	 **Transient Plane Source**	 **LaserFlash Diffusivity**
Range				
k-Range (W/mK)	**0 – 100**	0 – 2	0 – 100 (100 – 500 requires C_p)	0 – 500
Temperature Range (°F) (°C)	**-58° to 392°F -50° to 200°C**	-4° to 392°F -20° to 200°C	-148° to 2552°F -100° to 1400°C	-148° to 3627°F -100° to 2000°C
Pricing	$	$ $	$ $	$ $ $

Comparison to Traditional Techniques

Material	TCi Result (W/mK)	Reference Value (W/mK)	Comparative Technique	Source	% Difference
PYREX	1.17	1.135	Guarded Hot Plate (GHP)	BCR Certification Report for a Pyrex Reference Sample	3.04%
PDMS	0.162	0.159	Hot Wire (HW)	Bashar, University of New Brunswick	1.87%
LAF	0.0880	0.086	Transient Plane Source (TPS)	Hume, 3rd Party Contract Lab	2.30%
Water -gel	0.626	0.627	Hot Wire (HW) & Modified Hot Wire (MHW)	Picot & Bashar, University of New Brunswick	0.16%

Presented by Dr. Robert Bateman of the University of New Brunswick at ITCC (International Thermal Conductivity Conference) 2009, Pittsburgh PA

Client Testimonial

Website: www.ctherm.com

- Resources
- Technology
- Video Demonstration
- Client Testimonials
- News

Upcoming Webinars

Date	Topic
Thur., April 7th	TCi Application Highlight: Rock On! (Geology)
Tue., April 12th	TCi Application Highlight: Hit the Road (Asphalt & Concrete)

Questions for C-Therm?

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THANK YOU!