An Introduction to Thermal Conductivity Techniques

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C-THERM TECHNOLOGIES Ltd.

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

Manning Innovation Awards – Prix d'innovation Manning

R&D 100 WINNER

C-THERM PRODUCT LINES

THERMAL CHARACTERIZATION

C-Therm TCi™ Thermal Conductivity Analyzer

Clients include:

- NRC
- Whirlpool
- Kodak
- Philip Morris
- US Navy
- ICI

PHARMACEUTICAL APPLICATIONS

C-Therm ESP™ Effusivity Sensor System

Clients include:

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

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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/m^3)

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

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What is Thermal Conductivity?

Definition : Thermal conductivity (k) is the rate at which heat flows through a material under a temperature gradient. It is a physical property of a material. The value of thermal conductivity determines the quantity of heat passing per unit of time per unit area at a temperature drop of 1-degree C per unit length. In the limit of infinitesimal thickness and difference in temperature, the fundamental law of heat conduction is:

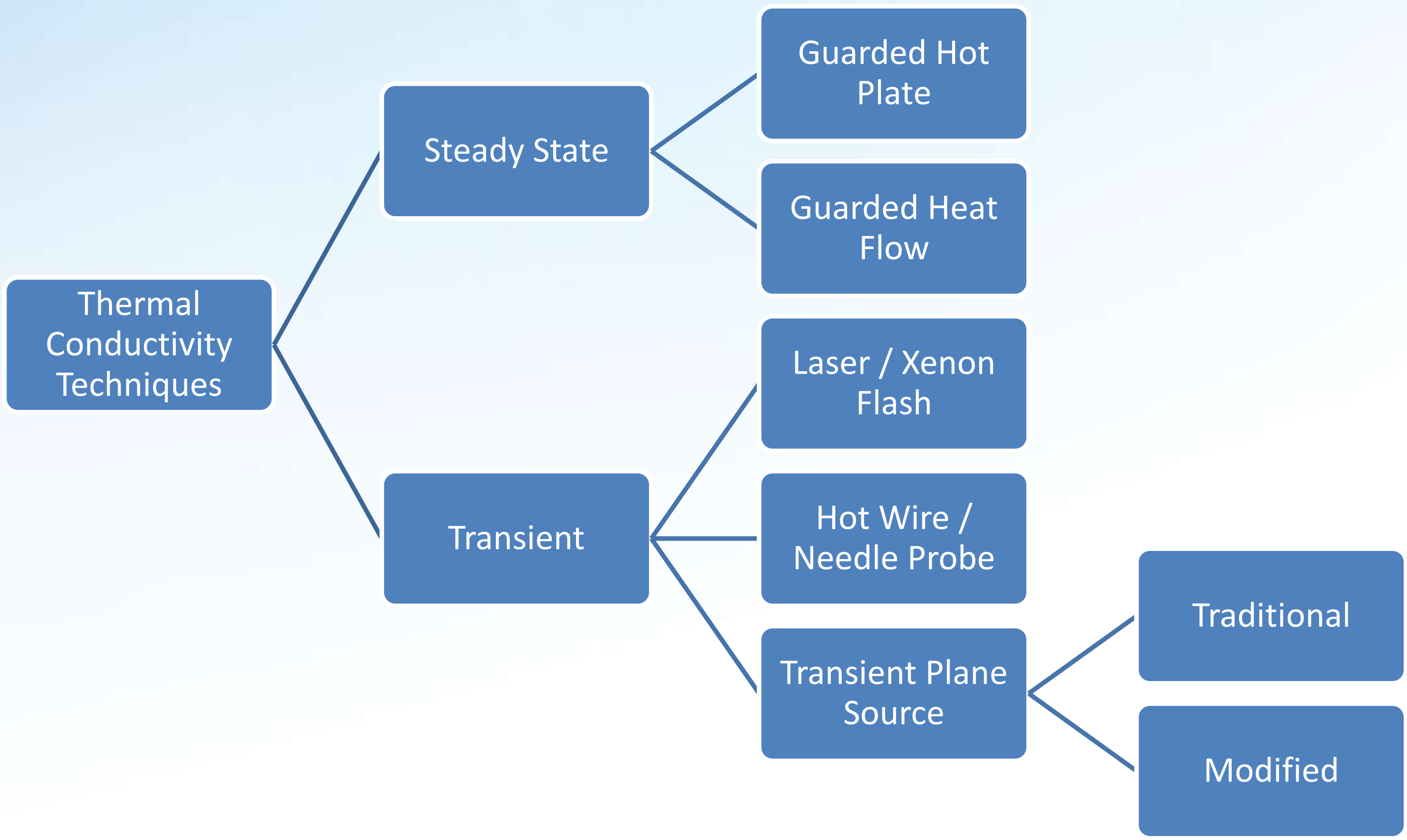
$$Q = \lambda A dT / dx$$

Where:

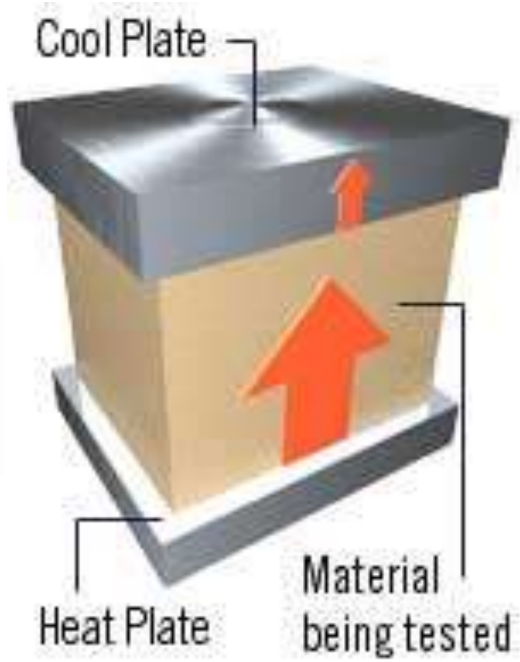
- Q is a measure of the heat flow
- A is a the cross sectional area
- dT / dx is the temperature / thickness gradient
- k is defined as the thermal conductivity

Thermal conductivity differs with each substance and may depend on the structure, density, humidity, pressure and temperature. Materials having a large thermal conductivity value are good conductors of heat; one with a small thermal conductivity value is a poor heat conductor i.e. good insulator. Hence, knowledge of the thermal conductivity value (units W/m•K) allows for quantitative comparisons to be made between the thermal insulation efficiencies of different materials.

Thermal Conductivity Techniques



Guarded Hot Plate & Guarded Heat Flow



How it works: Both are steady state techniques that involve placing a solid sample of fixed dimension between two temperature controlled plates. One plate is heated while the other is cooled and temperatures of the plates are monitored until they are constant. The steady state temperatures, the thickness of the sample and the heat input to the hot plate are used to calculate the thermal conductivity.

Variations

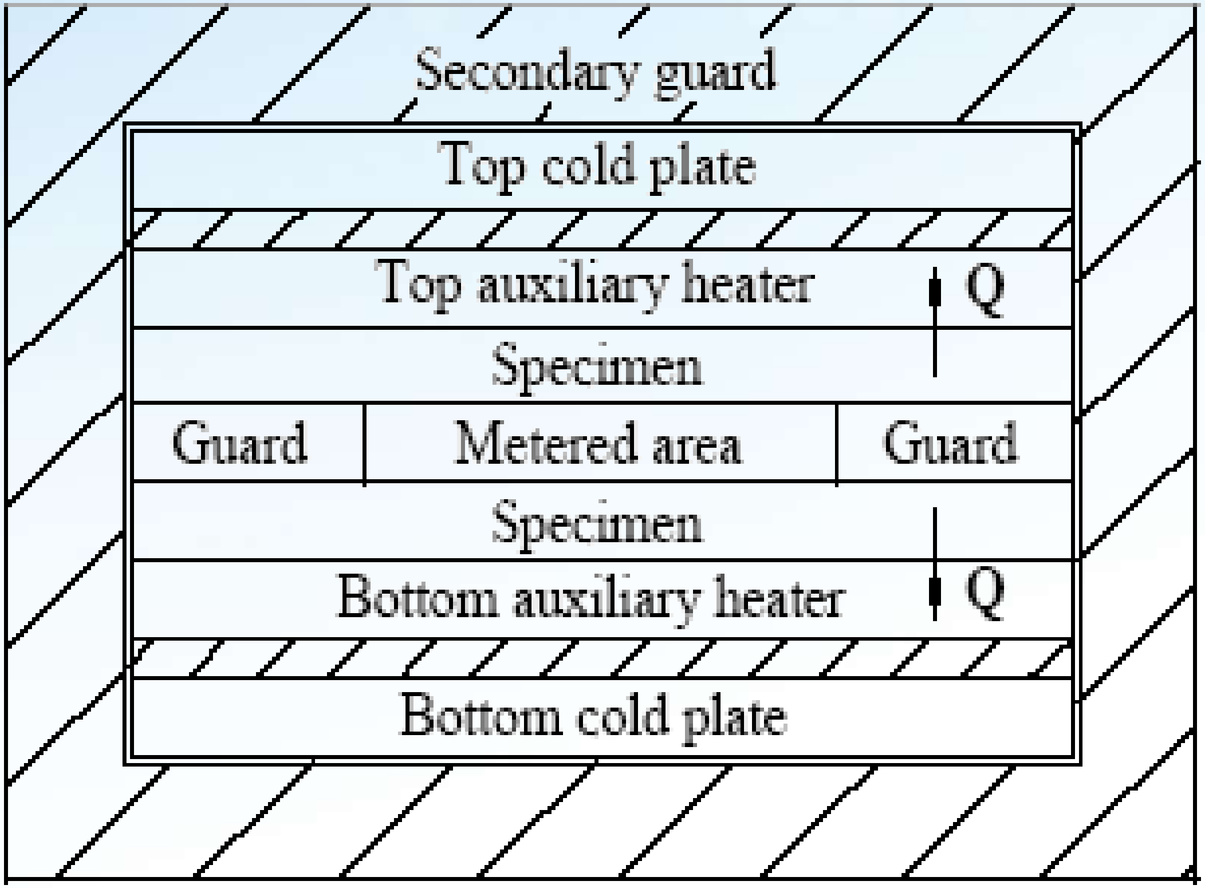
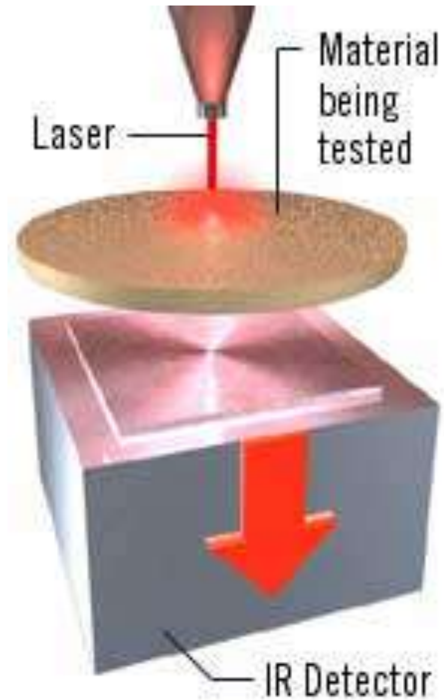


Image Source: http://www.azom.com/article.aspx?ArticleID=2667

Laser / Xenon Flash Measurement



How it works: Laser flash diffusivity is a transient method that involves applying a short pulse of heat to the front face of a specimen using a laser flash, and measuring the temperature change of the rear face with an infrared (IR) detector. The resulting temperature rise of the other face of the test specimen is monitored as a function of time and used, together with the sample thickness, to determine the thermal diffusivity. This can be combined with density and heat capacity data to calculate thermal conductivity.

Caution on use of Laser Flash (LF) on some composite materials

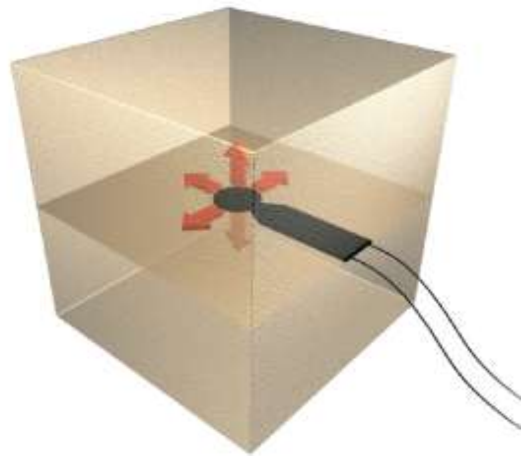
"Testing of Composite Materials – When substantial inhomogeneity and anisotropy is present in a material, the thermal diffusivity data obtained with this method may be substantially in error. Nevertheless, such data, while usually lacking absolute accuracy, may be useful in comparing materials of similar structure. Extreme caution must be exercised when related properties, such as thermal conductivity, are derived, as composites may have heat flow patterns substantially different than uniaxial."

ASTM E 1461

Hot Wire / Needle Probe Methods

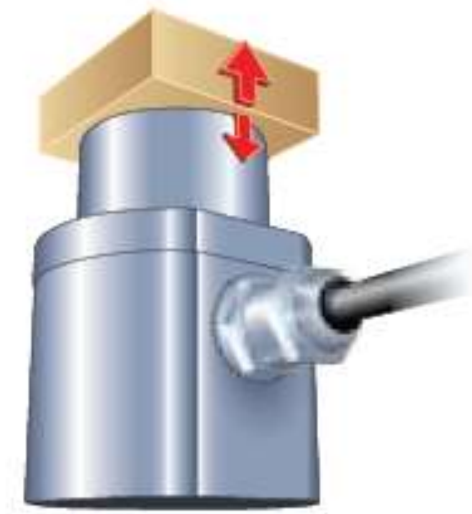
How it works: a transient technique involves placing an electrically heated wire into a material. This method is generally limited to testing foams, fluids, soil and melted plastics. The heat flows out radially from the wire into the sample and the temperature of the wire is measured. By plotting the temperature of the wire versus the logarithm of time, thermal conductivity can be calculated.

(Traditional) Transient Plane Source



How it works: The probe is a flat sensor with a continuous double spiral of electrically conducting nickel (Ni) metal etched out of thin foil and clad between two layers of Kapton. The thin Kapton provides electrical insulation and mechanical stability to the sensor. The sensor is placed between the surfaces of two sample pieces of the sample to be measured. During the measurement a current passes through the nickel and creates an increase in temperature. The heat generated dissipates through the sample on either side of the sensor at a rate depending on the thermal transport characteristics of the material. By recording temperature vs. time response in the sensor, the characteristics of the material can be calculated.

Modified Transient Plane Source (MTPS)



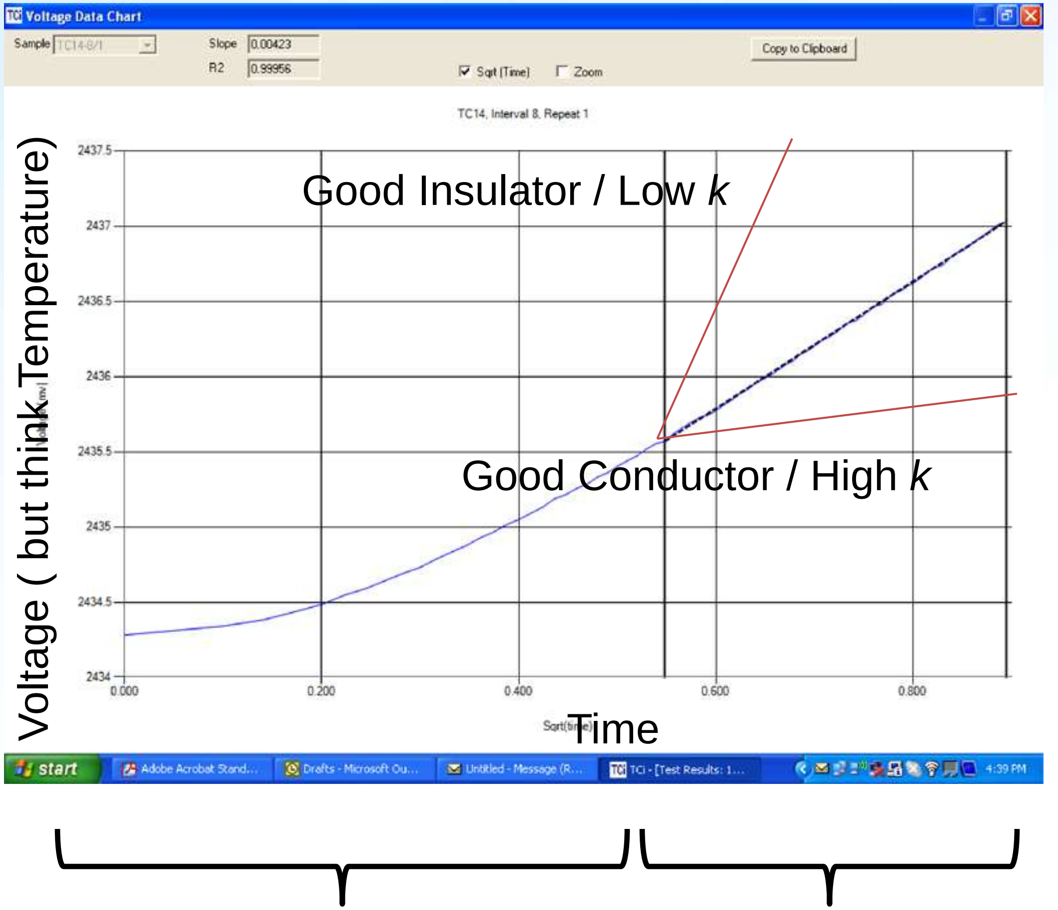
How it works: this approach is a transient technique that uses heat reflectance, similar to Hot Wire testing. The modification is that the heating element is supported on a backing, thus allowing a one-directional heat flow. This allows the testing to be non-intrusive and permits the testing of solids without the need to be melted. Therefore, the temperature of the heating element versus the time function is used to calculate the thermal conductivity and thermal effusivity.

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.

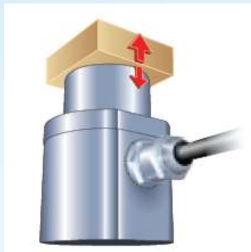
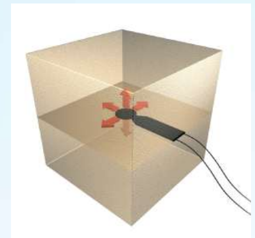
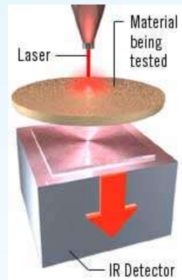
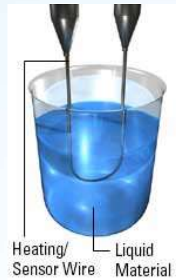
Results are displayed on the system's laptop computer in real time.



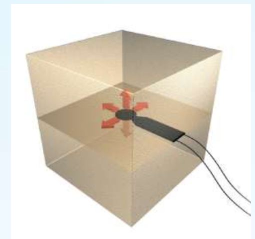
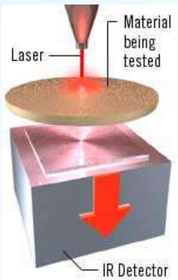
First 0.3 Seconds: Addressing Contact Resistance, Non-Linear

0.3 – 0.8 Seconds: Within Sample, Linear

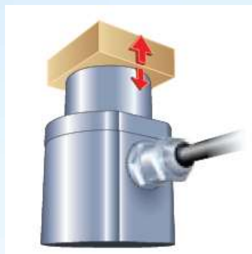
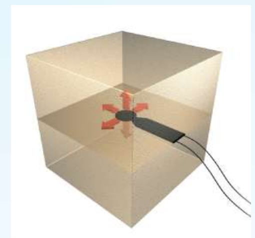
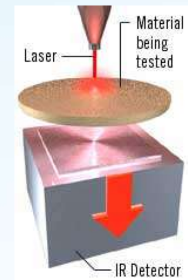
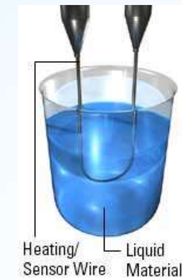
Sample Configuration

	MTPS	GHP	TPS	Laser Flash	Hot Wire
					
Minimum	17mm	150 x 150mm	two identical samples: 25 x 25mm	12.4 mm diameter, 1mm thick	30 mm, 1.27 mm Dia.
Maximum	unlimited	600 x 600mm	Two Identical Samples Unlimited	12.4mm diameter , 1mm thick	unlimited
Format	Solids, Liquids, Powders & Pastes	Solids	Solids & Liquids	Solids	Liquids and Powders

Speed and Versatility

	MTPS	GHP	TPS	Laser Flash	Hot Wire
					
Sample Prep	None	Extensive	None	Moderate	Some
Testing Time	Seconds	Hours	Minutes	Seconds (but requires Cp data)	Minutes
Training Time	Minimal	Significant	Moderate	Significant	Minimal
Non-Destructive	Yes	No	No	No	Depends

Ranges & Cost

	MTPS	GHP	TPS	Laser Flash	Hot Wire
					
k-range (W/mK)	0 - 100	0 - 2	0 – 100 (100 – 500 requires Cp)	0 – 500	0 – 0.6
Temp (°C)	-50 to 200	-20 to 200	-100 to 1400	-100 to 2000	-15 to 60
Cost ($)	$$	$$$$	$$$	$$$$	$

Some Considerations in Comparing Results

- Sample Homogeneity
- Scale of Scrutiny / Evaluated Volume
- Compression Bias / Densification
- Convection Error
- Impact of Contact Resistance

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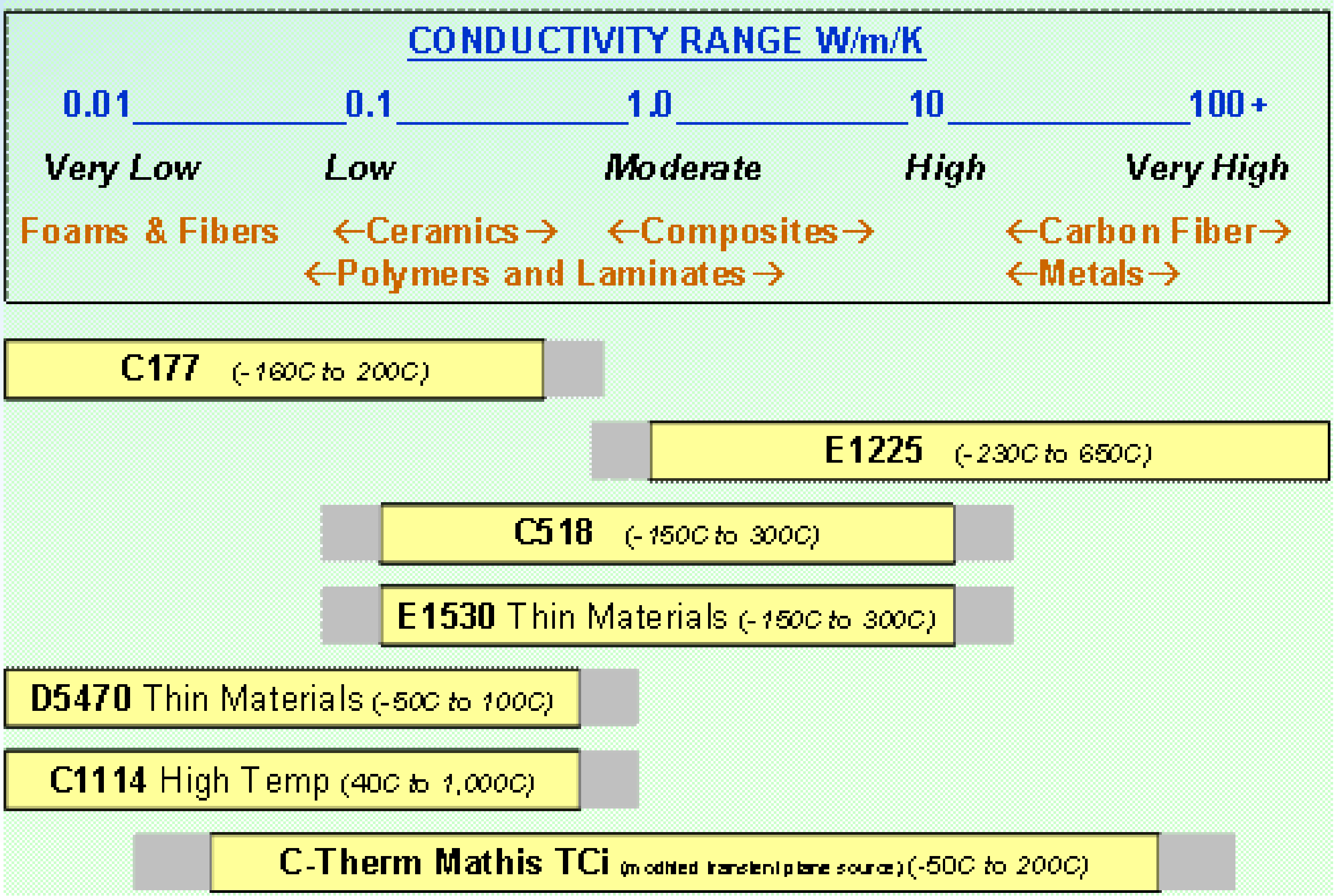
Test Selector used by Contract Testing Lab



Provided by PMIC, Corvallis OR USA

ASTM Methods – Thermal Conductivity Related

C177 - Guarded Hot Plate

C335 – pipe insulation

C408 – whiteware ceramics

C518 – heat flow meter apparatus

C653 – Thermal resistance of low-density mineral blanket-type Fiber insulation

C687 – loose fill

C1041- heat flux in industrial thermal insulation , using heat flux transducers

C1043 – guarded hot plate

C1044 - steady state thermal transmission, guarded hot plate, one-sided mode

C1045 - calculating R value, steady state

C1046 - building envelopes

C1058 – thermal insulation

C1113 – hot wire

C1114 - steady-state thermal transmission, thin heater

C1130 - calibrating thin heat flux transducers

C1132 – calibration of heat flow meter apparatus

C1155 – building envelopes

C1199 - hot box methods

D1518 – textiles

D2717 - liquids

D5334 – Thermal needle probe

D5470 – electrical insulation

D5930 – line source

D6744 - guarded heat flow meter

D7024 - textiles

E1225 – metered steady state

E1423 thermal transmittance

E1461 – laser flash

E1530 – Guarded heat Flow meter

E1952 - moderated DSC

E2584 – slug calorimeter

F433 – gaskets

F955 - clothing

ISO-8301 – similar to C518

Website: www.ctherm.com

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

Questions?

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THANK YOU!

C-THERM TECHNOLOGIES Ltd.