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Closer Tolerance Thermal Management at the Device-Under-Test

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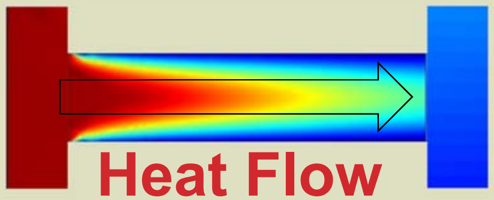
Thermal Management

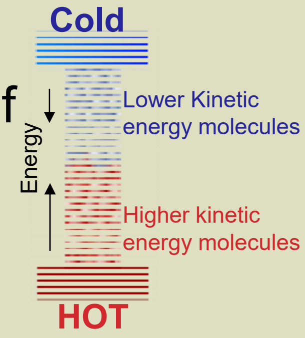
- Thermal Management is the ability to control the temperature of a system
- Heat by definition is energy in transit due to a temperature difference Heat flows from higher temperature to lower temperature

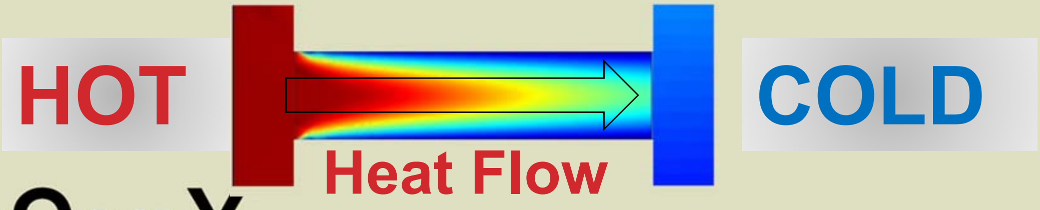


Nature Likes Balance

Temperature and Heat

- What is temperature and what is heat
  - Temperature is the physical property which determines the direction of **heat** flow
  - Temperature is the physical property of a system that provides a measure of **hotness** or **coldness**
  - Temperature is a measure of the average kinetic energy of molecules in a body
  - Heat flows from higher temperature to lower temperature





Analogies

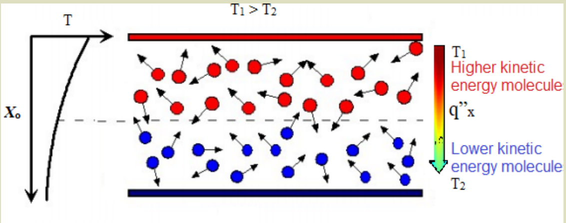
- Electrical engineers use Ohm's law as an analogy when doing thermal resistance calculations
- Mechanical and structural engineers use Hooke's Law and use it as an analogy when doing thermal resistance calculations

Type	**Structural Analog**	**Hydraulic Analogy**	**Thermal**	**Electrical**
Quantity		Volume V [m^3]	Heat Q [J]	Charge q[C]
Potential	Displacement X[m]	Pressure P[n/m^2]	Temperature T[$K=j/k_b$]	Potential V[V=J/C]
Flux	Load of force F [N]	Flow rate Q [$N/m^3/s$]	Heat Transfer rate Q [W=J/s]	Current I [A=C/s]
Flux Density	Stress σ[$Pa=N/m^2$]	Velocity **v**[m/s]	Heat Flux q [W/m^2]	Current Density **j** [$C/(m^2 \cdot s)=A/m^2$]
Resistance	Flexibility 1/k […]	Fluid resistance R[…]	Thermal Resistance R [K/W]	Electrical Resistance R [Ω]
Conductivity	Stiffness k [N/m]		Thermal Conductivity 1/R [W/(K·m)]	Electrical Conductance 1/R […]
Lumped element linear model	Hooke's Law $\Delta X=F/k$	Hagen-Poiseuille Equation P=QR	Newton Law of Cooling T=QR	Ohms Law V=IR
Distributed linear model			Fourier's law $Q=-k\nabla T$	Ohm's law $J=\sigma E$

Closer Tolerance Thermal Management at the Device-Under-Test

Heat Transfer

- Heat flows in response to a temperature gradient
- If two points are in thermal contact and at different temperatures, (e.g., T 1 and T 2) then energy is transferred between the two in the form of heat, Q
- The rate of heat flow from T1 to T2 depends on the two temperatures and the material conductivity
- If heat flows from hot to cold, (the standard convention)



$$Q = \frac{kA}{l}(T_1 - T_2)$$

A is area
l is length
k is thermal conductivity

Thermal diffusivity of selected materials and substances

Material	Thermal diffusivity (mm²/s)
Gold	127
Copper at 25 °C	111
PVC (Polyvinyl Chloride)	0.08
Brick, adobe	0.27
Wood (Yellow Pine)	0.082

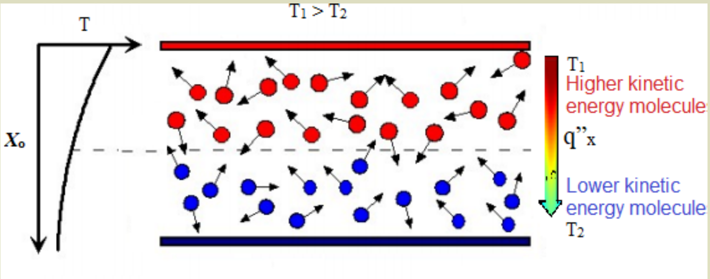
In heat transfer analysis: Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at constant pressure

Conduction Heat Transfer

$$q''_x = -k\frac{dT}{dx} \qquad \frac{dT}{dx} = \frac{T_2 - T_1}{L}$$

- *q*” is the heat flux i.e., the heat transfer rate
- *x* is the transfer rate per unit area perpendicular to the direction
- *k* is the thermal conductivity (W/m) and is characteristic of the contact probe material and device lead material
- - the minus sign is a consequence of heat transferred in the direction of decreasing temperature
- In short: Heat flow is in response to temperature gradient

If two points are in thermal contact and at different temperatures, T1 and T2, then energy is transferred between the two



Forced Convection Heat Transfer

Convection is heat energy transferred between a surface and a moving fluid with different temperatures as convection.

A fluid is anything that has loosely moving molecules that can move easily from one place to another, i.e., Liquids and gases

Though the convection thermal transport is more complicated than with conduction, convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate). Fluid motion and convection go beyond the scope of the paper.

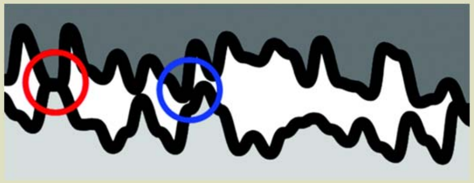
The basic convection heat transfer equation is quite simple: $q = k\,A\,\Delta T$ (Fourier’s Law)

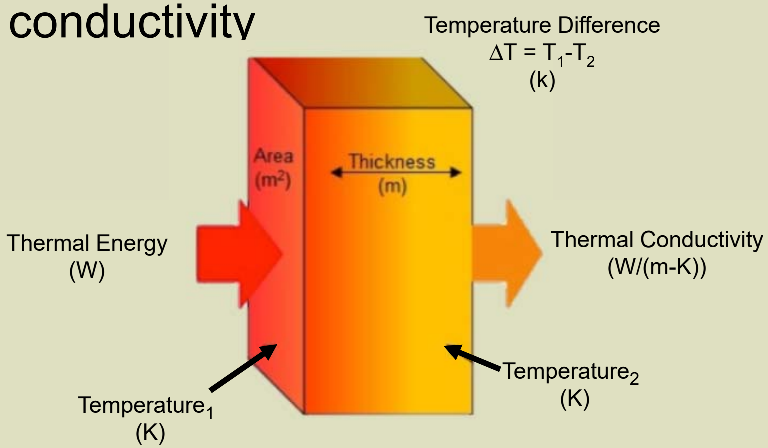
- *q*” is the heat flux i.e., the heat transfer rate (*Q is heat transport per unit of time)*
- *k* is the thermal conductivity (W/m) and is characteristic of the contact probe material and device lead material
- A is the heat transfer area of the surface (m^2)
- ΔT is the difference between the surface and the bulk fluid (°C)

Good Thermal Management /Heat Transfer at the Device-Under-Test

- Conduction and Forced Convection heat transfer
  - Required:
    - A low pin surface Ra value with repeatable pin force biasing
    - A large surface area
    - A *material with good* thermal conductivity

Poor surface-to-surface heat conduction





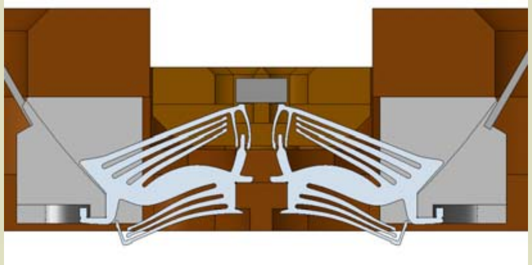
cDragon

- Thermal
  - Multi beam design allows for better airflow thru contact pin elements
    - Integrated airflow tunnels allow the pins to remain very close to handler's set temperature during testing
    - Heat by definition is energy in transit due to a temperature difference

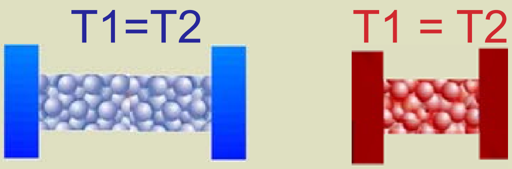
Conduction

$$Q = \frac{kA}{l}(T_1 - T_2)$$

- *Q is heat transport per unit of time*
- A is area
- l is length
- k is thermal conductivity



Nature Likes Balance



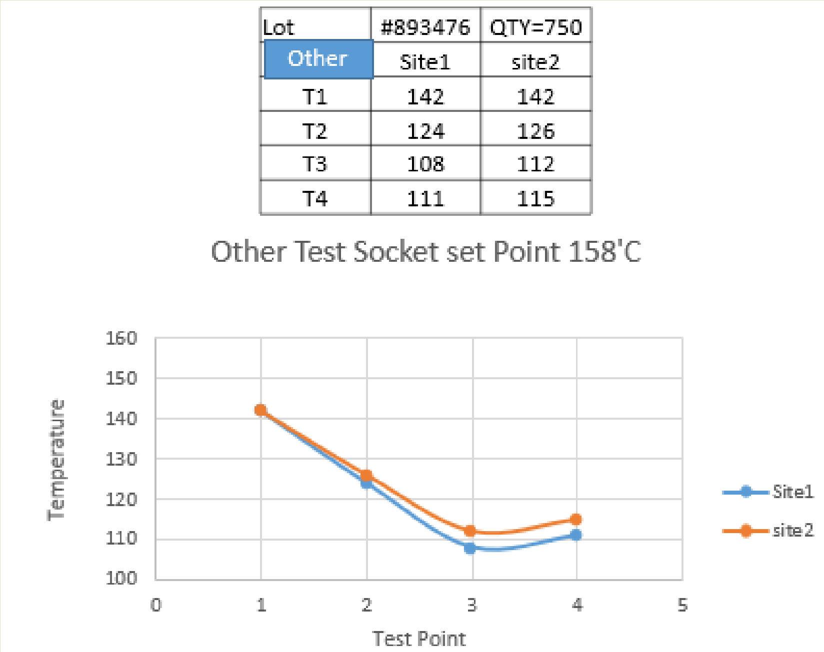
Convection

$$q = k A \Delta T$$

- q” is the heat transfer rate k is the thermal conductivity
- A is the heat transfer area of the surface (m^2)
- ΔT is the difference between the surface and the bulk fluid (°C) temperature

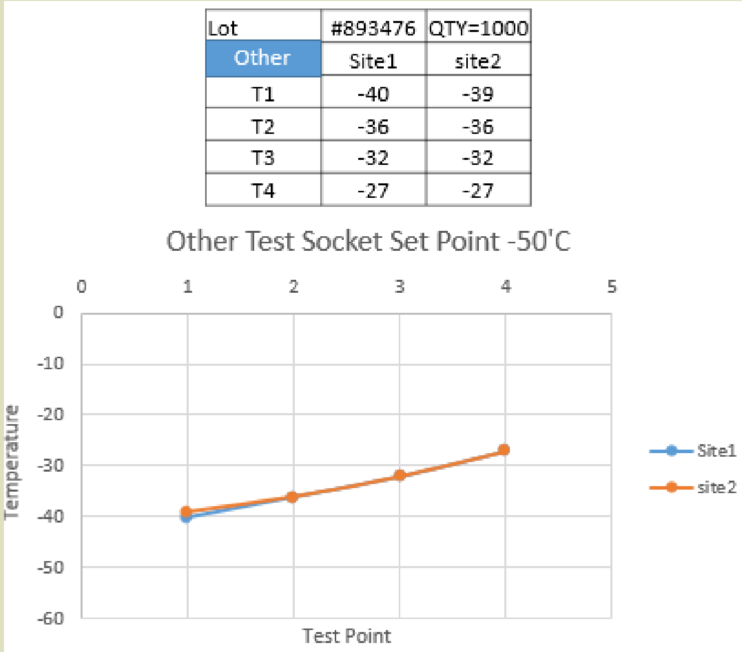
Customer Validation

- Imbedded Thermal Diode



Lot	#893476	QTY=750
Other	Site1	site2
T1	142	142
T2	124	126
T3	108	112
T4	111	115

Other Test Socket set Point 158'C

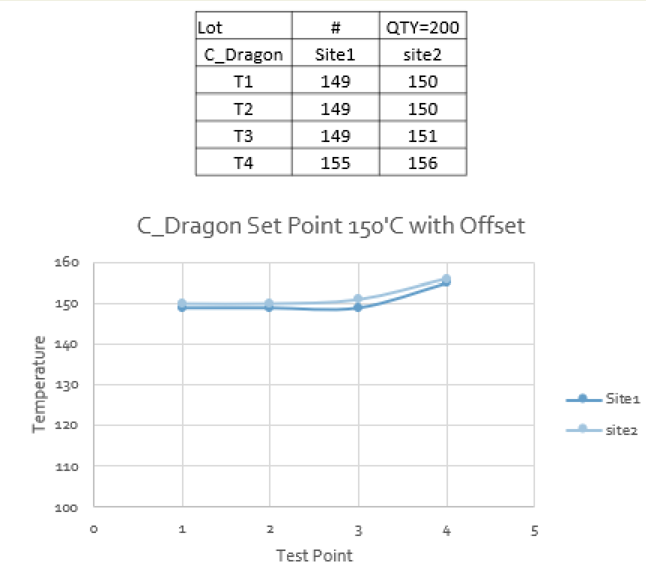


Lot	#893476	QTY=1000
Other	Site1	site2
T1	-40	-39
T2	-36	-36
T3	-32	-32
T4	-27	-27

Other Test Socket Set Point -50'C

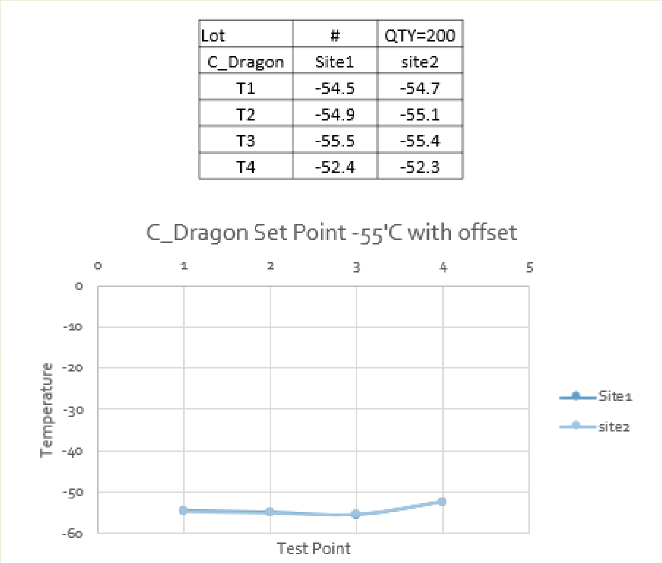
Customer Validation

- The C-Dragon allows the temperature set point to be achieved and maintained throughout the test program



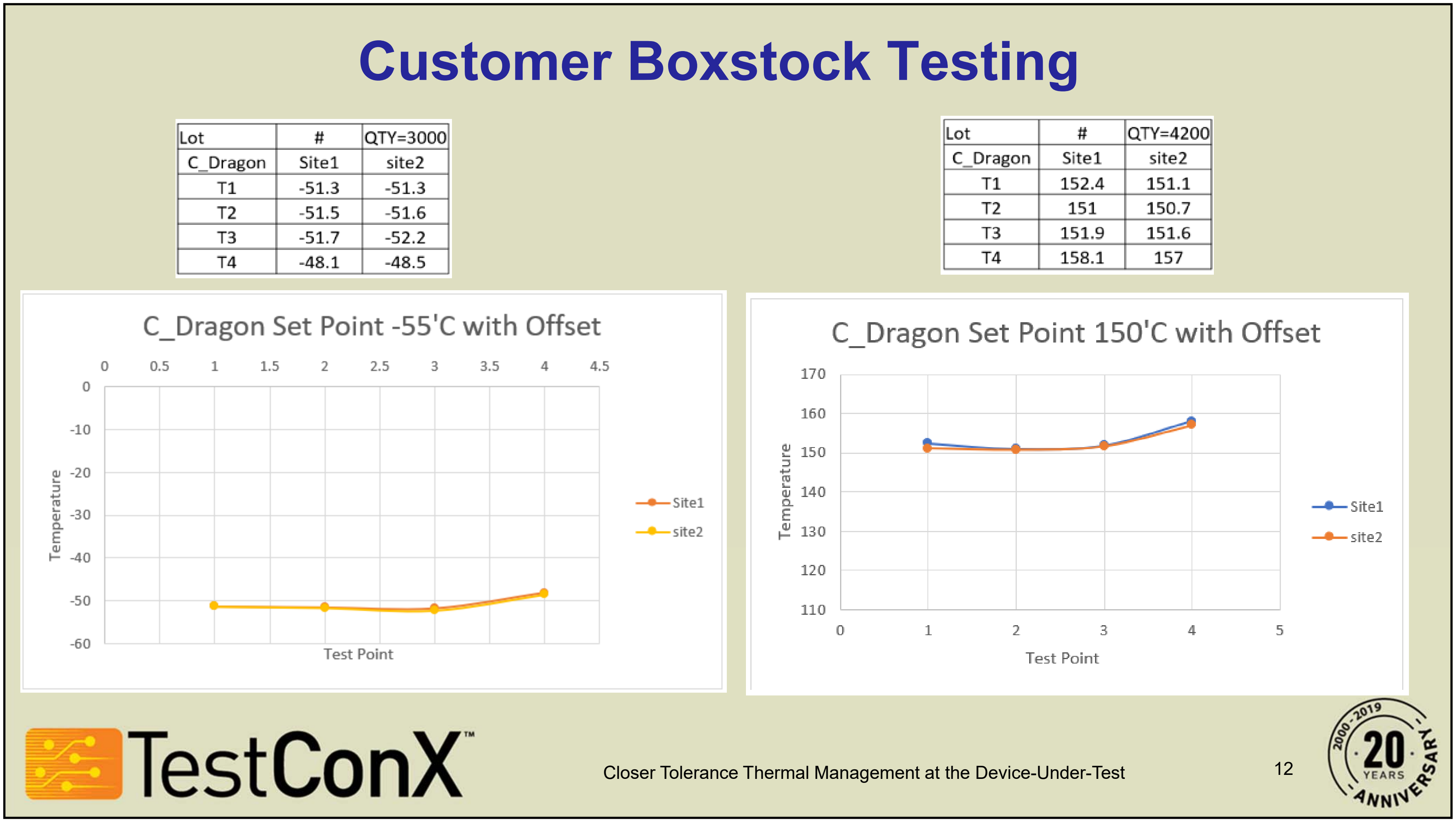
Lot	#	QTY=200
C_Dragon	Site1	site2
T1	149	150
T2	149	150
T3	149	151
T4	155	156

C_Dragon Set Point 150'C with Offset



Lot	#	QTY=200
C_Dragon	Site1	site2
T1	-54.5	-54.7
T2	-54.9	-55.1
T3	-55.5	-55.4
T4	-52.4	-52.3

C_Dragon Set Point -55'C with offset



Customer Boxstock Testing

Lot	#	QTY=3000
C_Dragon	Site1	site2
T1	-51.3	-51.3
T2	-51.5	-51.6
T3	-51.7	-52.2
T4	-48.1	-48.5

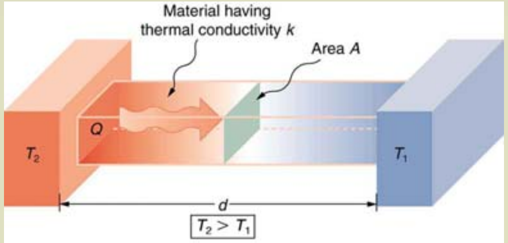
Lot	#	QTY=4200
C_Dragon	Site1	site2
T1	152.4	151.1
T2	151	150.7
T3	151.9	151.6
T4	158.1	157

C_Dragon Set Point -55'C with Offset

C_Dragon Set Point 150'C with Offset

Conclusion

- With the use of Thermal Conduction physics, a contactor with better heat response time and Temperature set point accuracy can be developed and deployed
- This was proven in the laboratory and again on the test floor.
- By design, heat transfer in a contactor takes place in two modes: convection and conduction
- Thermal Resistance is analogous to Electrical Resistance in that it is inversely proportional to the flow of heat.



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