# The Coefficient of Thermal Expansion and your Heating System

*By: Admin* - May 06, 2021

We've all been there. The lid on pickle jar is impossibly tight, but when you run hot water over the jar you can easily unscrew the lid. The metal lid expands more than the glass jar, which is a simple illustration of how materials, when heated, expand at different rates. The relationship of how materials expand or contract through temperature change is driven by the coefficient of thermal expansion or CTE of those materials and is a critical factor when designing a heater.

Determining the appropriate materials for the heater is not as simple as running warm water over a metal lid. The coefficient of thermal expansion is a critical factor when pairing dissimilar materials in a system. With the help of Watlow representatives, you can make sure your system is designed for success, efficiency and a long lifespan.

## What is the coefficient of thermal expansion?

To understand the science behind the coefficient of thermal expansion (CTE), one must first understand the basics of thermal expansion. Physical property changes, such as shape, area, volume and density, occur during thermal expansion. Every material or metal/metal alloy will have a slightly different expansion rate. CTE, then, is the relative expansion or contraction of materials driven by a change in temperature.

Metals, ceramics and other materials have unique coefficients of thermal expansion and do not expand and contract at equal rates. For example, if the volume of a section of aluminum and a section of ceramic are equal and are heated from X to Y degrees, the aluminum could increase in dimension by a factor of four compared to the ceramic. While that may not seem like much of a difference, such variations could cause a catastrophic failure within a thermal system.

Metal sheathed heaters, such as cartridge or tubular heaters, are designed with a variety of metal alloys carefully chosen for each application. The CTE of these materials should always be considered in the design phase of a project.

# The coefficient of thermal expansion calculation

The coefficient of thermal expansion is determined with this formula:

$\Delta L = \alpha L(\Delta T)$

In this equation, $\Delta L$ is the change in length in the direction of interest; L is equal to the starting length of material in direction of interest; and $\Delta T$ is the temperature difference from start to end. $\alpha$ is the CTE and can be determined from various materials databases.

It is important to note: All units of the equation must be consistent in Celsius or Fahrenheit as there are two different sets of coefficients for each measurement system.

# What happens when materials are heated?

When metals or ceramics are heated or cooled, the substance expands or contracts depending on the material and the temperature at which it is heated. If the material is restricted, this stress can be destructive, as a tremendous amount of force can be generated with thermal expansion.

Consider railroad tracks. Modern railroad tracks are made of hot-rolled iron. As the track is installed, railway workers leave space between each rail. This space allows the track to expand as it is exposed to the hot summer sun. Without adequate spacing, the railway could buckle, potentially causing a derailment.

Roadway bridges have a similar feature with bridge joints. Bridge temperatures change faster than road temperatures. The bridge joint allows the pieces of the bridge to expand and contract at their respective rates. Without a bridge joint, bridge could suffer damage or be destroyed from expansion or contraction.

When designing a thermal system where a heater is necessary, it is critically important to accommodate for the movement of the materials within the system. As the examples above illustrate, failure to account for the coefficient of thermal expansion can have devastating effects on a system. While a failure in your system may not make headlines in the local newspaper like a train derailment, downtime is costly and leaves your business scrambling to fix the issue.

# The hazards of using materials with different CTE

Using materials with different CTE in the same application can be problematic. For example, if enough force is generated by thermal expansion, damage to the heater system can produce enough force to cause a catastrophic system failure and potentially injure workers.

Failure to match CTE can cause the heated system to damage itself. When materials with different CTE are used together in the same heated application, they may experience failures such as fretting, galling, bending, cracking or warping. Fretting occurs when two materials rub against each other causing a degradation of the materials surface qualities. Galling occurs when certain materials rub together and form a bond, like a cold weld causing permanent damage.

Many of Watlow's customers have very complex, thermal systems. Heater damage can cause a system to be underproductive or shut down. In business, time is money, and losing a system for even a couple hours could cost a business hundreds of thousands of dollars.

Designing and accounting for the CTE of various materials involved in the thermal process is one of the many ways Watlow can help design engineers to overcome these challenges.

## Other considerations when selecting metals

While CTE is a vital design factor to consider, there are many other considerations. By working with a Watlow specialist, we will walk through the unique variables of your system. We provide insight and options on all aspects of the thermal system and materials, including:

**Ramp rate:** The rate of change in temperature over time, ramp rate involves the speed at which the material is heated. A heater that causes one part of the system to get hotter than another (aka "thermal nonuniformity") can create problems, even if the material has a compatible CTE. If the thermal energy is not allowed to spread evenly to all components of the system, expansion can occur at an uneven rate.

**Properties of the metal:** Understanding other properties of the metal is also critical. For example, aluminum has one of the highest thermal conductivity rates. However, aluminum melts at a much lower temperature compared to other metals. A system that needs to be heated to, say, 1500º F would leave a puddle of aluminum in the system. Another example is titanium, which has a low thermal conductivity. Titanium may not expand as much as other materials, but it acts almost as insulation instead of a thermal conductor.

**Cost versus life of the system:** When designing your system, cost may be a consideration. Some materials are more expensive than others. However, the more expensive substance may last 10 times longer than the less expensive material, so an understanding of quality and lifespan is important.

## The right materials and the best information

Watlow representatives are prepared to evaluate your system and provide valuable expertise and advice on the best type, size and shape of materials for your application. Our team will help you avoid any issues that might be caused by thermal expansion or contraction. Allow our knowledgeable specialists to ensure that your heating system is well designed to serve you for years to come.

Contact a Watlow® representative today (https://www.watlow.com/contact-us)to learn more about the coefficient of thermal expansion and how it applies to your system.