Factors to consider when choosing a laboratory microwave

Wayne Love

Distributed By:
Ladd Research
83 Holly Court
Williston, VT 05495
802-658-4961
https://www.laddresearch.com

Contents

Using microwaves in laboratories or industrial applications

Microwave heating basics
Cooking food – the home microwave oven
Laboratory use
Common feature of laboratory microwaves

Controlling the heating (temperature) of your samples

Power control
The control system

Temperature measurement methods in a microwave cavity

Thermocouple probe
Infrared temperature sensor
Fiber optic system

Tips for using your microwave

Discussion about established protocol
Other tips

High Temperature Operation

Using microwaves in laboratory or industrial applications

Microwaves make great additions to many process and laboratory applications. Just as microwave ovens (ovens is the term used to designate a device for heating food) heat food in the kitchen quickly, they can significantly reduce time heating samples or solutions in the process or laboratory environment. To get the most from your microwave in it is not “one size fit all”, there are many choices in the features on a microwave. The choice of a microwave unit should be done after consideration of the use of the microwave and the features of the microwaves available.

Be sure to discuss your needs with the manufacturer before you purchase the microwave. There may be a microwave with features more suitable for your application or there may be a lower cost microwave alternatives that is adequate for your application.

Microwave heating basics

Microwaves heat materials differently than most conventional ovens, furnaces or kilns. We are often asked *“How hot will your microwave heat to?”* or *How fast will your microwave heat my material/product?”* There really is no good answer that we can give to someone without knowing more details. The reason is microwave heat materials differently than conventional hot environment ovens. Heating occurs when energy is absorbed into a material or product.

In a conventional oven you have a heat source – fire from gas, wood, oil, charcoal or some other combustionable materials or from electric heaters. The oven, grill, skillet or stove top gets hot – at least to the temperature equal or even greater than what you want your material or product to attain. You then expose your material or product inside the hot environment and wait long enough for the heat to transfer to and throughout your material or product. Depending on the mass and the heat transfer characteristics of your material or product, this can take hours or even much longer. Everything will eventually heat in a conventional oven given enough time and a hot enough environment.

In a microwave, the environment (oven or more often the cavity) does not intentionally get hot. It sometimes gets hot because of secondary heating from the material or products inside it get hot. Microwaves use electromagnetic energy to add energy to a material or product, but not all materials or products will absorb microwave energy and therefore not all materials heat in a microwave. Some materials do not heat well in a microwave including PTFE Teflon, polypropylene, many types of glass, some high purity ceramics and quartz (fused silica). Some materials will heat quite well including water, carbon, Silicon Carbide (SiC), iron oxide and many ceramics. Some materials will heat to over 900 °C and some will even heat to over 1,800 °C in the case of sintering of ceramics.

How well a material or product heats in a microwave depends on how well it “couples” or absorbs the microwave energy and the power level of the microwave. This is controlled in a high degree by the absorption characteristics of the material or product and are more commonly called their dielectric properties.

For a microwave to heat materials or product to very high temperatures, the microwave must be carefully designed and made to contain the heat inside the heating cavity and then provide cooling for the wiring and electronics so they do not overheat.

Everyone has experience with conventional heating, from using a stove or oven in the kitchen to adding heat for heating your home to using high temperature ovens or localized heaters in industrial or laboratory processing. However fundamentally microwave heating is different and is beyond most people’s direct experiences. Generally the only experience people have with microwave heating is the home microwave oven and even there, most people do not understand how it heats, just that they pop in their food and chose (guess) at a power level and a time. As in any type of processing, cooking or manufacturing, the more you understand the process, the better the results will be.

Heating materials

Much of what we have learned with cooking food using microwaves can be applied to using a microwave for heating other materials. It is common knowledge that microwaves heat food differently than other heating methods. Microwaves generate and use electromagnetic radiation and follow the laws of electricity and magnetism. There is a belief that microwave ovens heat from the “inside out”. Understanding how microwaves really heat is important to understanding how to best use the microwave and apply it to your process or laboratory.

Microwaves heat materials because polar molecules such as water rotate and charged molecules including salt ions move linearly in the presence of a strong electromagnetic (microwave) field. That movement causes collisions and friction and thus heat. The stronger the field and the stronger the material absorption characteristics, the quicker the material heats up. While microwave energy penetrates into food to cause heating, they do not have the ability to penetrate all food to the same degree. Microwave energy will penetrate differently into different foods with different types of molecules such as bone, meat, fat, water oil, and salt contents differently. How far they penetrate is called the depth of penetration, and the energy in the microwave field is reduced to the point where very little heating occurs. Depth of penetration is not unique to food, all material heated in a microwave will have a depth of penetration associated with it depending on its chemical make-up and physical state of matter. Also some of the materials that absorb microwave energy well will absorb a significant portion of the available microwave energy and it might “shield” the energy from other samples in the same cavity or container. Care should be taken when deciding how much and the orientation of samples that will be heated in a microwave. Often sample need to be separated to allow for good heating. State of matter is important. For instance, the penetration depth at 2.450 GHz into room temperature water is about 2.5 cm, but it increases substantially when it is ice. This also means that the absorption characteristics of ice are such that microwaves do not heat ice well. This is why you need to defrost a food item before trying to heat it in a microwave, of when one area thaws it will absorb much of the energy and overheat while the bulk of the item remains frozen.

Microwaves can have 3 different (or combined) effects when in a microwave field; a microwave can heat a materials, it can pass through the materials or it can be reflected by a materials. Heating we discussed a little bit above. Think of materials such as carbon, water, silicon carbide. Microwaves pass through materials is where the material does not affect the microwave signal (think about materials such as gasses, many plastics (PTFE, polypropylene, UHMW (Ultra High Molecular Weight) & Acrylic for instance), although there is no material that doesn't absorb some of the energy, just as there is no such thing as perpetual motion or frictionless materials. Materials that reflect microwaves are often metals.

Another microwave rule that everyone knows about is food should be stirred and then stand a minute or so before eating. The reason for this is fairly simple. Stirring tends to even out the temperature caused by uneven heating (yep, all microwaves have hot spots and cold spots caused by the interference patterns of the waves set-up within the cavity, just as waves in a wave tank interfere with peaks and troughs greater than the original wave) and the uneven heating of the reduced heating in the central portions of food caused by limited depth of penetration, especially true on larger sized food products. The waiting period is called "rest time cooking or heating" which allows the temperature to even out after the microwaves are turned off and it allows the heat to spread out over the entire food volume. There is sort of a rule of thumb in microwave heating "to heat as quickly as you can slowly" If you have material that may heat unevenly, due to non-homogonous material or from different physical sizes, if you can heat more slowly, you will likely have more uniform temperatures.

Laboratory or industrial use

Laboratory microwaves almost exclusively operate at the same frequency – 2.45 GHz and it is the same as home microwave ovens. Laboratory or industrial microwaves differ from home microwave ovens in their robustness, often their power level, lack of a turntable, the control method of the process and other features available with the microwave.

Most microwave ovens for the home kitchen really operate pretty much the same. Using a touchpad, you set a power level and time based on your experience with cooking similar product/s. We call this type of control of the cooking process power level and time based. *<u>This type of control offers the least consistency and accuracy in the heating process, but it can be built at a low cost</u>.* The microwave ovens where designed for cooking food and they really do a pretty good job heating food especially if you consider they have really been in the marketplace since the mid 1970's. Heating consistency and accuracy is not that important in cooking food, warming leftovers or popping pop corn.

Knowledge of how a microwave operates and the understanding of processes to get the most out of your microwave are very important.

Microwaves for use in the laboratory offer a variety of features that make them adept at heating or processing materials, samples or solutions. Consistent and accurate processing is important in most laboratory applications. Consistency and accuracy becomes more difficult as the sample size becomes small. Therefore it is extremely important to get the right microwave for your application.

The first step is to decide what you will be using your microwave for. Then discuss the applications in as much detail with the microwave supplier your particular application and expectations of the microwave as possible. This is the best way to get the microwave that will best fit your application and budget. As you would expect, the features and processes required from a microwave heating water to 70 – 85 °C to prepare a liter of agar solution or quickly heat a liter of corrosive acid or process a lung tissue sample so a pathologist can make a determination while the patient is waiting for surgery or to prepare as sample is 10 micro-liters of solution or to sinter a ceramic material at 1,800 °C would all require different features and processes from a microwave. No single microwave could process all of those samples well or economically. Different levels of features, consistency and accuracy is needed. Discussion with the microwave manufacturer is the best way to get the best microwave for your needs.

However, all laboratory grade microwaves should have some features that are the same.

Common features to all laboratory grade microwaves.

- Laboratory grade microwaves should be used in the laboratory. Home microwave ovens are intended for domestic use only and not laboratory applications and thus have not been designed for the heavy duty use in laboratories. This means that the microwaves you buy at your local store should not be used in the laboratory. Most safety groups (including OSHA, CLSI and CAP in the US) will not allow a domestic microwave in the laboratory for this reason alone and most insurance companies will reject claims on damage caused from domestic microwaves used in a laboratory or industrial setting.

- The heavy duty construction of a laboratory grade microwave is a must and results in to ability of the microwave to take the hard everyday use of laboratory operation. Look for or ask about:
    - Heavy duty door hinges will keep the door in alignment and not begin to leak microwave energy
    - Door hooks made of metal or heavy duty plastic, not the thin plastic used by domestic microwaves.
    - Pull open door instead of light duty plastic push button door openers
    - Heavy duty high voltage components to increases life.
    - High volume cooling of the electronics to increase life
    - Stainless steel cavities and housings give the microwave protection against most corrosive chemicals and are easy to keep clean.
    - Mode stirrer for better heating uniformity. Turntables normally have glass trays that are easily broken and protrude into the cavity

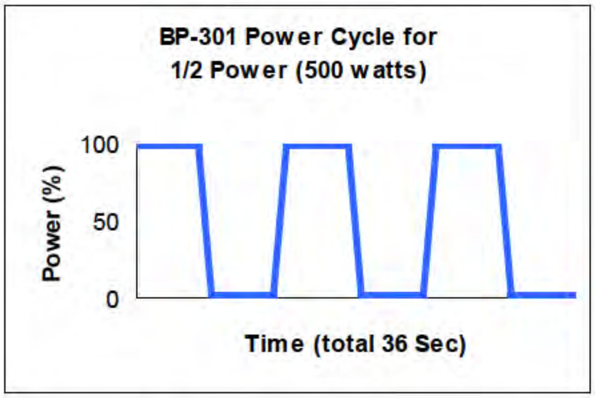
- Powered cavity venting removes obnoxious fumes from the cavity and there should be a method to attach an exhaust port to a fume hood or house gas system to properly vent the fumes. Note – Some vendors simply put a fan that is rated for xxx-cfm but do not measure the airflow. The rated airflow of a fan is in free space, but can be significantly reduced in actual use due to reductions or restrictions in airflow. Be sure the ***measured*** airflow is sufficient to exchange the air in the cavity 4 or 5 or more times per minute.

Controlling the heating of your samples

There are a number of factors that go into controlling the heating (or temperature)of your samples. Two of the most important ones are discussed below:

Power control

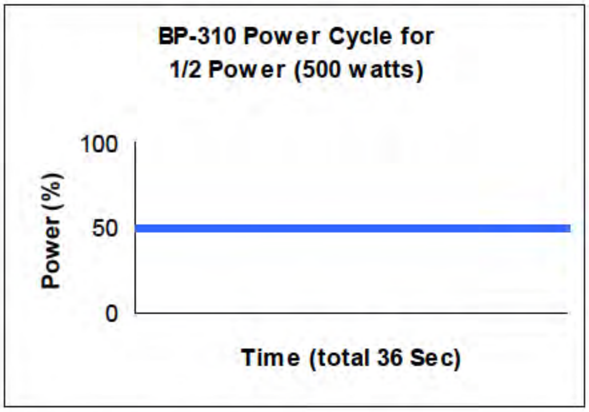
Power control refers to how your microwave controls the output power going into the cavity. Most home microwave ovens and some laboratory grade microwaves, such as our LBP-301, by simply cycling the microwave power on and off. The ratio of power on time and off time determines the average power applied. This is a low cost method of controlling power and works well for many cases where the sample is large and can handle the higher power during the on time. Generally the microwaves are on for 6 seconds at a time and then off for the corresponding time.



In a slight variation to this method, some laboratory microwave ovens use this type of power control but in much shorter on time slices. If the sample is small or sensitive to high pulse power, true power adjustment must be used.

This is analogous to dimming the lights in a dinning room by turning the light switch on and off – the average light level is lower, but it would not make for a enjoyable dinner.

Our True-To-Power™ power control system allows you to set virtually any power setting from about 20 watts to full power without the on-off power cycling. This type of power control does not use pulsing to control power, the power can be set to any level desired. For small samples or those samples that are sensitive to higher power this type of power control will allow heating without damage to the sample.



Our True-To-Power™ power control system is analogous to using a dimmer switch in the dinning room to dim the lights. It a smooth and continuous method of dimming the lights or reducing the microwave power level.

The Control system

The control system refers to how the microwave applies energy to the sample, thus controlling the temperature of the sample.

- Domestic microwave ovens and low cost laboratory microwaves use time and power as the control method of the heating process. This type of control relies on a guess of power and time settings. This is an acceptable method especially if you can control many of the variables that affect the end temperature. You can not generally maintain a desired temperature as the sample will just keep heating with time. It is also very dependant on the sample (how well it adsorbs microwaves) and its size (large samples heat slowly and small samples heat quickly). This is a low cost method may be acceptable on samples, where the acceptable temperature range is large or you can control most of the variables:

  To reduce some of the variables that can cause inconsistent readings, we are going to reduce the affect of them by careful measurement and selection of the conditions during the measurement.

❖ **Denotes a process tip**

- Because the starting temperature will affect the ending temperature, we are looking for a change (rise) in temperature of a known amount of water.

❖ For consistent processing, it is important that you start with reagents or samples at (or very nearly at) the same temperature. Reagents at room temperature will yield different results if they just come from the refrigerator.

- Because the amount of water used will affect the temperature rise, we will use a measured amount of water.

❖ Always use the same amount of reagents for each microwave run. When possible, always place the same amount of reagents in the microwave for each run. The results will be different if you place 1 sample with 15 ml of reagents compared to 100 sample each with 15 ml of reagents.

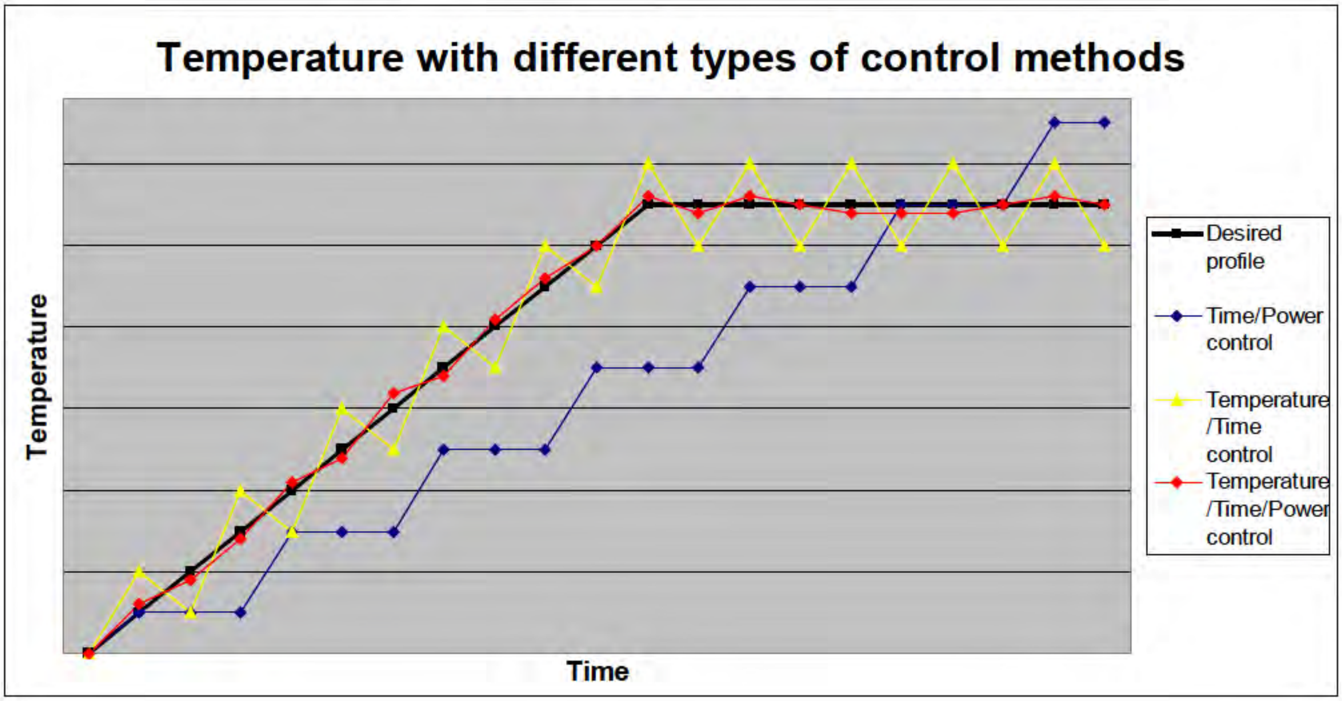
    - Because the temperature of the components inside of the microwave will affect the temperature rise, we will be careful with the operating conditions.

    ❖ Consider "warming" the microwave in the morning or after long periods of cooling time, if you have inconsistencies that affect the diagnostic quality. Simply place a couple of liters of water (in microwave safe containers) and operate the microwave on high for 10-15 minutes (replace the water if it boils). Tissue run in a cold microwave in the morning will be different than late in the afternoon when the microwave is warm.

  - Temperature and time control refers to using the sample temperature to control the heating cycle. This method is much better than the time and power control method as it negates a number of variables. This method turns the microwave on and off based on the actual measured temperature vs. the programmed temperature at that time. Consistency is pretty good as it follows a programmed heating profile and negates a number of variables that could cause inconsistency in consecutive processes, but the microwave power level is at 100% during the on period. This describes our LBP-125 laboratory microwave.

  - The best control method is a method that uses temperature, time and True-To-Power™ power adjustment. This control method is much like the one above, but the controller sets the power level based on the temperature measurement to maintain the user set heating profile. This method is even better as it negates a lot of process variables and allows for more consistent processing. Most high end microwave tissue processors used for high volume pathology and other high end microwaves designed specifically for chemical processing use this type of control for heating/processing samples. Our LBP-111 and LBP-111-RS use this form of process control. This method can also be used on some microwaves in a manual mode for process development.

Shown below is a graph that represents each control method and how the temperature of each method compares to a desired temperature profile (Black). You can see that the Time and Power control system (blue) does not follow the desired profile and would not be ideal if you wanted to maintain the temperate. The Temperature and Power control system (yellow) follows the desired curve but varies from the desired temperate sometimes significantly. The Temperature, Time and Power control system (red) follows the desired curve reasonably well.



In all cases, there are a number of factors that affect the variation from the desired curve. Some of these factors include:

- Sample size. Smaller samples sizes are more difficult to control accurately as it is easy to over heat and overshoot your desired temperature. This will also cause greater temperature variation from your desired temperature profile.
- Maximum power level of the microwave. Lower microwave power will reduce overshoot and variation, but may not be able to heat larger samples in the desired time.
- How often the controller evaluates the actual temperature and makes adjustment to the process. The more often it evaluates and makes adjustments, the better it should follow the desired curve.
- The ability of the sample to adsorb microwave energy. Some materials readily adsorb microwaves and thus heat well, while others do not. Sometimes even

rather small changes in the composition of the sample make large differences. The state of matter may also have significant effect, i.e. water heats well, but ice heats poorly.

Power Measurements inside a Microwave Cavity

Accurate power measurement is based on a calorimetric method that depends on heating a known amount of water for a certain amount of time. The exact method is specified in IEC 60705 ED 3:1999, 2004-11 and is very specific in the measurement technique. We recommend a simplified version but suggest that you are consistent in the shape of the water/vessel, chose the vessel not to absorb microwave energy and the position in the microwave always be the same as they can cause variation in the measurement.

We suggest that you use a vessel and amount of water that is similar to that you will use in actual practice. The vessel must not absorb microwaves or the measurement will have errors. Clean virgin PTFE, Polypropylene, most glass, quartz and high percentage alumina (>96% Al_2O_3) containers will work fine.

Measure the amount of water you are going to use (typically 0.5 liter) or more is used. Weighing the water sample is preferred, but it you can accurately measure volume is acceptable.

Measure and record the starting temperature using a fast heating thermocouple. Do not use a thermocouple with a sleeve or coating as it will take a long time to register the temperature. Starting temperature should be 15-25 °C. Stir the water to get a uniform temperature.

Place the water and vessel in the center of the cavity. Close the door and set the power level to the desired value.

Microwave for an appropriate time (1-2 minutes is common longer if using low power and/or copious amount of water). Remove the water immediately after the end of the heating cycle.

Gently stir the water to get a uniform temperature – do not stir excessively and add heat to the water. Measure and record the water temperature, using a fast heating thermocouple. Measure the temperature in a few places in the water (top, bottom and sides) to be sure the water is stirred properly and has uniform temperature.

Power can be calculated by;

Power = $[M * C_p * k * (\Delta T)] / t$

Where Power is in watts (joules/sec)

M is mass in grams (g)
C_p is specific heat (cal/g deg C) and is 0.9997 @ 25 °C
k is a conversion factor for thermochemical cal/sec to watts and is 4.184 joule/cal
ΔT is temperature change T_2-T_1 Final temperature – starting temperature (°C)
t is time in seconds

Temperature Measurements inside a Microwave Cavity

A note about safety: **NEVER put a thermocouple into a sample and close the door on the thermocouple!** The thermocouple will act as an antenna and could transmit enough of the microwaves to scramble the meter, damage the meter or CAUSE HARM OR INJURY to people.

There is no perfect way to determine temperature in a microwave cavity. Each temperature measurement method has challenges and associated costs. There are some options better suited for some conditions:

Thermocouple probe

A thermocouple is the most simple and lowest cost method. It directly reads the temperature when touching the sample. Normally a thermocouple in a microwave field can act as an antenna and damage or scramble the temperature meter or “self heat”. Thermocouple probes must be shielded to protect the temperature meter and “self heating”, even a properly shielded one could pick-up some of the microwave energy and “self heat”. This self heating can cause errors or uncertainties in the temperature measurement.

Also the thermocouple must make contact to the sample, often acting as a heat sink, further causing errors or uncertainties in the measurement. Only properly designed and built thermocouples should only be used in a microwave cavity.

We offer a selection of thermoprobes; the standard thermoprobe is 1/8” diameter tube with the actual thermocouple near the end of the probe. There is a section that transitions into a braided flexible section. The thermoprobes are designed and produced to shield the thermocouples from acting as an antenna and picking up microwave signals from the cavity and interfering with the operation of the electronics or radiating personnel in near the microwave.

As part of the shielding, the thermoprobes are at ground potential and as such, it is possible to create an arc from the thermoprobe to the inside surfaces of the cavity or to your sample. Care should be taken not to make contact with the thermoprobe to the inside surfaces of the cavity and limit the contact to your samples. It is possible that the thermoprobe will arc to your sample; this is especially true with solid samples and samples that are powder. Consider a different type of temperature sensor, often an infrared temperature sensor may be the right solution. When first running a new set-up, be aware of any arcing and turn the microwave off or significantly reduce power as damage to the thermoprobe and damage to the sample or cavity may occur during arcing.

- Smaller thermocouples give better results as do larger samples.
- To keep errors and the chance of arcing to a minimum, we do not recommend the use of a thermocouple if the sample is less than 250 ml or for samples that are dry.
- Care must be taken with routing the thermocouple and the wire to keep them away from the walls of the cavity as there is the chance of arcing.
- It is possible that the thermocouple probe will change the heat pattern in the microwave cavity as it is metal and can change the field pattern.
- There should be a number of sizes and configurations at the probe end available. Make sure if you discuss the pros and cons with the manufacturer if you plan to use a thermocouple probe.
- Also be sure the thermocouple probe is easily replaceable as it can become damaged through arcing, handling or through corrosion.
- A thermal couple temperature probe should cost under $300 or so.

Infrared temperature sensor

Infrared temperature sensors are now in common use and somewhat reasonably priced. Infrared temperature sensors do not need to be in the cavity, located outside of the cavity they are a non-contact way to read temperature. All materials give off infrared energy based on the temperature of that object. Basically an infrared sensor consists of a lens to focus the infrared (IR) energy on to a detector, which converts the energy to an electrical signal that can be displayed in units of temperature.

Important factors for accurate temperature readings include field of view (target size and distance), type of surface being measured (emissivity considerations), angle of view and temperature range. The field of view is determined by the optics of the unit. To obtain an accurate temperature reading, the target being measured should completely fill the field of view of the instrument. Since the infrared device determines the average temperature of all surfaces within the field of view, if the background temperature is different from the object temperature, a measurement error can occur. However, since this method averages the temperature in the target field of view, it tends to even out local hot and cool spots. Emissivity is defined as the ratio of the energy radiated by an object at a given temperature to the energy emitted by a perfect radiator, or blackbody, at the same temperature. The emissivity of a blackbody is 1.0. All values of emissivity fall between 0.0 and 1.0. If the emissivity of the sample you are measuring is different from that which is calibrated in the sensor, an error can occur. For most applications a factory setting is usually sufficient. These infrared temperature sensors tend to have a limited temperature range (typically 0-200 °C) that they can sense, making them limited in the scope of samples they can measure. An infrared temperature sensor system can add $1,500 or more.

Fiber optic system
There is a third method to measure temperature of samples within a microwave cavity. It is however very expensive. This method uses fiber optic probes to make contact with the sample. At the end of the fiber optic probe, there is a material, often Gallium Arsenide that will shift the color of light that is sent down the fiber optic. That shift is well defined and known as a function of temperature. The instrument then reads the shifted color of the light and converts it to a temperature. As the probe is glass, there is little chance of arcing or significantly changing the field pattern inside the microwave cavity. Again as this probe touches the sample, it can heat sink some of the heat away from small samples, but they can be ordered with very small sizes reducing significantly this affect. Also as they are glass, a thermal insulator, the heat sinking errors are minimized. They are fairly inert to chemical attack but they also have limited temperature ranges. These fiber optic systems can measure more than 1 sample at the same time. The cost for these systems range from $5,000 to $15,000 or more depending on number of probes.

Temperature measurement options

	Thermocouple probe	**Infrared sensor**	**Fiber optic system**
Cost	Low	Moderate	Very costly
Temperature range	Wide	Limited	Limited
Recommended for small samples	Discuss applications	Yes	Consult factory
Ease of use	Moderate	Moderate	Easy
Accuracy	Medium	Very good	Good
Potential to change to heat pattern	Potentially Yes	No	Minimal, if any
Potential for arcing	Yes	No	Minimal, if any
Multiple probes	Consult factory	No	Yes

Tips for using your microwave in the laboratory

Here are some tips and suggestions to get the results that you expect.

Discussion about established protocol

Do not expect established protocol to work optimally with a new microwave model. Remember, all processes have variation in them, microwave processing is no exception. Variations can occur from local environmental conditions (humidity, temperature and altitude), different compositions of process solution, different amounts of solutions, different sizes of samples, different input voltages from the outlet, different temperatures of the components within the microwave (a protocol run 1st thing in the morning maybe 15% quicker than one run later in the day) and other factors that may affect the protocol.

You should run some test samples following the established protocol. You may need to vary the protocol slightly to get the best results with you microwave at your location. Just as a photographer takes a picture with the proper f-stop and shutter speed, based on the light readings, a good photographer will often “bracket” that picture with additional pictures with slightly different locations, shutter times or f-stops. It is often these “bracketed” pictures that make the best pictures. “Bracket” the established protocol, change the heating time or temperature by a little bit or let the sample stand for a minute after heating. You will likely make improvements in the quality of the process or image.

Once you get good results, you can modify your existing protocol.

Other tips

- Read the entire owner’s manual.

- Calibrate your microwave for power and timer. This is especially important if the microwave is power and time based controls or you plan to use the microwave in a manual mode.

- If you are using a time and power level process control microwave, consider warming the microwave first by operating it with a couple of liters of water in it for 20-30 minutes at the power level that you will use. This will warm the magnetron and high voltage transformer – the 2 main components in the microwave generator. The output power can change by 15% or more as these components heat up.

- Use the same dedicated outlet. Microwave power can fluctuate with line voltage. Using the same outlet without other equipment on the same circuit will reduce variations. We have heard that results can be different when the microwave was moved and used a different outlet and circuit.

- Use the same size sample and solution. Different sizes can give different results.

- Likewise start with the samples and solution at the same temperature. The time it takes to get a sample to 70°C will not be the same if the samples start at 5 °C as with samples that are 30 °C at the start of the heating cycle.

- Put the samples in the same location in the cavity. Even microwaves with exceptionally good heat patterns will still have hot and cool spots. Minimize variation by placing the samples in the same location.

- Use a microwave that is based on temperature. Temperature based processes in microwaves with temperature measuring capability eliminates or substantially reduces variation by the sources for errors listed above.

- Use the minimum amount of power to get the job done. There is less chance of sample damage and the process should be more controllable.

- If possible, allow the samples to sit for 1-2 minutes after heating. Be consistent with this rest time.

- Use common sense and look for ways to reduce variation. Try to keep the times it takes between each process step the same.

Maximum Temperature

It becomes difficult for us to answer questions about the highest temperature the microwaves can heat material to. This is because microwaves do not heat like a kiln or conventional hot air ovens that are limited to how high their heating element or air temperature can reach. Microwaves heat just the material being heated (or absorbing microwave energy) and the ultimate temperature depends on how well the sample absorbs microwave energy, how well the sample converts that absorbed energy into heat, how much microwave power is available, the cooling rate of the sample (radiant, and convection) and how well insulated the microwave is to protect it from the hot samples.

As most of these parameters are specific to the composition, shape characteristics of the sample materials, it becomes virtually impossible for us to tell you the maximum temperature the microwave will get you sample to. Some applications include sintering ceramics in our microwaves. Many ceramic materials simply do not heat at relatively low temperatures in microwave fields until they are at a high temperature. While other materials such as lower (than 96%) purity Al_2O_3 and SiC heat fairly well.

One method to heat poor heating ceramic materials when cool is to surround the ceramic materials with other materials that do heat well. This will heat the slow heating materials as the faster heating materials increase the temperature in the general area. These faster heating materials are called susceptor materials. Once the ceramic material is at a relatively high temperature, it begins to absorb the microwave energy and heat on its own.

No matter what the sample temperature is, the inside of the cavity should not exceed 150 °C continuously. This means that for samples that exceed 150 °C and of sufficient heat load to increase the cavity temperature, the microwave must be insulated from the samples. We offer a microwave safe muffle to protect the microwave from the intense heat generated by some samples. The muffle is thermally insulating, but allows microwave energy to pass through it so the samples may be heated using the microwave energy. Our muffles are made from boards with an Al_2O_3 (Alumina ceramic) & fused silica (Quartz) mix and can operate at 1,100 °C continuously and even higher temperatures for short periods of time.

The microwave should have air flow between the cavity walls and the outside of the muffle to help remove excess heat from the cavity walls and reduce the temperature. Because we do not know the thermal mass, your desired temperature, the heat load, the microwave coupling of energy to your sample and the muffle (insulation factor) you will use, it is not possible to determine the maximum temperature that the microwave will produce.

Thermoprobes

Exceeding the temperature ratings shortens thermoprobe life. Temperatures rating of the thermoprobes are as follows:

	Tip rating		**Transition rating**	
	Continuous	**Intermittent**	**Continuous**	**Intermittent**
Standard type "K"	900 °C	1000 °C	600 °C	700 °C
High temp type "K"	1000 °C	1100 °C	600 °C	800 °C
High temp type "S"	1,400 °C	1500 °C	600 °C	800 °C

Because of the expense of the "S" type thermoprobe, many users use the high temperature "K" type probe even if the temperature they are processing to pushes the limit of the lower priced "K" type probe and replace it when it fails. This often make excellent economical sense as the "S" type probe is often 30 times the price of the High temperature "K" type probe