

**Environmental Remediation with Convected Heat
and Sterilizing the 2019 Novel Coronavirus
SARS-CoV-2**

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Summary

Every living organism has a thermal death point. While not technically “alive”, this statement also applies to the deactivation of viruses.

Independent scientific laboratory studies have shown coronaviruses are inactivated by elevated temperatures between 56°C/133°F^{1,2,3,4,5,26} and 75°C/167°F⁵.

GreenTech Heat Solutions is a technology and application methodology currently utilized in structural pasteurization treatments for biological agents including mold⁶ that safely, quickly, and efficiently decontaminates an entire structure and all its contents—including *all obvious fomites as well as any contamination in inaccessible or hidden areas*—of pathogens and other organisms using convected heat. The GreenTech Heat Solutions technology has been tested and proven over the course of decades in both the laboratory and in the field.

The GreenTech Heat process applied by a GreenTech Heat Titan 800 heated the test chamber to “lethal” temperatures and achieved a sterilization as determined by *Geobacillus stearothermophilus* surrogate testing. The process indiscriminately treats the entirety of the structure and its contents. As long as the required temperatures are achieved throughout the structure for the required amount of time, the structure is disinfected. Both time and temperature can be empirically measured and confirmed.

The GreenTech Heat sanitization process can be applied to sterilize hospital and PPE items in an existing room within a health care center. GreenTech Heat has also developed a stand-alone, 1,280 cubic-foot heat chamber that allows for sterilization treatments of larger items including furniture, mattresses, and gurneys, items on pallets, garments on hangars, and items on wire shelves in open-mesh wire baskets.

Research published in July 2020 from the School of Engineering at the University of St. Thomas at St. Paul, Minnesota, recommends these same temperatures and durations in laboratory settings ranging from 3 minutes at 75°C/167°F to 20 minutes at temperatures above 60°C/140°F. At these temperature saturations, the researchers expect the viral concentration to be lowered by log 5-7, near or below the detectable limit.²⁶ These recommendations are consistent with those provided by GreenTech Heat Solutions and are in agreement with WHO guidelines which report a 4 log reduction of coronavirus for 56°C/133°F with 15-minute exposures.²⁷

This sterilization process is not recommended for any item that cannot withstand exposure to highly-convected and heated air at a minimum temperature of 60°C/140°F. A lower level of sanitization may be achieved when items and/or the treatment area cannot withstand sterilization temperatures.

Decontamination Terminology

When attempting to decontaminate an environment of microbials, it is important to understand the nuances of the terminology. Generally speaking, decontamination renders an item or material safe to handle; the level of microbial contamination is reduced enough that it can be reasonably assumed free of risk of infection transmission. Four different processes (cleaning, sanitization, disinfection, and sterilization) are commonly referred to as “decontamination.” Each process has a different level of risk reduction and is clinically different from sterilization.

clean: removing debris or dirt, without necessarily killing or removing microorganisms.

sanitize: the process of reducing a contamination microorganism to a safe level.

disinfect: the process of killing everything on a particular surface.

sterilize: to destroy all microorganisms in an environment or on an item, usually by bringing to a high temperature with steam, dry heat, or boiling liquid.

Sanitization is the process of eliminating or reducing harmful microorganisms from fomites, inanimate objects, and surfaces. Sterilization is the process of killing all microorganisms and any spores present on an item or in an environment.

Depending upon treatment temperatures and durations, the GreenTech Heat process can be used to either sanitize or sterilize environments and items.

Laboratory and Academic Studies on Heat and Coronaviruses

As of this publication date, little original scientific research has been conducted on the thermal deactivation temperature of SARS-CoV-2.

In a letter to the editor of the Journal of Hospital Infection, Kampf and associates cited 10 published studies with data to determine which temperature and exposure time is necessary for inactivation of coronaviruses including human (Severe Acute Respiratory Syndrome [SARS] coronavirus and Middle East Respiratory Syndrome [MERS] coronavirus) or zoonotic coronaviruses (Transmissible Gastroenteritis Virus [TGEV], Mouse Hepatitis Virus [MHV] and Porcine Epidemic Diarrhoea Virus [PEDV]) and their inactivation by various temperatures used for thermal disinfection. Their findings suggest “Overall a thermal disinfection at 60°C for 30 min, 65°C for 15 min and 80°C for 1 min was effective to strongly reduce coronavirus infectivity by at least 4 log¹⁰.”⁷ Abraham, et.al., found a reduction in viral concentration in the range of log 5-7.²⁶

As published in peer-reviewed journals available via *pubmed.gov*, specific analysis of two major coronavirus strains found these viruses were inactivated in the laboratory by the following minimum heat levels and exposure times:

55°C/131°F for unspecified time	SARS-CoV-1 ⁸
56°C/133°F for 25 minutes	MERS-CoV ¹
56°C/133°F for 60 minutes	SARS-CoV-1 ³
56°C/133°F for 90 minutes	SARS-CoV-1 ⁵
56°C/133°F for unspecified time	SARS-CoV-1 ²
60°C/140°F for 15 to 30 minutes	SARS-CoV-1 ⁹
60°C/140°F for 30 minutes	SARS-CoV-1 ^{4,10}
65°C/149°F for 1 minute	MERS-CoV ¹
65°C/149°F for unspecified time	SARS-CoV-1 ¹¹
67°C/153°F for 60 minutes	SARS-CoV-1 ⁵
75°C/167°F for 30 minutes	SARS-CoV-1 ⁵

Henwood postulated that “heating samples to 56°C, as used in routine tissue processing, were found to inactivate several coronaviruses and it is believed that 2019-nCoV would be similarly affected.”²²

There appears to be a growing scientific consensus that heat is a viable method to inactivate

SARS-CoV-2.

Testing of the GreenTech Heat Process

Sterilization is a crucial metric in all clean environments. Many microbial agents are either not readily available for use in testing or may be deemed too dangerous for general use. One accepted method to test a specific environment for sterilization efficacy is through the use of biological surrogate indicators. *Geobacillus stearothermophilus* is a suitable microorganism for testing the effectiveness of sterilization protocols using heat or steam, given the bacteria's high heat resistance. The spores withstand temperatures of 121°C/250°F for up to 12 minutes.^{12,13}

GreenTech Heat Solutions conducted internal testing on 13 April 2020. A Titan 800 direct fired heater was utilized to heat the test chamber to 121°C/250°F. Three separate SporView strips were tested for three different times. The SporView strips and controls were tested by Natural Link Mold Lab. The report on strip deactivation is included in this document. Summary results are as follows:

121°C/250°F	15 minutes	Growth detected
121°C/250°F	30 minutes	No growth detected
121°C/250°F	60 minutes	No growth detected

The GreenTech Heat process applied with a GreenTech Heat Titan 800 heated the test chamber to “lethal” temperatures and achieved a sterilization as determined by surrogate testing.

State of the treatment market

The SARS-CoV-2 pandemic has created an environment of fear and desperation. People and organizations are seeking any relief from the effects of the virus. Organizations lacking experience in or proven efficacy with viral sanitization are advertising their services. Many of these companies are environmental remediation or pest control companies. The National Pest Management Association states: “No single best practice or standard operating procedure has been established for disinfection services. Businesses are developing disinfection protocols based on label instructions for the antimicrobial products being incorporated into the service.”¹⁴

GreenTech Heat equipment has been used to provide successful environmental remediation treatments since 1995. Additional information can be found in the *Historical Applications of Heat with Other Viruses* section.

Comparisons of Efficacy of Other Sanitization Methodologies

Chemical Fogging/Gaseous Treatment

The National Pest Management Association states (emphasis added): “*As with every pesticide, always read and follow all label instructions.* Efficacy of antimicrobial products is highly dependent on the length of time that the treated surface remains wet. *Information about contact time will be specified on the label...* Unless fogging is specified on the label, it should not be used.”¹⁴

Without clear direction, labeling, and protocols, gaseous application of chemical treatments

may fail to achieve efficacious results, potentially exposing individuals and companies to unexpected consequences. As an example, Kinderman discusses the efficacy of fogging with vaporized hydrogen peroxide (VHP) solution at 33.8% on samples of Minute virus of mice (MVM), Bovine viral diarrhoea virus (BVDV), and Hepatitis A virus (HAV). Results indicated that when applying decontamination conditions as recommended by the supplier (release of 18.3g H₂O₂/m³), only incomplete inactivation was observed for MVM.

When the amount of H₂O₂ as well as treatment time were significantly increased to 40.6–42.52g H₂O₂/m³, MVM was inactivated to below the detection limit. These harsher conditions were also sufficient to inactivate BVDV and HAV. A 3-hour treatment with vaporized H₂O₂ was most effective against MVM.¹⁵

The current OSHA permissible exposure limit (PEL) for H₂O₂ is 1 ppm (1.4 mg/m³) total weight average (TWA). The 8-hour TWA PEL is defined in the Federal Register, Vol. 57, No. 114, June 12 1992, pps 26539, 26556, 26572, 26573 and 26590 as follows: “TWA is the employee’s average airborne exposure in any 8-hour work shift of a 40-hour work week which shall not be exceeded.”¹⁶ (16Cake, 1995) The concentration required for successful H₂O₂ decontamination is approximately 30,000 times the OSHA TWA PEL.

Following any fogging, the room, container, or area must be rinsed with fresh air. Staff may not enter the room or sensitive items may not be brought into the space until an air analysis demonstrates the concentration of H₂O₂ has been reduced through ventilation to non-hazardous levels, usually less than 1 ppm.

When considering the efficacy of fogging or gaseous viral disinfection against SARS-CoV-2, many chemical disinfectants will be required in concentrations in excess of limits safe for humans. PPE exposed to gaseous chemicals must be tested to ensure residual concentrations are at safe levels prior to the equipment being placed back into use. The potential for residual allergic or adverse reaction after disinfection needs to be considered in this treatment strategy.

Sprayed Chemicals

Chemical sanitization is achieved by spraying, wetting, fogging, bathing, or wiping the surface of an item with the sanitizing agent. Sanitization only occurs on the surface of an object where it is sprayed, wetted, or wiped. Any viral agent not located on the exterior surface that does not receive sufficient volume and time contact with the sanitizer is not deactivated, and the chemical disinfection is active only as long as the surface remains wet.

Hulkower tested chlorine bleach, Vesphene IIse, Cidex-OPA, 70% ethanol, Purell hand sanitizer, and Clorox Anywhere hand sanitizing spray for effectiveness against MHV and TGEV as SARS-CoV-1 surrogates. The report stated: “A log₁₀ viral reduction factor of >3 has been previously suggested as a benchmark for effective virucidal activity against coronaviruses and other viruses on surfaces. The results of this study show that, of the commonly used hospital germicides tested, only the ethanol-based germicides were able to achieve this level of reduction of infectious virus after 1 minute of contact time.”¹⁷ Alcohol-based germicides include Purell hand sanitizer and Clorox Anywhere hand sanitizing spray.

Kariwa determined exposure of SARS-CoV-1 with several PVP-I products (Isodine® solution, Isodine Scrub®, Isodine Palm®, Isodine Gargle® and Isodine Nodo Fresh®) for 2 min reduced the vi-

rus infectivity from 1.17×10^6 TCID₅₀/ml to below the detectable level. The efficacy of 70% ethanol was equivalent to that of PVP-I products.³

Rabenau tested the following compounds: 2-propanol (70 and 100%), Desderman N (78% ethanol, 0.2% 2-biphenylol), Sterillium (45% 2-propanol, 30% 1-propanol), formaldehyde (0.7 and 1%) and glutardialdehyde (0.5%), Incidin plus (2%; containing 26% glucoprotamin). The researchers determined that “Isopropanol 70% and 100% achieved a $>3.31\log_{10}$ reduction of virus infectivity after 30 s, while Desderman reduced the virus titre by $>5.01\log_{10}$ and Sterillium by $>2.78\log_{10}$... The minimum reduction factor for formaldehyde (0.7 and 1%) was $>3.01\log_{10}$, for glutardialdehyde (0.5%) $>4.01\log_{10}$, and for Incidin plus $>1.68\log_{10}$, after 2 min of incubation. The reduction factor for wine vinegar was $\geq 3.0\log_{10}$, achieved within 60 s.”⁵

PPE exposed to liquid chemical virucidal agents must be tested to ensure residual concentrations are at safe levels prior to the equipment being placed back into use.

UV Irradiation

UV irradiation is an effective treatment for items small enough to fit within the effective range of the UV light. UV irradiation will not be effective on items with complex surface structures or internal locations that could act as a fomite for the virus.

Kariwa determined irradiation “with ultraviolet light at 134 microW/cm² for 15 min reduced the infectivity from 3.8×10^7 to 180 TCID₅₀/ml; however, prolonged irradiation (60 min) failed to eliminate the remaining virus, leaving 18.8 TCID₅₀/ml.”³ (3Kariwa, 2006)

Darnell “determined that greater than 15 min of UVC treatment inactivated the virus.”¹¹ (11Darnell, 2004)

Heat

Unlike surface sanitizations utilizing chemicals or UV light, heat conducts, radiates, and penetrates through items and objects, such as mattresses, masks, flooring, walls, ceilings, gurneys, desks, chairs, and other furniture and can sterilize the entire object.

Convected air transfers heat energy into the treatment area: building materials, contents, and all items, including but not limited to metal, fabric, wood, ceramic, and concrete. The energy then conducts through all the layers of the items and building materials. Heat radiates through the item into the voids and throughout the entire system. Given sufficient time, energized or heated air will conduct heat into and throughout all items in the treatment zone or chamber, and every item will achieve thermal equilibrium with the treatment environment. Convected heat reaches thermal equilibrium faster than stagnant, radiant heat.

Kariwa determined that “heating [SARS-CoV-1] at 56° C for 60 minutes or longer reduced the infectivity of the virus from 2.6×10^7 to undetectable levels.”³

Rabenau determined “thermal inactivation [of SARS-CoV-1] at 56°C was highly effective in the absence of protein, reducing the virus titre to below detectability; however, the addition of 20% protein exerted a protective effect resulting in residual infectivity. If protein-containing solutions are to be inactivated, heat treatment at 60°C for at least 30 min must be used.”⁴

Unlike other treatment modalities, convected heat is not subject to a limit on the size of the treatment area, nor the quantity of items within said treatment area. Convected heat penetrates

completely through the entire treatment area and into and through all contents within, and is not subject to only deactivating viruses on the visible surface of items. Upon completion of a convected heat treatment, cool air is flushed throughout the treatment area; there are no lingering chemicals to evacuate prior to reentry or removal of items.

Heat Treatment Protocol for Viruses

The GreenTech Heat process has successfully been used to decontaminate microbial contamination, including molds, fungi, bacterial, and viral contaminations. This document demonstrates environmental remediation with heat and provides a summary of thermal death points as determined by independent, academic, and laboratory research.

Now that current scientific research documents consistency of physical properties displayed between MERS, SARS-CoV-2, and SARS-CoV-1^{2,18}, Dr Michael R. Linford, GreenTech Heat founder and CEO, and Tom Costello, Technical Director, propose the following coronavirus heat treatment protocol for disinfecting structures from individual rooms all the way up to an entire structure. GreenTech Heat has developed this protocol based on the published and reviewed deactivation temperatures of SARS-CoV-1, MERS-CoV, and SARS-CoV-2.

When conducting a microbial treatment with GreenTech Heat equipment, heat and hold the treatment zone according to the following time and temperature protocol:

60°C/140°F for 6 hours

66°C/150°F for 4 hours

71°C/160°F for 3 hours

Once the above temperature is achieved, maintain temperatures until the hardest-to-heat locations maintain that temperature for the prescribed time as indicated with a temperature probe.

Laboratory confirmation may be achieved by surface swabs or by utilizing surrogate testing.

Historical Applications of Heat with Other Viruses

In the early 1860s, Louis Pasteur conducted tests that verified germ theory and convinced most of Europe that it was factual. Pasteur discovered that microorganisms are susceptible to elevated temperatures and that all living organisms have a specific thermal death point. The process of heating food products to reduce bacteria to safe levels without damaging the food product became known as pasteurization.

Hantavirus

Beginning in 1995, Hantavirus outbreaks focused the nation's attention on the need for vector control. However, killing and removal of the infectious rodents did little to alleviate the virus the animals left in their environment. These rodents are often found in areas of a structure which are easily accessible by humans, and rodents are often trapped or baited in places such as attics, sub-areas, and garages. These areas are relatively easy to disinfect once the vermin are exterminated. *However, large portions of the rodent population spend a substantial time in the inaccessible areas that are impractical or impossible to disinfect by conventional methods.*

The World Health Organization (WHO) identified several methods of inactivating Hantavirus, including exposure to 60°C/140°F heat for 30 minutes. The Centers for Disease Control (CDC) states that most bacteria die from exposure to 60°C/140°F for 1 hour. The California Department of Public Health determined that Hantavirus is disinfected with exposure to 66°C/150°F for 2 hours. The GreenTech Heat process is capable of elevating and maintaining these temperatures throughout the entirety of a structure during the treatment.

William Currie, director of the International Pest Management Institute and former US EPA training officer for the office of pesticide programs, wrote that thermal pest eradication can be a viable method for disinfecting Hantavirus in rodent infected construction voids in structures.

H5N1 Bird Flu

The United Nations Agricultural Department laboratory determined heat inactivates the H5N1 bird flu virus at 60°C/140°F with 30 minutes duration. Just like rodents, birds also infest homes, offices, and other commercial structures. A crack or a hole as small as the size of a quarter will allow birds to penetrate and inhabit buildings and grant access to areas of a structure that are inaccessible to chemical treatments. The GreenTech Heat process has been successfully applied to disinfect H5N1 affected buildings.

Fomites

The 2002 SARS outbreak in southern China produced a total of 8,098 cases, with 774 deaths reported in 17 countries, resulting in a 9.6% case fatality rate. The primary route of transmission for SARS is contact of the mucous membranes with respiratory droplets or via fomites. Generally speaking, everyone understands aerosol and direct droplet transmission, so we will examine the situations regarding fomites.

Common examples of fomites include our cell phones and tablets; car keys and house keys, keyboards and mice; pens and staplers; doorknobs; desks and counter tops; soda cans, water bottles, and drinking glasses; and light switches... pretty much everything you can think of, including the kitchen sink. As HVAC systems circulate air through a structure, the HVAC system may become one large fomite.

On March 17, 2020, the *New England Journal of Medicine* published a letter from a research team titled *Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1*. The team consisted of researchers from the National Institute of Allergy and Infectious Diseases; Princeton University; University of California, Los Angeles; and the Centers for Disease Control and Prevention determined the length of time for fomite viability was consistent with SARS-CoV-1. The research team presented that their “results indicate that aerosol and fomite transmission of SARS-CoV-2 is plausible, since the virus can remain viable and infectious in aerosols for hours and on surfaces up to days (depending on the inoculum shed).”¹⁸

The letter specifically identifies

- SARS-CoV-2 is more stable on plastic and stainless steel than on copper and cardboard.
- Viable virus was detected up to 72 hours after application to plastic and stainless steel.
- On copper, no viable SARS-CoV-2 was measured after 4 hours.

- On cardboard, no viable SARS-CoV-2 was measured after 24 hours and no viable SARS-CoV-1 was measured after 8 hours.
- On cardboard, the half-life of SARS-CoV-2 was longer than that of SARS-CoV-1.
- The longest viability of both viruses was on stainless steel and plastic; the estimated median half-life of SARS-CoV-2 was approximately 5.6 hours on stainless steel and 6.8 hours on plastic.

As far as we can surmise, no study has been done on the viability of MERS-CoV, SARS-CoV-1, or SARS-CoV-2 viruses on cloth, fabric, or leather. This extends to the viability on items such as furniture, clothing, and carpeting.

In reference to the fomite stability of the virus outside the body for SARS-CoV-2, the WHO consensus document reported: “Data from the Chinese University in Hong Kong indicated that SARS-CoV-1 has been isolated from stool on paper, a Formica surface and a plastered wall after 36 hours, on a plastic surface and stainless steel after 72 hours, and after 96 hours on a glass slide. Hospital environmental samples from a number of sites, including walls and the ventilation system, tested PCR positive in Canada.” (World Health Organization, 2003, Consensus document on the epidemiology of severe acute respiratory syndrome [SARS], p. 29)

The problem with novel coronavirus fomites is two-fold: (1) finding all of them and disinfecting all of them, and (2) knowing how long the coronavirus will remain viable on a fomite surface.

Structural pasteurization

The Institute of Inspection Cleaning and Restoration Certification (6IICRC) defines *structural pasteurization* as “an engineered process in which high temperatures are introduced to a structure or portion of a structure for the purpose of reducing bio-organisms to acceptable levels without damage to the structure.”⁶. In 2008, the Second Edition to the IICRC S520 Standard and Reference Guide for Professional Mold Remediation was approved by the American National Standards Institute (ANSI) for publication. The concept of structural pasteurization and its identification as a remediation process is a significant acknowledgment of the technology. Structural pasteurization is a process that will improve indoor air quality. It is significant that this recognition exists in an important standards development such as the S520.

The S520 is a voluntary Standard and Reference Guide, but it is the single most significant document regarding the process of mold remediation. The document is written for use by those involved in the mold remediation industry – primarily for mold remediation companies and workers, but also for those who investigate or assess mold complaints, prepare specifications, protocols or procedures and manage remediation projects. It is also the primary document for materially interested parties such as property owners, consumers, insurance companies, and government and regulatory bodies. The S520 is the most significant published document governing the remediation of mold in structures, structural components, and/or contents.

Mold infests and affects structures far beyond the surface and fomites. Heat is an approved treatment and remediation methodology for destroying mold where ever it can be found in a structure, not just on the surfaces of walls, floors, and items in a structure. Similarly, applied heat will destroy and denature viruses where ever they are in a structure.

The IICRC is currently in development of a new industry Standard on Infection Control: BSR/IICRC S410 Standard for Infection Control During Professional Cleaning and Maintenance of the Commercial Built Environment to provide a specific set of principles, methods, and processes to clean, sanitize, and evaluate the cleaning of the built environment where verifiable, hygienic cleaning is required. This Standard will also establish methods and processes to document, evaluate, clean, sanitize/disinfect, and sterilize facilities that require a higher level of cleaning.

A More Thorough Disinfection: especially in the hidden places

Recent reports suggest coronavirus transmission may be caused by asymptomatic people.^{19,20,21,22,23} It may be impossible to identify asymptomatic carriers and every space or fomite they have come into contact with.²⁴ The GreenTech Heat process is the only methodology which requires no formal identification of a treatment zone within an identified structure, or specific identification of items within a given room or rooms to be sanitized.

Heat is the only disinfection process that can be safely administered across an entire structure with minimal exposure to treatment teams with the expectation of a successful disinfection of the entire structure, surfaces, contents, and unexpected areas, including the HVAC system. Heat is the only sterilization process that is completely allergy-free and leaves no chemical residue that can aggravate the respiratory system. This point is an especially important consideration when sanitizing PPE, especially masks.

The GreenTech Heat process provides a more thorough disinfection throughout more elements of a structure and all its contents. The engineered application of heat allows building owners, health preservation staff, environmental remediation, and maintenance teams to disinfect the entire structure and all its contents in one empirically-measurable heat treatment—including the HVAC system.

It is imperative to sanitize the HVAC system concurrently with the rest of the structure. Failure to disinfect the entire structure leaves the potential to agitate, recirculate, and reintroduce virus particles in the HVAC system back into and throughout the occupied portions of the structure.

Recent medical speculation concerns community transmission of SARS-CoV-2 through breathing and speaking²⁵, and as reported by numerous news outlets^{26,27}, have raised a concern that aerosolized transmission may be possible. Any aerosolized virus particles suspended within a structure or circulated through the HVAC system may remain viable during traditional surface sanitizations.

There is the potential that all the work disinfecting the obvious fomites and surfaces in the occupied portions of the structure will be recontaminated once the HVAC system is turned back on. The HVAC can disburse dried virus particles back on to fomite surfaces.

Unlike manual surface disinfection, the GreenTech Heat process does not require a large treatment team and is not subject to unmeasurable human inadequacies within the treatment area. The process indiscriminately treats the entirety of the structure and its contents. As long as the required temperatures are achieved throughout the structure for the required amount of time, the structure is disinfected. Both time and temperature can be empirically measured and confirmed.

Treating structures and contents with the GreenTech Heat convected heat process will slow

this contagion without the need to manually wipe down contents to eliminate the virus on surfaces of fomites. Previous coronaviruses including SARS and MERS could last as long as two weeks in an air-conditioned environment. The GreenTech Heat process will also provide legitimate peace of mind that the structure is free of viral contamination.

Exhaust filtration

Many traditional structural pasteurization and environmental remediation projects for mold and bacteria recommend or require filtering of exhaust gases. Filtration is less effective in viral heat treatments than treatments with larger pathogens such as bacteria (generally 0.2 micron to 2.0 micron) or mold (often 3 micron to 40 microns). Viruses typically range from 0.01 micron to 0.2 micron in size, although they may cluster or attach to larger particles.

Description	Virus	Approximate size
SARS	coronavirus	0.08 to 0.16 microns
MERS-CoV	coronavirus	0.08 to 0.16 microns
Swine flu	H1N1	0.08 to 0.12 microns
Avian flu	H5N1 and H7N9	0.1 microns

HEPA certification requires the filter to capture 99.97% of the 0.3-micron or 0.1-micron particles in the air passing through the filter. Typical coronavirus sizes fall on the lower end of filter ability. Viruses may pass through the filter when propelled by the exhaust pressures produced in a heat treatment.

Compendium of Thermal Death Points

The same process for treating bed bugs will also kill, and in some cases, completely eradicate other organisms. Generally speaking, treatments with air temperatures of 66°C/150°F for 2 hours will be lethal for most organisms. In laboratory testing with Dr. Walter Ebling, professor of entomology at UCLA, nearly all metamorphic stages of insects died at 49°C/120°F in 30 minutes or less, except for the egg stage. The eggs required an hour at this temperature. Remember, field conditions are not controlled as are conditions in the lab. The times and temperatures listed in the Compendium are not generic air temperatures. These conditions must be met where the organism is found and may require significantly more time to reach the stated thermal levels.

This Compendium includes common microorganisms and insects and also lists many less common organisms. These include insects, bacteria, fungi, protozoa, helminthes, and viruses. Many of these are human pathogens, and a number of them are considered pathogens for animal, avian, or plant, or some combination thereof.

This information comes from studies for food pasteurization, sewage treatment, pest control, soil pasteurization, and compost and timber sterilization. This Compendium also includes additional results from recent field studies by Dr. Michael R. Linford.

The cited thermal death points for any given organism may vary from source to source because control parameters and study conditions may vary from study to study.

About GreenTech Heat Solutions

GreenTech Heat Solutions combines a university-tested heat technology with the most affordable, portable, and effective heating equipment anywhere. The founder of GreenTech Heat Solutions pioneered the use of heat for wood-destroying insect eradication in the late 1980s. With more than 30 years of experience in treating structures with convected heat, GreenTech Heat Solutions is the most qualified company in the industry, boasting a proven track record of over one million successful heat treatments. The GreenTech Heat technology has an EPA registration and has been successfully used all over the world.

GreenTech Heat has designed and created solutions for numerous applications and industries.

Tom Costello, Technical Director at GreenTech Heat, designed a custom heat chamber for ATL Automotive Technologies Limited in 2018. This heat chamber system received the 2019 Mondiale Innovation Award at the recent Ministry for Primary Industries Biosecurity Awards and the system was also a finalist for the 2019 New Zealand Biosecurity GIA Industry Awards.

Attachment 1

Analytical laboratory report for *Geobacillus stearothermophilus* sterility test showing deactivation at 121 °C/250 °F for 30 minute and 60 minute durations.



Analytical Laboratory Report Bacterial Culture Sterility Test

Account Name:	Green Tech Heat Solutions	Control ID#:	50638
Project/P.O.:	Sterilization Efficacy	Date Received:	04-16-2020
Submitter:	Michael Linford	Date Reported:	04-21-2020

Sample Identification: 1, Heat chamber test 250° 15 min; SporView/Biological Indicator Strip; 04-15-2020

Geobacillus stearothermophilus SporView/Biological Indicator Strip – Heat Chamber

➤ *G. stearothermophilus*: Growth Detected

Geobacillus stearothermophilus SporView/Biological Indicator Strip – Control / Not Heat Treated

➤ *G. stearothermophilus*: Growth Detected

Summary: STERILITY - FAIL

- Test results indicate that the sterilization process of the tested heat chamber was not adequate to kill the test organism (*G. stearothermophilus*) contained within the autoclaved Biological Indicator Strip.

Sample Identification: 2, Heat chamber test 250° 30 min; SporView/Biological Indicator Strip; 04-15-2020

Geobacillus stearothermophilus SporView/Biological Indicator Strip – Heat Chamber

➤ *G. stearothermophilus*: No Growth Detected

Geobacillus stearothermophilus SporView/Biological Indicator Strip – Control / Not Heat Treated

➤ *G. stearothermophilus*: Growth Detected

Summary: STERILITY - PASS

- Test results indicate that the sterilization process of the tested heat chamber was adequate to kill the test organism (*G. stearothermophilus*) contained within the autoclaved Biological Indicator Strip.

Report#: 50638-R01 Analysis Date: 04-21-2020

Natural Link Mold Lab, Inc. (NLMLab) reports sample results as a record of the microbes identified by our analytical staff. Any guidance given with regards to sampling methods, interpretation of results, remediation, health effects, or other information given to the client, beyond microbial identification, is given as general information from published sources and is not an extension of liability to NLMLab. NLMLab establishes responsibility over analysis completed in the laboratory but cannot establish responsibility for activities completed in the field by the client, other personnel associated with the samples submitted, or other activities beyond the laboratory. All reports are confidential and are not to be reproduced except in whole, without the permission of NLMLab.

Laboratory Results authorized by Sean P. Abbott, Ph.D., Analytical Director
Natural Link Mold Lab, Inc., 4900 Mill Street, Suite 3, Reno, NV 89502

Attachment 1

Analytical laboratory report for *Geobacillus stearothermophilus* sterility test showing deactivation at 121 °C/250 °F for 30 minute and 60 minute durations.



Analytical Laboratory Report

Bacterial Culture
Sterility Test

Account Name:	Green Tech Heat Solutions	Control ID#:	50638
Project/P.O.:	Sterilization Efficacy	Date Received:	04-16-2020
Submitter:	Michael Linford	Date Reported:	04-21-2020

Sample Identification: 3, Heat chamber test 250° 60 min; SporView/Biological Indicator Strip; 04-15-2020

Geobacillus stearothermophilus SporView/Biological Indicator Strip – Heat Chamber

- *G. stearothermophilus*: No Growth Detected

Geobacillus stearothermophilus SporView/Biological Indicator Strip – Control / Not Heat Treated

- *G. stearothermophilus*: Growth Detected

Summary: STERILITY - PASS

- Test results indicate that the sterilization process of the tested heat chamber was adequate to kill the test organism (*G. stearothermophilus*) contained within the autoclaved Biological Indicator Strip.

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Laboratory Results authorized by Sean P. Abbott, Ph.D., Analytical Director
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Pathogen/Organism: Lab Studies	Group	Affects	Thermal Death Point	Time Required	Reference/Source ¹
<i>Adenovirus</i>	Virus	Human	60°C/140°F	20 min	Gerba, 1997; Mahnel, 1977
<i>Avian pneumovirus</i>	Virus	Avian	56°C/133°F	30 min	TIP, 2000; Collins, 1986
<i>Cercopithecine Herpes Virus 1</i>	Virus	Human Animal	60°C/140°F	30 min	Health Canada, 2007
<i>Coronavirus</i>	Virus	Human	55°C/131°F	2 min	Gerba, 1997; Laude, 1981
<i>Coxsackievirus</i>	Virus	Human	60°C/140°F	30 min	Health Canada, 2007
<i>Cytomegalovirus</i>	Virus	Human	60°C/140°F	30 min	Health Canada, 2007
Ebola virus	Virus	Human	60°C/140°F	60 min	Health Canada, 2007
<i>Echovirus</i>	Virus	Human	50°C/122°F	2 hr	Health Canada, 2007
<i>Enterovirus 70</i>	Virus	Human	60°C/140°F	30 min	Health Canada, 2007
<i>Enteroviruses, Reoviruses and Adenoviruses (All)</i>	Virus	Human	60°C/140°F	2 hr	Feachem, 1983
Hepatitis A	Virus	Human	70°C/158°F	4 min	Health Canada, 2007
Newcastle Disease Virus (NDV)	Virus	Human, Avian	60°C/140°F 70°C/158°F	1 hr 50 sec	TIP, 2000; Foster & Thompson, 1957
Norwalk virus	Virus	Human	>60°C/140°F	>30 min	Health Canada, 2007
Poliovirus	Virus	Human	60°C/140°F	25 min	Gerba, 1997; Larkin and Fasolitis, 1979
Poliovirus 1	Virus	Human	55°C/131°F 60°C/140°F	30 min 5 min	Feachem, 1983, p163; Wiley & Westerberg, 1969
Poxviruses	Virus	Human, Avian	60°C/140°F	8 min	TIP, 2000; Tripathy, 1993
Reovirus	Virus	Human	60°C/140°F	20 min	Gerba, 1997; Mahnel, 1977
Rotavirus	Virus	Human	50°C/122°F	30 min	Gerba, 1997; Estes, et al., 1979
SARS-CoV-1	Virus	Human	56°C/133°F	25 min	Leclercq, et.al., 2014
SARS-CoV-1	Virus	Human	60°C/140°F	30 min	Rabenau, et.al., 2005; Darnell & Taylor, 2006
Viruses (Most)	Virus	Human	70°C/158°F	20 min	Jones & Martin, 2003; Day & Shaw, 2000
Viruses (Most)	Virus	Human	70°C/158°F	25 min	Jones & Martin, 2003; Stern, 1974
<i>Agrilus planipennis</i> Emerald ash borer	Pests	Plant	71°C/160°F	75 min	APHIS Factsheet, 2009
American dust mite, <i>Dermatophagoides farinae</i>	Pests	Human	50°C/122°F 60°C/140°F	30 min 8 min	Chang, 1998
<i>Anoplophora glabripennis</i> Asian longhorned beetle	Pests	Plant	71°C/160°F	75 min	APHIS Factsheet, 2009
Bed bug, <i>Cimex lectularius</i>	Pests	Human	39-40°C/111- 113°F		Getty, 2006; Usinger, 1966
Bed bug (adults and nymphs), <i>Cimex lectularius</i>	Pests	Human	>40°C/113°F	15 min	Getty, 2006; Gulmahamad, 2002
Bed bug (eggs), <i>Cimex lectularius</i>	Pests	Human	>40°C/113°F	1 hr	Getty, 2006; Gulmahamad, 2002
Cockroach, German, <i>Blattella germanica</i>	Pests	Vector	54.4°C/130°F	7 min	Quarles, 2006; Forbes, Ebeling, 1987
<i>Dermanyssus gallinae</i> , Chicken Mite or Poultry Red Mite	Pests	Vector Human Avian	45°C/113°F	2 hr	Nordenfors, 1999
<i>Dermatophagoides pteronyssinus</i> European Dust Mite	Pests	Human	60°C/140°F	60 min	Ogg, 1997

Pathogen/Organism: Lab Studies	Group	Affects	Thermal Death Point	Time Required	Reference/Source ¹
<i>Incisitermes minor</i> , Western Drywood Termite	Pests	Damage - Structural	54.4°C/130°F	6 min	Quarles, 2006; Forbes, Ebeling, 1987
<i>Lithepuhema humile</i> , Argentine Ant	Pests	Damage - Structural	54.4°C/130°F	1 min	Quarles, 2006; Forbes, Ebeling, 1987
<i>Lyctus</i> Powder Post Beetle All Forms	Pests	Damage - Structural	54.4°C/130°F	2½ hr	Parkin, 1937; Fisher, 1928
<i>Lyctus</i> Powder Post Beetle Larvae	Pests	Damage - Structural	52°C/125°F	2-4 hr	Parkin, 1937
Rat flea (larvae), <i>Xenopsylla cheopis</i>	Pests	Vector	39.4°C/103°F	1 hr	Mellanby, 1932
Rat flea (adult), <i>Xenopsylla cheopis</i>	Pests	Vector	40.6°C/105°F	1 hr	Mellanby, 1932
<i>Tetropium fuscum</i> Brown Spruce Longhorn Beetle Larvae	Pests	Damage-Structural	50°C/122°F 55°C/131°F	30 min 15 min	Mushrow, 2004
<i>Tinibrio molitor</i> Yellow Mealworm	Pests	Damage - Food	42.8°C/109°F	1 hr	Mellanby, 1932
<i>Acinetobacter baumannii</i>	Bacteria	Human	63°C/145°F	15 min	Dumalisile, et al., 2005
<i>Aeromonas hydrophila</i>	Bacteria	Human	50°C/122°F	3 min ²	Gerba, 1997; Gordon et al., 1992
<i>Bacillus anthracis</i>	Bacteria	Human	140°C/284°F	3 hr	Hampil, 1932; Koch, 1881
<i>Bacillus pestis (Yersinia)</i>	Bacteria	Human	60°C/140°F	2 min	Hampil, 1932; Gladin, 1898
<i>Bacterium tularensis</i>	Bacteria	Human	56°C/133°F	10 min	Hampil, 1932; McCoy, 1912
<i>Brucella abortus</i>	Bacteria	Human	61°C/142°F	3 min	Jones & Martin, 2003; Golueke, 1982
<i>Brucella abortus</i>	Bacteria	Human	55°C/130°F 65°C/149°F	60 min 3 min	Jones & Martin, 2003; Stern, 1974
<i>Brucella abortus or suis</i>	Bacteria	Human	55°C/130°F 60°C/140°F	60 min 3 min	Jones & Martin, 2003; Day & Shaw, 2000
<i>Brucella melitensis</i>	Bacteria	Human Animal	55°C/130°F 60°C/140°F	30 min 15 min	Hampil, 1932; Zwick & Wedeman, 1913
<i>Burkholderia mallei</i>	Bacteria	Human Bio Warfare	55°C/130°F	10 min	Health Canada, 2007
<i>Campylobacter spp.</i>	Bacteria	Human	75°C/167°F	1 min	Gerba, 1997; Bandres et al., 1988
<i>Chlamydia psittaci</i>	Bacteria	Human, Avian	56°C/133°F	5 min	TIP, 2000; Anderson et al., 1997
<i>Chryseobacterium meningosepticum</i>	Bacteria	Human	63°C/145°F	15 min	Dumalisile, et al., 2005
<i>Corynebacterium diphtheriae</i>	Bacteria	Human	55°C/130°F 70°C/158°F	45 min 4 min	Jones & Martin, 2003; Stern, 1974
<i>Escherichia coli</i>	Bacteria	Human	45°C/113°F 60°C/140°F 65°C/149°F 70°C/158°F 75°C/167°F	24 hr 105 min 45 min 45 min 15 min	Abbott, 2009
<i>Escherichia coli</i>	Bacteria	Human	60°C/140°F	45 min	Padhye & Doyle, 1992
<i>Escherichia coli</i>	Bacteria	Human	65°C/149°F	1 min	Gerba, 1997; Bandres et al., 1988

Pathogen/Organism: Lab Studies	Group	Affects	Thermal Death Point	Time Required	Reference/Source ¹
<i>Escherichia coli</i>	Bacteria	Human	60°C/140°F 70°C/158°F	60 min 5 min	Jones & Martin, 2003; Stern, 1974
<i>Escherichia coli</i>	Bacteria	Human	55°C/130°F 60°C/140°F	60 min 20 min	Jones & Martin, 2003; Day & Shaw, 2000
<i>Escherichia coli</i>	Bacteria	Human	55°C/130°F 60°C/140°F	60 min 20 min	Jones & Martin, 2003; Golueke, 1982
<i>Escherichia coli</i>	Bacteria	Human	63°C/145°F	25 min	Dumalisile, et al., 2005
<i>Klebsiella pneumoniae</i>	Bacteria	Human	45°C/113°F 60°C/140°F 65°C/149°F 70°C/158°F	24 hr 105 min 45 min 45 min	Abbott, 2009
<i>Legionella</i>	Bacteria	Human	66°C/142°F	.45 min ²	Gerba, 1997; Sarden et al., 1989
<i>Legionella pneumophila</i>	Bacteria	Human	60°C/140°F	30 min	Stout, et al., 1986
<i>Listeria monocytogenes</i>	Bacteria	Human	63°C/145°F	20 min	Dumalisile, et al., 2005
<i>Mycobacterium avium sub. paratuberculosis</i>	Bacteria	Human	62°C/144°F 71°C/160°F	23 min 73 sec	Sung & Collins, 1998
<i>Mycobacterium diphtheriae</i>	Bacteria	Human	55°C/130°F 70°C/158°F	45 min 4 min	Jones & Martin, 2003; Stern, 1974
<i>Mycobacterium spp. M. avium</i>	Bacteria	Human	70°C/158°F	2 min 2.3 min ²	Gerba, 1997; Robbecke and Buchhottz, 1992
<i>Mycobacterium avium sub .paratuberculosis</i>	Bacteria	Human	72°C/162°F	15 sec	Pearce, 2001
<i>Mycobacterium tuberculosis</i>	Bacteria	Human	63°C/145°F	3 min	Hampil, 1932; North & Park, 1925
<i>Mycobacterium tuberculosis</i>	Bacteria	Human	63°C/145°F 72°C/162°F	30 min 15 sec	Connor, 2007
<i>Paratyphoid bacilli</i>	Bacteria	Human	60°C/140°F 63°C/145°F	20 min 3 min	Hampil, 1932; Krumwiede & Noble, 1921 Hampil, 1932; Orskov, 1926
<i>Pasteurella multocida</i>	Bacteria	Human and Avian	56°C/133°F 60°C/140°F	15 min 10 min	TIP, 2000; Rimler and Glisson, 1998
<i>Pasteurella spp.</i>	Bacteria	Human	55°C/131°F	15 min	Health Canada, 2007
<i>Pseudomonas aeruginosa</i>	Bacteria	Human	45°C/113°F 60°C/140°F 65°C/149°F 70°C/158°F	4 hr 75 min 45 min 45 min	Abbott, 2009
<i>Pseudomonas aeruginosa</i>	Bacteria	Human	60°C/140°F	<10 min	Spinks, et al., 2003
<i>Pseudomonas putida</i>	Bacteria	Human	63°C/145°F	20 min	Dumalisile, et al., 2005
<i>Salmonella</i>	Bacteria	Human	60°C/140°F	1 hr	Feachem, 1983
<i>Salmonella sp.</i>	Bacteria	Human	65°C/149°F	1 min	Gerba, 1997; Bandres et al., 1988
<i>Salmonella newport</i>	Bacteria	Human	60°C/140°F 65°C/149°F	40 min 30 min	Wiley & Westerberg (1969)
<i>Shigella sp.</i>	Bacteria	Human	50°C/122°F	1 hr	Jones & Martin, 2003; Stern, 1974
<i>Shigella sp.</i>	Bacteria	Human	55°C/131°F	1 hr	Feachem, 1983
<i>Shigella spp.</i>	Bacteria	Human	65°C/149°F	1 min	Gerba, 1997; Bandres et al., 1988

Pathogen/Organism: Lab Studies	Group	Affects	Thermal Death Point	Time Required	Reference/Source ¹
<i>Staphylococci</i>	Bacteria	Human	62°C/144°F	10 min	Hampil, 1932; Sternburg, 1887
<i>Staphylococcus aureus</i>	Bacteria	Human	45°C/113°F 50°C/122°F 60°C/140°F 65°C/149°F 70°C/158°F	96 hr 48 hr 105 min 45 min 45 min	Abbott, 2009
<i>Staphylococcus aureus</i>	Bacteria	Human	50°C/122°F	10 min	Jones & Martin, 2003; Golueke, 1982
<i>Staphylococcus aureus</i>	Bacteria	Human	63°C/145°F	20 min	Dumalisile, et al., 2005
<i>Streptococci</i>	Bacteria	Human	60°C/140°F	30 min	Hampil, 1932; Ayers & Johnson, 1918
<i>Streptococcus pyogenes</i>	Bacteria	Human	54°C/129°F	10 min	Jones & Martin, 2003; Golueke, 1982
<i>Streptococcus pyogenes</i>	Bacteria	Human	55°C/131°F	10 min	Jones & Martin, 2003; Day & Shaw, 2000
<i>Vibrio cholerae</i>	Bacteria	Human	55°C/131°F	15 min	Hampil, 1932; Kitasato, 1889
<i>Yersinia enterocolitica</i>	Bacteria	Human	60°C/140°F	30 min	Gerba, 1997; Frazier and Westhoff, 1988
<i>Coxiella burnetii</i>	Bacteria Rickettsia	Human Q Fever	63°C/145°F	30 min	Connor, 2007
<i>Coxiella burnetii</i>	Bacteria Rickettsia	Human Q Fever	63°C/145°F	30 min	Health Canada, 2007
<i>Alternaria alternata</i>	Fungi	Human	63°C/145°F	25 min	Domsch, 1993; Page 37
<i>Aspergillus fumigatus</i>	Fungi	Human	65°C/149°F ³	30 min	Bollen, 1969
<i>Aspergillus niger</i>	Fungi	Human	63°C/145°F	25 min	Domsch, 1993; Page 102
<i>Aspergillus ustus</i>	Fungi	Human	62°C/144°F	25 min	Domsch, 1993; Page 119
<i>Candida albicans</i>	Fungi/ Yeast	Human	70°C/158°F	60 min	Wiley & Westerberg (1969)
<i>Candida lipolytica</i>	Fungi/ Yeast	Human	63°C/145°F	15 min	Dumalisile, et al., 2005
<i>Chaetomium spp.</i> (Soft rot)	Fungi	Human	55°C/131°F	30 min	Bollen, 1969
<i>Cladosporium herbarum</i>	Fungi	Human	50°C/122°F	10 min	Ridley and Crabtree, 2001
<i>Cladosporium herbarum</i>	Fungi	Human	60°C/140°F	30 min	Bollen, 1969
<i>Fusarium cinctatum</i>	Fungi	Human, Plant	60°C/140°F	10 min	Ridley, G. unpublished data
<i>Fusarium oxysporum</i>	Fungi	Human	60°C/140°F	30 min	Bollen, 1969
<i>Fusarium redolens</i>	Fungi	Plant	60°C/140°F	30 min	Bollen, 1969
<i>Lasiodiplodia theobromae</i> formerly <i>Botryodiplodia theobromae</i>	Fungi	Plant, Human	60°C/140°F	10 min	Ridley and Crabtree, 2001
<i>Myrothecium verrucaria</i>	Fungi	Plant	60°C/140°F	30 min	Bollen, 1969
<i>Oómycetes</i>	Fungi	Plant, Human	50°C/122°F	30 min	Bollen, 1969
<i>Penicillium corylophilum</i>	Fungi	Plant	60°C/140°F ³	30 min	Bollen, 1969
<i>Penicillium funiculosum</i>	Fungi	Human	70°C/158°F ³	30 min	Bollen, 1969
<i>Peniophora spp.</i>	Fungi	Plant	54.4°C/130°F	15 min	Morrell, 1990

Pathogen/Organism: Lab Studies	Group	Affects	Thermal Death Point	Time Required	Reference/Source ¹
<i>Penicillium lapidosum</i>	Fungi	Plant	70°C/158°F ³	30 min	Bollen, 1969
<i>Phialophora mustea</i>	Fungi	Plant	60°C/140°F ³	30 min	Bollen, 1969
<i>Phoma herbarum</i>	Fungi	Human	75°C/167°F ³	30 min	Bollen, 1969
<i>Poria carbonica</i>	Fungi	Plant	60°C/140°F 70°C/158°F	3 hr 60 min	Morrell, 1987
<i>Poria placenta</i>	Fungi	Plant	60°C/140°F 65.5°C/150°F	6 hr 3 hr	Morrell, 1987
<i>Preussia fleischhakkii</i>	Fungi	Plant	60°C/140°F	30 min	Bollen, 1969
<i>Rhinochadiella mansonii</i>	Fungi	Plant	60°C/140°F	30 min	Bollen, 1969
<i>Serpula lacrymans</i> (Dry rot)	Fungi	Structure	45°C/113°F 50°C/122°F	3 hr 1 hr	Miric & Willeitner (1984)
<i>Sordaria carbonaria</i>	Fungi	Plant	65°C/149°F	30 min	Bollen, 1969
<i>Sordaria spp.</i>	Fungi	Plant	60°C/140°F	30 min	Bollen, 1969
<i>Sporormia aemulans</i>	Fungi	Plant	65°C/149°F	30 min	Bollen, 1969
<i>Stachybotrys atra</i> (<i>S. chartarum</i>)	Fungi	Human	60°C/140°F	30 min	Bollen, 1969
<i>Stachybotrys chartarum</i>	Fungi	Human	60°C/140°F	30 min	Domsch, 1993; Page 745
<i>Stereum sanguinolentum</i>	Fungi	Plant	54.4°C/130°F	15 min	Bollen, 1969
<i>Stemphylium botryosum</i>	Fungi	Plant	60°C/140°F ³	30 min	Morrell, 1990
<i>Trichocladium piriformis</i>	Fungi	Plant	80°C/176°F ³	30 min	Bollen, 1969
<i>Trichoderma lignorum</i>	Fungi	Plant, some Human	55°C/131°F	30 min	Bollen, 1969
<i>Zygorhynchus moelleri</i>	Fungi	Plant	55°C/131°F	30 min	Bollen, 1969
<i>Ascaris lumbricoides</i>	Helminths	Human	55°C/131°F	60 min	Bollen, 1969
<i>Ascaris lumbricoides</i> eggs	Helminths	Human	50°C/122°F 55°C/131°F	60 min 7 min	Feachem, 1983
<i>Necator americanus</i>	Helminths	Human	50°C/122°F	50 min	Jones & Martin, 2003; Stern, 1974
<i>Opisthorchis spp.</i>	Helminths	Human	56°C/133°F	30 min	Jones & Martin, 2003; Stern, 1974 Health Canada, 2007
<i>Taenia saginata</i>	Helminths	Human	71°C/160°F	5 min	Jones & Martin, 2003; Golueke, 1982
<i>Taenia saginata</i>	Helminths	Human	71°C/160°F	5 min	Jones & Martin, 2003; Golueke, 1982
<i>Taenia saginata</i>	Helminths	Human	70°C/158°F	5 min	Jones & Martin, 2003; Stern, 1974
<i>Entamoeba histolytica</i>	Protozoa	Human	60°C/140°F	1 min	Gerba, 1997; Chang, 1943
<i>Entamoeba histolytica</i> cysts	Protozoa	Human	50°C/122°F	5 min	Jones & Martin, 2003; Stern, 1974
<i>Giardia lamblia</i>	Protozoa	Human	60°C/140°F	2-3 min	Univ of Utah, 2005
<i>Giardia Lamblia</i>	Protozoa	Human	50°C/122°F	1 min ²	Gerba, 1997; Cerva, 1955
<i>Toxoplasma gondii</i> Oocysts	Protozoa	Human	>66°C/151°F	10 min	Health Canada, 2007

Common Organism	Group	Affects	Thermal Death Point	Time Required	Reference/Source ¹
Bed bug (adults and nymphs), <i>Cimex lectularius</i>	Pests	Human	60.5°C/141°F	23 min	Linford, 2013
Bed bug (eggs), <i>Cimex lectularius</i>	Pests	Human	60.5°C/141°F	59 min	Linford, 2013
American dust mite, <i>Dermatophagoides farinae</i>	Pests	Human	60°C/140°F	60 min	Ogg, 1997
American wheat weevil, <i>Rhyzopertha dominica</i>	Pests	Damage - Food	50°C/122°F	360 min	Opit, Arthur, Bonjour, Jones, and Phillips, 2011
Cockroach, American, <i>Periplaneta americana</i>	Pests	Damage - Food	66°C/150°F	32 min/68 min eggs	Linford, 2013
Cockroach, Oriental, <i>Blatta orientalis</i>	Pests	Damage - Food	63°F/145°F	20 min/45 min eggs	Linford, 2013
Cockroach, German, <i>Blatella germanica</i>	Pests	Damage - Food	65°C/149°F	24 min/55 min eggs	Linford, 2013
Carpet beetle, <i>Anthrenus verbasci</i>	Pests	Damage - Fibers	49°C/120°F	20 min/60 min eggs	Linford, 2013
Flea (eggs)	Pests	Vector	68°C/155°F	65 min	Linford, 2013
Flea (adults and larvae)	Pests	Vector	68°C/155°F	21 min	Linford, 2013
Flour beetle (adult), <i>Tribolium confusum</i>	Pests	Damage - Food	54.4°C/130°F	4 min	Quarles, 2006; Forbes, Ebeling, 1987
Red flour beetle, <i>Rhyzopertha dominica</i>	Pests	Damage - Food	50°C/122°F	360 min	Opit, Arthur, Bonjour, Jones, and Phillips, 2011
Human body louse, <i>Pediculus humanus</i>	Pests	Vector	46.6°C/116°F	60 min	Mellanby, 1932
Indian meal moth, <i>Plodia interpunctella</i>	Pests	Damage - Food	53°C/126°F	7 min/45 min eggs	Linford, 2013
Spiders (adult)	Pests	Human	66°C/150°F	23 min	Linford, 2013
Spiders (eggs)	Pests	Human	66°C/150°F	52 min	Linford, 2013
Webbing clothes moth, <i>Tineola bisselliella</i>	Pests	Damage - Fibers	53°C/127°F	7 min/40 min eggs	Linford, 2013
<i>Bacillus coli</i> (<i>E. coli</i>)	Bacteria	Human	60°C/140°F	10 min	Hampil, 1932; Loeffler, 1886
<i>Bacillus typhosus</i> , Salmonella	Bacteria	Human	56°C/133°F 63°C/145°F	10 min 4 min	Hampil, 1932; Sternburg, 1887 Hampil, 1932; Orskov, 1926
<i>Shigella</i> , Dysentery bacilli	Bacteria	Human	58-60°C/140°F	10 min	Hampil, 1932; Runge & O'Brien, 1924
<i>Escherichia coli</i>	Bacteria	Human	60°C/140°F 70°C/158°F 75°C/167°F	105 min 45 min 15 min	Abbott, 2009
<i>Hemophilus influenzae</i>	Bacteria	Human	62°C/144°F	2 min	Hampil, 1932; Onorato, 1902
<i>Klebsiella pneumoniae</i>	Bacteria	Human	60°C/140°F 70°C/158°F	105 min 45 min	Abbott, 2009
<i>Listeria monocytogenes</i>	Bacteria	Human	63°C/145°F	30 min	Rowan, 1998

Resources

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