Environmental Remediation and Sterilization with Convected Heat and Inactivating 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] and 75˚C/167˚F.[5] GreenTech Heat Solutions is a technology and application methodology currently utilized in structural pasteurization treatments for biological agents including mold[6] 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.

On May 27, 2020, Ford Motor Company announced a software update to the Police Interceptor Utility vehicle which utilizes the vehicle's powertrain and heating system to temporarily raise the interior temperature beyond 56˚C/133˚F for 15 minutes to help reduce the viral concentration inside the vehicle by greater than 99 percent on interior surfaces and materials inside the vehicle.[26]

When conducting a microbial treatment with GreenTech Heat equipment, a minimum of 60°C/140°F must be achieved and maintained for one hour as measured with a temperature probe at the hardest-to-heat locations.

This sterilization process is not recommended for any item that cannot withstand exposure to highly-convected and heated air at a minimum temperature of 66˚C/150˚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 $\log^{10}$."[7]

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[2,4]
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 (2020) 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."[2]

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 diarrhea virus (BVDV), and Hepatitis A virus (HAV). Results indicated that when applying decontamination conditions as recommended by the supplier (release of 18.3g H_2O_2/m^3), only incomplete inactivation was observed for MVM.

When the amount of H_2O_2 as well as treatment time were significantly increased to 40.6–42.52g H_2O_2/m^3, 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 H_2O_2 was most effective against MVM.[15]

The current OSHA permissible exposure limit (PEL) for H_2O_2 is 1 ppm (1.4 mg/m^3) 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] The concentration required for successful H_2O_2 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 H_2O_2 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 $\log_{10}$ 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 virus infectivity from 1.17×10^6 $TCID_{50}$/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 >3.31log$_{10}$ reduction of virus infectivity after 30 s, while Desderman reduced the virus titre by >5.01log$_{10}$ and Sterillium by >2.78log$_{10}$... The minimum reduction factor for formaldehyde (0.7 and 1%) was >3.01log$_{10}$, for glutardialdehyde (0.5%) >4.01log$_{10}$, and for Incidin plus >1.68log$_{10}$, after 2 min of incubation. The reduction factor for wine vinegar was ≥3.0log$_{10}$, 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/cm^2 for 15 min reduced the infectivity from 3.8x10^7 to 180 TCID$_{50}$/ml; however, prolonged irradiation (60 min) failed to eliminate the remaining virus, leaving 18.8 TCID$_{50}$/ml."[3]

Darnell "determined that greater than 15 min of UVC treatment inactivated the virus."[11]

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 x 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], GreenTech Heat can be considered as a viable protocol for coronavirus heat treatments 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, a minimum of 60°C/140°F must be achieved and maintained for one hour as measured with a temperature probe at the hardest-to-heat locations.

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 speaking,[25] 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.

Natural Link **MOLD LAB**
4900 Mill Street Suite 3 Reno, NV 89502

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 1

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Natural Link **MOLD LAB**
4900 Mill Street
Suite 3
Reno, NV 89502

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
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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.

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
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Pathogen/Organism: Lab Studies	Group	Affects	Thermal Death Point	Time Required	Reference/Source [1]
Adenovirus	Virus	Human	60˚C/140˚F	20 min	Gerba, 1997; Mahnel, 1977
Avian pneumovirus	Virus	Avian	56˚C/133˚F	30 min	TIP, 2000; Collins, 1986
Cercopithecine Herpes Virus 1	Virus	Human Animal	60˚C/140˚F	30 min	Health Canada, 2007
Coronovirus	Virus	Human	55˚C/131˚F	2 min	Gerba, 1997; Laude, 1981
Coxsackievirus	Virus	Human	60˚C/140˚F	30 min	Health Canada, 2007
Cytomegalovirus	Virus	Human	60˚C/140˚F	30 min	Health Canada, 2007
Ebola virus	Virus	Human	60˚C/140˚F	60 min	Health Canada, 2007
Echovirus	Virus	Human	50˚C/122˚F	2 hr	Health Canada, 2007
Enterovirus 70	Virus	Human	60˚C/140˚F	30 min	Health Canada, 2007
Enteroviruses, Reoviruses and Adenoviruses (All)	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
Agrilus planipennis Emerald ash borer	Pests	Plant	71˚C/160˚F	75 min	APHIS Factsheet, 2009
American dust mite, *Dermatophagoides farinae*	Pests	Human	50˚C/122˚F 60˚C/140˚F	30 min 8 min	Chang, 1998
Anoplophora glabripennis Asian longhorned beetle	Pests	Plant	71˚C/160˚F	75 min	APHIS Factsheet, 2009
Bed bug, *Cimex lectularius*	Pests	Human	39-40˚C/111-113˚F		Getty, 2006; Usinger, 1966
Bed bug (adults and nymphs), *Cimex lectularius*	Pests	Human	>40˚C/113˚F	15 min	Getty, 2006; Gulmahamad, 2002
Bed bug (eggs), *Cimex lectularius*	Pests	Human	>40˚C/113˚F	1 hr	Getty, 2006; Gulmahamad, 2002
Cockroach, German, *Blatella germanica*	Pests	Vector	54.4˚C/130˚F	7 min	Quarles, 2006; Forbes, Ebeling, 1987
Dermanyssus gallinae, Chicken Mite or Poultry Red Mite	Pests	Vector Human Avian	45˚C/113˚F	2 hr	Nordenfors, 1999
Dermatophagoides pteronyssinus 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]
Incisitermes minor, Western Drywood Termite	Pests	Damage - Structural	54.4˚C/130˚F	6 min	Quarles, 2006; Forbes, Ebeling, 1987
Lithepuhema humile, Argentine Ant	Pests	Damage - Structural	54.4˚C/130˚F	1 min	Quarles, 2006; Forbes, Ebeling, 1987
Lyctus Powder Post Beetle All Forms	Pests	Damage - Structural	54.4˚C/130˚F	2½ hr	Parkin, 1937; Fisher, 1928
Lyctus Powder Post Beetle Larvae	Pests	Damage - Structural	52˚C/125˚F	2-4 hr	Parkin, 1937
Rat flea (larvae), *Xenopsylla cheopis*	Pests	Vector	39.4˚C/103˚F	1 hr	Mellanby, 1932
Rat flea (adult), *Xenopsylla cheopis*	Pests	Vector	40.6˚C/105˚F	1 hr	Mellanby, 1932
Tetropium fuscum Brown Spruce Longhorn Beetle Larvae	Pests	Damage- Structural	50˚C/122˚F 55˚C/131˚F	30 min 15 min	Mushrow, 2004
Tinibrio molitor Yellow Mealworm	Pests	Damage - Food	42.8˚C/109˚F	1 hr	Mellanby, 1932
Acinetobacter baumannii	Bacteria	Human	63˚C/145˚F	15 min	Dumalisile, et al., 2005
Aeronomas hydrophila	Bacteria	Human	50˚C/122˚F	3 min [2]	Gerba, 1997; Gordon et al., 1992
Bacillus anthracis	Bacteria	Human	140˚C/284˚F	3 hr	Hampil, 1932; Koch, 1881
Bacillus pestis (Yersinia)	Bacteria	Human	60˚C/140˚F	2 min	Hampil, 1932; Gladin, 1898
Bacterium tularense	Bacteria	Human	56˚C/133˚F	10 min	Hampil, 1932; McCoy, 1912
Brucella abortus	Bacteria	Human	61˚C/142˚F	3 min	Jones & Martin, 2003; Golueke, 1982
Brucella abortus	Bacteria	Human	55˚C/130˚F 65˚C/149˚F	60 min 3 min	Jones & Martin, 2003; Stern, 1974
Brucella abortus or suis	Bacteria	Human	55˚C/130˚F 60˚C/140˚F	60 min 3 min	Jones & Martin, 2003; Day & Shaw, 2000
Brucella melitensis	Bacteria	Human Animal	55˚C/130˚F 60˚C/140˚F	30 min 15 min	Hampil, 1932; Zwick & Wedeman, 1913
Burkholderia mallei	Bacteria	Human Bio Warfare	55˚C/130˚F	10 min	Health Canada, 2007
Campylobacter spp.	Bacteria	Human	75˚C/167˚F	1 min	Gerba, 1997; Bandres et al., 1988
Chlamydia psittaci	Bacteria	Human, Avian	56˚C/133˚F	5 min	TIP, 2000; Anderson et al., 1997
Chryseobacterium meningosepticum	Bacteria	Human	63˚C/145˚F	15 min	Dumalisile, et al., 2005
Corynebacterium diphtheriae	Bacteria	Human	55˚C/130˚F 70˚C/158˚F	45 min 4 min	Jones & Martin, 2003; Stern, 1974
Escherichia coli	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
Escherichia coli	Bacteria	Human	60˚C/140˚F	45 min	Padhye & Doyle, 1992
Escherichia coli	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]
Escherichia coli	Bacteria	Human	60˚C/140˚F 70˚C/158˚F	60 min 5 min	Jones & Martin, 2003; Stern, 1974
Escherichia coli	Bacteria	Human	55˚C/130˚F 60˚C/140˚F	60 min 20 min	Jones & Martin, 2003; Day & Shaw, 2000
Escherichia coli	Bacteria	Human	55˚C/130˚F 60˚C/140˚F	60 min 20 min	Jones & Martin, 2003; Golueke, 1982
Escherichia coli	Bacteria	Human	63˚C/145˚F	25 min	Dumalisile, et al., 2005
Klebsiella pneumoniae	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
Legionella	Bacteria	Human	66˚C/142˚F	.45 min [2]	Gerba, 1997; Sarden et al., 1989
Legionella pneumophila	Bacteria	Human	60˚C/140˚F	30 min	Stout, et al., 1986
Listeria monocytogenes	Bacteria	Human	63˚C/145˚F	20 min	Dumalisile, et al., 2005
Mycobacterium avium sub. paratuberculosis	Bacteria	Human	62˚C/144˚F 71˚C/160˚F	23 min 73 sec	Sung & Collins, 1998
Mycobacterium diphtheriae	Bacteria	Human	55˚C/130˚F 70˚C/158˚F	45 min 4 min	Jones & Martin, 2003; Stern, 1974
Mycobacterium spp. M. avium	Bacteria	Human	70˚C/158˚F	2 min 2.3 min [2]	Gerba, 1997; Robbecke and Buchhottz, 1992
Mycobacterium avium sub .paratuberculosis	Bacteria	Human	72˚C/162˚F	15 sec	Pearce, 2001
Mycobacterium tuberculosis	Bacteria	Human	63˚C/145˚F	3 min	Hampil, 1932; North & Park, 1925
Mycobacterium tuberculosis	Bacteria	Human	63˚C/145˚F 72˚C/162˚F	30 min 15 sec	Connor, 2007
Paratyphoid bacilli	Bacteria	Human	60˚C/140˚F 63˚C/145˚F	20 min 3 min	Hampil, 1932; Krumwiede & Noble, 1921 Hampil, 1932; Orskov, 1926
Pasteurella multocida	Bacteria	Human and Avian	56˚C/133˚F 60˚C/140˚F	15 min 10 min	TIP, 2000; Rimler and Glisson, 1998
Pasteurella spp.	Bacteria	Human	55˚C/131˚F	15 min	Health Canada, 2007
Pseudomonas aeruginosa	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
Pseudomonas aeruginosa	Bacteria	Human	60˚C/140˚F	<10 min	Spinks, et al., 2003
Pseudomonas putida	Bacteria	Human	63˚C/145˚F	20 min	Dumalisile, et al., 2005
Salmonella	Bacteria	Human	60˚C/140˚F	1 hr	Feachem, 1983
Salmonella sp.	Bacteria	Human	65˚C/149˚F	1 min	Gerba, 1997; Bandres et al., 1988
Salmonella newport	Bacteria	Human	60˚C/140˚F 65˚C/149˚F	40 min 30 min	Wiley & Westerberg (1969)
Shigella sp.	Bacteria	Human	50˚C/122˚F	1 hr	Jones & Martin, 2003; Stern, 1974
Shigella sp.	Bacteria	Human	55˚C/131˚F	1 hr	Feachem, 1983
Shigella spp.	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]
Staphylococci	Bacteria	Human	62˚C/144˚F	10 min	Hampil, 1932; Sternburg, 1887
Staphylococcus aureus	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
Staphylococcus aureus	Bacteria	Human	50˚C/122˚F	10 min	Jones & Martin, 2003; Golueke, 1982
Staphylococcus aureus	Bacteria	Human	63˚C/145˚F	20 min	Dumalisile, et al., 2005
Streptococci	Bacteria	Human	60˚C/140˚F	30 min	Hampil, 1932; Ayers & Johnson, 1918
Streptococcus pyogenes	Bacteria	Human	54˚C/129˚F	10 min	Jones & Martin, 2003; Golueke, 1982
Streptococcus pyogenes	Bacteria	Human	55˚C/131˚F	10 min	Jones & Martin, 2003; Day & Shaw, 2000
Vibrio cholerae	Bacteria	Human	55˚C/131˚F	15 min	Hampil, 1932; Kitasato, 1889
Yersinia enterocolitica	Bacteria	Human	60˚C/140˚F	30 min	Gerba, 1997; Frazier and Westhoff, 1988
Coxiella burnetii	Bacteria Rickettsia	Human Q Fever	63˚C/145˚F	30 min	Connor, 2007
Coxiella burnetii	Bacteria Rickettsia	Human Q Fever	63˚C/145˚F	30 min	Health Canada, 2007
Alternaria alternata	Fungi	Human	63˚C/145˚F	25 min	Domsch, 1993; Page 37
Aspergillus fumigatus	Fungi	Human	65˚C/149˚F [3]	30 min	Bollen, 1969
Aspergillus niger	Fungi	Human	63˚C/145˚F	25 min	Domsch, 1993; Page 102
Aspergillus ustus	Fungi	Human	62˚C/144˚F	25 min	Domsch, 1993; Page 119
Candida albicans	Fungi/ Yeast	Human	70˚C/158˚F	60 min	Wiley & Westerberg (1969)
Candida lipolytica	Fungi/ Yeast	Human	63˚C/145˚F	15 min	Dumalisile, et al., 2005
Chaetomium spp.(Soft rot)	Fungi	Human	55˚C/131˚F	30 min	Bollen, 1969
Cladosporium herbarum	Fungi	Human	50˚C/122˚F	10 min	Ridley and Crabtree, 2001
Cladosporium herbarum	Fungi	Human	60˚C/140˚F	30 min	Bollen, 1969
Fusarium cincinatum	Fungi	Human, Plant	60˚C/140˚F	10 min	Ridley, G. unpublished data
Fusarium oxysporum	Fungi	Human	60˚C/140˚F	30 min	Bollen, 1969
Fusarium redolens	Fungi	Plant	60˚C/140˚F	30 min	Bollen, 1969
Lasiodiplodia theobromae formerly *Botryodiplodia theobromae*	Fungi	Plant, Human	60˚C/140˚F	10 min	Ridley and Crabtree, 2001
Myrothecium verrucaria	Fungi	Plant	60˚C/140˚F	30 min	Bollen, 1969
Oőmycetes	Fungi	Plant, Human	50˚C/122˚F	30 min	Bollen, 1969
Penicillium corylophilum	Fungi	Plant	60˚C/140˚F [3]	30 min	Bollen, 1969
Penicillium funiculosum	Fungi	Human	70˚C/158˚F [3]	30 min	Bollen, 1969
Peniophora spp.	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]
Penicillium lapidosum	Fungi	Plant	70˚C/158˚F [3]	30 min	Bollen, 1969
Phialaphora mustea	Fungi	Plant	60˚C/140˚F [3]	30 min	Bollen, 1969
Phoma herbarum	Fungi	Human	75˚C/167˚F [3]	30 min	Bollen, 1969
Poria carbonica	Fungi	Plant	60˚C/140˚F 70˚C/158˚F	3 hr 60 min	Morrell, 1987
Poria placenta	Fungi	Plant	60˚C/140˚F 65.5˚C/150˚F	6 hr 3 hr	Morrell, 1987
Preussia fleischhakii	Fungi	Plant	60˚C/140˚F	30 min	Bollen, 1969
Rhinocladiella mansonii	Fungi	Plant	60˚C/140˚F	30 min	Bollen, 1969
Serpula lacrymans (Dry rot)	Fungi	Structure	45˚C/113˚F 50˚C/122˚F	3 hr 1 hr	Miric & Willeitner (1984)
Sordaria carbonaria	Fungi	Plant	65˚C/149˚F	30 min	Bollen, 1969
Sordaria spp.	Fungi	Plant	60˚C/140˚F	30 min	Bollen, 1969
Sporormia aemulans	Fungi	Plant	65˚C/149˚F	30 min	Bollen, 1969
Stachybotrys atra (S. chartarum)	Fungi	Human	60˚C/140˚F	30 min	Bollen, 1969
Stachybotrys chartarum	Fungi	Human	60˚C/140˚F	30 min	Domsch, 1993; Page 745
Stereum sanguinolentum	Fungi	Plant	54.4˚C/130˚F	15 min	Bollen, 1969
Stemphyium botryosum	Fungi	Plant	60˚C/140˚F [3]	30 min	Morrell, 1990
Trichocladium piriformis	Fungi	Plant	80˚C/176˚F [3]	30 min	Bollen, 1969
Trichoderma lignorum	Fungi	Plant, some Human	55˚C/131˚F	30 min	Bollen, 1969
Zygorhynchus moelleri	Fungi	Plant	55˚C/131˚F	30 min	Bollen, 1969
Ascaris lumbricoides	Helminths	Human	55˚C/131˚F	60 min	Bollen, 1969
Ascaris lumbricoides eggs	Helminths	Human	50˚C/122˚F 55˚C/131˚F	60 min 7 min	Feachem, 1983
Necator americanus	Helminths	Human	50˚C/122˚F	50 min	Jones & Martin, 2003; Stern, 1974
Opisthorchis spp.	Helminths	Human	56˚C/133˚F	30 min	Jones & Martin, 2003; Stern, 1974 Health Canada, 2007
Taenia saginata	Helminths	Human	71˚C/160˚F	5 min	Jones & Martin, 2003; Golueke, 1982
Taenia saginata	Helminths	Human	71˚C/160˚F	5 min	Jones & Martin, 2003; Golueke, 1982
Taenia saginata	Helminths	Human	70˚C/158˚F	5 min	Jones & Martin, 2003; Stern, 1974
Entamoeba histolytica	Protozoa	Human	60˚C/140˚F	1 min	Gerba, 1997; Chang, 1943
Entamoeba histolytica cysts	Protozoa	Human	50˚C/122˚F	5 min	Jones & Martin, 2003; Stern, 1974
Giardia lamblia	Protozoa	Human	60˚C/140˚F	2-3 min	Univ of Utah, 2005
Giardia Lamblia	Protozoa	Human	50˚C/122˚F	1 min [2]	Gerba, 1997; Cerva, 1955
Toxoplasma gondii 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), *Cimex lectularius*	Pests	Human	60.5˚C/141˚F	23 min	Linford, 2013
Bed bug (eggs), *Cimex lectularius*	Pests	Human	60.5˚C/141˚F	59 min	Linford, 2013
American dust mite, *Dermatophagoides farinae*	Pests	Human	60˚C/140˚F	60 min	Ogg, 1997
American wheat weevil, *Rhyzopertha dominica*	Pests	Damage - Food	50˚C/122˚F	360 min	Opit, Arthur, Bonjour, Jones, and Phillips, 2011
Cockroach, American, *Periplaneta americana*	Pests	Damage - Food	66˚C/150˚F	32 min/68 min eggs	Linford, 2013
Cockroach, Oriental, *Blatta orientalis*	Pests	Damage - Food	63˚F/145˚F	20 min/45 min eggs	Linford, 2013
Cockroach, German, *Blatella germanica*	Pests	Damage - Food	65˚C/149˚F	24 min/55 min eggs	Linford, 2013
Carpet beetle, *Anthrenus verbasci*	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), *Triboltum confusum*	Pests	Damage - Food	54.4˚C/130˚F	4 min	Quarles, 2006; Forbes, Ebeling, 1987
Red flour beetle, *Rhyzopertha dominica*	Pests	Damage - Food	50˚C/122˚F	360 min	Opit, Arthur, Bonjour, Jones, and Phillips, 2011
Human body louse, *Pediculus humanus*	Pests	Vector	46.6˚C/116˚F	60 min	Mellanby, 1932
Indian meal moth, *Plodia interpunctella*	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, *Tineola bisselliella*	Pests	Damage - Fibers	53˚C/127˚F	7 min/40 min eggs	Linford, 2013
Bacillus coli (E. coli)	Bacteria	Human	60˚C/140˚F	10 min	Hampil, 1932; Loeffler, 1886
Bacillus typhosus, Salmonella	Bacteria	Human	56˚C/133˚F 63˚C/145˚F	10 min 4 min	Hampil, 1932; Sternburg, 1887 Hampil, 1932; Orskov, 1926
Shigella, Dysentery bacilli	Bacteria	Human	58-60˚C/140˚F	10 min	Hampil, 1932; Runge & O'Brien, 1924
Escherichia coli	Bacteria	Human	60˚C/140˚F 70˚C/158˚F 75˚C/167˚F	105 min 45 min 15 min	Abbott, 2009
Hemophilus influenzae	Bacteria	Human	62˚C/144˚F	2 min	Hampil, 1932; Onorato, 1902
Klebsiella pneumoniae	Bacteria	Human	60˚C/140˚F 70˚C/158˚F	105 min 45 min	Abbott, 2009
Listeria monocytogenes	Bacteria	Human	63˚C/145˚F	30 min	Rowan, 1998

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