

Lethality Calculations

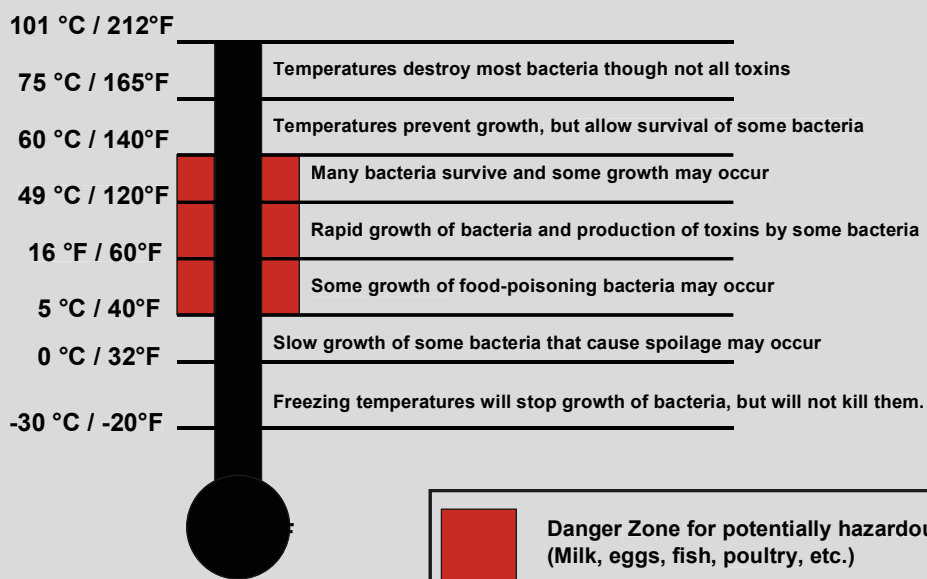
White Paper

The following document aims to explain the use of the F_0 calculation to quantify bacteria death rates in cooking processes.

Food poisoning comes in many forms but is in general caused by the human consumption of toxins released as a by-product of bacterial growth within food. To limit bacterial growth it is imperative that handling, processing, storage and transportation of food is carried out correctly. A schematic showing the effect of temperature on bacterial activity is shown below.



Effect of Temperature on Bacteria Growth



To kill bacteria at source two thermal processes are employed within the food industry, Sterilisation and Pasteurisation. The choice of process used is governed by the type of food product and additional forms of food preservation applied.

Sterilisation

Sterilisation is applied to food products that undergo no additional preservation regimes such as chilling or freezing and have had no preservation ingredients added to the product (Sugar, salt, vinegar, acid, alcohol, lemon juice etc). The effect of preservatives on pH will generally govern whether a product should be Pasteurised or Sterilised.

Food Product pH < 4.5	Pasteurise
Food Product pH > 4.5	Sterilise



Sterilisation is in most cases applied to canned and other packaged foodstuffs (glass jar / plastic pouch, vacuum packed) which are stored at room temperature after processing without additional preservation.

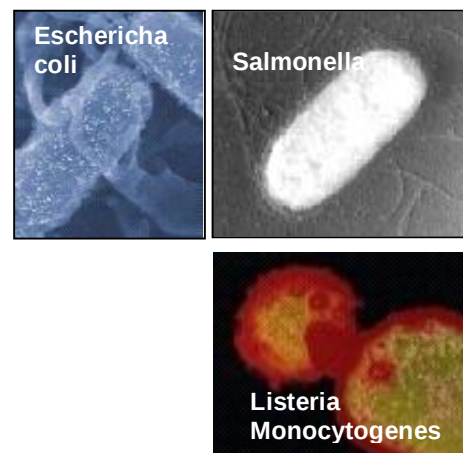
Without secondary preservation the most lethal bacterial threat is the anaerobic organism *Clostridium Botulinum*. Sterilisation is essential to kill such bacteria at source. For this reason *Clostridium Botulinum* is chosen as the ideal bacteria to model the effectiveness of a Sterilisation procedure. For *Clostridium Botulinum* a Sterilisation temperature of 121.1 °C is required to kill the bacteria.

Sterilisation is defined by F₀₃ (equivalent to heating for 3 minutes at 121 °C) to achieve twelve log reductions in the population of *Clostridium Botulinum* present in the food. Foods subjected to such treatment are stable at ambient temperatures and therefore considered commercially sterile.

Pasteurisation

Pasteurisation is applied to any food stuff where in addition to thermal processing other forms preservation are applied that would prevent the growth of *Clostridium Botulinum* (chill storage, reduced water activity, reduced pH and or high salt content). The target organism considered for Pasteurisation is governed by the type of food being processed. Thermal processing conditions required to kill different organism will vary but are documented in legislative procedures. Pasteurisation temperatures required to kill this group of bacteria are significantly lower than 121.1 °C used for Sterilisation.

Salmonella – Raw meats, Poultry, Eggs , Milk, Fish, Shrimp
Escherichia coli – Uncooked minced beef, Unpasteurised Milk



See Appendix for further general information on *Clostridium Botulinum* and *Listeria monocytogenes*.

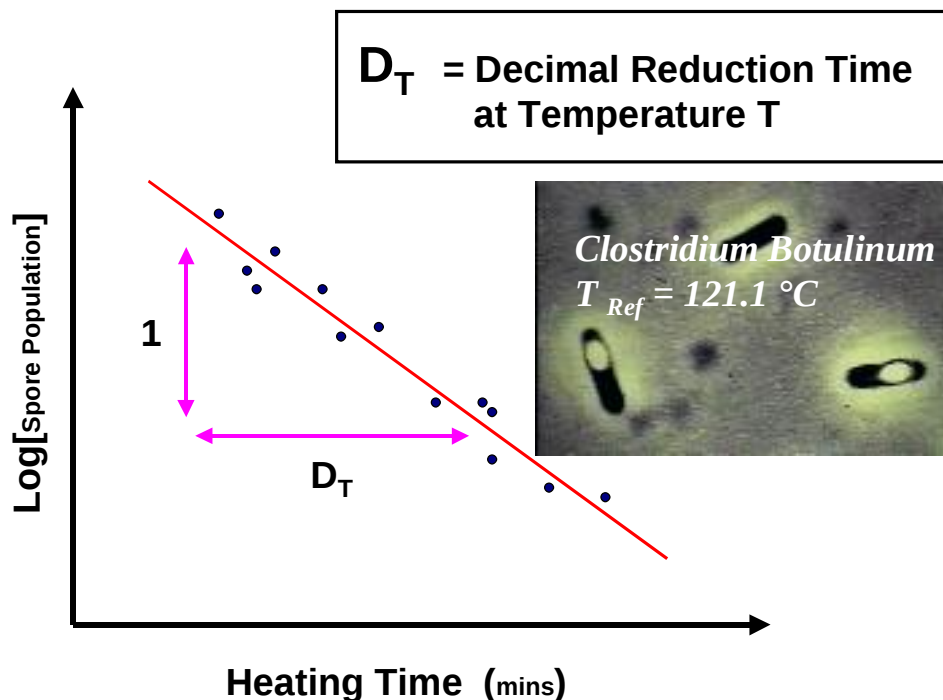
Bacteria Death Kinetics – Lethality Kinetics

For sterilisation processes the spore *Clostridium Botulinum* is used to quantify the effectiveness of bacterial kill as it is the most heat resistant pathogenic organism.

At a temperature of 121.1 °C (250 °F) 90% of the spore population is killed in 0.21 minutes. This time is known as the decimal reduction time.

D_T = Decimal Reduction Time – Time in minutes required at constant heating to reduce the number of surviving spores by a factor of 10 (90% reduction in population) which is also referred to as one logarithmic reduction.

The D_T is calculated by using first order kinetics as shown below.



In food industry it has been decided that for sterilisation it is necessary that a minimum of 12 log (or decimal) reductions of the *Clostridium Botulinum* spore population be achieved.

This requirement is quantified using the term F_0 .

$$F_0 = [N^{\circ} \text{ Decimal Reductions}][D_T]$$

$$\text{Target } F_0 \text{ for } \textit{Clostridium Botulinum} = 12 \times D_{121.1} = 12 \times 0.21 \text{ mins} = 2.52 \text{ mins } (\sim 3)$$

In practise as a safety issue the minimum target F_0 value is doubled to 6.

Pasteurisation procedures follow the same principles as the F₀ calculation but with the one exception that the bacteria spore and associated temperatures used to model the process are product specific. Legislative procedures document what bacteria should be used for each food type and gives recommended F₀ values that should be attained.

In most pasteurisation procedures it is common that the F₀ value be described as P_u or P value.

For Pasteurisation it has governed that for safe processing a minimum of 6 log reductions (decimal reductions) be achieved.

$$P_u = [N^{\circ} \text{ Decimal Reductions}][D_T]$$

In soups the target bacteria is Botulinum Type E

At a reference temperature of 90 °C the decimal reduction time is quoted as 0.79 minutes.

Applying these figures to the calculation;

Target Pu for Botulinum Type E = 6 x 0.79 mins = 4.74 mins

Although the target figure is 4.74 industry consensus has agreed that the safe Pu value for Botulinum Type E should be a minimum of 10. Tables of agreed Pu values for food groups are available from food legislative bodies.

Simplification of the F₀ or Pu unit for the above example a Pu value of 10 mins means in practise that if the food product is heated to 90°C and held exactly at that temperature for 10 mins the Botulinum Type E bacteria population would be reduced by 6 log reductions.

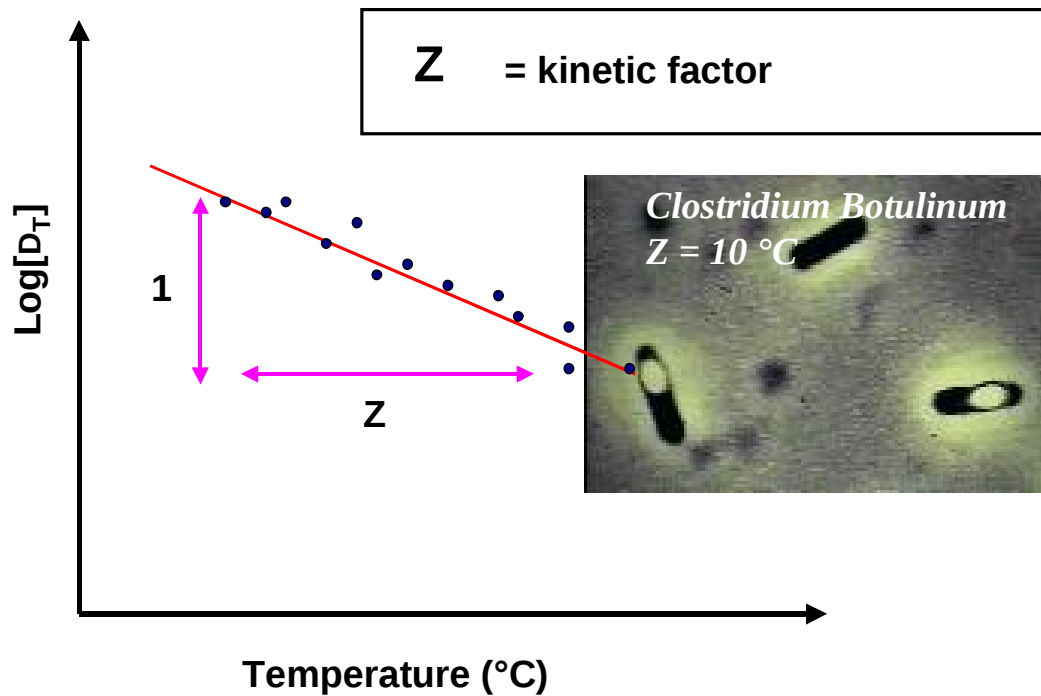
The Decimal Reduction Time (D_T) is quoted for a specific temperature T. In a real life situation, in food processing it is impossible to achieve a constant temperature (ramp up, cool down, hot and cold spots within oven retort etc).

To address this issue the Z value is derived which is the first order relationship between the decimal reduction time and heating temperature. The Z value is the temperature difference required to effect a ten-fold change in the decimal reduction time. The z value is often described as being the relative killing power of the heating temperature.

For a pasteurisation process if the z value is calculated to be 6 °C a change in product temperature of 6 °C will require an order of magnitude change in heating time to achieve the same degree of pasteurisation.

1 min @ 60 °C = 0.1 min @ 66 °C = 0.01 min @ 72 °C = 10 mins @ 54 °C

The Z value (°C) is derived experimentally by plotting the logarithmic D_T value against Heating Temperature as shown below.



Having derived the Z value it is possible compare numerically the relative lethality of different process temperatures using equation 1.

Equation 1: lethality Rate Calculation

$$L = \log 10^{-1} \left[(T - T_x) / z \right] = 10^{[(T - T_x) / z]}$$

L = lethal Ratio or Lethal rate (mins)
 T = Temperature under consideration (°C)
 T_x = Reference Temperature (°C)
 Z = Kinetic factor

The above expression can be used to determine how effective a cook process will be when the process temperature does not match exactly the reference temperature at which decimal reduction times are quoted. (See Example 1 on next page)

F₀ Calculations

Example 1: **Pasteurisation of Beef**
 Organism *Listeria Monocytogenes*

Temperature Reference	62 °C
Z Value	5.98 °C
Decimal Reduction Time*	4.2 mins

* 1 decimal / log reduction in *L. Monocytogenes* population

From such data and the lethality calculation it is possible to calculate the equivalent process duration for other product temperatures as illustrated below.

Product core temperature = 77 °C

$$L = 10^{[(T - T_x) / z]}$$

$$L = 10^{[(77 - 62) / 5.98]} = 10^{[2.51]}$$

$$L = 322.4$$

The lethality rate for the destruction of *Listeria Monocytogenes* is 322.4 higher at 77 °C than at 62 °C. Therefore, heating a product at 62°C for 1 min is equivalent in lethality (kill same population of *Listeria Monocytogenes*) to heating the same product at 77 °C for 1/322.4 mins (0.19 s).

For some situations different kinetic factors are applied depending on whether the process core temperature is above or below the reference temperature.

- If the process temperature is below the reference temperature use the lower z value
- If the process temperature is above the reference temperature use the higher z value

As a basic rule of thumb it is always assumed that the z value giving the longest therefore safer process heat duration should be used (worst case scenario)

In a real life situation a product experiences a range of different temperatures as it heats up during the cooking / pasteurisation process. Using the lethality relationship though it is possible to calculate the cumulative lethality against the reference temperature.

A worked example of this is shown in table 1 below where the change in core temperatures of a product during heat and cooling cycle are compared arithmetically against the reference temperature of 80 °C with corresponding Z value of 7°C. It is assumed for the example that each process temperature is held for 1 minute.

TABEL 1; Lethal Rate at 80 °C calculated for a process with a maximum temperature of 82 °C.

Product Temperature (°C) / 1 min segments	Lethal Rate at 80 °C (See Equation 1)	Cumulative Lethality ∫ lethal rates
T	L	∫ L
70	0.04	0.04
71	0.05	0.09
72	0.07	0.16
73	0.10	0.26
74	0.14	0.40
75	0.19	0.59
76	0.27	0.86
77	0.37	1.23
78	0.52	1.75
79	0.72	2.47
80	1.00	3.47
81	1.38	3.85
82	1.93	5.78
75	0.19	5.97
70	0.04	6.01

For the process which took 13 minutes to reach 82 °C from 70 °C and then began rapid cooling was therefore equivalent to 6.01 minutes at 80 °C.

For pasteurisation processes this can be represented in short hand as;

$$P_{80}^7 = 6.01$$

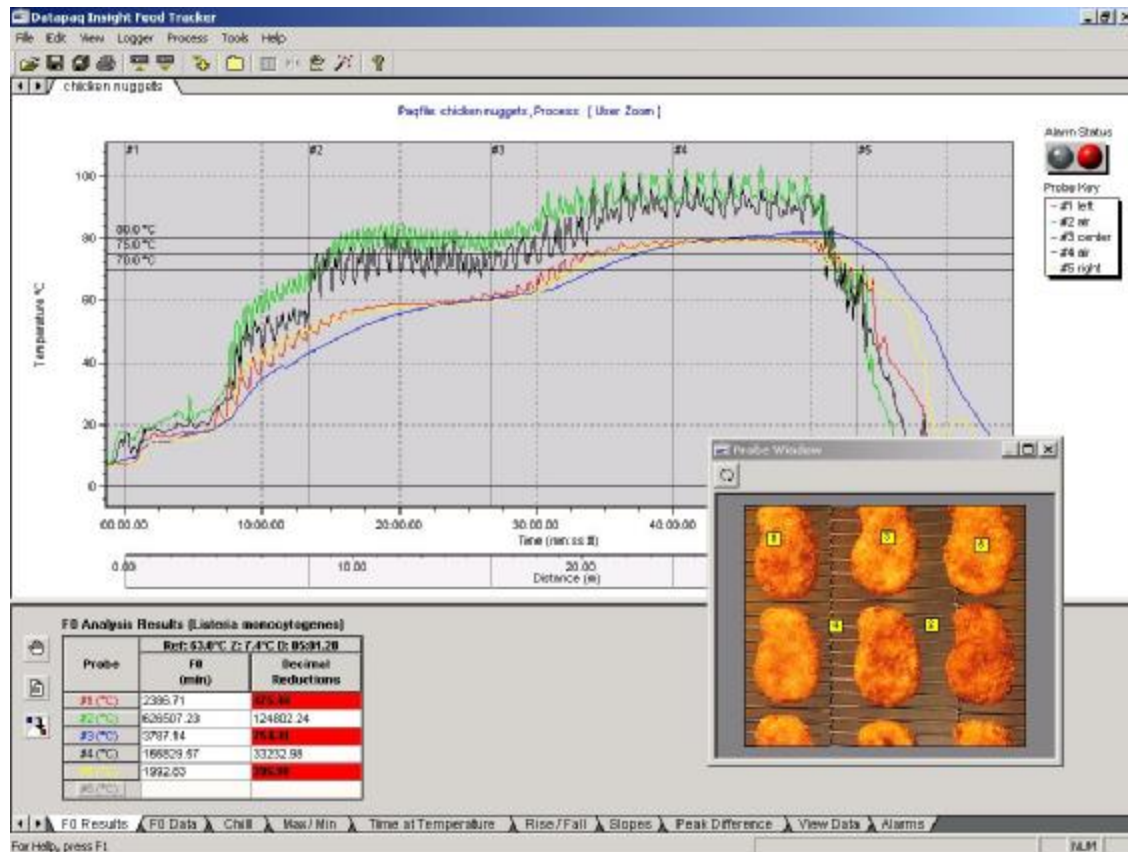
Utilising the lethal rate calculation it is possible to sum the cumulative lethality over the entire temperature profile using the relationship below as used in the Datapaq Multi Tracker software.

$$F_0 = \int_0^t L dt = \int_0^t 10^{[(T - T_x)/z]} dt$$

Equation 2:

T = Product Temperature at profile time t
T_x = Reference Temperature
Z = Kinetic factor
dt = Sample interval (mins)

Application of Lethality Calculations



The food Insight software provides the highest level of user functionality to allow accurate quantification of the profile data collected from a run. A key analysis tool provided as part of this process is the F_0 Analysis Lethality calculation described earlier in this document.

Utilising the power of the Insight software the F_0 value or number of decimal reductions can be automatically calculated on download of data. If appropriate as shown in the screen shot above the value can be alarmed to warn any operator as to when a critical F_0 or number of decimal reductions has not been attained.

Analysis Setup



F0 Analysis Results (Listeria monocytogenes)

Ref: 63.0°C Z: 7.4°C D: 05:01.20

Probe	F0 (min)	Decimal Reductions
#1 (°C)	2386.71	475.44
#2 (°C)	626507.23	124802.24
#3 (°C)	3787.14	754.41
#4 (°C)	166829.57	33232.98
#5 (°C)	1992.83	396.98
#6 (°C)		

Analysis Options

F0 Results | Colors

Display Options: ☐ Probe ☒ F0 ☐ File

Sort by: ☐ Probe ☐ F0 ☐ File

Calculate: ☒ Over Current Zoom ☐ By Zone ☐ For a Specific Zone

Zone Number:

Parameters:

Description:

Reference Temperature: °C

Z Value: °C

D Value: mm:ss.tt



From the FO results tab the operator inputs analysis options appropriate for the calculation. The variables should have been verified experimentally and been validated as fit for purpose for the product, micro-organism and process being studied*

Variables	Reference Temperature	°C / °F (check the temp units employed)
	Z value	°C / °F (check the temp units employed)
	D Value	Time (check the time units employed)

D Value: mm:ss.tt

D Value: ss.tt

To change units go to Tools / Options / Units

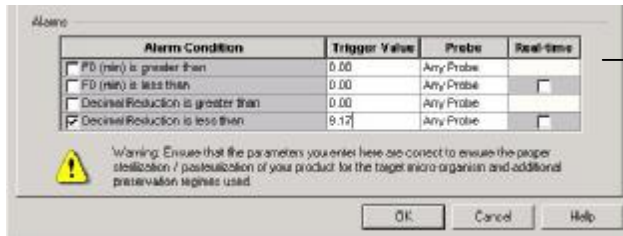
Note that these units will be applied globally throughout the software



*Note

Refer to Appendix 1 for relevant sources of information for the correct use of lethality variables for your product, micro-organism and process criteria.

Alarm Setup



F0 Analysis Results (Listeria monocytogenes)

Ref: 63.0°C Z: 7.4°C D: 05:01.20

Probe	F0 (min)	Decimal Reductions
#1 (°C)	44.43	8.85
#2 (°C)	50.05	9.97
#3 (°C)	38.30	7.63
#4 (°C)	47.69	9.50
#5 (°C)	31.63	6.30
#6 (°C)		

On the analysis options dialogue having input the lethality variables it is possible to set-up alarm conditions relating to either the resulting calculated Fo value or number of corresponding decimal reductions.

In the above chicken nugget case the minimum acceptable number of decimal reductions for safe cook is determined as 9.17 for Listeria Monocytogenes. This being the case the software is set-up to report an alarm if the calculated number of decimal reductions for any monitoring point is reported as less than 9.17.

Alarm Status



FAIL

F0 Analysis Results (Listeria monocytogenes)

Ref: 63.0°C Z: 7.4°C D: 05:01.20

Probe	F0 (min)	Decimal Reductions
#1 (°C)	44.43	8.85
#2 (°C)	50.05	9.97
#3 (°C)	38.30	7.63
#4 (°C)	47.69	9.50
#5 (°C)	31.63	6.30
#6 (°C)		

Cells marked Red to indicate which probes have failed the Alarm



Fail – Probe No 1
Number of Decimal Reductions

8.85 < 9.17

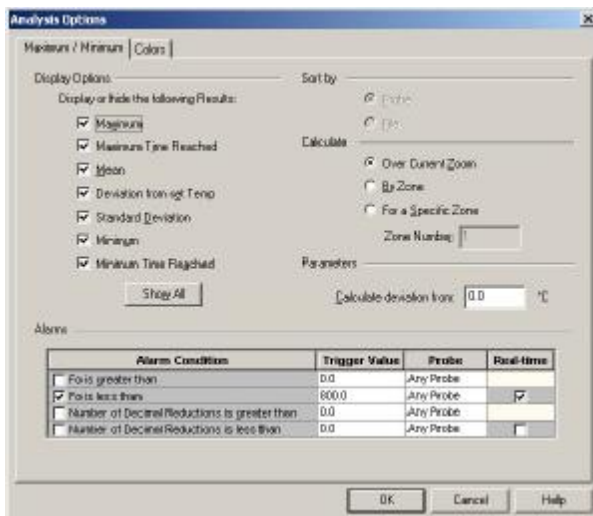
Alarm Tab documents exactly what alarms have been triggered and the failure criteria.

Real Time Alarms

The Multipaq21 system can be supplied with Real time RF Telemetry capability. As the system travels through the process it transmits profile data back to the PC via a cable free radio telemetry link.

Obviously employing such technology it is possible to analyse profile data live direct from the process.

To help with this real time alarm capability has been incorporated into the software which Fo and Decimal Reduction lethality calculations are included.



shown in the Analysis options dialogue left it is possible to select the Real Time alarm status

For

Fo is less than

and / or

Number of Decimal Reductions is less than a user definable trigger value;

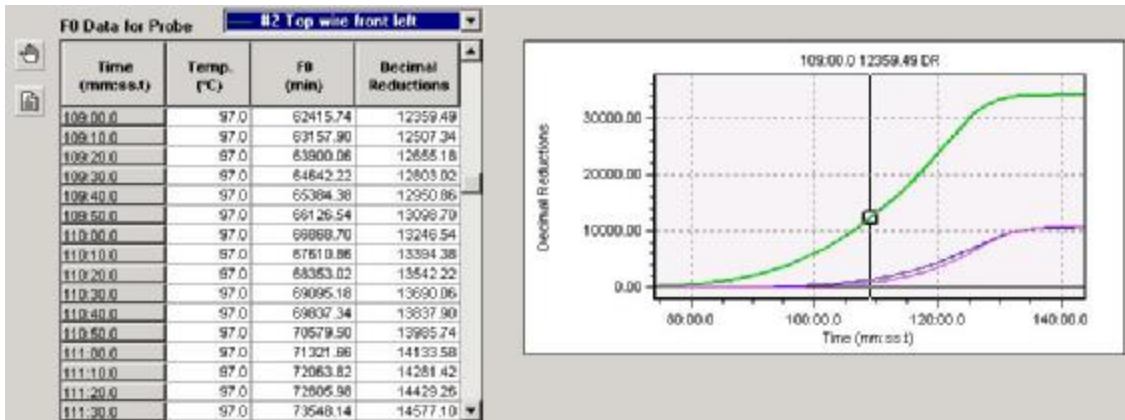
In the example the Fo (min) value will be calculated in real time and displayed on the FO results tab. If the Fo data calculated is < 800 min the cell is coloured red and the Alarm status is marked Red "Fail". As the process monitoring continues the Fo value should increase to the point at which the Fo values reach the minimum target of 800 satisfying the lethality requirements of the process indicating product safety. At this point an ALERT dialogue is displayed on the software informing the user that "Cook is completed" and the data cell is changed from red to white. This process will be repeated for each probe in turn. The Alarm status LED will remain red until all probes reach the minimum target Fo value.

For batch processes this function is invaluable for increasing productivity. Seeing the exact point at which the food monitored is quantified as being safe allows the current batch to be removed from the oven and replaced. Oven cook programmes need not therefore be set-up with such high levels of safety margins "duration" which limit productivity and risk low yields and compromised product quality.

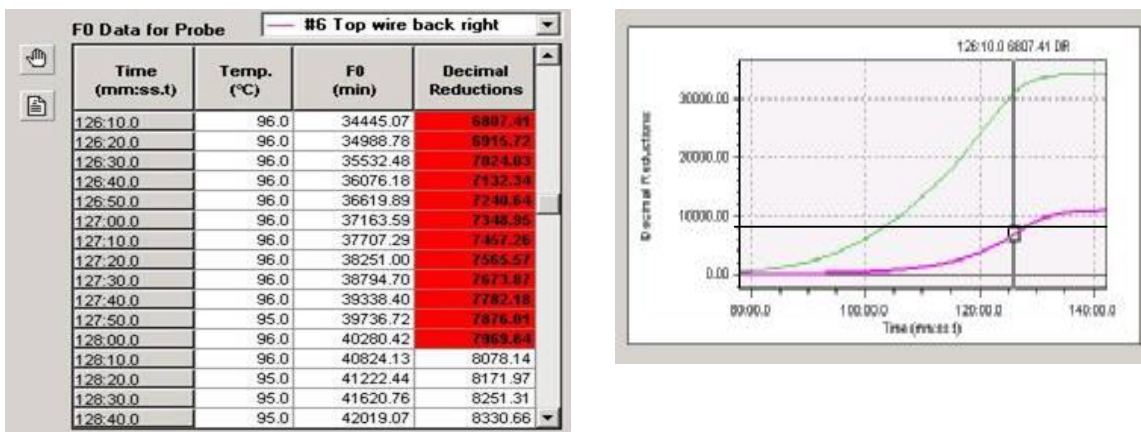


F₀ Calculations

FO Results FO Data



Complementing FO Results Food Insight software provides a function FO data which provides in graphical and numerical data the change in Fo or Decimal Reduction value with time over the profile length. From this function for each probe it is possible to see how the lethality of the process conditions changes with time. The same function can be used to see and the effect of process operating conditions (set points / line speed / steam levels etc) on lethality.

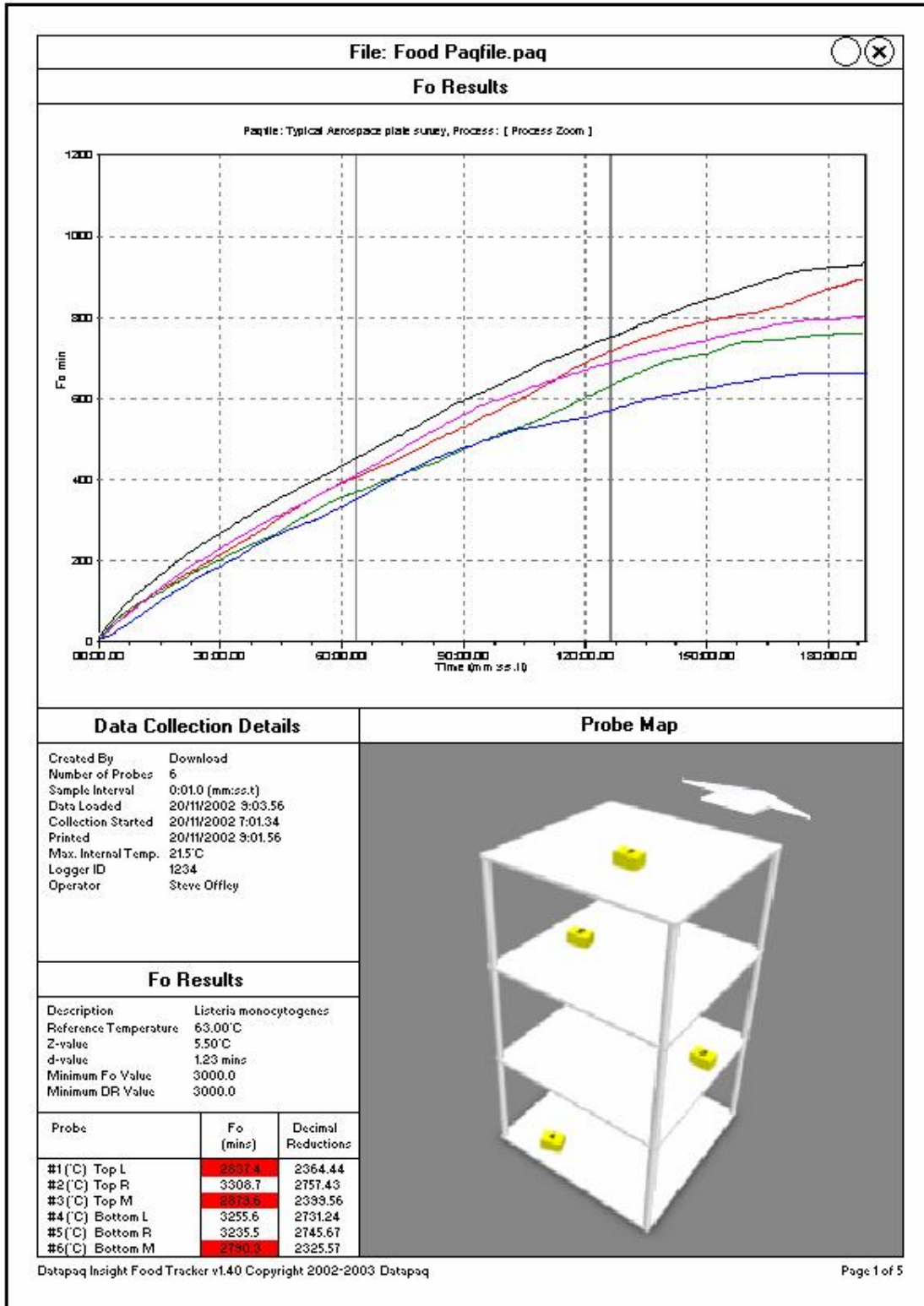


On the graphical view it is possible to view either Fo or Decimal Reductions as the lethality variable. Scrolling long a selected probe you can see exactly at what point in the process the critical lethality variable was attained. Moving the scroll bar on the lethality graph simultaneously moves a similar cursor on the main profile graph. This cursor allows you to see exactly where in the process time / distance through oven / zone position any lethality value was attained. Such information can be used to optimise the process to improve throughput, therefore, productivity and possibly improve actual product yield by eliminating over cook.

As is shown above it is possible to alarm either calculated Fo or Decimal Reduction values. On the Tabulated data out of specification data is displayed in red. Tabulated data can be view for individual probes probe by probe against the actual temperature recorded at that particular time instant. On the graphical view the minimum threshold level is shown as a horizontal threshold line.

Fo Data Report

Complimenting the Fo data report is the ability to create a stand alone Fo data report documenting the lethality status of the process . This report would be used in conjunction with the standard profile report to provide fully traceable documentary proof of HACCP compliance.



F₀ Calculations

As part of the Fo data report it is possible to print a hard copy of either Fo or decimal reduction data in tabular form as shown below.

File: Typical Aerospace plate survey.paq

Printed: 20/11/2002 10:43:26

Alarms

Analysis	Probe	Alarm Description
Maximum/Minimum	#1	Measurement (°C) is greater than the maximum (600 > 620)
Fo Results	#1	Fo is less than the minimum (2837.4 < 3000.0)
Fo Results	#3	Fo is less than the minimum (2879.6 < 3000.0)
Fo Results	#6	Fo is less than the minimum (2750.3 < 3000.0)

Fo Data

Time (mm:ss.00)	#1	#2	#3	#4	#5	#6
14:05:00	430.0	475.5	430.0	431.1	432.1	430.5
14:06:00	430.0	475.5	430.5	431.1	432.1	430.5
14:07:00	430.0	475.5	430.0	431.1	432.1	430.5
14:08:00	430.0	475.5	430.0	431.1	432.1	430.5
14:09:00	430.0	475.5	430.0	431.1	432.1	430.5
14:10:00	430.0	475.5	430.5	431.1	432.6	430.5
14:11:00	430.0	475.5	430.0	431.1	432.1	430.5
14:12:00	430.0	475.5	430.0	431.1	432.6	430.5
14:13:00	430.0	475.5	430.0	431.1	432.1	430.5
14:14:00	430.0	475.5	430.5	431.6	432.1	430.5
14:15:00	430.0	475.5	430.5	431.1	432.1	430.5
14:16:00	430.0	475.5	430.5	431.1	432.1	430.5
14:17:00	430.0	475.5	430.5	431.1	432.1	430.5
14:18:00	430.0	475.5	430.5	431.1	432.1	430.5
14:19:00	430.0	475.5	430.5	431.1	432.1	430.5
14:20:00	430.0	475.5	430.5	431.1	432.1	430.5
14:21:00	430.0	475.5	430.5	431.1	432.1	430.5
14:22:00	430.0	475.5	430.5	431.1	432.1	430.5
14:23:00	430.0	475.5	430.5	431.1	432.1	430.5
14:24:00	430.0	475.5	430.5	431.1	432.1	430.5
14:25:00	430.0	475.5	430.5	431.1	432.1	430.5
14:26:00	430.0	475.5	430.5	431.1	432.1	430.5
14:27:00	430.0	475.5	430.5	431.1	432.1	430.5
14:28:00	430.0	475.5	430.5	431.1	432.1	430.5
14:29:00	430.0	475.5	430.5	431.1	432.1	430.5
14:30:00	430.0	475.5	430.5	431.1	432.1	430.5
14:31:00	430.0	475.5	430.5	431.1	432.1	430.5
14:32:00	430.0	475.5	430.5	431.1	432.1	430.5
14:33:00	430.0	475.5	430.5	431.1	432.1	430.5
14:34:00	430.0	475.5	430.5	431.1	432.1	430.5
14:35:00	430.0	475.5	430.5	431.1	432.1	430.5
14:36:00	430.0	475.5	430.5	431.1	432.1	430.5
14:37:00	430.0	475.5	430.5	431.1	432.1	430.5
14:38:00	430.0	475.5	430.5	431.1	432.1	430.5
14:39:00	430.0	475.5	430.5	431.1	432.1	430.5
14:40:00	430.0	475.5	430.5	431.1	432.1	430.5
14:41:00	430.0	475.5	430.5	431.1	432.1	430.5
14:42:00	430.0	475.5	430.5	431.1	432.1	430.5
14:43:00	430.0	475.5	430.5	431.1	432.1	430.5
14:44:00	430.0	475.5	430.5	431.1	432.1	430.5
14:45:00	430.0	475.5	430.5	431.1	432.1	430.5
14:46:00	430.0	475.5	430.5	431.1	432.1	430.5
14:47:00	430.0	475.5	430.5	431.1	432.1	430.5
14:48:00	430.0	475.5	430.5	431.1	432.1	430.5
14:49:00	430.0	475.5	430.5	431.1	432.1	430.5
14:50:00	430.0	475.5	430.5	431.1	432.1	430.5
14:51:00	430.0	475.5	430.5	431.1	432.1	430.5
14:52:00	430.0	475.5	430.5	431.1	432.1	430.5
14:53:00	430.0	475.5	430.5	431.1	432.1	430.5
14:54:00	430.0	475.5	430.5	431.1	432.1	430.5
14:55:00	430.0	475.5	430.5	431.1	432.1	430.5
14:56:00	430.0	475.5	430.5	431.1	432.1	430.5
14:57:00	430.0	475.5	430.5	431.1	432.1	430.5
14:58:00	430.0	475.5	430.5	431.1	432.1	430.5
14:59:00	430.0	475.5	430.5	431.1	432.1	430.5
15:00:00	430.0	475.5	430.5	431.1	432.1	430.5
15:01:00	430.0	475.5	430.5	431.1	432.1	430.5
15:02:00	430.0	475.5	430.5	431.1	432.1	430.5
15:03:00	430.0	475.5	430.5	431.1	432.1	430.5
15:04:00	430.0	475.5	430.5	431.1	432.1	430.5
15:05:00	430.0	475.5	430.5	431.1	432.1	430.5
15:06:00	430.0	475.5	430.5	431.1	432.1	430.5
15:07:00	430.0	475.5	430.5	431.1	432.1	430.5
15:08:00	430.0	475.5	430.5	431.1	432.1	430.5
15:09:00	430.0	475.5	430.5	431.1	432.1	430.5
15:10:00	430.0	475.5	430.5	431.1	432.1	430.5
15:11:00	430.0	475.5	430.5	431.1	432.1	430.5
15:12:00	430.0	475.5	430.5	431.1	432.1	430.5
15:13:00	430.0	475.5	430.5	431.1	432.1	430.5
15:14:00	430.0	475.5	430.5	431.1	432.1	430.5
15:15:00	430.0	475.5	430.5	431.1	432.1	430.5
15:16:00	430.0	475.5	430.5	431.1	432.1	430.5
15:17:00	430.0	475.5	430.5	431.1	432.1	430.5
15:18:00	430.0	475.5	430.5	431.1	432.1	430.5
15:19:00	430.0	475.5	430.5	431.1	432.1	430.5
15:20:00	430.0	475.5	430.5	431.1	432.1	430.5

Datapac Insight Food Tracker v1.40

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Appendix 1

Variables –Tref, z, D Value

What Lethality Variables should I use?

With any calculation the value of the solution is reliant on the use of appropriate input variables for the task being performed. This situation applies greatly in the case of lethality calculations. It is essential that the correct variables are used to match the type of product being processed / micro-organism of interest and the process parameters being used in the processing.

Where experience of using lethality calculations is limited or when investigation new products or procedures it is essential that advice is sought from experienced external sources. Such sources maybe include academic technical papers¹ but may also include independent research associations or institutes as shown below;



Chipping Campden
Gloucestershire
GL55 6LD UK

Tel: +44 (0)1386 842000
Fax: +44 (0)1386 842100

www.campden.co.uk

Typical Sources:
Technical Manual No 27
Food Pasteurisation Treatments
Editor J.E. Gaze (Technical Secretary)

April 1992

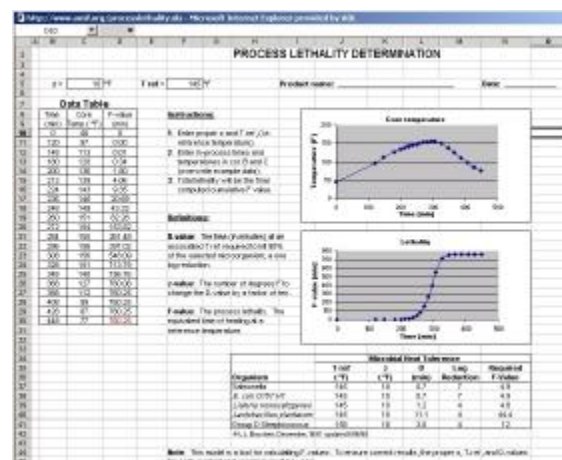


www.amif.org

Principles of Integrated Time-Temperature Processing

Jenny Seft and Lisa Woodling
National Food Processors Association
Office of Food Safety Programs
Presented at the 1998 Meat Industry Research Conference
Philadelphia, PA
September 16, 1998

Papers on the principles of Time-Temperature Processing Process lethality Spreadsheet.



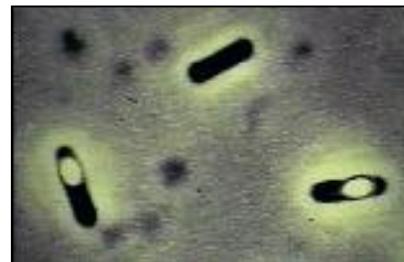
Appendix 2

Common Micro-organisms

Clostridium Botulinum

Botulism is a severe type of food poisoning caused by the ingestion of foods containing the neurotoxins formed from the growth of the bacteria.

The toxin can be destroyed if heated for 80 °C for at least 10 minutes. The disease is rare but is of concern because of its high mortality rate. The bacteria and its spores are widely distributed in nature.



Onset

4 hours to 8 days

18 to 36 hours

Symptoms

Early signs are weakness and vertigo, followed by double vision, difficulty in speaking, swallowing and breathing, muscle weakness, abdominal distension and constipation.

Paralysis and death may follow

Foods Incriminated

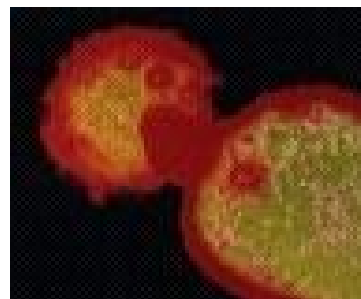
The organism is anaerobic and therefore normally associated with canned, vacuum packed, and modified atmosphere foods.

Target Populations

The toxin can be fatal when consumed in very small quantities and all people are believed to be susceptible.

Listeria monocytogenes

The bacterium is widely distributed in nature, being found in sewage, decaying vegetable matter, all farm animals, domestic pets and man. It is very hardy and is able to grow at low temperatures (i.e. in a refrigerator).



The presence of the bacteria usually indicates poor personal hygiene practices during manufacture or distribution.

Wash salad goods before use

Never eat cooked chilled food products after the 'use by' date

Ensure food that is reheated attains a core temperature of at least 70 °C Refrigerate temperature below 5 °C

Onset

8 days to 3 months

Symptoms

Nausea, vomiting and diarrhoea

More serious symptoms such as blood poisoning or meningitis may follow. Antibiotic treatment is effective.

Foods Incriminated

Foods known to have caused Listeriosis include commercially chilled foods such as prepared salads, sandwiches, pate, cooked meats and ready meals. Other suspect foods are milk, ice-cream, raw and smoked fish, soft cheeses.

Target Populations

Young Children, the elderly, the sick and pregnant women are most at risk.