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APPLICATION, LIMIT AND POTENTIALITY OF HTST TREATMENT

Roberto Massini
Institute of Food Production and Processing, University of Bari, Italy

High Temperature Short Time heat treatment

Former applications of High Temperature Short Time treatments were developed for:

- continuous flow sterilisation of pumpable foods;
- rotating retort sterilisation of stirable foods;
- pouch retorting of ready meals.

Then, new applications were allowed by non traditional heat processing means:

- microwave heating of solid foods;
- ohmic heating of particulate foods.

But the effective design and control of process parameters are still limit factors for the fully exploitation of the HTST potentiality.

HTST affects production costs

For any sterilization process, application of HTST parameters allows higher equipment output, but not necessarily lower cost.

Actually equipment may be more expensive because:

- the increased need of resistance to inner temperature and pressure;
- as well as the increased need of accuracy and automation for the process control.

On the other side, working costs may be higher because:

- the increased energy intensity and energy loss;
- as well as the increased fouling and the consequent shortening of the runs between cleaning cycles in continuous flow sterilisation.

HTST to optimise thermal effects

Usually an HTST treatment are applied with intent to obtain a food product having the best quality, by optimising the ratio between the useful thermal effect and the so called “thermal damage”.

However the same kind of thermal modification may be regarded alternatively as a target or a collateral thermal effect, depending on the food product and/or the overall process considered.

Ambiguity of thermal effects

Target thermal effect(s) may be:

- microbial forms destruction;
- enzyme inactivation;
- poison degradation;
- nutritional improvement;
- sensory changes.

Collateral thermal effect(s) may be:

- useful micro-flora destruction;
- useful enzyme inactivation;
- harmful substances neo-formation;
- nutritional and healthiness loss;
- distinctive sensory changes.

With the exclusion of the well assessed hygienic aspects, the same thermal modification may be considered alternatively a wished or an undesirable result of the thermal treatment, depending on the food product considered and depending on the actual knowledge of the direct and indirect implications.

The meaning of “thermal damage” is not at all absolute.

HTST to improve food quality

Preliminary condition:

- temperature dependence of the target and collateral effects must be measurable for the considered process conditions;
- temperature dependence of the target effect(s) must be smaller than that of the collateral one(s).

Limit of appliance:

- uniformity of thermal exchange throng the product mass must be greater as the temperature increases;
- sensibility of the control system must be greater as the temperature increases and the time shorts.

NOTE:

Oxidative damage of the food product during the process and/or during the shelf life may make useless the HTST thermal damage reduction.

Changing from a relatively low temperature long time process to an HTST one, may allows to improve the quality of the treated food if are valid the following two preliminary condition:

- temperature dependence of the target and collateral effects must be measurable for the considered process conditions;
- temperature dependence of the target effect(s) must be smaller than that of the collateral one(s).

However, even if the above conditions are valid, a progressive HTST approach can not be indefinitely applied, because at least two limits of appliance may vanish the potential advantages:

- uniformity of thermal exchange through the product mass must be greater as the temperature increases;
- sensibility of the control system must be greater as the temperature increases and the time shorts.

Many are the thermal effects on food components and their course may depends on the temperature level reached as well as on the substrate and environment composition (see some examples in Table 1).

Thermal food changes are characterised by quite different activation energy values (see some examples in Table 2).

In most cases the HTST approach can not permit a true optimisation of the thermal process, and the sensory quality must be sacrificed to respect the safety and stability aspects (see the example of Figure 1).

Moreover, for the same heat induced food modification, kinetic parameters may assume a large range of values.

Table 1 – Thermal effects on some food components

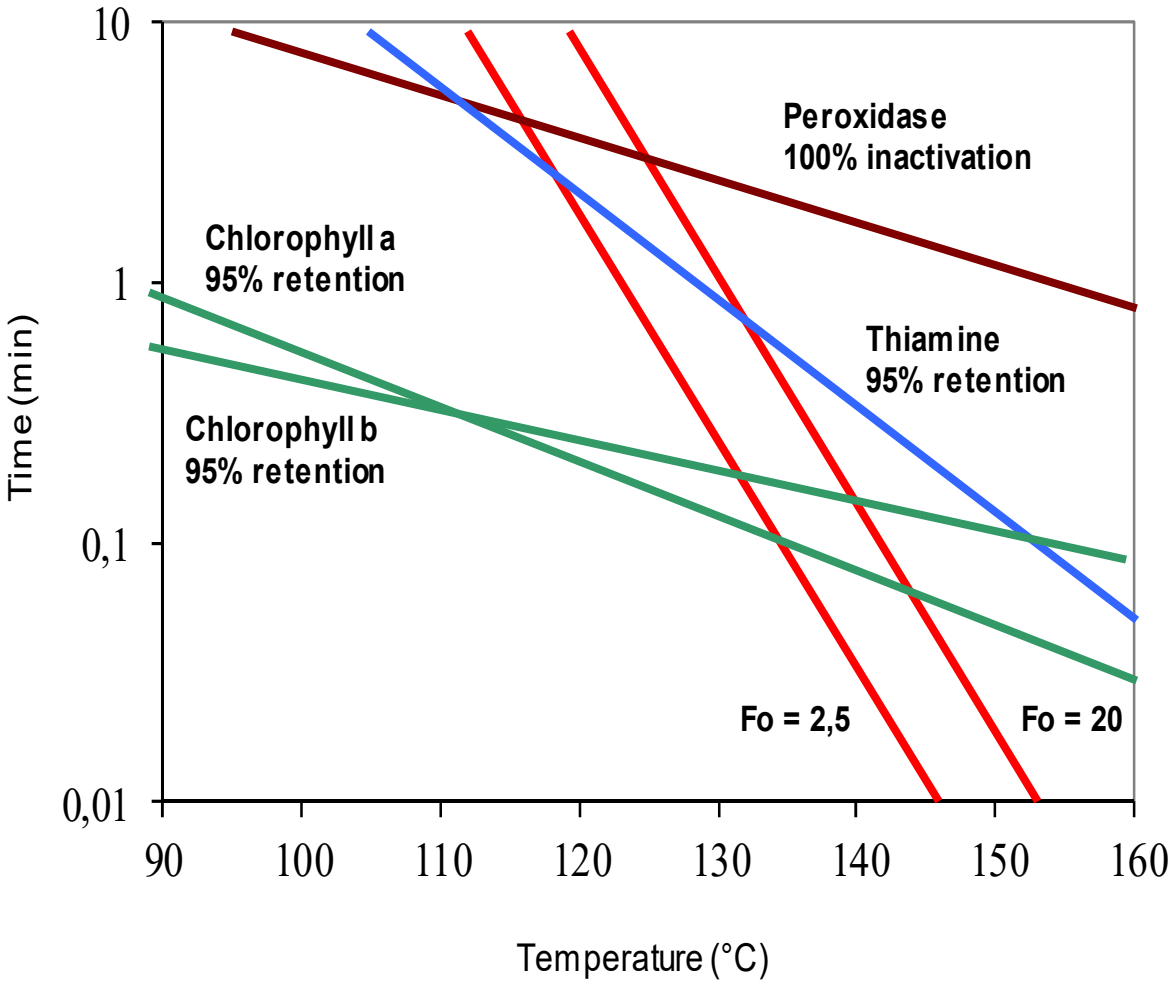
Component	Condition	Reaction	Sensory effect
CARBOHYDRATES			
vegetal tissues	+ H_2O	pectin degradation	softening
	+ Ca^{2+}	bridge linking	hardening
starch granules	+ H_2O	gelatinization	swelling
	+ H_2O + acid/enzyme	hydrolysis	solubilisation
sugars	T>100 °C, dry	condens./pyrolisys	colour, flavour
reducing sugars	+ lysine	Maillard reaction	colour, flavour
PROTEINS			
soluble	60<T<110 °C + H_2O	denaturation	solubility loss
all	T>110 °C + H_2O	crosslinking	flavour, texture
	T>110 °C + H_2O + acid	hydrolysis	digestibility
	T>110 °C + H_2O + O_2	desulphuration	colour, flavour
	T>110 °C + H_2O + -OO^*	Streicker reaction	nutrient loss
LIPIDS			
unsaturated	+ O_2/catalys./UV	oxidation	colour, flavour
PIGMENTS			
chlorophyll	+ H_2O + acid	Mn loss	colour change
anthocyanes	+ acid/base	electron mobility	colour change
mio/emo-globine	T>60 °C	denaturation	browning

Table 2 – Activation energy for some food changes
(Data adapted from various authors)

REACTION	E_a (kJ/mole)	D_T (min)	z_D (Δ°C)
sensorial changes	42 - 125	D_{121} = 5 -500	25 - 44
enzyme inactivation	50 - 418	D_{80} = 1 – 10	7 - 55
vitamin degradation	84 – 125	D_{121} = 100 - 1000	25 - 31
protein denaturation	84 - 350	D_{121} = 5 - 500	7 - 33
NEB	105 – 210		26 - 28
bacterial spore inactivation	222 - 347	D_{121} = 0,1 - 20	7 - 12
microbial cell inactivation	210 - 628	D_{60} = 1 – 10	4 - 7

For the same other conditions, E_a value depends on temperature (but changes only of about 10% for a 100°C variation), a_w, pH, E_{redox}, etc.

Figure 1 – Temperature dependance of several reactions in green beans
(Data adapted from various authors)



Temperature dependance of reaction rates in foods

For a large part of the available data, temperature dependence of reaction rates in food is expressed as z-value measured at temperatures for which the decimal reduction time is enough to be measured by using simple laboratory conditions.

But. Following Datta (1993), the approximate parameter z linearizes a more common non-linear relationship described by the Arrhenius equation for temperature dependence. For every time-temperature history, there exists a unique reference temperature that minimises the error.

Even if 121 °C is always used as the reference temperature, the extrapolation of the z-value outside the experimental temperature range may lead to severe calculation errors for very high temperature such as in UHT processing

Approach commonly used to determine thermal kinetic parameters is isothermal, due to conceptual simplicity and to the direct reaction order determination.

However, this approach is often criticised for unavoidable thermal lags which become more prevalent as either sample size or selected isothermal temperature increases.

Thus, non isothermal approaches may be preferred because they are specifically designed to accommodate thermal transients and allow determination of kinetic parameters from realistic dynamic processing conditions.

Moreover, although reactions of primary interest in food processing often involve complex mechanisms and multiple pathways, most follow apparent first-order kinetics with Arrhenius temperature dependence.

The Equivalent Point Method (EPM), developed by Swartzel (1982) in order to facilitate design of continuous flow UHT processes, represented an easy-to-use non isothermal method for kinetic parameters.

More recently Welt et al (1997) proposed the Paired Equivalent Isothermal Exposures (PEIE), a method which may overcome some inaccuracy of the EPM one without increasing substantially the need of experimental work.

Only for liquid food without particle, the immersed sealed capillary tube (ISCT) procedure (quasi-isothermal experimental conditions) or the flow-injection system (to mimic continuous flow-through continuous sterilization systems) allow to experimentally evaluate the z-value at high temperatures.

Heat resistance of microorganisms and of enzymes, as well as kinetics of sensory degradation, nutritional damage and healthy aspects are more and more expressed as Arrhenius parameters (see Tables 3-7).

Table 3 - Microbial heat resistance
(Data adapted from various authors)

MICROORGANISM	MEDIUM	D_T (min)	z_D (Δ°C)
Listeria monocytogenes F5069	egg	D_{51}= 22.6	7.2
Listeria monocytogenes F4642	milk	D_{70}= 0.14 –0.27	6-7.39
Listeria monocytogenes	syrup a_w 0,98	$D_{65.6}$ = 0.36	7.7
	syrup a_w0,90	$D_{65.6}$ =3.8	6.5
Salmonella typhimurium	syrup a_w 0,98	$D_{65.6}$ = 0.29	12.9
	syrup a_w0,83	$D_{65.6}$ =40.2	7.6
Pseudomonas paucimobilis	seafood products	D_{70}= 1.16-3.36	5.8-9.1
Enterococcus faecium RR1	cooked ham	D_{70}= 13.6	11.8
Streptococcus faecium	sous vide meals	D_{70}= 1.11	12.4
Clostridium botulinum type E	oyster	D_{80}= 0.78	6,9-7,6
Clostridium botulinum type E	surimi	$D_{82.2}$= 1.22	9.78
Clostridium botulinum type B and E	cod and carrot	D_{90}= 0.43-1.1	8.26-9.84
Clostridium butyrricum toxigenic strains	at pH<5	D_{77}= 2.3-2.5	
	grown on MEA	D_{80}= 50	4
Bacillus cereus 3 strains		D_{100}= 0.28-4.57	7.64

continues

MICROORGANISM	MEDIUM	D_T (min)	zD (Δ°C)
Bacillus coagulans	tomatoes pH 4.5	D_{110} = 0.46	10
Bacillus coagulans 44 strains	phos.buffer pH 7	D_{110} = 1.1-92.3	6.8-9.6
Bacillus licheniformis	pH 4	D_{100}= 1.05	10.2
	pH 7	D_{100}= 4.26	8.1
	tomato juice	D_{100}= 5.7	
Alicyclobacillus acidoterrestris spores	apple juice	D_{95} = 5.1-5.3	9.5-10.8
Talaromyces flavus var. macrosporus	fruit drink	D_{90} = 6	6.7
Byssochlamys nivea ascospores	grown on PDA	D_{80}= 24	6.1
Saccharomyces cerevisiae ascospores	yoghurt	D_{62}= 3.5	7.2
	peach puree	D_{60}= 0.1-0.53	3-4
Neosartorya fischeri ascospores	pineapple juice	D_{95}= 1.7-2.3	
	grapes	D_{86}= 28	6.9
Talaromyces flavus ascospores		D_{90} = 6.2	6.4

Variability of microbial heat resistance

Sublethal heat shock at 48 degree C for 10 min on *Listeria monocytogenes* increases the D_{55} 2.1-fold, but z-values remain constant.

Similar results were obtained for *Yersinia enterocolitica* heat-shocked in ground pork at 45 °C for 60 min.

Spores of *Bacillus licheniformis* (from canned asparagus) sporulated at 52 °C were 10 fold more heat resistant than those sporulated at 30°C. No significant difference was detected among z values.

For *Staphylococcus aureus* strains thermally stressed at 56 °C for 10 min in milk D_{58} = 3.0–26 min.

For *Enterococcus faecium* RR1 in cured pork, D_{65} increase from 15.5 to 34-40 when the heating rate is very slow (0.1 °C/min).

For *Bacillus subtilis*, *Clostridium sporogenes* and *Clostridium botulinum* 213B, D_T values decrease with pH, but the effect is lower the higher the temperature of treatment.

For *Bacillus licheniformis* (from canned asparagus) treated at 99 °C, heat resistance at pH 4 was 1/20 lower than at pH 7. However, the magnitude of this effect decreased as heat temperature increased and almost disappeared at 120 °C.

For Bacillus stearothermophilus spores treated at 135 °C, D-values obtained with pH 6.0 and 7.0 did not show any significant differences.

Heat resistance of yeast ascospores greatly increases with the ageing time.

Table 4 - Heat resistance of enzymes
(Data adapted from various authors)

EMZYME	D_T (min)	z_D (Δ°C)	E_a (kJ/mol)
Polygalacturonase (mango)		12,25	
Polygalacturonase I (tomato)	$D_{95,4}$ = 0,46	5,6	
Polygalacturonase II (tomato)	D_{73}= 0,24	9,4	
Polygalacturonase (papaya)	D_{80} = 23	6,1	
Pectin methilesterase (tomato)	$D_{74,5}$= 0,20	5	
Pectin methilesterase (pineapple juice)		44	
Pectinesterase (tomato)		15-24	
Pectinesterase I (papaya)	D_{80} = 0,2	9,2	258,3
Pectinesterase II (papaya)	D_{80} = 3,7	7,8	304,4
Pectinesterase (mango)		18,5	

continues

EMZYME	D_T (min)	z_D (Δ°C)	E_a (kJ/mol)
Peroxidase (asparagus)			83,7
Peroxidase (asparagus -regenerated)			56,9
Peroxidase (horseradish)			184-92
Peroxidase (horseradish)			81,6
Peroxidase (horseradish)	D_{121} = 3,5-13	34-27	84-100
Peroxidase (horseradish)	D_{80} = 232	27,7	
Peroxidase (turnips)	D_{80} = 73	25,5	
Peroxidase (sweetcorn)	D_{80} = 30	30	
Peroxidase (green beans)	D_{80} = 15	26,1	

continues

EMZYME	D_T (min)	z_D (Δ°C)	E_a (kJ/mol)
Catalase (spinach extract)	D_{80} = 0,02	8,3	
Catalase (spinach extract)	D_{60} = 22-31	20	
Catalase (spinach extract)	D_{65} = ca 1	8,3	
o-Diphenoloxidase (pear)	D_{80} = 0,82	5,5	
Lipoxygenase (+ pea solids)	D_{80} = 0,09	8,7	
Lipoxygenase (+ pea solids)	D_{73} = 12	3,4	
Lipoxygenase (+ pea solids)	D_{68} = 85	8,7	
Proteinase (P. fluoresc.) (whole milk)	D_{150} = 0,088		
Proteinase (P. spp.) (skim milk)		34	82

Table 5 - Heat resistance of healty substances
(Data adapted from various authors)

SUBSTANCE	MEDIUM	D_T (min)	z_D (Δ°C)	E_a (kJ/mol)
Bovine immunoglobulin G	Colostrum	$D_{81} = 2,5$	6,6	386,8
	Phosph. buffer	$D_{80} = 1,5$	6,7	353,5
	Boiled milk	$D_{80} = 3,3$	8,9	258,2
	UHT milk	$D_{80} = 2,8$	8,5	298,5
			6,29	
Bovine immunoglobulin A			4,00	
Bovine immunoglobulin M			5,17	
Immunoglobulin 3 (whey)	Raw milk		6,79	351
Bovine serum albumin (whey)	Raw milk		12,35	193
Alpha-lactoalbumin (whey)	Raw milk		18,06	132
Beta-lactoglobulin A (whey)	Raw milk		10,64	224
Beta-lactoglobulin B (whey)	Raw milk		8,33	286

Bovine immunoglobulins have the potential to be utilised as immunological supplements to infant formula and other hyperimmune foods. Bovine beta-lactoglobulin in UHT milk was easily digested by pepsin, than the same beta-LG in LTLT and HTST milk.

Table 6 – Kinetics of nutritional damage
(Data adapted from various authors)

COMPONENT	D_{121} (min)	z_D (Δ°C)
Lysine	786	21
Thiamine	150	25
Chlorophyll-b	48	59
Betanine	47	59
Chlorophyll-a	34	45
Anthocyanin	18	23
Carotenoids	0,038	19

Table 7 – Kinetics of sensory degradation
(Data adapted from various authors)

PRODUCT	ATTRIBUTE	z_D (Δ°C)
Asparagus	colour	42
Green beans	green colour	39
Peas	green colour	39
Peas mashed	appearance	35
	taste	24
	texture	16
Potatoes	taste	27
Strained beef	sensory	19-22
Fish pudding	sensory	23-29
Liver paste	sensory	25-34
Tomato sauce	sensory	16-27
Vanilla sauce	sensory	13-22
Strained vegs	sensory	18-24
Milk	browning	26-28

HTST process control

Other problems arising from the HTST processing are connected with the process control, namely for the sensitivity of temperature measuring devices.

Following the EHEDG - European Hygienic Equipment Design Group (1992) for aseptic plants, the distance between the temperature probe that controls flow diversion and the flow diversion valve must be large enough to ensure that insufficiently treated product will always be diverted when the temperature is too low.

Hence, the flow rate and the response time of the control loop (temperature probe, controller and valve) must be taken into account, and it should be realized that fouling of the temperature probe will increase the response time.

The control system must be capable of compensating for sudden temperature deviations at the inlet of the heating section (e.g. due to switching over from the intake of hot water to cold product after pre-sterilization).

Time constant (τ) is the time required for an instrument to register 63,2% of an instantaneous change in the measured parameter (see Figure 2).

Generally, it is assumed that the final value is achieved after 5 time constants.

The temperature controller device will compensate a temperature decrease, but the displayed and recorded values may be more or less over-estimate depending on the sensitivity of the temperature probe (see Figure 3 and Table 8).

Figure 2 – Response of a first order system to a step input (Corona, 1999)

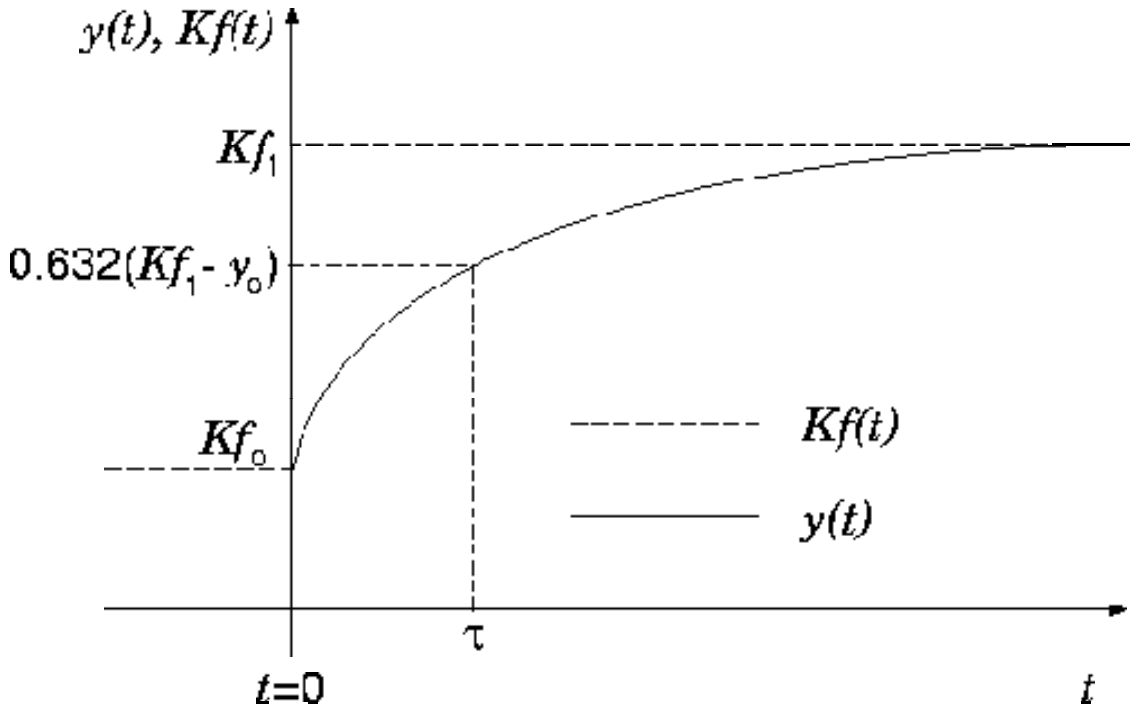


Figure 3 – Harmonic input and output for a first order system (Corona, 1999)

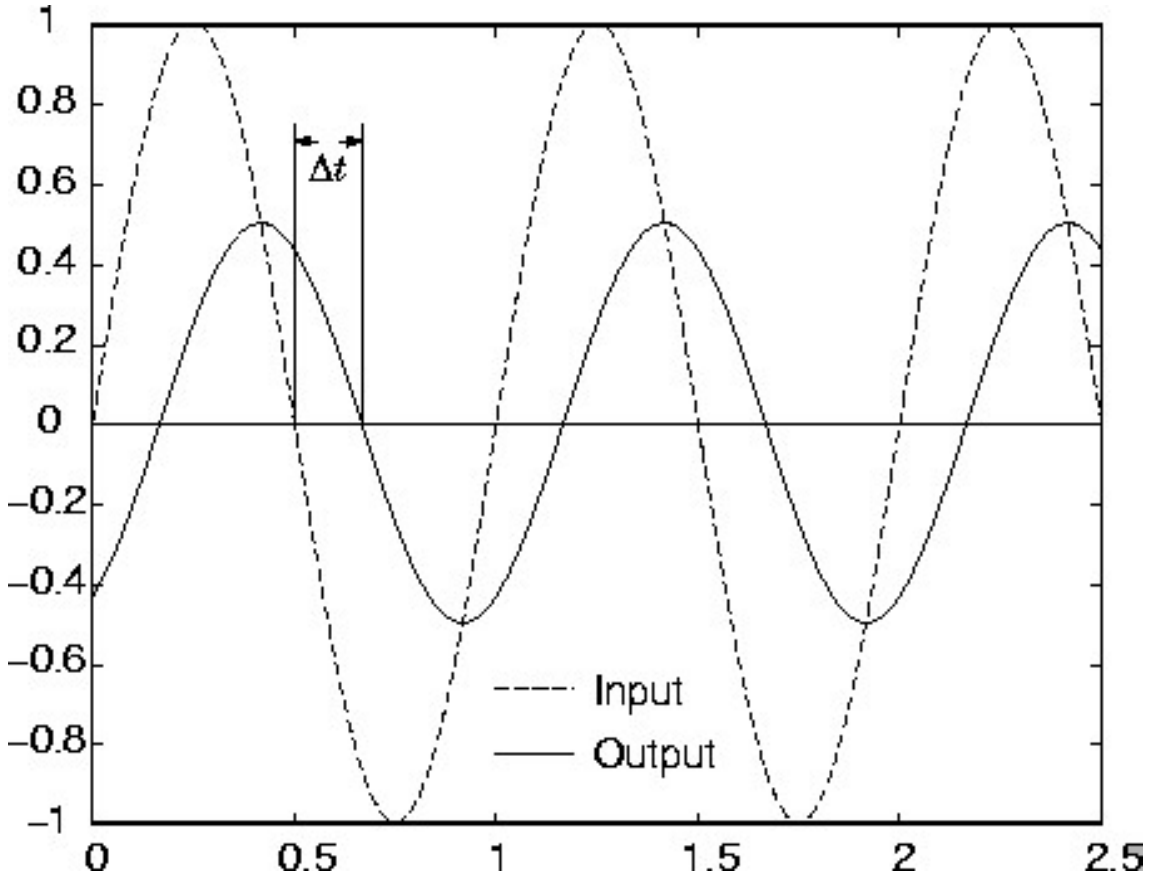


Table 8 – Examples of time constant for different temperature probes (unpublished data)

PROBE	TIME CONSTANT (s)
Liquid in metal capillary expansion type	480 - 540
6 mm Pt100RTD in a sheath without oil	21.8
6 mm Pt100RTD in a sheath filled with oil	8.8
6 mm Pt100RTD without sheath	5.9
3 mm Pt100RTD without sheath	2.7
Thermocouple microprobe	0.1

For a continuous flow thermal process, the decrease of the F_o contribute originated from an over-estimating of 2 °C during a same small time is always 37%, but the total F_o value decreases with the scheduled temperature if the above time become comparable with the total holding time.

Depending on the kind and the setting of the controller, if the temperature swinging wavelength is small to respect the holding time, different product portions will acquire correspondingly variable values of F_o.

In a continuous flow sterilization systems the sterilisation effect acquired is measured by the residence time in the holding tube.

The ratio of average velocity to maximum velocity in a holding tube varies between 0,5 in laminar flow to 0,82 in fully turbulent flow.

To ensure that the minimum residence time is maintained, it is essential that, during the run the following conditions are assured:

- the flow rate cannot be increased (it must be monitored with an alarm action);
- air pockets will not reduce the volume of the holding section (it must be enough sloped upwards);
- fouling does not become significant (it must be predictable or measured).

Due to fouling on heated surfaces of heat exchangers in UHT plants, inside volume of exchangers is reduced during running.

Therefore average heating time is reduced, residence time distribution is modified, and sterilizing efficiency is reduced if holding temperature is kept constant (see the example in Table 9).

Since fouling results in increasing pressure drop across heat exchanger, extent of fouling can be measured. However, higher process temperatures increase the fouling rate and short the run between

Table 9 - Effect of the fouling for an holding tube diameter 25.4 mm and length 20 m, with flow rate1000 l/h of a Newtonian food (unpublished data)

Fouling layer thickness (mm)	0	1	2	3
Minimum residence time (s)	18,2	15,5	12,9	10,6
Degree of time shortage (%)	-	15	29	42
F_o applied at 135 °C	7,4	6,3	5,3	4,3

The reliability of a temperature controller depends upon the chosen control strategy.

Traditional single loop feedback control gives the most rapid responses to temperature changes, but the temperature response curve becomes oscillatory and slowly returns to its set point, because the overcompensating on recovery.

Cascade control gives slow recoveries to temperature changes, but the temperature response curve is relatively smooth, reducing fluctuations and overshoot.

Multivariable control (Negiz et all. 1996) gives an intermediate behaviour and can regulate simultaneously product flow rate and temperature by use of a lethality computation.

Actually self-learning, neuro-fuzzy logic control appears to be the more promising new control strategy for HTST thermal processing.

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