Heat Process Values F (2nd Ed.) for several Commercial Pasteurization and Sterilization Processes: Overview, Uses, and Restrictions

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Which heat process value F should a particular food receive to make it safe and shelf stable?

* **Section 1** lists reported sterilization values $F_0 = F^{10}_{121.1}$ (= F zero) for commercial food preservation processes of all types of food products, for several package sizes and types.

* **Section2** contains reported pasteurization values F, or P, of a great variety of foods. The required storage conditions of the pasteurized foods, either at ambient temperature, or refrigerated (4-7 °C), are indicated.

* **Section 3** shows a decision scheme: should a particular food be pasteurized or sterilized? This depends on the intended storage temperature (refrigerated or ambient) after heating, the required shelf life (7 days to 4 years), the food pH (high acid, acid, or low acid), the food water activity a_W, and on the presence of preservatives such as nitrite NO_2^- (E250) mixed with salt NaCl, or nisin.

* In **Section 4**, two worked examples are presented on how to use an F value when calculating the actual sterilization time Pt:
- C.R. Stumbo's (1973) calculation method has been manually applied, verified by computer program STUMBO.exe, to find the sterilization time and the thiamine retention of bottled liquid milk in a rotating steam retort;
- O.T. Pham's (1987; 1990) formula method, incorporated in Excel program "Heat Process calculations according to Pham.xls", has been used to find the sterilization time and the nutrient retention of canned carrot purée in a still steam retort.

* The worked example in **Section 5** illustrates the use of the pasteurization value F of apple juice, in calculating the required (average) residence time in the holding tube of a heat exchanger. The Excel program Build-Heat-Exchanger.xls next calculates the juice's spoilage rate by a mold, a yeast and an enzyme, and the nutrient retention of vitamins C and folic acid in the pasteurized juice.

* **Section 6** explains how F values can be calculated when a microbial analysis of the food is available. The actual pasteurization or sterilization time calculations should be based on **all** micro-organisms of concern present, and rather NOT on the highest F value only!
An example calculation shows that the required F value for a food, to be sold in a moderate climate country, usually differs considerably from the F, required for the same food, to be sold in tropical areas.

1. STERILIZATION VALUES: $F_0 = F^{10\,°C}_{121.1\,°C}$

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
		Vegetables	
Almonds, roasted in oil	4 Decimal reductions of *Salmonella* sp 5 Decimal reductions of *Salmonella* sp	Heating for 1.6 min. in oil of 126.7 ºC. Commercially Heating for 2 min. in oil of 126.7 ºC.	Silva & Gibbs (2012), p. 698 Due to the low water activity of dried almonds, the D value of *Salmonella* in almonds is increased considerably.
Asparages		3 min.	Stork in Reichert (1985)
		2 - 4 min.	Alstrand-Ecklund in Reichert (1985)
	All	2 - 4 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
		3.5 - 6 min.	Stumbo in Reichert (1985)

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
		4 - 6 min.	Smith (2011) p. 254
		2.8 - 3.3 min.	NCA in Reichert (1985)
		2 - 4 min.	Andersen in Reichert (1985)
Baby foods	**Baby food**; 52x72; 140 ml	3 - 5 min.	Brennan (1979) p. 261; Holdsworth (1997) p. 175-176
Beans in tomato sauce		8 - 15 min.	Alstrand-Ecklund in Reichert (1985)
		1.6 - 3.4 min.	NCA in Reichert (1985)
	All	4 - 6 min.	Brennan (1979) p. 261
	A2; 83x114; 580 ml	7.0 min. in core; 11.6 min. total.	Holdsworth (1997) p. 188 [1])
	UT; 73x115; 445 ml	5.8 min. in core; 8.3 min. total.	Holdsworth (1997) p. 188 [1])
Carrots		3 min.	Stork in Reichert (1985)
		8 - 11 min.	Stumbo in Reichert (1985)
		3.5 - 10.4 min.	NCA in Reichert (1985)
	All	3 - 4 min.	Brennan (1979) p. 261
Carrot purée	**A1**; 65x101; 315 ml	5.5 min. in core; 8.0 min. total.	Holdsworth (1997) p. 188 [1])
Celery	**A2**; 83x114; 580 ml	3 - 4 min.	Brennan (1979) p. 261
Celeriac purée	**A1**; 65x101; 315 ml	4.2 min. in core; 6.0 min. total.	Holdsworth (1997) p. 188 [1])
Champignons		4.1 - 9.3 min.	NCA in Reichert (1985)
Chili con carne	**Various**	6 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
	UT; 73x115; 445 ml	4.5 min. in core; 6.6 min. total.	Holdsworth (1997) p. 188 [1])
Corn		5.6 min.	Stork in Reichert (1985)
		8.9 - 12.4 min.	NCA in Reichert (1985)
Corn, whole kernel, brine packed	**No. 2/A2**; 83x114; 580 ml	9 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
	No. 10/A10; 153x178; 3110 ml	15 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Corn, Cream style corn	**No. 2/A2**; 83x114; 580 ml	5 - 6 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
	No. 10/A10; 153x178; 3110 ml	2.3 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Drinks; still drinks		F_{123} = 15 s if 4.2 < pH < 4.6.	Tetrapak (2013)
	.	F_{138} = 4 s if pH > 4.6.	Tetrapak (2013)
Green beans		3.0 min.	Stork in Reichert (1985)
		3.5 - 6.0 min.	Alstrand-Ecklund in Reichert (1985)
		3.5 - 6 min.	Stumbo in Reichert (1985)
		3.0 - 6.3 min.	NCA in Reichert (1985)
		3 - 4 min.	Andersen in Reichert (1985)
Green beans in brine	**up to A2**; up to 83x114; up to 580 ml	4 - 6 min.	Brennan (1979) p. 261
	A2 to A10; 83x114; 580 ml; to 153x178;	6 - 8 min.	Brennan (1979) p. 261

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
	110 ml		
	No. 2; **A2** 87.3x115.9; 591 ml	3.5 min.	American Can Co. (1952)
	No. 10/A10; 153x178; 3110 ml	6 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Gudeg = young jackfruits; also known as Gori	Canned in mixture of spices, palm sugar and coconut milk	F_0 = 20 min. (preferably at TR = 121 min and Pt = 57.1 min.).	Hariyadi et al (2013)
Jackfruits	see at Gudeg		
Juices, Nectars and Still Drinks (JNSD)		F_{123} = 15 s if 4.2 < pH < 4.6.	Tetrapak (2013)
		F_{138} = 4 s if pH > 4.6.	Tetrapak (2013)
Mushrooms		4.2 - 7 min.	Stork in Reichert (1985)
Mushrooms: Champignons		4.1 - 9.3 min.	NCA in Reichert (1985)
Mushrooms in brine	**A1**; 65x101; 315 ml	8 - 10 min.	Brennan (1979) p. 261
Mushrooms in butter	**up to A1**; up to65x101; up to 315 ml	6 - 8 min.	Brennan (1979) p. 261
Mushroom soup, cream	**A1;** 65x101; 315 ml	$F^{10}_{115.7}$ = 3.5 min. in core; $F^{10}_{115.7}$ = 5.8 min. total.	Holdsworth (1997) p. 188 [1])
Lentils with pork		3.9 - 4.6 min.	Wirth, Tacács, Leistner in Reichert (1985)
Nectars		F_{123} = 15 s if 4.2 < pH < 4.6.	Tetrapak (2013)
		F_{138} = 4 s if pH > 4.6.	Tetrapak (2013)
Onions		4 - 7 min.	Stumbo in Reichert (1985)
Peas		5.6 - 8 min.	Stork in Reichert (1985)
		6.0 - 11.3 min.	NCA in Reichert (1985)
Peas and potatoes		7.3 - 13.9 min.	NCA in Reichert (1985)
Peas in brine	**up to A2**; up to 83x114; up to 580 ml	6 min.	Brennan (1979) p. 261
	A2 to A10; 83x114; 580 ml; to 153x178; 3110 ml	6 - 8 min.	Brennan (1979) p. 261
	No. 2/A2; 83x114; 580 ml	7 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
	No. 10/A10; 153x178; 3110 ml	7 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Potatoes		3 - 3.5 min.	Stork in Reichert (1985)
		3.0 - 10.8 min.	NCA in Reichert (1985)
Spinach		4 min.	Stork in Reichert (1985)
		7 - 11 min.	Alstrand-Ecklund in Reichert (1985)
		3.0 - 4.3 min.	NCA in Reichert (1985)
Tomato juice (see also at section 2 of		0.7 min.	Schobinger, U. (Ed.) (1987) p. 513

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
pasteurized products)			
Tomato soup, non-cream	**All**	3 min.	Brennan (1979) p. 261
Tomato soup		0.5 min. if pH < 4.5	Taylor, K.; Crosby, D. (2006) p. 7-9
Vegetable juices		4 min.; 5 - 6 min.; 10 min.	Schobinger, U. (Ed.) (1987) p. 513
Vegetables		3 - 6 min.	Smith (2011) p. 254
Meat & Poultry			
Beef in own gravy		4.1 - 4.3 min.	Wirth, Tacács, Leistner in Reichert (1985)
Beef: Minced Beef	**UT**; 73x115; 445 ml	6 min. in core; 8.6 min. total.	Holdsworth (1997) p. 188 [1])
Brawn		4.5 - 4.7 min.	Wirth, Tacács, Leistner in Reichert (1985)
"Brühwurst"; can completely filled; so no separate sausages. NO_2^- added.		0.6 min.	Reichert (1985) p. 97; table 26
Chicken		6 - 8 min.	Alstrand-Ecklund in Reichert (1985)
Chicken, boned	**All**	6 - 8 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Chicken supreme sauce	**UT**; 73x115; 445 ml	4.5 min. in core; 6.6 min. total.	Holdsworth (1997) p. 188 [1])
Chicken fillets (breast) in jelly	**up to 16 oz**; up to 73x118; 454 ml	6 - 10 min.	Brennan (1979) p. 261
Corned Beef		5 min.	Stumbo in Reichert (1985)
		4.0 - 4.9 min.	Wirth, Tacács, Leistner in Reichert (1985)
		≥ 4.0 min.	Reichert (1985) p. 130
	300x200; 76x51; 180 ml	4.5 min. in core; 6.6 min. total.	Holdsworth (1997) p. 188 [1])
Corned Beef for tropics		≥ 12 min.	Reichert (1985) p. 130
Frankfurters in brine	**up to 16A/16Z**	3 - 4 min.	Brennan (1979) p. 261
Game: Poultry and Game, whole in brine	**A2½ to A10**; 99x119; 850 ml; to 153x178; 3110 ml	15 - 18 min.	Brennan (1979) p. 261
Goulash		4.0 - 4.5 min.	Wirth, Tacács, Leistner in Reichert (1985)
Ham		5 min.	Alstrand-Ecklund in Reichert (1985)
		0.1 - 0.3 min.	NCA in Reichert (1985)
Ham 'sterile'	**1 and 2 lb**;	3 - 4 min.	Holdsworth (1997) p. 175-176
Ham 3.3% brine		0.3 - 0.5 min.	Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Ham 4.0% brine		0.1 - 0.2 min.	Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Ham and Shoulder 3.3% brine (150 ppm NO_2^-)		0.3 - 0.5 min.	Footitt (1995) p. 203-204
Ham and Shoulder 4.0% brine (150 ppm NO_2^-)		0.1 - 0.2 min.	Footitt (1995) p. 203-204
Liver pate; coarse liver pate = "Grobe leberwurst"; NO_2^- added.		1.2 min.	Reichert (1985) p. 103-105 Pre-heating ingredients at 80 ºC while stirring. Rotating retort; retort temperature 110 ºC; slow cooling. This all to prevent fat separation. Use small, flat cans or glass jars;

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
			preferably H:D = 1:1; preferably product mass ≤ 200 grams. A very high fat % reduces water activity, and thus increases shelf life.
Liver pate; fine; spread NO_2^- added.		1.2 min.	Reichert (1985) p. 103-105 For organoleptic quality: Pre-heating ingredients at 80 ºC while stirring. Rotating retort; retort temperature 110 ºC; slow cooling. This all to prevent fat separation. Use small, flat cans or glass jars; preferably H:D = 1:1; preferably product mass ≤ 200 grams. A very high fat % reduces water activity, and thus increases shelf life.
Liver pate (spread): fine liver pate.		5 min.	Reichert (1985) p. 105-113 For organoleptic quality: Use small flat cans; large diameter, small height, such as DxH = 163x10 mm. Retort temp 140 ºC, maximum product temperature 120 ºC. Preferably product mass ≤ 200 grams.
Luncheon Meat		0.3 - 0.8 min.	Andersen in Reichert (1985)
Luncheon Meat 3.0 - 4.0% brine (150 ppm NO_2^-)		1.0 - 1.5 min.	Footitt (1995) p 203-204; Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Luncheon Meat 4.0 - 4.5% brine (150 ppm NO_2^-)		1.0 min.	Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176 Codex Alimentarius (1986)
Luncheon Meat 5.0 - 5.5% brine (150 ppm NO_2^-)		0.5 min.	Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Meats: Cured meats and vegetables	**up to 16Z**	8 - 12 min.	Brennan (1979) p. 261; Holdsworth (1997) p. 175-176
Meats: Low acid canned cured meats: pH ≥ 4.5		0.5 min. to 1.5 min.	Holdsworth (1997) p. 174 A mixture of salt NaCl and sodium nitrite (NO2-), together with refrigerated storage, and control of the initial spore load, inhibit spore growth.
		0.65 to 0.85 min.	Reichert (1985); Sielaff (1996) **Shelf life** at least 1 year if storage temperature T < 20 °C, and "cured" by a mixture of salt NaCl and sodium nitrite (NO2-).
Meats in gravy	**All**	12 - 15 min.	Brennan (1979) p. 261; Holdsworth (1997) p. 175-176; Smith (2011) p. 254
Meat, Sliced meat in gravy	**Ovals**	10 min.	Brennan (1979) p. 261; Holdsworth (1997) p. 175-176
Meat loaf	**No. 2; A2**; 83x114; 580 ml	6 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Meat pies	**Tapered; flat**	10 min.	Brennan (1979) p. 261
Pork in own gravy		3.9 - 4.1 min.	Wirth, Tacács, Leistner in Reichert (1985)
Poultry and Game, whole in brine	**A2½ to A10**; 99x119;	15 - 18 min.	Brennan (1979) p. 261

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
	850 ml		
Roast Beef		5 min.	Stumbo in Reichert (1985)
Sausages		1 - 3 min.	Andersen in Reichert (1985)
		4.2 - 4.7 min.	Wirth, Tacács, Leistner in Reichert (1985)
		0.6 - 0.8 min.	Heldtmann-Reichert in Reichert (1985)
		0.6 - 0.8 min.	Reichert (1985) p. 105. Preferably retort temperatures lower than 115 ºC to reduce quality deterioration. Shelf life 1 year.
Sausages in brine. NO_2^- added.		0.8 min.	Reichert (1985) p. 97. Shelf life at least 1 year.
Sausages, 2.5% brine (150 ppm NO_2^-)		1.5 min.	Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176
Sausages, Vienna, in brine	**Various**	5 min.	American Can Co. (1952); Ahlstrand & Ecklund (1952)
Sausages: Frankfurters in brine	**up to 16A/16Z**	3 - 4 min.	Brennan (1979) p. 261
Sausages in fat	**up to 1 lb**	4 - 6 min.	Brennan (1979) p. 261
Sausage meat dough in can; "Brühwurst"; can completely filled; so no separate sausages. NO_2^- added.		0.6 min.	Reichert (1985) p. 97; table 26
"Schmatzfleisch". NO_2^- added.		1.2 min.	Reichert (1985) p. 103-105 Pre-heating ingredients at 80 ºC while stirring. Rotating retort; retort temperature 110 ºC; slow cooling. This all to prevent fat separation. Use small, flat cans; preferably H:D = 1:1; preferably product mass ≤ 200 grams.
Steak: Stewed Steak	**UT**; 73x115; 445 ml	9.0 min. in core; 12.0 min. total.	Holdsworth (1997) p. 188 [1])
Fish products			
Crab in brine		3.5 - 3.9 min.	NCA in Reichert (1985)
Crab	Crabs shall be cooked under steam pressure until such time that the internal temperature of the centermost crab reaches 235 degrees F(112.8 degrees C).		Georgia Dept of Agricultture
Fish in brine		5.6 - 8 min.	Stumbo in Reichert (1985)
		5 - 6 min.	Andersen in Reichert (1985)
Fish products		5 - 20 min.	Frott & Lewis (1994)
Herrings in tomato sauce	**Ovals**	6 - 8 min.	Brennan (1979) p. 261
		6 - 8 min.	Smith (2011) p. 254
Langoustines		3.6 - 7.2 min.	NCA in Reichert (1985)
		3 - 4 min.	Andersen in Reichert (1985)
Lobsters		3.6 - 7.2 min.	NCA in Reichert (1985)
		3 - 4 min.	Andersen in Reichert (1985)
Mackerel in brine	**301x411**; 78x118; 479 ml	2.9 - 3.6 min.	American Can Co. (1952)
	301x411; 78x118;	3 - 4 min.	Ahlstrand & Ecklund (1952)

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
	479 ml		
Mackerel in tomato sauce	**UT**; 73x115; 445 ml	7.0 min. in core; 10.9 min. total.	Holdsworth (1997) p. 188 [1])
Oysters - Atlantic		5.9 - 6.0 min.	NCA in Reichert (1985)
Oysters - Pacific		2.7 - 6.0 min.	NCA in Reichert (1985)
Sardines in mustard sauce		0.7 min.	NCA in Reichert (1985)
Sardines in tomato sauce		1.5 min.	NCA in Reichert (1985)
Sardines in oil		2.4 min.	NCA in Reichert (1985)
Tuna		2.7 - 7.8 min.	NCA in Reichert (1985)
Tuna; in oil, or in 2% brine, or in tomato sauce, or in curry.		10 min.	Ali et all (2005);
	307 x 109; 87 x 40; 6 oz ≈ 170 ml	10 min.	Martin Xavier et al (2007) p. 162
Dairy products			
Baby foods (in glass bottles)	**Baby food**; 52x72; 140 ml	3 - 5 min.	Brennan (1979) p. 261; Holdsworth (1997) p. 175-176
Chocolate Drinks		Pre-heating mixture at F_{90} = 15 min. Autoclave sterilization of bottled product F_{120} = 30 min.	De Wit (2001) p. 48
Cream	**4 and 6 oz** 114 and 170 ml	3 - 4 min.	Brennan (1979) p. 261; Holdsworth (1997) p. 175-176
	130 - 200 ml	3 - 4 min.	Holdsworth (1997) p. 175-176
	16 Z (approx 500 ml)	6 min.	Brennan (1979) p. 261
		≥ 45 min. at T ≥ 104 °C	Statutory Instruments 1509 (1983; UK).
		≥ 45 min. at T ≥ 108 °C	Rees & Bettison (1991) p. 31
		140 ºC for 2 seconds.	UK Statutory heat treatment requirements for UHT products, quoted by Lewis (2003) in Smit (2003) p. 95-96); and by Lewis (2006) in Brennan (2007) p. 62
Cream; sterilized coffee cream 20% fat	sterilization in bottle	20 min. 115 °C; 9 log reductions of *Bacillus subtilus.*	Walstra (2006) p. 449
Cream; sterilized coffee cream 20% fat; UHT	UHT sterilization	10 sec at 140 °C.	Walstra (2006) p. 449
Cream; UHT	UHT sterilization	≥ 2 s at T ≥ 140 °C.	Lewis & Heppell (2000) p. 271
Evaporated milk; coffee milk	**up to 16 oz**; up to 73x118; 454 ml	5 min.	Brennan (1979) p. 261
Evaporated milk		5 min.	Smith (2011) p. 254
Evaporated milk; coffee milk	In bottle sterilization	10 - 40 min at 115 - 120 °C.	HAS
Evaporated whole milk	In bottle sterilization	Pre-heating in heat exchanger 30 s 130 °C. In past: preheating in tank 20 min at T < 100 °C. Sterilization in bottle or can:	Walstra (2006) p. 499

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
		15 min. 120 °C.	
Evaporated whole milk	UHT sterilization	Pre-heating in heat exchanger 30 s 130 °C. In past: preheating in tank 20 min at T < 100 °C. Flowing UHT sterilization 15 s 140 °C.	Walstra (2006) p. 499
Evaporated whole milk	UHT sterilization	Pre-heating in heat exchanger 15 s 135-145 °C. Next concentrate 2.5 to 3x. Then UHT 142 ºC 5 s; Homogenize; packaging.	Lewis & Heppell (2000) p. 274
	UHT sterilization	Pre-heating 10 min. 90 ºC or in heat exchanger 15 s 135-145 °C. Next concentrate 2.5 to 3x. Then UHT 142 ºC 15 s; cool, Reheat to 115 ºC 20 min. Homogenize; packaging.	Lewis & Heppell (2000) p. 274
Evaporated whole milk, recombined from skim milk powder, water and milk fat		13 min. 117 °C.	Walstra (2006) p. 501
Ice cream mix (UHT)		2 seconds at 148.9 ºC.	UK Statutory heat treatment requirements for UHT products, quoted by Lewis (2003) in Smit (2003) p. 95-96); and in Lewis (2006) in Brennan (2007) p. 62
Milk, Cocoa taste		10 - 40 min at 115 - 120 °C.	HAS
Milk		5 - 8 min.	Stumbo in Reichert (1985)
		8 min.	Lewis (2003) in Smit (2003) p. 93
Milk; in bottle or can		5 - 8 min.	Reichert (1985); Shapton (1994)
Milk: full cream		F_{125} = 2-4 min.	Westergaard (1994) p. 16
Milk; sterilized UHT	UHT	F_{149} = 2 sec.	Shapton (1994)
	UHT	F^{10}_{149} = 2 s.	Reichert (1985)
	UHT	2 s - 40 s at 140 - 145 °C.	HAS
Milk; sterilized UHT; skimmed and semi-skimmed		≥ 1 s at T ≥ 135 °C.	The Milk and Dairy Regulations (1988): No. 2208, schedule 2; UK Govt; Lewis (2006) in Brennan (2006) p. 62
Milk, "ultra-pasteurized"	UHT direct; not hermetically sealed, so refrigeration required.	2 - 4 s at 138 ºC; refrigerated unopened shelf life 30-90 days.	Lewis (2003) in Smit (2003) p. 92; Cornell University (2010)

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Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
Milk, first UHT sterilized, next filled in bottles, sealed and then mildly retorted	UHT	UHT 4 s at 137 ºC, next mild conventional retorting to kill recontamination caused during filling stage.	Lewis (2003) in Smit (2003) p. 94
Milk powder: Milk to produce high heat milk powder (WPN Index ≤ 5 mg N/g)		5 min. 90 °C; 1 min. 120 °C.	Walstra (2006) p. 530
Milk powder: Skim milk to produce high heat milk powder (WPN Index ≤ 5 mg N/g)		UHT: 30 s at 121 °C - 148 °C.	Caric (1994) p. 98-99
Milk powder: Milk to produce milk powder		3-5 min. at 88 - 90 °C; several seconds at 130 °C.	Caric (1994) p. 65-66
Milk powder: Milk to produce full-cream milk powder		1 min. at 95 ºC (also to prevent auto-oxidation).	Walstra (2006) p. 515
Milk powder: Milk to produce full-cream milk powder	From 60 ºC to 80 ºC indirect heating; from 80 ºC to 110 ºC direct steam injection to avoid interactions between whey proteins; from 110 ºC to 125 ºC direct steam injection.	F_{125} = 2 - 4 min.	Westergaard (1994) p. 16
Milk powder; for skim milk powder to produce recombined evaporated milk	UHT of skim milk	1 min. at 130 °C.	Walstra (2006) p. 500
Milk puddings	**up to 16 Z** (approx 450 ml)	4 - 10 min.	Brennan (1979) p. 261
		4 - 10 min.	Smith (2011) p. 254
Milk-based drinks		≥ 45 min. at T ≥ 104 °C.	Statutory Instruments 1508 (1983) UK).
Milk-based products		UHT; 2 seconds at 140 ºC.	UK Statutory heat treatment requirements for UHT products, quoted by Lewis (2003) in Smit (2003) p. 95-96; and Lewis (2006) in Brennan (2006) p. 62
Sweetened condensed milk	a_W ≈ 0.84	2 min. in can; or 5 s at 135 °C (UHT).	Walstra (2006) p. 508
Other products			
Dog food	**No. 2**; 83x114; 580 ml	12 min.	American Can Co. (1952)
	No. 10; 153x178; 3110 ml	6 min.	American Can Co. (1952)
Petfoods		6 - 12 min.	Stork in Reichert (1985)
	up to 16 Z;	15 - 18 min.	Brennan (1979) p. 261
		15 - 18 min.	Smith (2011) p. 254

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approximate **sterilization** value $F^{10}_{121.1}$	Source
	A2; 83x114; 580 ml	12 min.	Ahlstrand & Ecklund (1952)
	A10; 153x178; 3110 ml	6 min.	Ahlstrand & Ecklund (1952)
	UT; 73x115; 445 ml	$F^{10}_{128.5}$ = 12.0 min. in core; $F^{10}_{128.5}$ = 20.0 min. overall.	Holdsworth (1997) p. 188 [1])
Soup		10 - 12 min.	Andersen in Reichert (1985)
Soup		4 - 5 min.	Smith (2011) p. 254
Soup: Cream soups	**A1;** 65x101; 315 ml **to 16 Z**	4 - 5 min.	Brennan (1979) p. 261
	up to A10; up to 153x178; 3110 ml	6 - 10 min.	Brennan (1979) p. 261
Soup: Meat soups	**up to 16 Z**	10 min.	Brennan (1979) p. 261
Soup: Mushroom soup, cream	**A1;** 65x101; 315 ml	$F^{10}_{115.7}$ = 3.5 min. in core; $F^{10}_{115.7}$ = 5.8 min. total.	Holdsworth (1997) p. 188 [1])
Soup: Tomato soup, non-cream	**All**	3 min.	Brennan (1979) p. 261
Soup: Ox tail soup		4.0 - 4.9 min.	Wirth, Tacács, Leistner in Reichert (1985)
Spaghetti		5.5 min.	Stumbo in Reichert (1985)
Spaghetti hoops in tomato sauce	**U8**; 73x61; 230 ml	7.5 min. in core; 11.6 min. total.	Holdsworth (1997) p. 188 [1])
Spaghetti in tomato sauce	**A2½**; 99x119; 850 ml	6.0 min. in core; 9.0 min. total.	Holdsworth (1997) p. 188 [1])
White wine sauce	**UT**; 73x115; 445 ml	4.5 min. in core; 6.5 min. total.	Holdsworth (1997) p. 188 [1])
Low water activity products			
Almonds, roasted in oil	4D reduction of *Salmonella* sp 5D reductions of *Salmonella* sp	Heating for 1.6 min. in oil of 126.7 ºC. Commercially Heating for 2 min. in oil of 126.7 ºC.	Silva & Gibbs (2012) p. 698 Due to the low water activity, the D value of *Salmonella* in almonds is increased considerably.

[1]) Holdsworth (1997: 188) lists two different $F^{10}_{121.1}$ values: the lowest value measured in the coldest spot ("core") of the packaged food; the higher value is the overall or integrated F value.

General principles on $F^{10}_{121.1}$ sterilization values
for groups of foods

Type of food	Remarks	Approx. sterilizing value $F^{10}_{121.1}$	Sources
Low acid canned foods: pH ≥ 4.5	**Food safety**: *Botulinum* Cook for safety: after heat processing less than 1 *C. botulinum* spore per 10^{12} cans. Spoilage still possible.	$F^{10}_{121.1}$ > 3.0 min.	Holdsworth (1997) p. 174
Low acid canned foods: pH ≥ 4.5	**Food safety**: Botulinum Cook for safety: after heat processing less than 1 *C. botulinum* spore per 10^{12} cans. Assumption: initially 1 spore of *Clostridium botulinum* per cm^3. Spoilage still possible.	Small cans D x H = 54.0 mm x 57.2 mm (96.54 cm^3): $F^{10}_{121.1}$ ≥ 2.80 min. Large cans D x H = 157.2 mm x 177.8 mm (3133.96 cm^3): $F^{10}_{121.1}$ ≥ 3.10 min. For convection heating (= liquid) foods: F in coldest spot (core); for conduction heating foods (solids): F total = integral lethal capacity.	Stumbo (1983) p. 537-538
Low acid canned foods: pH ≥ 4.5	**Shelf life**: To be safe, and to prevent spoilage.	Frequently $F^{10}_{121.1}$ ≥ 6.0 min.	Holdsworth (1997) p. 174
Low acid canned foods: pH ≥ 4.5		12-log reduction of *C. botulinum*, or probability of a viable spore being present < 10^{-9} per can (a can = 1kg) (if N_0 = 1 g^{-1})	ICMSF (2002); IOM NRC (2003); Bean (2012), table 2.1
Low acid canned foods: pH ≥ 4.5	**Shelf life**: To be safe, and to prevent spoilage. Organism of concern is spoilage spore *Clostridium sporogenes.* Assumption: initially 1 spoilage spore of *Clostridium sporogenes* per cm^3. After heat processing less than 1 *Clostridium sporogenes* spore per 10^4 cans.	Small cans D x H = 54.0 mm x 57.2 mm (96.54 cm^3): $F^{10}_{121.1}$ ≥ 8.99 min. Large cans D x H = 157.2 mm x 177.8 mm (3133.96 cm^3): $F^{10}_{121.1}$ ≥ 11.24 min. For convection heating (= liquid) foods: F in coldest spot (core); for conduction heating foods (solids): F total = integral lethal capacity.	Stumbo (1983) p. 537-538
Low acid canned foods: pH ≥ 4.5	**Shelf life in moderate climate:** 4 months to 4 years if storage temperature T ≤ 25 °C. Microbial stable; thermophilic spoilage spores, which germinate at T > 35 °C, are present in 1:100 cans. Shelf life limited due to sensory deterioration by enzymatic and/or chemical spoilage at moderate storage temperature.	$F^{10}_{121.1}$ = 3.0 min. to 8.0 min.	Reichert (1985); Sielaff (1996)
Low acid canned foods: pH ≥ 4.5	**Shelf life in moderate climate**: up to 4 years. "In the food industry the most heat resistant *pathogens* are ***Clostridium botulinum*** spores for which a minimum	$F^{10}_{121.1}$ = 4.0 - 5.5 min.	FAO (2007) Ch. 22

General principles on $F^{10}_{121.1}$ sterilization values
for groups of foods

Type of food	Remarks	Approx. sterilizing value $F^{10}_{121.1}$	Sources
	F-value of 2.52 needed. The most heat resistant spores for *spoilage* are the ***Clostridium sporogenes*** spores which require minimum **F-values of 2.58**. Based on these microbiological considerations and including a sufficient safety margin, sterilized canned products should be produced with **F-values of 4.0-5.5**. The retort temperatures to be used may vary between **117** and **130°C** (depending on the heat sensitivity of the individual products). A shelf life of up to **four years** at storage temperatures of 25°C or below can be achieved."		
Low acid canned foods: pH ≥ 4.5 (for tropics)	**Shelf life in tropical climate:** 1 year at storage temperature T ≥ 35-40 °C. Food is microbial stable. Thermophilic spoilage spores, which germinate at T > 35 °C, are present in the heated food in 1:100 000 cans. Shelf life in tropics is limited due to rapid sensory deterioration by enzymatic and/or chemical spoilage at high storage temperatures.	$F^{10}_{121.1}$ = 16 min. to 20 min.	Reichert (1985); Sielaff (1996)
	In **tropical countries**, where the storage temperatures may exceed 25°C, specific canned products for tropical conditions are manufactured. In these cases the summary F-values have to be increased to **F-value = 12-15 min.**, which permits safe storage of the finished products under storage temperatures up to **40°C**.	$F^{10}_{121.1}$ = 12 - 15 min.	FAO (2007) Ch. 22
Low acid canned cured meats: pH ≥ 4.5	A mixture of salt NaCl and sodium nitrite (NO_2^-), together with refrigerated storage, and control of the initial spore load, inhibit spore growth.	$F^{10}_{121.1}$ = 0.5 min. to $F^{10}_{121.1}$ = 1.5 min.	Holdsworth (1997) p. 174
	Shelf life at least 1 year if storage temperature T < 20 °C, and salt NaCl and sodium nitrite (NO_2^-).	$F^{10}_{121.1}$ = 0.65-0.85 min.	Reichert (1985); Sielaff (1996)
Acid products: 3.7 < pH < 4.5 (in the past: acid products were defined as 4.0 < pH < 4.5)	Control survival and growth of spoilage spore formers such as *Bacillus coagulans, Bacillus polymyxa, Bacillus macerans*, and of the spoilage butyric anaerobes *Clostridium butyricum* and *Clostridium pasteurianum.*	$F^{10}_{121.1}$ = 0.7 min. $F^{8.3}_{93.3}$ = 10 min. if pH = 4.3 - 4.5. $F^{8.3}_{93.3}$ = 5 min. if pH = 4.0 - 4.3.	Hersom & Hulland (1980); Somers (1968) p. 67 Somers (1968) p. 67

2. PASTEURIZATION VALUES F or P

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Beer and Beverages (see also section "***Fruits and Vegetables***")			
Beer	F^{7}_{60} = 5.6 min.	F^{7}_{60} = 5.6 min. is also called 5.6 pasteurization units: 5.6 PU.	Holdsworth (1992) p. 57; Holdsworth (1997) p. 106-107; Tucker (2011) p. 59
Beer	F_{65-68} = 20 min. (in bottle)	Destruction of spoilage micro-organisms (wild yeasts, *Lactobacillus* species), and residual yeasts (*Saccharomyces* species).	Ramaswamy et al (2005), table 3.1
Beer	F_{60} = 15 min. (= 15 PU)	Either flash pasteurization, followed by aseptically packaging in metal barrels, or pasteurization in bottles or cans in a tunnel pasteurizer.	Silva et al (2014) p. 588 - 589
	F_{60} = 1 - 5 min. (= 1 - 5 PU)	"Effective for microbial inactivation".	
	F_{60} = 8 - 30 min. (= 8 - 30 PU)	"Generally used to ensure the absence of resistant organisms".	
Beer, stabilized at room temperature	F^{7}_{60} = 20 - 120 min. (= 20 - 120 PU)	If beer is carbonated, contains alcohol, and is bittered with hops (all natural antimicrobials).	Silva & Gibbs (2008) section 2.4.2.1
Beer	$F^{6.9}_{75}$ = 30 s		Lewis & Heppell (2000) p. 223
Pilsner beer	F^{7}_{60} = 20 min.		Heineken
Beer: Pilsner and Lager	15 min. < F^{7}_{60} < 25 min.		EBC (1995) p. 13
Beer: Ales and Stout	20 min. < F^{7}_{60} < 35 min.		EBC (1995) p. 13
Beer: low alcoholic	40 min. < F^{7}_{60} < 60 min.		EBC (1995) p. 13
Beer: non alcoholic beers; less bitter beers	80 min. < F^{7}_{60} < 120 min.		EBC (1995) p. 13
	120 min. < F^{7}_{60} < 300 min. (= 120 - 300 PU)	In non-alcoholic beers the spoilage lactic acid bacteria (LAB) and the pathogens such as *E. coli* and *S. typhimurium* are considerably more heat resistant compared to beer with 5 % v/v of alcohol.	Lanthoen and Ingledew (1996), cited in Silva & Gibbs (2008) section 2.4.2.1
Lemonades	300 min. < F^{7}_{60} < 500 min.		EBC (1995) p. 13
Fruit juices	3000 min. < F^{7}_{60} < 5000 min.		EBC (1995) p. 13
Meat & Poultry			
Beef: Ready-to-Eat (RTE) cooked beef products		6.5-log reduction of *Salmonella* Internal temperature 62.8 ºC.	FSIS (1999): Appendix A ; IOM NRC (2003); Bean et al (2012), table 2.1; p. 8+9
Beef: Ready-to-Eat (RTE) cooked beef products	See at "**Meats: Ready-To-Eat (RTE) Meats**"		
Burgers; Beef burger	F^{6}_{70} = 2 min.	6-log reduction of *E. coli* O157:H7 cells in minced meat; z = 6 ºC.	ACMSF (2007) p. 27
Cooked Beef	See at "**Meats: Ready-To-Eat (RTE) Meats**"		
Cooking sauce	F_{85} = 5 min.	pH = 3.7; aW = 0.92.	Taylor, K.; Crosby,

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		In jar process. No preservatives. Storage instructions: refrigerate on opening; use within 1 week.	D. (2006) p. 46
Corned beef; Cooked Corned Beef	See at "**Meats: Ready-To-Eat (RTE) Meats**"		
Game: Commercially raised game animals, and exotic species of game animals	F_{63} = 15 s		FDA (2013) Summary Chart 4A
Game: Commuted commercially raised game animals, and exotic species of game animals	F_{70} < 1 s F_{68} = 15 s F_{66} = 1 min. F_{63} = 3 min.		FDA (2013) Summary Chart 4A
Game: Wild game animals	F_{74} = 15 s		FDA (2013) Summary Chart 4A
Ham 3.3% brine	$F^{10}_{121.1}$ = 0.3 - 0.5 min.	see table with "Sterilization values" at section "meat and poultry". Can be stored at ambient temperatures.	Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Ham 4.0% brine	$F^{10}_{121.1}$ = 0.1 - 0.2 min.		Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Ham and Shoulder 3.3% brine (150 ppm NO_2^-)	$F^{10}_{121.1}$ = 0.3 - 0.5 min.		Footitt (1995) p. 203-204
Ham and Shoulder 4.0% brine (150 ppm NO_2^-)	$F^{10}_{121.1}$ = 0.1 - 0.2 min.		Footitt (1995) p. 203-204
Ham (Kochschinken)	F^{10}_{70} = 30 - 50 min.	Refrigerated storage. Depending on the initial number of micro-organisms, in particular D-streptococcus.	Reichert (1985) p. 146 + 148
Ham filler (sauce)	F_{95} = 5 min.	pH = 4; aW = 0.97. Process and in-bottle pasteurize. No preservatives. Storage instructions: Refrigerate on opening; use within 1 week.	Taylor, K.; Crosby, D. (2006) p. 46
Luncheon Meat 3.0 - 4.0% brine (150 ppm NO_2^-)	$F^{10}_{121.1}$ = 1.0 - 1.5 min.	see table with "Sterilization values" at section "meat and poultry". Can be stored at ambient temperatures.	Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176); Codex Alimentarius (1986)
Luncheon Meat 4.0 - 4.5% brine (150 ppm NO_2^-)	$F^{10}_{121.1}$ = 1.0 min.		Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176 Codex Alimentarius (1986)
Luncheon Meat 5.0 - 5.5% brine (150 ppm NO_2^-)	$F^{10}_{121.1}$ = 0.5 min.		Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176; Codex Alimentarius (1986)
Meat: Cooked meat as an ingredient for chilled foods	F_{70} ≥ 2 min.	Storage time ≤ 10 days if chilled at storage temp. 4 - 7 °C.	DOH (1989); Tucker (2011) p. 87; p. 90
Meat	F_{63} = 15 s		FDA (2013), Summary Chart 4A
Meat, chilled storage	F_{85} > 19 min. and stored at T < 12 °C	Chilled shelf life of not more than 28 days to reduce risk of food botulism.	Peck (1995), cited in Silva & Gibbs (2008), section

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES

Product	Approximate **pasteurization** value F or P	Additional information; Remarks		Source
	F_{95} = 15 min. and stored at T < 12 ºC	No botulism growth during chilled shelf life of 60days.		2.4.1
Meat Products	F_{70} = 2 min.	to achieve a 6-*D* reduction of *E. coli* O157:H7, *Salmonella* spp. and *L. monocytogenes*.		ACMSF (2007); Bean (2012) p. 13 and p. 15
Meat: Commuted meats and Injected meats and Mechanically tenderized meats	F_{70} < 1 s F_{68} = 15 s F_{66} = 1 min. F_{63} = 3 min.			FDA (2013), Summary Chart 4A
Meat, Minced meats	F^{6}_{70} = 2 min.	6-log reduction of E. coli O157:H7 cells in minced meat; z = 6 ºC.		ACMSF (2007) p. 27
Meats: stuffed	F_{74} = 15 s			FDA (2013) Summary Chart 4A
Meats: Ready-To-Eat (RTE) Meats: cooked beef, cooked roast beef; cooked corned beef	These should receive a time and temperature combinations to meet either a 6.5-log_{10} or a 7 log_{10} reduction of Salmonella.	F = Minimum processing time **after** minimum (= reference) temperature is reached for a **7 log₁₀ eduction** of *Salmonella*: $F_{54.4}$ = 121 min. F_{55} = 97 min. $F_{55.6}$ = 77 min. $F_{56.1}$ = 62 min. $F_{56.7}$ = 47 min. $F_{57.2}$ = 37 min. $F_{57.8}$ = 32 min. $F_{58.4}$ = 24 min. $F_{58.9}$ = 19 min. $F_{59.5}$ = 15 min. F_{60} = 12 min. $F_{60.6}$ = 10 min. $F_{61.1}$ = 8 min. $F_{61.7}$ = 6 min. $F_{62.2}$ = 5 min. $F_{62.8}$ = 4 min. $F_{63.3}$ = 182 s. $F_{63.9}$ = 144 s. $F_{64.4}$ = 115 s. F_{65} = 95 s. $F_{65.6}$ = 72 s. $F_{66.1}$ = 58 s. $F_{66.7}$ = 46 s. $F_{67.2}$ = 37 s. $F_{67.8}$ = 29 s. $F_{68.3}$ = 23 s. $F_{68.9}$ = 19 s. $F_{69.5}$ = 15 s. F_{70} = 0 s; *) $F_{70.6}$ = 0 s; *) $F_{71.1}$ = 0 s. *) *) The required lethalities are	F = Minimum processing time **after** minimum (= reference) temperature is reached for a **6.5 log₁₀ reduction** of *Salmonella*: $F_{54.4}$ = 112 min. F_{55} = 89 min. $F_{55.6}$ = 71 min. $F_{56.1}$ = 56 min. $F_{56.7}$ = 45 min. $F_{57.2}$ = 36 min. $F_{57.8}$ = 28 min. $F_{58.4}$ = 23 min. $F_{58.9}$ = 18 min. $F_{59.5}$ = 15 min. F_{60} = 12 min. $F_{60.6}$ = 9 min. $F_{61.1}$ = 8 min. $F_{61.7}$ = 6 min. $F_{62.2}$ = 5 min. $F_{62.8}$ = 4 min. $F_{63.3}$ = 169 s. $F_{63.9}$ = 134 s. $F_{64.4}$ = 107 s. F_{65} = 85 s. $F_{65.6}$ = 67 s. $F_{66.1}$ = 54 s. $F_{66.7}$ = 43 s. $F_{67.2}$ = 34 s. $F_{67.8}$ = 27 s. $F_{68.3}$ = 22 s. $F_{68.9}$ = 17 s. $F_{69.5}$ = 14 s. F_{70} = 0 s; *) $F_{70.6}$ = 0 s; *) $F_{71.1}$ = 0 s. *) *) The required	FSIS (1999): Appendix A - Compliance Guidelines For Meeting Lethality Performance Standards For Certain Meat And Poultry Products. Food Safety Inspection Service, USDA.

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		achieved instantly when the internal temperature of a cooked meat product reaches 70.0 °C or above; only heating time required until coldest point = 70 ºC. lethalities are achieved instantly when the internal temperature of a cooked meat product reaches 70.0 °C or above; only heating time required until coldest point = 70 ºC.	
Pork	F_{63} = 15 s		FDA (2013) Summary Chart 4A
Poulty	Heating to a core temperature of 74 °C.	To destruct *Campylobacter*, *Salmonella*, and viruses.	NACMCF (2006)
Poultry	F_{74} = 15 s		FDA (2013) Summary Chart 4A
Poultry: stuffed	F_{74} = 15 s		FDA (2013) Summary Chart 4A
Poultry: Cooked poultry; sold chilled	F_{70} ≥ 2 min.	Storage time ≤ 10 days if chilled at storage temp. 4 - 7 °C.	DOH (1989) in Tucker (2011) p. 90
Poultry: Cooked poultry rolls and other cooked poultry products	These products should reach an internal temperature of at least 71.1 °C prior to being removed from the cooking medium, except that cured and smoked poultry rolls and other cured and smoked poultry should reach an internal temperature of at least 68.3 °C prior to being removed from the cooking medium.		FSIS (1999): Appendix A - Compliance Guidelines For Meeting Lethality Performance Standards For Certain Meat And Poultry Products. Food Safety Inspection Service, USDA.
Poultry: cured and smoked poultry rolls and other cured and smoked poultry			
Poultry; Ready to eat	Minimum proces-sing time **after** minimum (= reference) temperature is reached: F_{55} = 476 min. (as D_{55} = 68 min.) F_{60} = 112 min. (as D_{60} = 16 min.) F_{65} = 14 min. (as D_{65} = 2.0 min.) F_{70} = 91 s. (as D_{70} = 13 s.) $F^{6}{}_{75}$ = 21 s. (as $D^{6}{}_{75}$ = 3.0 s.) $F^{6}{}_{80}$ = 3.2 s. (as $D^{6}{}_{80}$ = 0.45 s.) $F^{6}{}_{85}$ = 0 s; only heating time required until coldest point = 85 ºC (as $D^{6}{}_{85}$ ≈ 0 s.)	For cooked ready-to-eat (RTE) meat products, the Canadian Food Inspection Agency requires a P_T-value (pasteurization value, minimum time of food exposure to a specific temperature T) of 6.5 decimal reductions (**6.5D**) in *Salmonella* spp. in the slowest heating point (usually the geometric centre) of foods not containing poultry; whereas a minimum pasteurization causing **7D** is needed if food contains poultry. D values derived from a cocktail of *Salmonella senftenberg* with highest D value; the most thermally resistant Salmonella spp. (Senftenberg ATCC 43845).	Silva & Gibbs (2012) p. 698; table 2
Poultry; Ready to eat cooked poultry products		Internal temperature of 62.8 ºC; 7 log reductions of *Salmonella*.	ICMSF (2002); Bean (2012) table

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
			2.1
Poultry; Ready to eat	F = Minimum processing time **after** minimum (= reference) temperature is reached: $F_{54.4}$ = 121 min. F_{55} = 97 min. $F_{55.6}$ = 77 min. $F_{56.1}$ = 62 min. $F_{56.7}$ = 47 min. $F_{57.2}$ = 37 min. $F_{57.8}$ = 32 min. $F_{58.4}$ = 24 min. $F_{58.9}$ = 19 min. $F_{59.5}$ = 15 min. F_{60} = 12 min. $F_{60.6}$ = 10 min. $F_{61.1}$ = 8 min. $F_{61.7}$ = 6 min. $F_{62.2}$ = 5 min. $F_{62.8}$ = 4 min. $F_{63.3}$ = 182 s. $F_{63.9}$ = 144 s. $F_{64.4}$ = 115 s. F_{65} = 95 s. $F_{65.6}$ = 72 s. $F_{66.1}$ = 58 s. $F_{66.7}$ = 46 s. $F_{67.2}$ = 37 s. $F_{67.8}$ = 29 s. $F_{68.3}$ = 23 s. $F_{68.9}$ = 19 s. $F_{69.5}$ = 15 s. F_{70} = 0 s; the required lethalities are achieved instantly when the internal temperature of a cooked meat product reaches 70.0 °C or above; only heating time required until coldest point = 70 ºC.	A minimum pasteurization causing **7D** reduction of *Salmonella* is needed if food contains poultry. These USDA recommended values for pasteurizing meat and poultry products are considerably lower than the values, suggested by Silva & Gibbs above.	FSIS (1999) USDA guidelines, Appendix A; ICMSF (2002); Bean et al (2012) table 2.1; p. 8+9; Also partly reported in Silva & Gibbs (2012) p. 698; table 2
Proteins: Cooked proteins (such as meat) in an assembled food	$F^{7.5}_{70} \geq$ 2 min.	Pasteurization and next frozen shipment from country of origin to importing country. Be aware of latent heat of freezing when processing.	Tucker (2011) p. 100; p. 104
Roast beef	See at "**Meats: Ready-To-Eat (RTE) Meats**"		
Sausages, 2.5% brine (150 ppm NO_2^-)	$F^{10}_{121.1}$ = 1.5 min.	See also table with "Sterilization values" at section "**meat and poultry**". Can be stored at ambient	Footitt (1995) p. 203-204; Holdsworth (1997) p. 175-176

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		temperatures.	
Sausage: Cooked Sausages; Brühwurst	F^{10}_{70} = 40 min.	Refrigerated storage. Nitrite NO_2^- added as preservative.	
Sausages: Liver sausages; Brühwurst	F^{10}_{70} = 40 min.	Refrigerated storage.	Reichert (1985) p. 41-42; p. 96
Sausages: Liver sausages	$F^{10}_{121.1}$ = 0.6 min.	If 0.9550 < aW < 0.9600 and stored at temperature T < 15 °C: shelf life 6 - 12 months.	Reichert (1985) p. 113
		If aW < 0.9550 and stored at temperature T ≤ 20 °C: shelf life 1 year.	Reichert (1985) p. 113
Turkey slurry; refrigerated storage	F_{90} = 6 min.	Target organism: *C. botulinum;* approximately 6D reductions	Silva & Gibbs (2010) p. 102
Meat of BSE cattle should be destructed by	A single cycle at 134 ºC (± 4 ºC) for 18 min. holding time; or six separate cycles at 134 ºC (± 4 ºC) for 3 min. holding time	BSE is closely related to scrapie in sheep and may cause Creuzfeld-Jacobs disease in man.	Rees & Bettison (1991) p. 39
Fish			
Crab; blue crab meat	F^{9}_{85} = 31 min.	For pasteurization processes that target *C. botulinum* type E and non-proteolytic types B and F, generally a reduction of six orders of magnitude (six logarithms, e.g., from 10^3 to 10^{-3}) in the level of contamination is suitable. This is called a 6D process.	FDA (2011) p. 316-317
Crab; blue crab	$F^{8.9}_{85}$ = 31 min.	The process provides a wide margin of safety for the destruction of *C. botulinum* type E spores. After that: refrigeration to ≤ 2.2 ºC. A refrigerated shelf life of about 9 months is possible.	Gates et al (1993)
	$F^{8.9}_{85}$ = 10-15 min.	Refrigerated shelf life (≤ 2.2 ºC) of about 1.5 months.	
	$F^{8.9}_{85}$ = 15-20 min.	Refrigerated shelf life (≤ 2.2 ºC) of about 2 - 4 months.	
	$F^{8.9}_{85}$ = 20-25 min.	Refrigerated shelf life (≤ 2.2 ºC) of about 4 - 6 months.	
	$F^{8.9}_{85}$ = 25 - 30 min.	Refrigerated shelf life (≤ 2.2 ºC) of about 6 - 9 months.	
	$F^{8.9}_{85}$ = 30 - 40 min.	Refrigerated shelf life (≤ 2.2 ºC) of about 9 - 18 months.	
	$F^{8.9}_{85}$ ≤ 40 min.	Refrigerated shelf life (≤ 2.2 ºC) of about 12 - 36 months.	
Blue crab; refrigerated storage	F_{85} = 6 min.	Target organism: *C. botulinum*; approximately 6D reductions.	Silva & Gibbs (2010) p. 102
Crab meat; refrigerated storage	$F >_{95}$ = 6 min.	Target organism: *C. botulinum;* approximately 6D reductions.	Silva & Gibbs (2010) p. 102
Cod homogenate; refrigerated storage	F_{95} = 6 min.	Target organism: *C. botulinum;* approximately 6D reductions.	Silva & Gibbs (2010) p. 102
Crab; dungenes crabmeat	$F^{8.6}_{90}$ = 57 min.	For pasteurization processes that target *C. botulinum* type E and non-proteolytic types B and F, generally a reduction of six orders of magnitude (six logarithms, e.g., from 103 to 10-3) in the level of contamination is suitable. This is called a 6D process.	FDA (2011) p. 316-317

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Crabmeat homogenate; refrigerated storage	F_{85} = 1 min.	"Sufficient to inactivate 10^6 cfu/g of type E *C. botulinum* spores (6*D*) and keep the food safe (nontoxic) for 6 months at 4.4°C".	Cockey and Tatro (1974), cited in Silva & Gibbs (2008) section 2.4.1
Fish; raw fish	F_{63} = 15 s		FDA (2013) Summary Chart 4A
		Target organism: *Salmonella*.	NACMCF (2007); Bean (2012) table 2.1
Fish: stuffed	F_{74} = 15 s		FDA (2013) Summary Chart 4A
		Target organism: *Salmonella.*	NACMCF (2007); Bean (2012) table 2.1
Fish: stuffing containing fish	F_{74} = 15 s	Target organism: *Salmonella.*	NACMCF (2007); Bean (2012) table 2.1
Fish: Commuted fish	F_{70} < 1 s F_{68} = 15 s F_{66} = 1 min. F_{63} = 3 min.		FDA (2013), Summary Chart 4A
Fish: Commuted fish	F_{68} = 15 s	Target organism: *Salmonella.*	NACMCF (2007); Bean (2012) table 2.1
Fish and fishery products	F_{90} = 10 min., with z = 7 ºC for reference temperatures < 90 ºC , and z = 10 ºC for reference temperatures > 90 ºC.		FDA (2011) p. 316
Fish: Ready-to-Eat (RTE) cooked fish and seafoods	F_{70} = 2 min.	6-log reduction of *L. monocytogenes.*	NACMCF (2007); ICMSF(2002); Bean (2012) table 2.1
Fish sauces Fish soups	F_{90} = 10 min., with z = 7 ºC for reference temperatures < 90 ºC , and z = 10 ºC for reference temperatures > 90 ºC.		FDA (2011) p. 316
Molluscan shellfish	F_{100} = 5 min.	To destruct hepatitis A virus.	Rees & Bettison (1991) p. 40
Oyster homogenisate; refrigerated storage	F_{85} = 6 min.	Target organism: *C. botulinum;* approximately 6D reductions.	Silva & Gibbs (2010) p. 102
Salmon	F_{90} = 15 min.	Sous vide heating; effective to ensure safety and to extend the shelf life of sous-vide salmon.	Silva et al (2014) p. 589
Seafoods: Ready-to-Eat (RTE)	F_{70} = 2 min.	6-log reduction of *L. monocytogenes.*	NACMCF (2007); ICMSF(2002); Bean (2012) table 2.1, and p. 14
Shrimps: Ready-to-Eat (RTE)	F_{70} = 2 min.	6-log reduction of *L. monocytogenes.* To achieve absence per 25 g, or per extention, absence per 100 g in	NACMCF (2008); Bean et al (2012) p. 14

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		the RTE products.	
Surimi based products	F_{90} = 10 min., with z = 7 ºC for reference temperatures < 90 ºC , and z = 10 ºC for reference temperatures > 90 ºC.		FDA (2011) p 316
Surimi (with 2.4% salt on water basis)	F_{85} ≥ 15 min.	An example of a properly pasteurized surimi-based product in which 2.4% water phase salt is present is one that has been pasteurized at an internal temperature of 85°C for at least 15 minutes.	FDA (2011) p..316-317
Whitefish paste; refrigerated storage	F_{90} = 6 min.	Target organism: *C. botulinum;* approximately 6D reductions.	Silva & Gibbs (2010) p. 102
Egg, Liquid Egg and Liquid Egg products			
Albumen (without use of chemicals)	$F_{56.7}$ ≥ 3.5 min. $F_{55.6}$ ≥ 6.2 min.		USDA (1980); FDA (2002); in Froning (2002) table 6
Baluts (= boiled, fertilized egg)	F_{74} = 15 s		FDA (2013) Summary Chart 4A
Eggs: In shell pasteurization of eggs		5 log reduction of *Salmonella.*	NACMCF (2006); Bean (2012) table 2.1
Eggs; raw eggs, broken and prepared for immediate service	F_{63} = 15 s		FDA (2013) Summary Chart 4A
Eggs; raw eggs, broken and NOT prepared for immediate service	F_{70} < 1 s F_{68} = 15 s F_{66} = 1 min. F_{63} = 3 min.		FDA (2013) Summary Chart 4A
Egg: Whole egg, liquid	$F_{60.0}$ ≥ 3.5 min.		USDA (1980); FDA (2002) in Froning (2002) table 6
	$F_{60.0}$ ≥ 3.5 min.	2.75 log reductions of *L. monocytogenes;* 14 log reductions of *Salmonella enteritidis.*	Toledo (2007) p. 325
	$F_{60.0}$ ≥ 3.5 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
	$F_{60.0}$ ≥ 3.5 min.	8.75-log reductions in *Salmonella.*	Bean (2012) NACMCF (2006 table 2.1; NACMCF (2006)
	$F_{60.0}$ ≥ 3.5 min.	for USA.	Lewis & Heppell (2000) p. 219
	$F_{63.3}$ ≥ 2.5 min.	for China.	Froning (2002) p. 9; Lewis & Heppell (2000) p. 219
	F_{62} ≥ 2.5 min.	for Australia.	Froning (2002) p. 9
	$F_{62.5}$ ≥ 2.5 min.	for Australia.	Lewis & Heppell (2000) p. 219
	F_{65} = 90-180 s.	for Denmark.	Froning (2002) p. 9
	F_{65-69} = 1.5 - 3	for Denmark.	Lewis & Heppell (2000) p. 219

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	min.		
	$F_{64.4}$ ≥ 2.5 min. $F_{64.4}$ ≥ 2.5 min.	for Great Britain. (to negative alpha amylase activity).	Froning (2002) p. 9; Lewis & Heppell (2000) p. 219
	$F_{64.4}$ ≥ 2.5 min.	Destruction of pathogens *Salmonella senftenberg.*	Ramaswamy et al (2005) table 3.1
	$F_{66.1 - 67.8}$ ≥ 3 min.	for Poland.	Lewis & Heppell (2000) p. 219
Egg: Liquid whole eggs	F_{70} = 90 s	3 months shelf life at storage temp. of 5 ºC.	Tetrapak, in Toledo (2007) p. 325
Egg: Whole egg blends, liquid	$F_{61.1}$ ≥ 3.5 min. F_{60} ≥ 6.2 min.	If less than 2% added non-egg ingredients.	USDA (1980); FDA (2002); in Froning (2002) table 6
Egg: Fortified whole egg and blends	$F_{62.2}$ ≥ 3.5 min. $F_{61.1}$ ≥ 6.2 min.	If 24-38% solids, 2-12% added non-egg ingredients.	USDA (1980); FDA (2002); in Froning (2002) table 6
Egg: Fortified whole egg "Tex" product; 32% solids	$F_{62.2}$ ≥ 2 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg: USDA Scrambled egg mix (30% solids)	$F_{62.2}$ ≥ 2.0 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg: Scrambled egg mix (22% solids)	F_{60} ≥ 2.4 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg: Salted whole egg	$F_{63.3}$ ≥ 3.5 min. $F_{62.2}$ ≥ 6.2 min.	with 2% or more salt added.	USDA (1980); FDA (2002); in Froning (2002) table 6
Egg: Salted whole egg (10%) without storage	$F_{63.3}$ ≥ 5,7 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg: Salted whole egg (10%) with 96-hours storage after salt addition	$F_{63.3}$ ≥ 3.5 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg: Sugared whole egg	$F_{61.1}$ ≥ 3.5 min. F_{60} ≥ 6.2 min.	with 2% or more sugar added.	USDA (1980); FDA (2002); in Froning (2002) table 6
Egg: Sugared whole egg (10%)	$F_{61.1}$ ≥ 3.5 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg yolk: Fortified egg yolk "Tex" product; 49% solids	$F_{63.3}$ ≥ 3.5 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg yolk: Plain yolk, liquid	$F_{61.1}$ ≥ 3.5 min. F_{60} ≥ 6.2 min.		USDA (1980); FDA (2002); in Froning (2002) table 6
	$F_{61.1}$ ≥ 3.5 min. F_{60} ≥ 6.2 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg yolk: Salted yolk	$F_{63.3}$ ≥ 3.5 min. $F_{62.2}$ ≥ 6.2 min.	with 2% - 12% salt added.	USDA (1980); FDA (2002); in Froning (2002) table 6)
Egg yolk: Salted yolk (10%)	$F_{63.3}$ ≥ 4.5 min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg yolk: Sugared yolk	$F_{63.3}$ ≥ 3.5 min.	with 2% or more sugar added.	USDA (1980); FDA (2002); in

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	$F_{62.2} \geq 6.2$ min.		Froning (2002) table 6
Egg yolk: Sugared yolk (10%)	$F_{63.3} \geq 3.5$ min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg white; liquid; plain	$F_{56.7} \geq 3.5$ min. $F_{55.6} \geq 6.2$ min.	Heat without chemicals.	Froning (2002) p. 9
Egg white: liquid; without pH adjusted	$F_{57.7} \geq 6.3$ min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
	$F_{56.7} \geq 4.3$ min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Egg white: liquid; pH = 8.6 with hydrogen peroxide (Standard Brands Process)	$F_{54.4} \geq 3.5$ min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Imitation egg product	$F_{56.7} \geq 4.6$ min.	New Pasteurization guidelines; based on 5 log reduction of *Salmonella.*	Froning (2002) p. 25
Mayonaise	No heat process required	pH = 3.9; aW = 0.88. Preservative: sorbate in larger sizes for open shelf life. Storage instructions: refrigerate after opening.	Taylor, K.; Crosby, D. (2006) p. 46
Dried Egg and Dried Egg products			
Dried egg white; bulk packed	$F_{54.4}$ =7 - 10 **days.**	Hot room pasteurization of the dry powder. Moisture content to be 6%.	Froning (2002) p. 10
Dairy products			
Baby milk powder	See at ***Infant Formula***		
Butter: skim milk and cream for butter production	Skim milk fraction: F_{90} = 30 min. Cream fraction: F_{85} = 15 s.	Kill micro-organisms; inactivate enzymes. Destruction of bacterial inhibitors to make the skim milk a better substrate for the starter bacteria.	Walstra (2006) p. 468; p. 487
Buttermilk, conventional and cultured buttermilk: skim milk for the production of buttermilk	15-25 s at 85-95 °C.	Kill micro-organisms; inactivate enzymes. Destruction of bacterial inhibitors to make the cream a better substrate for the starter bacteria.	HAS
Cheese: milk for production of Gouda and Edam type cheeses	F_{72} = 15 s (Gouda); F_{72} = 20 s (Edam).	Flowing low pasteurization in heat exchanger. Kills pathogenic and harmful organisms (inactivation of alkaline phosphatase), but serum proteins remain soluble, Xantine oxidase is not destructed; native milk lipase is not destructed. Limited loss of soluble calcium.	Walstra (2006) p. 585; p. 703-704
Cheese: Kochkäse; Cancaillotte	10 min. at 90 ºC. Recently: heating to 115 ºC.	Ripened low fat quarg with low Ca^{2+}; next yeasts + *coryneform* bacteria grow; mixing with 1-2% of NaCl, butter, stirring and heating; next hot fill in cups and cooling.	Walstra (2006) p. 739
Cheese: Cottage cheese; milk for production of cottage cheese: Cream for the production of cottage cheese:	F_{73} = 15 s. F_{90} = 15 s.	Flowing low pasteurization in heat exchanger. Kills pathogenic and harmful organisms (inactivation of alkaline phosphatase), but serum proteins remain soluble for better rennetability.	Walstra (2006) p. 700

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Cheese: Cheddar cheese; milk for production of cheddar cheese	F_{71} = 15 s.		Walstra (2006) p. 713
Cheese: Emmentaler cheese; milk for production of Emmentaler cheese	F_{53} = 35 min.		Walstra (2006) p. 720
Cheese: Mozzarella cheese; milk for production of traditional Mozzarella	F_{72} = 15 s.		Walstra (2006) p. 723
Cheese: Soft cheeses, having a surface mold; milk for production of soft cheese	F_{72} = 15 s.		Walstra (2006) p. 726
Cheese: Fresh Cheese:	see at **Quark**		
Cheese: Processed:	see at **Processed cheese**		
Cream, pasteurized; 18% fat	F_{75} = 15 s		Rees & Bettison (1991) p. 32
Cream, pasteurized; ≥ 35% fat	F_{80} = 15 s		
Cream; whipping cream; 35% fat	F_{85} = 30 min.	Batch pasteurization in tank. Native milk lipase destructed; anti-oxidants produced.	Walstra (2006) p. 453
	Over 100 °C.	Flowing pasteurization in a heat exchanger. Native milk lipase destructed; anti-oxidants produced.	Walstra (2006) p. 453)
	F_{103} = 20 min.	In bottle pasteurization; in can pasteurization. Native milk lipase destructed; anti-oxidants produced.	Walstra (2006) p. 453
Cream	200 s to 15 s at 80 °C to 115 °C.	Flowing pasteurization in heat exchanger. Production of anti-oxidants.	HAS
	F_{72} ≥ 15 s	Minimum requirement in UK for HTST.	Lewis (2003) in Smit (2003) p. 90
Custard: Dutch custard	See at **Vla**		
Ice cream mixture	F_{80} = 25 s.	Vegetative pathogens and spoilage organisms are killed. Milk lipase should be destructed. Susceptibility to auto-oxidation is decreased.	Walstra (2006) p. 459
	F_{66} = 30 min. (batch); F_{71} = 10 min. (batch); F_{79} = 15 sec (HTST).		Lewis & Heppel (2000) p. 218
	F_{79} ≥ 15 s	Minimum requirement in UK for HTST.	Lewis (2003) in Smit (2003) p. 90
	F_{80} = 20 s	UK Food Safety Act (1990).	Smith (2011) p. 250
	F_{80} = 15 s	Destruction of pathogens.	Ramaswamy et al (2005) table 3.1
Infant formula; milk powder for babies	F_{75} = 20 s for the initial skim milk; F_{110} = 60 s after mixing the other ingredients.	First pasteurization of the skim milk (F_{75} = 20 s). Next concentration to 40-48 mass% dry matter; addition of other ingredients, homogenizing; followed by pasteurization (F_{110} = 60 s) of concentrated mixture prior to spray drying.	Caric (1994) p. 128-131
Infant formula	$F_{73.2}$ = 20 s	Tube heat exchanger; killing pathogenic micro-organisms.	Dutch whey processing plant (2010)

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Kochkäse	See at **Cheese: Kochkäse; Cansailotte**		
Milk; low pasteurized	F_{63} = 30 min.	Batch pasteurization in tank; "Holder process". Constant stirring required. "Great advantages of the batch system are that it does not significantly modify the properties of milk, the milk maintains its nutritional value, and the germicidal effect is approximately 95%".	Lewis (2003) in Smit (2003) p. 89; Toledo (2007) p. 325; Silva et al (2014) p. 588
Milk; low pasteurized	$F_{62.7}$ = 30 min.	Batch pasteurization achieves a 5 log reduction in the number of viable micro-organisms in milk.	European Economic Community (1992)
	F_{63} = 30 min.	5 log reductions of *Coxiella burnetti.* Constant stirring required.	IOM NRC (2003)
	$F_{68.3}$ = 30 min.	Batch pasteurization in tank; Low Temperature Holding (LTH). Thermoduric non-sporevormers survive.	Shapton (1994) p. 319
	≥ 30 min. at 62.8 °C < T < 65.6 °C.	Batch pasteurization. Constant stirring required.	The Milk and Dairy Regulations (1988)
	F_{72} ≥ 15 s to F_{77} ≥ 15 s	Fast pasteurization, also known as HTST, involves heating the milk to 72–77 ºC for at least 15 s. The germicidal efficiency of this method is approximately 99.5%, and alterations in the milk components are insignificant. This process is carried out in tubular or plate heat exchangers.	Silva et al (2014) p. 588
	$F_{71.5}$ = 15 s F_{88} = 1 s F_{94} = 0.1 s	HTST in plate heat exchanger.	Smith (2011) p. 250
	$F_{71.7}$ > 15 s.	Flowing pasteurization in heat exchanger.	The Milk and Dairy Regulations (1988)
		HTST pasteurization achieves a 5 log reduction in the number of viable micro-organisms in milk.	European Economic Community (1992)
	F_{72} = 15 s.	UK Food Safety Act (1990).	Smith (2011) p. 250
	F_{76} > 15 s.	Flowing pasteurization in heat exchanger. Native milk lipase is destructed; part of the bacterial inhibitors are destructed; homogenization is possible.	Walstra (2006) p. 425
	F_{77} ≥ 15 s.	USA for HTST.	Lewis (2003) in Smit (2003) p. 90
	F_{90} ≥ 0.5 s.	USA for HTST.	Lewis (2003) in Smit (2003) p. 90
	F_{100} ≥ 0.05 s.	USA for HTST.	Lewis (2003) in Smit (2003) p. 90
	F^{8}_{72} = 1 min.		Holdsworth (1997) p. 106-107
	$F_{79.5}$ = 25 s.	Flowing pasteurization in heat exchanger. High Temperature Short Time HTST. Thermoduric non-sporevormers survive.	Shapton (1994) p. 319
		6 log reductions of *Salmonella.*	Farber et al. (1988)
Milk; Microwave pasteurization	F71.1 = 8 min	Complete inactivation (8–9 log_{10}) of *Yersinia enterocolitica*.	Silva et al (2014) p. 590
	F71.1 = 3 min	Complete inactivation (8–9 log_{10}) of *Campylobacter jejuni*.	

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	F71.1 = 10 min	Complete inactivation (8–9 $\log_{10}$) of *Listeria monocytogenes.*	
Raw milk	F_{75} = 15 s	6 log reduction of *L. monocytogenes.*	Farber et al. (1988); Bean et al (2012), table 2.1; p. 8
Milk; also skim milk	F_{63} = 30 min. (batch process) F_{72} = 15 s; (continuous process)	5 log reduction of *Coxiella burnetii.*	Farber et al. (1988); Bean et al (2012), table 2.1; Rees & Bettison (1991) p. 32
Milk	F_{63} = 30 min. F_{75} = 15 s; F_{89} = 1 sec; F_{90} = 0.1 s; F_{96} = 0.05 s	Batch. Constant stirring required. Continuous process. Continuous process. Continuous process. Continuous process.	Toledo (2007) p. 325
	F_{75} = 15 s;	58 log reductions of *Mycobacterium tuberculosis;* 18.7 log reductions of *L. monocytogenes;* > 100 log reductions of *E. coli* 0157:H7; > 100 log reductions of *Salmonella* spp.	
Milk	F_{72} = 15 s - 25 s F_{75} = 15 s - 25 s F_{78} = 15 s - 25 s	Results in 4 to > 6 log reductions of *Mycobacterium avium* ssp. *paratuberculosis* (MAP), a vegetative pathogen which causes Johne's disease in cattle; the pathogenic effect of MAP in humans is not yet established.	McDonald (2005), cited in Silva et al (2014) p. 583 and p. 588, cited in Silva&Gibbs (2008), section 2.4.1.1, and cited in Silva & Gibbs (2010) p. 100
	F_{72} = 15 s F_{75} = 20 s F_{78} = 25 s		
Milk		Shelf life = time required for number of colony forming units CFU) to reach 10^6 per ml at storage temperature of 5 ºC.	Kessler and Horak (1984); cited in Toledo (2007) p. 325
	F_{74} = 40 s; or F_{78} = 15 s	21 days at 5 ºC.	
	F_{74} = 15 s; or F_{71} = 40 s	17 days at 5 ºC.	
	F_{78} = 14 s; or F_{85} = 15 s	16 days at 5 ºC.	
	F_{71} = 15 s	12 days at 5 ºC.	
Milk; low pasteurized, non-homogenized	F_{72} = 15 s.	Flowing pasteurization in heat exchanger. Vegetative pathogens such as *Mycobacterium tuberculosis*, *Salmonella* spp, enteropathogenic *E. coli*, *Campylobacter jejuni*, *Listeria monocytogenes*. Alkaline phosfatase inactivated (indicator enzyme). Vegetative psychrotropic spoilage organisms sufficiently destructed. Also most of the other vegetative spoilage micro-organisms in raw milk are killed such as coliforms, mesophilic lactic acid bacteria. Anti-bacterial properties (bacterial	Walstra (2006) p. 425

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		inhibitors) of milk remain intact.	
	$F_{72.5}$ = 15 s.	Sufficiently destruction (2 log reductions) of native milk lipase to produce non-homogenized milk.	Walstra (2006) p. 425
Milk; low pasteurized; homogenized	F_{75} = 20 s.	Sufficiently destruction (3 to 4 log reductions) of native milk lipase to produce homogenized milk.	Walstra (2006) p. 425
Milk; low pasteurized, refrigerated storage	15 s to 25 s at 72 ºC to 76 ºC	If refrigerated: safe product; pathogenic micro-organisms sufficiently destructed (alkaline phosphatase negative). If refrigerated: shelf stable product (1 week): spoilage micro-organisms destructed which can grow at refrigerator temperature.	Walstra (2006) chapter 16
Milk; pasteurized by HTST	F_{72} =15 s	Lactoperoxidase system still active, thus exhibiting strong anti-microbial activity on *Pseudomonas aeruginosa*, *S. aureus*, and *S. thermophilus*.	Lewis (2003) in Smit (2003) p. 86; p. 87
Milk; pasteurized by HTST	F_{72} =25 s	Recommendation by the UK Food Standards Agency as part of a strategy for controlling *Mycobacterium avium* ssp. *paratuberculosis* (MAP) in cow's milk. MAP is a vegetative pathogen which causes Johne's disease in cattle; the pathogenic effect of MAP in humans is not yet established.	Lewis (2003) in Smit (2003) p. 90
Milk; high pasteurized	F_{85} = 15 s.	Bacterial growth inhibitors are eliminated. Despite its lower initial count, high pasteurized milk may have a shorter shelf life tan low pasteurized milk due to lack of inhibition at recontamination. Thus high pasteurized milk is often heated in the bottle because then recontamination cannot occur, and shelf life will be longer.	Walstra (2006) p. 426
	Heating over 100 °C.	To kill spores of *Bacillus cereus*, thereby enhancing shelf life. Mild browning and cooking flavor due to Maillard reactions.	Walstra (2006) p. 426
Milk; high pasteurized	30 s to 60 s at 90°C to 95 °C.	Full cream milk. This heating process produces anti-oxidants.	Westergaard (1994) p.15
Milk; sous vide pasteurization	Internal product temperature of 70 ºC if 2 min. at 80 ºC or 2 min. at 91 ºC	Target organisms: Lactic acid bacterias, *Bacillus cereus, Pseudomonas.*	Silva et al (2014) p. 589
Milk: Ultra heat treated	$F_{132.2}$ > 1 s		Rees & Bettison (1991) p. 31
Milk: Ultra-pasteurized milk	F_{138} = 2 s	Ultra-Pasteurization milk is heated to 138 °C for a minimum of 2 seconds. This much higher heat treatment results in the destruction of virtually all spoilage organisms. Coupled with near sterile handling systems, UP processing results in milk with 60-90+ days of shelf-life."	S. C. Murphy (2010) Basic Dairy-Microbiology 06-10-CU-DFScience-Notes- (1)
Milk: Extended shelf life pasteurized milk	F_{115} ≥ 15 s	Much better keeping quality than milks with F_{72} = 15 s or F_{90} = 15s.	Lewis (2003) in Smit (2003) p. 92
	F_{115} - F_{120} = 1 s - 5 s	These time-temperature combinations are more effective than temperatures below 100 ºC for	Lewis (2003) in Smit (2003) p. 92

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		extending the shelf life of refrigerated products.	
	F_{120} = 2 s		Lewis & Heppel (2000) p. 228
	F_{72} ≥ 15 s + 40 IU/ml of nisin; F_{90} ≥ 15 s + 40 IU/ml of nisin	Addition of 40 IU/ml of nisin, a bacteriocin, reduced bacterial growth, in particular of *Lactobacillus.* In several countries addition of nisin is NOT permitted to milk or milk-based beverages.	Lewis (2003) in Smit (2003) p. 92
Milk: Extended shelf life pasteurized milk, stored at ambient temperature	F_{117} ≥ 2 s + 140 IU/ml of nisin	Such milks have been stored for over 150 days at 30 ºC with only very low levels of spoilage.	Lewis (2003) in Smit (2003) p. 92
	$F_{115-120}$ = 2 s + 75 - 150 IU/ml of nisin	Such milks have been stored for over 100 days at 30 ºC with only low levels (1:50) of spoilage. If stored at 10 ºC, the majority of the samples showed no sign of spoilage after 1 year.	Lewis & Heppell (2000) p. 231
Milk: concentrated, evaporated pasteurized	F_{80} = 25 s		Rees & Bettison (1991) p. 32
Milk powder: Milk to produce high heat milk powder (WPN Index ≤ 1.5 mg N/g)	F_{90} = 5 min.; or F_{120} = 1 min.	F value to be received in raw milk pasteurizer.	Walstra (2006) p. 530
Milk powder: Skim milk to produce high heat milk powder (WPN Index ≤ 1.5 mg N/g)	UHT: 30 s at 121 °C - 148 °C.	In a plate or tube heat exchanger.	Caric (1994) p. 98-99
	15 - 30 min. at 85 - 88 ºC	In a “hot well” semi batch process. Skim milk powder for bread production.	
Milk powder: Milk to produce medium heat skim milk powder WPN Index: 1.5 < WPNI < 6 mg N/g	F_{85} =1 min.		De Wit (2001) p. 43
Milk powder: Milk to produce low heat milk powder (WPN Index ≥ 6 mg N/g)	F_{72} = 15 s.	F value to be received in raw milk pasteurizer. 1st stage of milk evaporator: T < 70 °C; Keep concentrate T < 60 °C; In milk dryer: ensure low temperature of air dryer out.	Walstra (2006) p. 530
Milk powder: Milk to produce milk powder	3 - 5 min. at 88 -90 °C; or several seconds at 130 °C.		Caric (1994) p. 65-66
Milk powder: Milk to produce skim milk powder	$F_{71.7}$ = 15 s.	Plate or tube heat exchanger. “Destroys all pathogenic and most saprophytic microorganisms and inactivates enzymes with minimum detrimental heat induced changes, such as serum protein denaturation”.	Caric (1994) p. 98-99
Milk powder: Milk to produce full cream milk powder; Next: concentrated milk	Milk prior to drying: F_{95} = 1 min. Concentrate: heating at 78 °C.	Intense pasteurization required to obtain resistance to auto-oxidation. Pasteurization of concentrate: to kill recontamination due to concentration, and to lower the viscosity during atomization.	Walstra (2006) p. 515 - 516
Milk powder: Milk to produce full cream milk powder	30 to 60 seconds at 90 ºC to 95 ºC	To produce anti-oxidants.	Westergaard (1994) p. 15
Porridge; sweet	30 - 60 min. at 90 -	Batch pasteurization in tank; kill	HAS

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	95 °C.	vegetative micro-organisms; "cooking" of oats or rice.	
Porridge; sour; barley gruel	20 - 120 min. at 90-95 °C.	Batch pasteurization in tank; kill vegetative micro-organisms; "cooking" of flour or barley.	HAS
Processed cheese	≥ 30 s at ≥ 65.5 °C	"Pasteurized process Cheese". Moisture ≤ 43%. Fat ≥ 47%. USA Legislation.	Nath (1993) p. 230
	≥ 30 s at ≥ 65.5 °C	"Pasteurized process cheese food". Moisture ≤ 44%. Fat ≥ 23%. Cheese ingredients > 51%. USA legislation.	
	≥ 30 s at ≥ 65.5 °C	"Pasteurized process cheese spread". 44% < moisture < 60%. Fat ≥ 20%. Cheese ingredients > 51%. USA legislation.	
	Max. 15 min. at 75 °C	No substantial change in structure and consistency. Optimum temperature for transfer from disperse casein gel to homogenous casein "solution"; casein peptization.	Meyer (1970) p. 58; p. 156
	5 - 15 min. at 70 - 85 °C	Batch; direct (steam injection) or indirect heating.	Shaw (1986)
	5 min at 75 °C	Steam jacketed processor that grinds, mixes, processes; steam injection.	Caric (1987) p. 347
	4 - 15 min. at 71 °C - 95 °C	Batch processing, constant agitation; direct or indirect heating. Also a pasteurizing effect.	Caric (1987) p. 346-347
	71 °C - 80 °C; 80 °C - 85 °C; 4 - 8 min. 74 °C - 85 °C	Processed cheese for slicing; block cheese. If moisture ≤ 45% .	Caric (1987) p. 340; p. 348; Nath (1993) p. 235
	79 °C - 85 °C	Processed Cheese for food, and Processed Cheese analogue. If moisture ≤ 44%, and fat < 23%.	Caric (1987) p. 340; Nath (1993) p. 235
	Several minutes at 80 °C	Batch heating while stirring; next hot filling in container, and then cooling.	Walstra (2006) p. 737-739)
	4 - 8 min. at 80°C to 85 °C	Processed cheese for slicing; block cheese.	Meyer (1970) p. 60; p. 158; Caric (1987) p. 340
	4 - 8 min. at 80 °C - 85 °C	Processed cheese for slicing; block cheese; usually aW ≈ 0.95 so no outgrowth of *Clostridium* spores.	Kammerlehner (2003) p. 748-749
	4 - 6 min. at 78 °C - 85 °C	Processed cheese for toast.	Kammerlehner (2003) p. 749
	85 °C	Processed cheese.	Nath (1993) p. 230
	8 - 15 min. at 85 °C - 98 °C (-150 °C) 30 min. at 85 °C - 98 °C if cheese is very young	Processed cheese for spread. Above 90 °C all vegetative micro-organisms will be destructed (pasteurization).	Meyer (1970) p. 60; p. 156; p. 158; Caric (1987) p. 340; p. 348
	8 - 15 min. at 85 °C - 98 °C; UHT to 145 °C	Processed cheese for spread.	Kammerlehner (2003) p. 748

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	88 ºC - 91 ºC 90 ºC - 95 ºC	Processed cheese for spread. If 44 % ≤ % moisture ≤ 60%. If moisture ≤ 55%.	Caric (1987) p. 340; Nath (1993) p. 235
	over 70 ºC to a max. of 90 ºC	Water absorption capacity of casein increases; cream like consistency	Meyer (1970) p. 156
	4 - 5 min. 70 ºC - 95 ºC; or even higher.	Block cheese. Processing in steam jacketed cookers, and by direct steam injection; constant agitation. Hot packaging at cooking temperatures; slow cooling!	Tetrapak (2003) p. 342-343
	10 - 15 min. 70 ºC - 95 ºC;	Spread cheese Processing in steam jacketed cookers, and by direct steam injection; constant agitation. Hot packaging at cooking temperatures; rapid cooling!	
	Over 90 ºC	Low viscosity product.	Meyer (1970) p. 156
	80 ºC - 120 ºC	Batch processing; vigorous mixing (and cutting) during the heating process.	Meyer (1970) p. 147
	(3 - 5 min. at) 125 ºC	Batch process in stirred tank; next cooling to < 100 ºC; hot fill at 85 ºC.	Kammerlehner (2003) p. 747
	130 ºC - 145 ºC; at 145 ºC only some seconds	Continuous processing: heating by direct steam injection; rapid cooling by flash evaporation and in scraped heat exchanger (votator). Spore destruction; sterilization.	Meyer (1970) p. 58; p. 148-151; p. 156
	2 - 3 s at 130 ºC - 145 ºC	Continuous processing.	Caric (1987) p. 340
	110 ºC; max 140 ºC	Continuous processing: heating and cooling by scraped heat exchanger (votator).	Meyer (1970) p. 151
Processed Cheese	110 ºC - 125 ºC	Continuous processing: heating and cooling (to 80 ºC) by stirrers or scraped heat exchanger (votator); next packaging.	Kammerlehner (2003) p. 747
	125 ºC	Continuous process; heating; next cooling and hot fill at 85 ºC; packaging air tight and hermetically sealed; cold storage and distribution. Then 4 - 6 months shelf life.	Kammerlehner (2003) p. 747-748
	4 min. 121 ºC or seconds at 140 ºC	Sufficiently inactivation of spores of *Clostridium tyrobutiricum, C. butyricum, C. sporogenes*. UHT to 140 ºC only suitable for cheese spreads.	Kammerlehner (2003) p. 748
	4 - 180 seconds at 100 ºC	Continuous processing; steam injection in mixing tubes; next flash cooling and further processing.	Kammerlehner (2003) p. 747
Processed cheese, to be sold in cans or in consumer tubes	130 ºC - 145 ºC UHT	UHT Sterilization; next aseptically filling in tubes or cans.	Meyer (1970) p. 157
	Heating at 95 ºC.	Only if the % of dry matter is over 53%; next "aseptically" filling in cans or tubes, or hot filling and next cooling.	
	10 - 15 min. at 95 ºC	Heating in bulk during mixing; next "aseptically" filling in tubes or cans, or hot filling and then cooling.	Meyer (1970) p. 158
	Processing of bulk at max. 95 ºC; next in container	Retort processing in packaging.	Meyer (1970) p. 157

PASTEURIZATION **VALUES F FOR COMMERCIAL FOOD PROCESSES**			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	sterilization in retort		
Processed Cheese with additional lactose	Max. 95 ºC; or UHT heating to max. 120 ºC	Prevention of Maillard browning = non-enzymatic browning reaction between casein and lactose.	
Processed Cheese for slicing	4 - 8 min. at 80ºC to 85 ºC	Processed cheese for slicing; block cheese	Meyer (1970) p. 60; p. 157
	70ºC - 75 ºC	Processed cheese for slicing; block spread cheese. Only for very large batches of cheese which cool extremely slow.	Meyer (1970) p. 157
Processed Cheese spread	8 - 15 min. at 85 ºC - 98 ºC (-150 ºC)	Processed cheese spread; creamlike consistency.	Meyer (1970) p. 60; p. 157)
Quark: milk for production of low fat quark	F_{74} = 15 s.	Flowing low pasteurization in heat exchanger. Kills pathogenic and harmful organisms (inactivation of alkaline phosphatase), but serum proteins remain soluble for better rennetability.	Walstra (2006) p. 697-698
Vla (Dutch custard)	10 - 30 min. at 90-95 °C.	Batch pasteurization in tank; kills vegetative micro-organisms; gelation of starch.	HAS
	10 - 30 seconds at 110 °C to 140 °C.	Flowing pasteurization in heat exchanger; kills vegetative micro-organisms; gelation of starch.	
	F_{125} = 4 s.	Flowing pasteurization by UHT Direct steam injection.	
Whey; whey for production of whey powders	heat processing at 70 - 100 ºC	in tube heat exchanger; or in plate heat exchanger. Using direct steam injection.	Dutch whey processing plants (2010)
Yoghurt: milk for production of yoghurt	20 min. to 5 min. at 85 °C to 95 °C.	Batch pasteurization in tank. Bacterial inhibitors destructed; viscosity of yoghurt increases.	Walstra (2006) p. 563
	10 min. to 5 min. at 85°C to 90 °C.	Flowing pasteurization in heat exchanger. Safe: pathogenic vegetative micro-organisms destructed; Vegetative spoilage organisms which could grow during fermentation, destructed. Bacterial inhibitors destructed, and phages destructed; thus lactic acid bacteria can grow during fermentation; viscosity of yoghurt increases.	Walstra (2006) p. 563; Walstra (2006); chapter 22.4.2.
	5 min. at 90 °C to 95 °C.	Flowing pasteurization in heat exchanger. Improves properties of milk for yoghurt starter; ensures firm structure of the finished product with less risk of serum separation.	De Wit (2001) p. 46
Yoghurt drinks: milk for production of yoghurt drinks	15 min. at 85 °C to 95 °C initially. After fermentation to yoghurt: F_{75} = 20 s or F_{110} = 5 s.	Either batch or flowing. Destruction of bacterial inhibitors and of all other vegetative micro-organisms. Flowing pasteurization of yoghurt itself. Destruction of lactic acid bacteria and of yoghurt viscosity.	Walstra (2006) p. 564-565
Yoghurt-like, acidified, flavored milks;	F_{140} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 4.6.	Von Bockelman (1998) cited in Toledo (2007) p. 326
	F_{130} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 4.5.	
	F_{120} = 40 s	3 month shelf life at ambient temperature storage if ph = 4.4.	

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	(continuous flow)		
	F_{110} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 4.3.	
	F_{100} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 4.2.	
	F_{98} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 4.1.	
	F_{94} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 4.0.	
	F_{90} = 40 s (continuous flow)	3 month shelf life at ambient temperature storage if ph = 3.9.	
Yoghurt-like, acidified, flavored milks	F_{115} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.6.	Von Bockelman (1998) cited in Toledo (2007) p. 326
	F_{110} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.5.	
	F_{105} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.4.	
	F_{100} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.3.	
	F_{95} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.2.	
	F_{90} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.1.	
	F_{85} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 4.0.	
	F_{75} = 20 min. (batch process)	3 month shelf life at ambient temperature storage if ph = 3.9.	
Acid products, High acid products, Acidified products			
Ambient (= at room temperature) safe and stable acidified foods:	$F^{5.5}_{65}$ = 16.7 min. or F_{70} = 2.1 min.	if pH < 3.7 and target organism is yeasts.	CCFRA-Tucker (1999) p. 8-11
	$F^{8.3}_{85}$ = 5 min. or $F^{8.3}_{95}$ = 30 s	if 3.7 ≤ pH ≤ 4.2, and target organisms are butyric anaerobes such as *B. macerans* and *B. polymyxa.*	Tucker (2011) p. 83
	$F^{8.3}_{93.3}$ = 5 min.	if 4.0 < pH ≤ 4.3, and target organisms are butyric anaerobes such as *B. macerans* and *B. polymyxa.*	National Food Processors Association (USA), in Tucker (2011) p. 67; p. 83
	$F^{8.3}_{93.3}$ = 10 min.	if 4.3 < pH < 4.6, and target organisms are butyric anaerobes such as *B. macerans* and *B. polymyxa* (e.g. tomato based products).	
Ambient (= at room temperature) safe and stable high acid and acidified foods:	$F^{8.9}_{93.3}$ = 0.1 min.	if pH < 3.9.	Tucker (2011) p. 80
	$F^{8.9}_{93.3}$ = 1.0 min.	if 3.9 < pH < 4.1 min.	
	$F^{8.9}_{93.3}$ = 2.5 min.	if 4.1 < pH < 4.2 min.	
	$F^{8.9}_{93.3}$ = 5.0 min.	if 4.2 < pH < 4.3 min.	
	$F^{8.9}_{93.3}$ = 10 min.	if 4.3 < pH < 4.4 min.	
	$F^{8.9}_{93.3}$ = 20 min.	if 4.4 < pH < 4.5 min.	
Acidic sauces and acidic soups in cans	F^{10}_{85} = 200 min.	if pH ≈ 4.4; to sufficiently kill D-*streptococcus* and *Micrococcus luteus.*	Unox
Acidic vegetables and fruits	See at "Pasteurization Values" in section **Fruits and Vegetables**		
Yoghurt, Quark, and Cheese:	See at "Pasteurization values" in section **Dairy products**		
Fruits and Vegetables			

PASTEURIZATION **VALUES F FOR COMMERCIAL FOOD PROCESSES**			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Acidified or naturally high acid vegetables, acidified by acetic acid, stored at ambient temperature	$F^{10.83}_{71.11}$ = 1.2 min.	If pH ≤ 4.1, then 5 log reductions in bacterial pathogens (*E. coli* O157:H7, *Salmonella*, and *Listeria*), for acidified products with a pH of 4.1 or below.	Breidt et al (2010)
Apple juice	$F_{71.1}$ = 6 s $F_{73.9}$ = 2.8 s $F_{76.7}$ = 1.3 s $F_{79.4}$ = 0.6 s $F_{82.2}$ = 0.3 s $F_{71.7}$ = 15 s is also considered adequate	pH ≤ 4.0; 5-log reduction for oocysts of parasite *Cryptosporidium parvum*., Because this parasite is believed to be more heat resistant than *E. coli* O157:H7, *Salmonella*, and *Listeria*, these F parameters will also control bacterial pathogens. $F_{71.7}$ = 15 s is also considered adequate to achieve a 5-log reduction of oocysts of *Cryptosporidium parvum* and the three vegetative bacterial pathogens (*E. coli* O157:H7, *Salmonella* and *Listeria monocytogenes*) when this process is used for apple juice (at juice pH values of 4.0 or less).	Penn State University (2010); Derived from FDA/CFSAN (2004) section C.V.5.2; FDA/CFSAN (2004) section C.V.5.2
Apple juice: Single strength apple juice, adjusted to a pH of 3.9.	$F_{71.1}$ = 3 s	Adequate to ensure a 5-log reduction of the three vegetative bacterial pathogens *E. coli* O157:H7, *Salmonella* and *Listeria monocytogenes* at juice pH values pH ≤ 3.9.	Penn State University (2010) quoting FDA Comments/Recommendations; FDA/CFSAN (2004) section V.C.5.2
Apple cider	$F_{68.8}$ = 14 s $F_{71.1}$ = 6 s	5-log reduction of acid adapted *E. coli* O157:H7 in apple cider (pH values of 3.3 and 4.1). These F values are "adequate to ensure a 5-log reduction of the three stated bacterial pathogens, (*E. coli* O157:H7, *Salmonella,* and *Listeria monocytogenes*) (..) if any of these pathogens are the pertinent microorganism in your juice". FDA/CFSAN (2004).	Penn State University (2010); FDA/CFSAN (2004) section V.C.5.2
Apples; canned; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.2 - 0.6 min.	pH = 3.3.	Eisner (1988) in Tucker (2011) p. 68
Apples; canned; stored at ambient temperature	Heating until can centre temperature (CCT) = 85 °C for 5 min.; or to Can Centre Temperature of 95 °C for 30 s	If 3.8 < pH < 4.2.	Tucker (2011) p. 65
Apple puree	F_{78} = 10 seconds	Effective for polyphenol-oxidase inactivation.	Silva & Gibbs (2004) p. 355
Apricots; stored at ambient temperature	$F^{8.9}_{93.3}$ = 1.0 - 8.0 min.	pH = 3.2 - 4.0.	Eisner (1988) in Tucker (2011) p. 68
Apricot puree	F_{78} = 10 s.	Effective for polyphenol-oxidase inactivation.	Silva & Gibbs (2004) p. 355
Beetroot; 1% acidity	F_{82} = 20 min.	Measured in liquor, not centre, for whole baby beetroot. 1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Bilberries; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 min.	pH 3.7.	Eisner (1988) in Tucker (2011) p. 68

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Blackberries; stored at ambient temperature	??	pH = 3.3.	Eisner (1988) in Tucker (2011) p. 68
Brown sauce	F_{65} = 17 min.	pH = 3; aW = 0.95. Heat during process. No preservatives.	Taylor, K.; Crosby, D. (2006) p. 46
Capers pickles, 1-2% acetic acid, no sugar; stored at ambient temperature	F^{7}_{87} > 5 min.	pH < 3.7.	Holdsworth & Simpson (2007) p. 136
Carrot pickles, 1-2 % acetic acid, with sugar; stored at ambient temperature	F^{7}_{87} > 20 - 25 min.	pH = 3.7 - 3.9.	
Carrot homogenate; refrigerated	F_{90} = 6 min.	Target organism: *C. botulinum;* approximately 6D reductions.	Silva & Gibbs (2010) p. 102
Catsup:	see at **Ketchup**		
Cauliflower; pickled; 1% acidity	F_{71} = 15 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Cherries: Sour cherries; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.2 - 0.4 min.	pH = 3.5.	Eisner (1988) in Tucker (2011) p. 68
Cherries: Sweet cherries; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.6 - 2.5 min.	pH 3.8.	
Citrus juice		If you are a citrus juice processor and rely on, as your pathogen control measure, a series of surface sanitization treatments and an extraction process that limits juice/peel contact as provided for under 21 CFR 120.24 (b), these treatments must consistently achieve at least a 5-log reduction in the "pertinent microorganism."	FDA/CFSAN (2004): section V.C.1.0
Cucumber pickles, 1-2% acetic acid, no sugar; stored at ambient temperature	F^{7}_{87} > 5 min.	pH < 3.7.	Holdsworth & Simpson (2007) p. 136
Cucumbers; 1% acidity	F_{74} = 25 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Cupuacu nectar; = 25% of Cupuacu (Theobroma grandiflorum) pulp and 15% sugar	$F^{7.8}_{98}$ = 9 min. in a continuous system (rapid heating in plate heat exchanger; hot fill and hold)	5D reduction of spores of *Alicyclobacillus acidoterrestris* results in 55 % retention of ascorbic acid z and F for fresh, NOT for long-time frozen, Cupuacu.	Vieira et al (2002)
	$F^{7.8}_{115}$ = 8 seconds in a continuous system (plate heat exchanger; HTST)	5D reduction of spores of *Alicyclobacillus acidoterrestris* results in 98.5 % retention of ascorbic acid. z and F for fresh, NOT for long-time frozen stored, Cupuacu.	
Cupuacu (*Theobroma grandiflorum*) puree	F_{90} = 80 sec., (excluding heating time Come Up Time of 220 sec.)	pH = 3.3 (non-heated). pH = 3.4 immediately after pasteurization. pH = 3.5 after pasteurization and 26 weeks of storage at 38 ºC.	Silva & Silva (2000) p. 56
	F_{70} = 5 min.	No peroxidase activity.	Silva & Gibbs (2004) p. 355
Drinks: still drinks, juices, nectars (JNSD)	F_{95} = 15 s	if pH < 4.2.	Tetrapak (2013)
	F_{123} = 15 s	if 4.2 < pH < 4.6.	
	F_{138} = 4 s.	pH > 4.6.	

PASTEURIZATION **VALUES F FOR COMMERCIAL FOOD PROCESSES**			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Fruits: Acid fruits, stored at ambient temperature	F^{10}_{85} = 5 min.	3.7 < pH < 4.2.	Tucker (1999) p. 225
Fruit juices:	see at **Juices**		
Fruit products: High acid (pH < 4.0) fruit products; shelf life at ambient temperature	30 - 90 s at 90 - 95 °C	to inactivate yeasts, moulds, and *Lactobacillus* organisms.	Skudder (1993) p. 76
Fruit products: High acid (pH < 4.0) fruit products	F_{60} = 5 min.	Spores and vegetative cells of most molds are inactivated upon exposure to 60 °C for 5 min. Notable exceptions are the ascospores of certain strains of *Neosartorya fischeri, Byssochlamys nivea, Talaromyces flavus, Eupenicillium javanicum,* and *Byssochlamys fulva* molds.	Silva & Gibbs (2004) p. 356
Fruit products: Acid (high acid) fruit products (pH < 4.6), stored at ambient temperature	Pasteurization should be based on *Alicyclobacillus acidoterrestris* spores, because: 1) The heat resistance of other microorganisms (vegetative/spore forms) is much lower than that found for spores of *Alicyclobacillus acidoterrestris.* 2) Although the common assumption is that microbial spores present in pasteurized acidic fruit products (pH<4.6) do not grow because of the acidity of the product, several cases of *A. acidoterrestris* spore germination and growth in high-acid fruit products have been reported in the literature. The required F value should be based on the following experiments performed with the product to be pasteurized: i. Determination of D-value and z-value of *Alicyclobacillus acidoterrestris* spores; ii. Potential for *A. acidoterrestris* spore germination and growth during product storage for at least 1 month at 25 and 43 °C; iii. Monitor product quality during storage following pasteurization treatments of different severities. In fruit concentrates, the high content of soluble solids (i.e. the low water activity a_w) inhibits the growth of *Alicyclobacillus acidoterrestris* spores; so a F value of less than 6D may be applied. Growth of *Alicyclobacillus acidoterrestris* spores in drinks can also be prevented by carbonation, or by adding 300 mg/L of sorbic acid, 150 mg/L benzoic acid, or both.		Silva & Gibbs (2004) p. 358; Silva & Gibbs (2006) section 2.4.2
Fruit puree	F_{80} = 5 min.	If pH < 3.7.	Taylor, K.; Crosby, D. (2006) p. 7-9
	Heat to 90 °C	If pH < 3.7, for *Byssochlamys*. Most spoilage caused by yeast/mould.	
	F_{65} = 17 min.	If pH < 3.7.	
	Heat to 90 °C	If pH < 3.7, for *Byssochlamys*.	
Gherkins; 1% acidity	F_{74} = 25 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Gherkins: Pickled gherkins, stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 - 1.0 min.	pH 3.5 - 3.8.	Eisner (1988) in Tucker (2011) p. 68
Gherkins: Sweet and sour gherkins, stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 - 1.0 min.	pH 3.6 - 4.1.	
Gooseberries; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 min.	pH = 3.0.	Eisner (1988) in Tucker (2011) p. 68

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Grape juice: Single strength white grape juices adjusted to a pH of 3.9.	$F_{71.1}$ = 3 s	Adequate to ensure a 5-log reduction of the three vegetative bacterial pathogens *E. coli* O157:H7, *Salmonella* and *Listeria monocytogenes* at juice pH values pH ≤ 3.9.	Penn State University (2010) quoting FDA Comments/Recommendations; FDA/CFSAN (2004) section V.C.5.2
Grape puree	F_{78} = 10 seconds	Effective for polyphenol-oxidase inactivation.	Silva & Gibbs (2004) p. 355
Grapefruit juice; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.2 - 0.4 min.	pH = 3.2.	Eisner (1988) in Tucker (2011) p. 68
Grapefruit juice; stored at ambient temperature	Flash pasteurization: F_{74} = 16 s, or F_{85} = 1 sec		Toledo (2007) p. 325
Greengages; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.8 min.	pH = 3.2.	Eisner (1988) in Tucker (2011) p. 68
Guavas; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.8 min.	pH = 3.8.	Eisner (1988) in Tucker (2011) p. 68
Honey	F_{80} = 4 min.	"There were practically no differences between the raw, the liquefied (48 h at 45 ºC), and the pasteurized samples of each honey. .... industrial processes conducted under controlled conditions should not significantly alter the intrinsic aroma of honey".	Escriche, I, et al (2009)
Jalepeno:	see at **Peppers**		
Jams; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.8 min.	pH = 3.5.	Eisner (1988) in Tucker (2011) p. 68
Juices: High acid fruit juices; stored at ambient temperature	F_{80} = 30 s.	if pH < 4.5, and flowing heating in heat exchanger.	Shapton (1994) p. 348-349
	3000 min. ≤ F^{7}_{60} ≤ 5000 min.		EBC (1995) p. 13
Juices: Fruit juices, shelf stable after hot fill-hold pasteurization	First Heating in a heat exchanger to 90 ºC: F_{90} = 2 seconds; next Filling at 85 ºC; then Holding: F_{85} = 1 min.	"The National Food Processors Association states that a typical hot fill/hold process used for shelf stable juices might be to treat the juice at 90 degrees C (194 degrees F) for 2 seconds, followed by filling at 85 degrees C (185 degrees F) and holding for 1 minute at that temperature. Based upon research it conducted for *E. coli* O157:H7, *Salmonella* species (spp.) and *Listeria monocytogenes* in fruit juices, NFPA calculated that this typical process used for shelf stable juices would achieve a 50,000 log reduction for these pathogens without taking into account the cumulative lethality during the cool down period.	National Food Processors Association (NFPA), cited in FDA/CFSAN (2004) Section V 4.2. Mena et al (2013) p. 2127
		The normal processing conditions of hot-filled shelf-stable juices cause often microbial lethality in excess, flavor loss, browning and nutritional degradation.	Mena et al (2013) p. 2127
Juices: Fruit juices, shelf stable after hot fill-hold pasteurization	First Heating (in a heat exchanger) to T > 85 ºC; Next Filling, and can sealing.	Hot fill-cool procedure for fruits with pH < 4.0. Filling temperature higher than 85ºC, followed by can sealing, and (immediately) immersion for 2 min.	National Canners Association cited in Silva & Silva (1997) p. 535

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	Then Holding: F_{88} = 2 min.	in steam or water of 88 °C before cooling.	
Juices: Fruit juices	$F_{71.1}$ = 3 seconds for 5-log reduction of the pathogenic *E. coli* O157:H7, *Salm onella,* and *Listeria monocytogenes* in fruit juices.	"Recommended general thermal process of 3 seconds at 71.1 degrees C (160 degrees F), for achieving a 5-log reduction for *E. coli* O157:H7, *Salmonella,* and *Liste ria monocytogenes* in fruit juices. The efficacy of this process was measured using single strength apple, orange, and white grape juices adjusted to a pH of 3.9. The authors noted that a pH in the range of 3.6 to 4.0 has been reported as a non-significant variable in the heat resistance of *E. coli* O157:H7. The authors also noted that the heat resistance of these vegetative bacterial pathogens might be considerably greater at pH values of 4.0 and higher. This process assumes that the pathogens will have increased thermal resistance due to their being acid-adapted."	National Food Processors Association, cited in Mazzotta (2001), and in FDA/CFSAN (2004) Section V.C.5.2
Juices: Fresh juices, stored at ambient temperature	30 - 15 s at 93 °C - 96 °C.	Inactivation of micro-organisms (shelf life).	Shapton (1994) p. 348-349
Juices: Fruit juices, stored at ambient temperature	F_{88} = 15 s.	Inactivation of enzymes (pectin esterase; polygalacturonase).	Ramaswamy et al (2005) table 3.1
	F_{88} = 15 s.	UK Food Safety Act (1990).	Smith (2011) p. 250
	F_{90} = 1 min.	Inactivation of micro-organisms (shelf life) and inactivation of heat-stable pectin methyl esterase (PME) to prevent cloud loss.	Eagerman and Rouse (1976) in Timmermans et al (2011) p. 235
Juices: Fruit juice	F_{80} = 5 min.	if pH < 3.7.	Taylor, K.; Crosby, D. (2006) p. 7-9
	Heat to 90 °C	if pH < 3.7, for *Byssochlamys*. Most spoilage caused by yeast/mould.	
	F_{65} = 17 min.	if pH < 3.7.	
	Heat to 90 °C	if pH < 3.7, for *Byssochlamys*.	
Juices: Fruit juice		5 log reductions of *E. coli* O157:H7, and *Salmonella*.	NACMCF (2006); Bean (2012) table 2.1
		"The initial number of pathogens present in your untreated juice is likely to be far less than 10^5 organisms per gram, i.e., only 10^1 or 10^2 organisms per gram. Applying a 5-log treatment to juice that may contain such levels of pathogens achieves a tolerable level of risk by ensuring that the process is adequate to destroy microorganisms of public health significance or to prevent their growth." "Thus, if you use pasteurization as your pathogen control measure, that treatment must be carried out to achieve consistently at least a 5-log reduction in the "pertinent microorganism."	FDA/CFSAN (2004): section V.C. 1.0
Juices:	F_{80} = 30 s.	"To ensure the safety of a	FDA/CFSAN (2004):

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Fruit juice concentrates		"thermally processed concentrate" we recommend all of the juice receive a pretreatment consisting of a thermal treatment of at least 80 degrees Centigrade for thirty seconds. Such a process delivers a degree of thermal inactivation of pathogens that is extraordinarily beyond the required 5-log reduction".	section V.C.4.3
Juices: Fruit juices; premium	F_{90} = 2 s; F_{84} = 20 s.	"These processing conditions by far exceed the criterion for microbial inactivation".	Mazzotta (2001); Timmermans et al (2011) p. 235
Juices, Nectars and Still Drinks (JNSD)	F_{95} = 15 s traditionally. New approach: F_{95-98} = 10-30 s.: first pasteurization, to deactivate enzymes and kill micro-organisms. F_{80} = 15 s: second pasteurization (prior to filling)	If pH < 4.2.	Tetrapak (2013)
	F_{80} = 15 s	Juice with pulp if pH < 4.2.	
	F_{123} = 15 s	If 4.2 < pH < 4.6.	
	F_{138} = 4 s.	pH > 4.6.	
Ketchup; (Catsup) 1% acidity	F_{71} = 15 min.; or hot fill at 82 ºC	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Leek pickles, 1-2 % acetic acid, with sugar; stored at ambient temperature	F^{7}_{87} > 20 - 25 min.	pH = 3.7 - 3.9.	Holdsworth & Simpson (2007) p. 136
Lemonades; stored at ambient temperature	300 min. ≤ F^{7}_{60} ≤ 500 min.		EBC (1995) p. 13
Lemon juice; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.1 min.	pH = 2.5.	Eisner (1988) in Tucker (2011) p. 68
Mandarins; stored at ambient temperature	$F^{8.9}_{93.3}$ = 1.0 - 2.0 min.	pH = 3.2 - 3.4.	Eisner (1988) in Tucker (2011) p. 68
Mango extract	$F_{76.7}$ = 1 min.	Sufficient for inactivation of mango pectin-esterase (PE).	Silva & Gibbs (2004) p. 355
Mango puree	Heat puree to 76 to 80 ºC; fill can; seal; keep inverted for 2-3 min. for lid sterilization	"Hot fill - cool" process. 0.57 L cans of DxH = 103.2x119.1 mm. This process ensured adequate commercial sterility.	Nanjudaswamy (1973), cited in Silva & Silva (1997) p 353
	F_{99} = 1 min.	Sufficient for inactivation of mango pectin-esterase (PE).	Silva & Gibbs (2004) p. 355
Nectarines; stored at ambient temperature	$F^{8.9}_{93.3}$ = 1.5 - 8.0 min.	pH = 4.0.	Eisner (1988) in Tucker (2011) p. 68
Nectars	F_{95} = 15 s traditionally. New: F_{80} = 15 s if turbulent flow	If pH < 4.2.	Tetrapak (2013)
	F_{123} = 15 s.	If 4.2 < pH < 4.6.	
	F138 = 4 s.	pH > 4.6.	
Olives, green; stored at ambient temperature	$F^{20}_{62.5}$ > 15 min.	pH = 3.6.	Holdsworth & Simpson (2007) p. 136
Olives; 1% acidity	F_{66} = 10 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Onion pickles, 1-2% acetic acid, no sugar; stored at ambient temperature	F^{7}_{87} > 5 min.	pH < 3.7.	Holdsworth & Simpson (2007) p. 136
Onions; 1% acidity	F_{80} = 10 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Onions: silverskin onions; 1% acidity	F_{71} = 15 min.	1% acidity.	
Orange juice; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.2 - 0.6 min.	If pH = 3.5 - 3.8.	Eisner (1988) in Tucker (2011) p. 68
	Flash pasteurization; hold time = F_{90} = 1 min. or F_{95} = 15 seconds.		Toledo (2007) p. 325
Orange juice: Single strength orange juice, adjusted to a pH of 3.9.	$F_{71.1}$ = 3 s	Adequate to ensure a 5-log reduction of the three vegetative bacterial pathogens *E. coli* O157:H7, *Salmonella* and *Listeria monocytogenes* at juice pH values pH ≤ 3.9.	Penn State University (2010) quoting FDA Comments/Recommendations; FDA/CFSAN (2004) section V 5.2
Orange juice	$F_{71.1}$ = 3 s	5 log reduction of the "pertinent micro-organism"; in orange juice this is *E. coli* 0157:H7. If pH = 3.6 - 4.0. "This specific temperature-time is insufficient to inactivate spoilage organisms".	FDA /CFSAN (2004) section V.C. 1.0; section V.C.1.3; section VII.B.3.0 Timmermans (2011) p. 236
	F_{72} = 20 s	"Mild heat pasteurization of orange juice".	Timmermans (2011) p. 236
Orange juice; 12 Brix	Second pasteurization, prior to filling: F_{95} = 15 s (traditionally). F_{80} = 15 s: New	If pH < 4.2. See also at Juices, Nectars and Still Drinks (JNSD).	Tetrapak (2013)
Papaya pulp	F_{70} = 5 min.	No peroxidase activity.	Silva & Gibbs (2004) p. 355
Papaya puree; papaya nectar	F_{99} = 1 min.	Sufficient for inactivation of papaya pectin-esterase (PE).	Silva & Gibbs (2004) p. 355
Peaches; stored at ambient temperature	$F^{8.9}_{93.3}$ = 1.5 - 8.0 min.	pH = 4.0.	Eisner (1988) in Tucker (2011) p. 68
	Heating until can centre temperature = 85 °C for 5 min.; or to can centre temperature of 95 °C for 30 s.	If 3.8 < pH < 4.2.	Tucker (2011) p. 65
	Flash pasteurization; hold time = F_{110} = 30 seconds	If pH < 4.5.	Toledo (2007) p. 325
Pears	F_{100} = 6 min.	pH = 4.2 to 4.49.	Taylor, K.; Crosby, D. (2006) p. 7-9
Pears; stored at ambient temperature	$F^{8.9}_{93.3}$ = 1.3 - 10 min.	pH = 4.0.	Eisner (1988) in Tucker (2011) p. 68
	Heating until can centre temperature (CCT) ≥ 96 °C.	pH must be pH < 4.2. Green fruit is significantly	Tucker (2011) p. 68

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		harder and takes longer to process.	
	Heating until can centre temperature (CCT) = 85 °C for 5 min.; or to CCT of 95 °C for 30 s	If 3.8 < pH < 4.2.	Tucker (2011) p. 65
	Heating until can centre temperature (CCT) = 100 °C to 104 °C	If 4.2 < pH < 4.5. If product texture is unable to withstand this high process, the product must be acidified and a lower process applied.	Tucker (2011) p. 66
Pear puree	F_{78} = 10 seconds	Effective for polyphenol-oxidase inactivation.	Silva & Gibbs (2004) p. 355
Peppers: Whole pepper pickles, fresh-packed; stored at ambient temperature. Sweet cherry peppers; stored at ambient temperature. Hot cherry peppers; stored at ambient temperature. Jalepeno; stored at ambient temperature.	Blanching in hot water of 70 - 80 °C for 3-6 min.; Jars pasteurized until can centre temperature CCT = 70-80 °C.	Blanched product is "packed into jars, which are then filled with hot brine, containing approximately 5% acetic acid and 9% salt. The jars are then capped and pasteurized to achieve 70–80°C at the coldest spot in the container. The jars are cooled with cold water. Preservatives, like sodium benzoate, may be added to extend the shelf-life of the product once the jar has been opened. Calcium chloride (0.2%) may be added to the brine to help the peppers retain their texture (calcium in the brine replaces calcium lost in the cell wall, which helps it retain its structure)".	Tucker (2011) p. 80
Piccalilli; 1% acidity	F_{71} = 15 min.; or hot fill at 82 ºC	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Piccalilli pickle	F_{65} = 17 min.	pH = 3; aW = 0.97. Heat during process. Preservative: mustard.	Taylor, K.; Crosby, D. (2006) p. 46
Pickled vegetables; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 min.	pH = 3.0.	Eisner (1988) in Tucker (2011) p. 68
Pickles, Leek, Carrot, 1-2 % acetic acid, with sugar; stored at ambient temperature	F^{7}_{87} > 20 - 25 min.	pH = 3.7 - 3.9.	Holdsworth & Simpson (2007) p. 136
Pickles: Onion, Cucumber, Capers, 1-2% acetic acid, no sugar; stored at ambient temperature	F^{7}_{87} > 5 min.	pH < 3.7.	
Pickles	F_{80} = 5 min.	if pH < 3.7.	Taylor, K.; Crosby, D. (2006) p. 7 - 9
	Heat to 90 ºC	if pH < 3.7, for *Byssochlamys*. Most spoilage caused by yeast/mould.	
	F_{65} = 17 min.	if pH < 3.7.	
	Heat to 90 ºC	if pH < 3.7, for *Byssochlamys*.	
Pickles; 1% acidity	F_{71} = 15 min.; or hot fill at 82 ºC	1% acidity.	
Pickles: Clear pickled vegetables; 1% acidity	F_{71} = 15 min.	1% acidity.	
Pickles: Fresh-pack dill pickles; stored at ambient temperature	F_{74} = 15 min.	Shelf stable; microbial stability and quality factors, including the inactivation of softening enzymes.	Monroe et al (1969)
Pickles: Quick fresh-pack	After water in	Fill canner halfway with water and	Iowa State

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
dill pickles. Raw pack; jar size: Pint	canner reboils again at 100 °C: 10 min.	preheat to 83 °C for hot pack or 60 °C for raw pack. Load jars into canner. Be sure water can circulate freely around each jar. Add boiling water to a level of 2,5 - 5 cm above the jars. Bring water in canner to a vigorous boil, adjust heat to maintain a gentle boil, cover, and process for the time specified in column at left. Leave the lid on the canner. Keep water boiling (100°C) during the entire processing period. If water evaporates, add boiling water to keep it at least one inch over the top of jars. Do not reduce the processing time. When processed for the recommended time, turn off the heat and remove the canner lid. Wait five minutes before removing the jars.	University (2014)
Pickles: Quick fresh-pack dill pickles. Raw pack; jar size: Quart	After water in canner reboils again at 100 °C: 15 min.		
Pickles: Bread and butter pickles. Hot pack; jar size: Pint or Quart	After water in canner reboils again at 100 °C: 10 min.		
Pickles: Pickle relish. Hot pack; jar size: Half pint or Pint	After water in canner reboils again at 100 °C: 10 min.		
Pickles: Dill pickles. Raw pack; jar size: Pint	After water in canner reboils again at 100 °C: 10 min.		
Pickles: Dill pickles. Raw pack; jar size:Quart	After water in canner reboils again at 100 °C: 15 min.		
Pickled Gherkins:	see at **Gherkins**		
Pineapples	F_{100} = 6 min.	pH = 4.2 to 4.49.	Taylor, K.; Crosby, D. (2006) p. 7-9
Pineapples; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.6 - 0.8 min.	if pH = 3.5.	Eisner (1988) in Tucker (2011) p. 68
	$F^{8.9}_{93.3}$ = 5 min.	if 4.0 < pH < 4.3.	Toledo (2007) p. 325
	$F^{8.33}_{98.9}$ = 1.06 min.	pH = 4.0.	
	$F^{8.9}_{93.3}$ = 10 min.	pH > 4.3.	
	$F^{8.9}_{93.3}$ = 0.2 min.	pH = 2.8.	Eisner (1988) in Tucker (2011) p. 68
Pomegranate juice	F_{65} = 30 s; LTP F_{90} = 5 s; HTP	If refrigerated storage (5 °C), no microbial spoilage within 120 days. If stored at 25 °C, browning was unacceptable in 7 days.	Vegara et al (2013)
Pomegranate juice (cloudy and clarified or centrifuged)	F_{65} = 30 s (LTP low temperature pasteurization) F_{90} = 5 s (HTP high temperature pasteurization)	"**Both heat treatments combined with refrigeration (5 °C) prevented microbial growth for 120 days.** Although processing and storage of pomegranate juice had a decisive impact on the degradation of anthocyanin compounds and the consequent formation of brown pigments, **storage temperature was the main factor affecting both browning index (BI) and red color loss in pasteurized pomegranate juices.** Samples stored at 5 °C had a lower and slower loss of red color than those stored at 25 °C. Results showed that browning indexes BIs increased rapidly with time **in juices stored at 25 °C, being not acceptable (>1.00) after 7 days.** The juices stored at 5 °C showed less browning regardless of pasteurization treatment they were subjected. **In particular LTP-treated cloudy and clarified**	

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
		juices stored at 5 °C for 90 days exhibited BI values of 0.93 and 0.85, respectively.”	
Pomegranate juice	F_{80} = 30 s; F_{80} = 60 s; F_{90} = 30s; F_{90} = 60 s.	The F_{80} values were sufficiently effective to decrease the mean Aerobic Plate Counts (APC) for a significant inactivation (approx 4.5 log reductions); The F_{90} values resulted in a nil mean Aerobic Plate Counts (APC).	Mena, P. et al (2013) p. 2122; p. 2124
Rhubarb; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.2 - 0.4 min.	pH = 3.2.	Eisner (1988) in Tucker (2011) p. 68
Salad cream	F_{65} = 17 min. Heat liquor phase only	pH = 3.4; aW = 0.94. Preservatives: Mustard/sorbate. Storage instructions: refrigerate after opening.	Taylor, K.; Crosby, D. (2006) p. 46
Salad cream, Light	F_{65} = 17 min. Heat liquor phase only	pH = 3.4; aW = 0.96. Preservatives: Mustard.	
Sandwich spread	F_{80} = 5 min.	if pH < 3.7.	Taylor, K.; Crosby, D. (2006) p. 7-9
	Heat to 90 °C	if pH < 3.7, for *Byssochlamys*. Most spoilage caused by yeast/mould.	
Sandwich spread	F_{65} = 17 min.	if pH < 3.7.	
	Heat to 90 °C	if pH < 3.7, for *Byssochlamys*.	
Sandwich spread, mild	F_{85} = 5 min.	pH = 3.7; aW = 0.94. In bottle pasteurization. No preservatives. Storage instructions: Refrigerate after opening.	Taylor, K.; Crosby, D. (2006) p. 46
Sauerkraut; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 min.	pH = 3.5 - 3.9.	Eisner (1988) in Tucker (2011) p. 68
Silverskin onions; 1% acidity	F_{71} = 15 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
Soft drinks	F_{95} = 10 s	UK Food Safety Act (1990).	Smith (2011) p. 250
Soups and Sauces:	see at Pasteurization Values, section **Other Food Products**		
Still drinks	F_{95} = 15 s (traditionally). New: F_{80} = 15 s	If pH < 4.2.	Tetrapak (2013)
	F_{123} = 15 s	If 4.2 < pH < 4.6.	
	F_{138} = 4 s.	pH > 4.6.	
Strawberries; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.8 min.	pH = 2.3 - 4.0.	Eisner (1988) in Tucker (2011) p. 68
Tomatoes	F_{100} = 6 min.	pH = 4.2 to 4.49.	Taylor, K.; Crosby, D. (2006) p. 7-9
Tomato products; stored at ambient temperature	$F^{8.9}_{93.3}$ = 2.0 - 10.0 min.	pH = 4.2 - 4.5.	Eisner (1988) in Tucker (2011) p. 68
	$F^{8.8}_{93}$ > 20 min.	If pH = 3.9 - 4.6	Holdsworth & Simpson (2007) p. 136
	Heating until can center temperature (CCT) = 100 °C to 104 °C	if 4.2 < pH < 4.5. If product texture is unable to withstand this high process, the product must be acidified and a lower process applied.	Tucker (2011) p. 66
	$F^{8.9}_{93.3}$ = 5 min.	If pH = 4.0 - 4.3.	Tucker (1999) p. 225
	$F^{8.9}_{93.3}$ = 10 min.	If 4.3 < pH < 4.5.	
	$F^{8.9}_{93.3}$ = 1 min.	If pH = 4.1.	Toledo (2007) p.

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
	$F^{8.9}_{93.3}$ = 3 min.	If pH = 4.2.	324+325
	$F^{8.9}_{93.3}$ = 5 min.	If pH = 4.3.	
Tomato products	$F_{93.3}$ = 5 min.	If pH = 4 to 4.3. At pH range 3.80 to 4.50 the heat resistant thermophile *Bacillus coagulans* var. *thermoacidurans* may grow; use cooling to prevent outgrowth.	Taylor, K.; Crosby, D. (2006) p. 7-9
	$F_{93.3}$ = 10 min.	If pH = 4.3 to < 4.50. Based on tomato products.	
Tomato based products	$F_{93.3}$ = 10 min.	If 4.3 < pH < 4.6.	Tucker (2011) p. 83
Tomato based products (i.e. ketchup)	F_{85} = 5 min.	If pH = 3.7 to 4.2. At product pH of pH > 3.80 butyric anaerobes may grow.	Taylor, K.; Crosby, D. (2006) p. 7-9
Tomato products with starch or sugar added; stored at ambient temperature	$F^{8.9}_{121.1}$ = 0.5 min.	if pH = 4.3.	Toledo (2007) p. 325
Tomato juice; stored at ambient temperature	45 - 30 s at 124 °C - 126.7 °C.	Destruction of *Bacillus coagulans*, a thermophilic spoilage spore forming micro-organism, in tomato juice with pH close to 4.6.	Shapton (1994) p. 348-349
Tomato juice	F_{118} = 60 s.	UK Food Safety Act (1990).	Smith (2011) p. 250
Tomato ketchup	F_{85} = 5 min.	If pH = 3.7 to 4.2. At product pH's of pH > 3.80 butyric anaerobes may grow	Taylor, K.; Crosby, D. (2006) p. 7-9
	F_{85} = 5 min. (pre filling). Heat and clean fill.	pH = 3.7; aW = 0.94. No preservatives. Storage instructions: refrigerate after opening.	Taylor, K.; Crosby, D. (2006) p. 46
	F_{85} = 5 min. In bottle pasteurization.	pH = 3.7; aW = 0.94. No preservatives. Storage instructions: refrigerate after opening.	
Tomato paste	First heating; next hot fill at either 94 ºC, or 92 ºC, or 90 ºC. Then pasteurization of filled glass jars of F_{90} = 24.5 min.	Hot fill-hold-cool process of tomato paste in glass jars; target organism *Bacillus coagulans*; initial bacterial population 10^5 per jar.	Sandoval (1994), cited in Silva & Silva (1997) p. 353
		Fill temperature 94 ºC if jar of 0.2 L.	
		Fill temperature 92 ºC if jar of 0.5 L.	
		Fill temperature 90 ºC if jar of 4 L.	
Tomato paste; stored at ambient temperature	$F^{8.9}_{93.3}$ = 1.0 - 5.0 min.	pH = 4.2 - 4.5.	Eisner (1988) in Tucker (2011) p. 68
Tomato soup	$F^{10}_{121.1}$ = 0.5 min.	if pH < 4.5.	Taylor, K.; Crosby, D. (2006) p. 7-9
Vegetables: Acidified or naturally high acid vegetables, acidified by acetic acid, stored at ambient temperature	$F^{10.83}_{71.11}$ = 1.2 min.	If pH ≤ 4.1, then 5 log reductions in bacterial pathogens (*E. coli* O157:H7, *Salmonella*, and *Listeria*), for acidified products with a pH of 4.1 or below.	Breidt et al (2010)
Vegetables: Pickled vegetables, stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.5 min.	pH = 3.0.	Eisner (1988) in Tucker (2011) p. 68
Vegetables:	see also at **pickles**		
Walnuts; pickled; 1% acidity	F_{71} = 15 min.	1% acidity.	Taylor, K.; Crosby, D. (2006) p. 7-9
a_W reduced foods			

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
Almonds, roasted in oil (low moisture food)	A minimum P-value of 4D of *Salmonella* spp. was recommended for almond producers in California. A process exposing almonds to oil at 126.7 °C for 1.6 min. is sufficient, although commercially 2.0 min. is applied (this treatment achieves 5D in Salmonella numbers).	D value of *Salmonella*, so its heat resistance, increases tremendously at low water activity.	Silva & Gibbs (2012) p. 698
Honey	F_{57} = 1 hour; F_{60} = 22 min. F_{63} = 7.5 min. F_{60-63} = 30 min. F_{70} = 10 min. F_{80} = 2-4 min.	Aim is to prevent yeast growth.	Verma, L.R.; Joshi, V.K. (2000) p. 968
	F_{71} = 300 s	UK Food Safety Act (1990).	Smith (2011) p. 250
Safe refrigerated foods with a_W < 0.96	F_{70} = 2 min.	*C. botulinum* can NOT grow at a_W < 0.96.	Hygiënecode (1994) p. 5
Safe and shelf stable food with a_W < 0.92; stored at ambient temperature	High pasteurization.	Food of a_W < 0.92 and of any pH. Due to high pasteurization, no vegetative micro-organisms are present. Due to a_W < 0.92, no spores can germinate.	FDA Food Code (2005) Chapter 1, p. 14-16
Safe and shelf stable food with a_W < 0.95 ànd pH < 5.6; stored at ambient temperature	High pasteurization.	Food of a_W < 0.95 and of pH < 5.6. Due to high pasteurization, no vegetative micro-organisms are present. Due to a_W < 0.95 ànd pH < 5.6, no spores can germinate.	
Safe packed, not heat treated foods, foods, stored at ambient temperatures, but spoilage is possible	No heat treatment necessary.	Safe food if a_W < 0.88 (spoilage is possible!). Safe food is pH < 4.2 (spoilage is possible!). Safe food if pH < 5.0 and a_W ≤ 0.90 (spoilage is possible!). Safe food if pH < 4.6 and a_W ≤ 0.92 (spoilage is possible!). Simultaneous action of pH and a_W blocks the germination of pathogenic spores, and blocks the growth of pathogenic vegetative micro-organisms.	
Other food products			
Food cooked in a microwave oven	T = 74 ºC	and hold for 2 minutes after removing from microwave oven.	FDA (2013) Summary Chart 4A
Pasta: stuffed	F_{74} = 15 s		FDA (2013) Summary Chart 4A
Pies and pastries	F_{70} ≥ 2 min.	Storage time ≤ 10 days if chilled at storage temp. 4 - 7 °C.	DOH (1989); in Tucker (2011) p. 87; p. 90
Rarities: stuffed	F_{74} = 15 s		FDA (2013)

PASTEURIZATION VALUES F FOR COMMERCIAL FOOD PROCESSES			
Product	Approximate **pasteurization** value F or P	Additional information; Remarks	Source
			Summary Chart 4A
Ready meals	F_{70} ≥ 2 min.	Storage time ≤ 10 days if chilled at storage temp. 4 - 7 °C.	DOH (1989); in Tucker (2011) p. 87; p. 90
Soups and sauces	F_{70} ≥ 2 min.	Storage time ≤ 10 days if chilled at storage temp. 4 - 7 °C.	DOH (1989); in Tucker (2011) p. 87; p. 90
	F_{90} = 10 min. with z = 7 ºC if converted to T < 90 ºC, and z = 10 ºC if converted to T > 90 ºC	To eliminate *C. botulinum* type E and non-proteolytic types B and F.	FDA (2011) p. 318
Stuffing, containing fish, meat, poultry or rarities	F_{74} = 15 s		FDA (2013) Summary Chart 4A

General principles on pasteurization values

for groups of foods

Product	Additional information; Remarks	Pasteurization value F or P	Source
	Refrigerated foods; (storage temperature 4 °C - 7 °C)		
Refrigerated foods	Safe food, and shelf life 3 - 6 weeks if refrigerated at 4-7 °C.	F^{10}_{70} = 1000 min.; or F^{10}_{90} = 10 min. If pasteurizing temperature T < 90 °C: F^{7}_{90} = 10 min.	Hygiënecode (1994)
Low-acid cooked and chilled foods	Recommended target organism of low acid foods: non-proteolytic *C. botulinum*, because its lethality to humans and its higher heat resistance compared to other psychrotropic pathogens. *C. botulinum* is anaerobic, so it can grow in vacuum-packed and semi-preserved foods such as cured and cooked ham, cold-smoked fish, fermented marine foods, and dried fish. Check if other psychrotropic spore-forming pathogens and spoilage microorganisms, present in the food, have a higher heat resistance than the non-proteolytic *C. botulinum*. If F_{90} = 10 min. is not sufficient to achieve 6*D* inactivation of *C. botulinum*, add preservatives for food safety. Surviving *Clostridium* and *Bacillus* spores must be controlled with refrigeration (*T* < 8°C) and other hurdles such as salts (>3.5% salt-on-water, e.g., sodium chloride, sodium lactate) and nitrites (>100 ppm, e.g., sodium nitrite); or a_w < 0.97. A salt content ≥3.5% in the food stops botulinum growth during chill storage. The addition of salt to levels of 2.5% and 4.3% increase the number of days required for growth of non-proteolytic *C. botulinum* strains in an anaerobic meat medium stored at temperatures from 5°C to 16°C.	F_{90} = 10 min. for shelf life ≤ 10 days.	Silva & Gibbs (2008) section 2.4.1; Silva & Gibbs (2010) p. 100
Low-acid cooked and chilled foods	In addition to chill temperatures which should be maintained throughout the food chain, the following controlling factors should be used **singly or in combination** to prevent growth and toxin production by non-proteolytic *C. botulinum* in chilled foods with a shelf-life of more than 10 days: • a heat treatment of 90°C for 10 minutes or equivalent lethality; • a pH of 5 or less throughout the food and throughout all components of complex foods; • a minimum salt level of 3.5% in the aqueous phase throughout the food and throughout all components of complex foods; • a water activity of 0.97 or less throughout the food and throughout all components of complex foods; • a combination of heat and preservative factors which can be shown consistently to prevent growth and toxin production by non-proteolytic *C. botulinum*.	F_{90} = 10 min. if target organism is non-proteolitic strains of *C. botulinum.*	FSA (2008) item 13 and item 16; Silva & Gibbs (2010) p. 102

General principles on pasteurization values

for groups of foods

Product	Additional information; Remarks	Pasteurization value F or P	Source
Refrigerated foods; Heat preserved chilled foods	Food products sold chilled, with shelf life up to 10 days. Target organisms are vegetative, non-spore forming aerobic pathogens such as *Listeria monocytogenes*, *Salmonella* spp, *E. coli*.	$F_{70} \geq 2$ min.	Tucker (2011) p. 87-88; p. 90-91; Campden (1992); DOH (1989)
Refrigerated foods	If packed under aerobic conditions, and if refrigerated at storage temp. T ≤ 5 °C: shelf life 6 - 10 days. If **an**aerobic conditions may occur in the product, and if stored at T ≤ 5 °C: shelf life less than 10 days. If **an**aerobic conditions may occur in the product, if stored at T ≤ 5 °C, and shelf life should be greater than than 10 days.	$F_{70} = 2$ min. $F_{70} = 100$ min. $F_{90} = 10$ min.	Tucker (1999) p. 8-10) Campden (1992)
Safe refrigerated foods; if *Listeria monocytogenes* is organism of concern	Destruction of pathogenic vegetative micro-organisms such as *Listeria monocytogenes*.	$F^{7.5}_{70} \geq 2$ min.	Hygiënecode (1994); Tucker (2011) p. 100
	6 decimal destructions of pathogenic vegetative micro-organisms such as *Listeria monocytogenes*. Shelf life 10-14 days at 4 - 7 °C. 8 decimal destructions of pathogenic vegetative micro-organisms such as *Listeria monocytogenes*. Shelf life 10-14 days at 4 - 7 °C.	$F^{7.5}_{70} \geq 2$ min. $F^{7.5}_{72} \geq 2$ min.	Brown (2000) p. 312-316
	6 decimal destructions of pathogenic vegetative micro-organisms such as *Listeria monocytogenes*. Shelf life 6-10 days at storage temperature ≤ 5 °C.	$F_{70} \geq 2$ min.	Tucker (1999) p. 8-10 Campden (1992)
	L. monocytogenes is now considered to be the most heat-resistant vegetative pathogenic bacterium in high water activity foods excluding milk and, as such, is regarded as the target organism in setting performance objectives in thermal processing. The current consensus is that the *D*-value of *L. monocytogenes* at 72°C does not exceed 15 s in foods. This means that the pasteurization of cooked chilled foods, for a minimum of 2 min at 72°C would result in at least an 8-log reduction of the organism. To address variability in microbial populations as well as in the application of thermal processes, some processors apply time and temperature combinations that are above the minimum requirements.	$F^{10}_{72} \geq 2$ min.	Bean et al (2012) p. 8
Cook-chill refrigerated foods	if pH > 4.5.	$F^{10}_{70} \geq 2$ min.	Tucker (1999) p. 225
Safe refrigerated foods; if *Clostridium botulinum* is organism of concern	Destruction of the heat resistant, psychrotropic, non-proteolytic spores of *Clostridium botulinum* types B, E and F. To prevent growth of such *C. botulinum:* Advised storage temperature T = 0 °C -	$F_{90} = 10$ min. * If conversion to pasteurizing temperatures T ≥ 90 °C: z = 10 °C; so $F^{10}_{90} = 10$ min. = F^{10}_{95} =	Hygiënecode (1994)

General principles on pasteurization values for groups of foods			
Product	Additional information; Remarks	Pasteurization value F or P	Source
	5 °C. Even better: storage temperature T < 3.3 °C (catering)	3.2 min. = F^{10}_{100} = 1 min. * If conversion to pasteurizing temperatures T < 90 °C: z = 7 °C; so F^{7}_{90} = 10 min. = F^{7}_{85} =52 min.	
Safe refrigerated foods; if non-proteolytic *Clostridium botulinum* is organism of concern	6-log reduction of non-proteolytic *C. botulinum;* combined with storage at chill temperature	F_{90} = 10 min. (or equivalent lethality e.g. F_{80} = 129 min. or F_{85} = 36 min.).	Peck (2006); ICMSF (2002); Bean (2012) table 2.1
	6 decimal destructions of the heat resistant, psychrotropic, non-proteolytic spores of *Clostridium botulinum* types B, E and F.	F_{90} = 10 min.	Brown (2000) p. 312-316); FSA (2008); Tucker (1999) p. 8-10; Tucker 2011) p. 88; 93; Campden (1992)
Safe refrigerated foods	6 decimal destructions of the psychrotropic spores of *Clostridium botulinum*. Chilled shelf life: 30 days.	F^{9}_{90} = 10 min. so z = 9 °C.	FSA (2008) in Tucker (2011) p. 99; Tucker (1999) p. 225)
Refrigerated foods; assembled after primary pasteurization	Safe food, and shelf life 3 weeks if refrigerated at 4-7 °C. Target organism: sufficient destruction of the heat resistant, psychrotropic, non-proteolytic spores of *Clostridium botulinum* types B, E and F.	Initial pasteurization of all individual components: F^{10}_{90} = 10 min. If assembled at good hygienic conditions, recontamination can be destructed by secondary pasteurization of F^{10}_{70} = 2 min.	Profood (HAS)
Refrigerated foods	Destruction of most thermo resistant vegetative spoilage organisms such as fecal *Streptococcus.* Shelf life 43 days at 4-7 °C; consisting of 3 weeks internal shelf life at cold storage (< 3 °C), and 3 weeks external shelf life at refrigerator 4-7 °C.	F^{10}_{70} = 1000 min. or F^{10}_{90} = 10 min.	HAS
Sous vide processes	Safe food; shelf life over 10 days if chilled; 6 log reductions of target organism *C. botulinum*.	F_{90} = 10 min. Originally F^{10}_{70} = 40 min. when storage temp. < 3.3 °C.	Campden (1992); Tucker (2011) p. 88, p. 91; Tucker (1999) p. 225; FSA (2008)
Pasteurized high acid foods, stored at ambient temperatures			
Acidified or naturally high acid fruit juices	Apple juice, orange juice, pear juice, juice blends, canned diced tomatoes, and ice tea, of pH ≤ 4.5, if cooled slowly after pasteurization, or to be stored at	Pasteurization temperature of 95 ºC required to sufficiently destruct *Alicyclobacillus acidoterrestris* spores.	Silva & Gibbs (2008) section

General principles on pasteurization values

for groups of foods

Product	Additional information; Remarks	Pasteurization value F or P	Source
	relatively high ambient temperatures, and if thermo-acidophilic (pH 3.5–4.5; temperature 35–53 ºC), non-pathogen, spoilage spore-forming *Alicyclobacillus acidoterrestris* is present.		2.4.2; Silva et al (2014) p. 583-584.
Acidified or naturally high acid products	If pH < 4.0 then	$F_{87.8}$ = 1 min.	Toledo (2007) p. 324
	If pH = 4.0, then	$F_{96.1}$ = 30 seconds.	
	If pH = 4.1, then	F_{100} = 30 seconds.	
	If pH = 4.2, then	$F_{102.2}$ = 30 seconds.	
	If pH > 4.2, to pH = 4.5 then	$F_{118.3}$ = 30 seconds.	
	If sugar or starch is added to the product, the time/temperature for the next higher pH should be used.	For Example: if sugar or starch is a component of a product with pH = 4.1, use a process of $F_{102.2}$ = 30 seconds (process for pH = 4.2 if no sugar or starch is added).	
Acid products that may contain butyric anaerobes	If product has 4.0 < pH < 4.3	Process equivalent to $F^{8.3}_{93.3}$ > 5 min. "More severe processes may be required to control excessive contamination".	National Food Processors Association in Tucker (2012) p. 342, and in Rees & Bettison (1991) p. 33
	If product has 4.3 < pH < 4.6	Process equivalent to $F^{8.3}_{93.3}$ = 10 min. "More severe processes may be required to control excessive contamination".	
Acidified or naturally high acid products	If pH ≤ 4.1, then 5 log reductions in bacterial pathogens (*E. coli* O157:H7, *Salmonella*, and *Listeria*), for acidified products with a pH of 4.1 or below:	$F^{10.83}_{71.11}$ = 1.2 min. thus: $F^{10.83}_{60}$ = 12.7 min. $F^{10.83}_{65}$ = 4.4 min. $F^{10.83}_{70}$ = 1.5 min. $F^{10.83}_{71.11}$ = 1.2 min. $F^{10.83}_{75}$ = 0.5 min. $F^{10.83}_{80}$ = 0.2 min. $F^{10.83}_{82.78}$ = 0.1 min.	Breidt et al (2010) table 3
Acidified or naturally high acid products	If pH < 3.9	$F^{8.9}_{93.3}$ = 0.1 min.	Tucker (2011) p. 80
	If 3.9 < pH < 4.1	$F^{8.9}_{93.3}$ = 1.0 min.	
	If 4.1 < pH < 4.2	$F^{8.9}_{93.3}$ = 2.5 min.	
	If 4.2 < pH < 4.3	$F^{8.9}_{93.3}$ = 5.0 min.	
	If 4.3 < pH < 4.4	$F^{8.9}_{93.3}$ = 10.0 min.	
	If 4.4 < pH < 4.5	$F^{8.9}_{93.3}$ = 20.0 min.	
Acid foods, with normal contamination loading	If pH < 3.7	F_{65} ≥ 16.7 min. or F_{70} ≥ 2.1 min. both at slowest heating spot of container.	Tucker (2011) p. 83
	If 3.7 < pH < 4.2	F_{85} ≥ 5 min. or F_{95} ≥ 30 s. both at slowest heating spot of container.	
	If 4.0 < pH < 4.3	$F_{93.3}$ ≥ 5 min.	
	If 4.3 < pH < 4.6	$F_{93.3}$ ≥ 10 min.	
Acidified foods	If finished equilibrium pH = 3.1 - 3.2	$F^{5.6}_{90.6}$ = 0.1 min.	FDA (2010), table 8, p. 25 in pdf version. (The several
	If finished equilibrium pH = 3.3 - 3.5	$F^{5.6}_{90.6}$ = 1.0 min.	
	If finished equilibrium pH = 3.5 - 4.0	$F^{5.6}_{90.6}$ = 16 - 23 min.	
	If finished equilibrium pH = 4.0 - 4.2	$F^{8.3}_{93.3}$ = 5.0 min	
	If finished equilibrium pH = 4.3 - 4.4	$F^{8.3}_{93.3}$ = 23 min.	

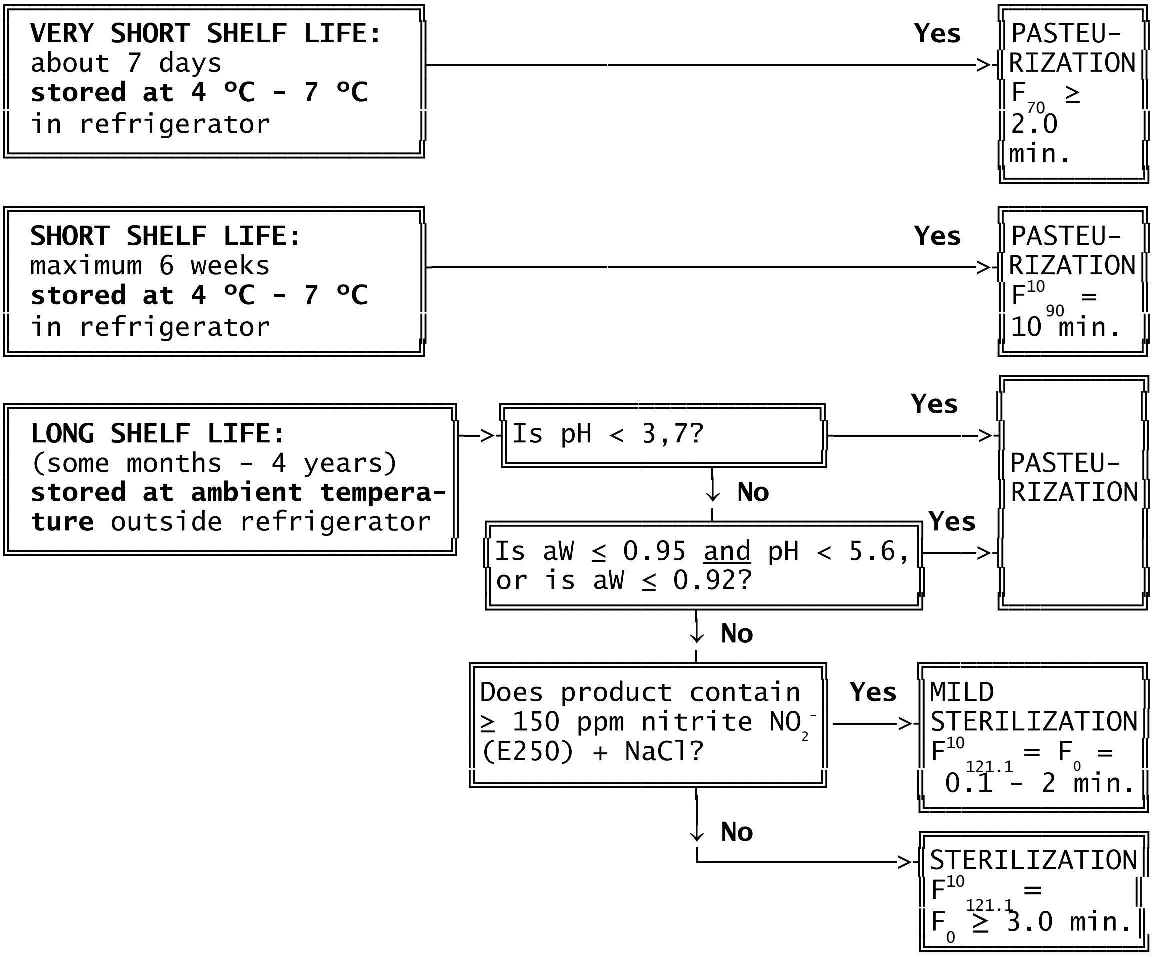
General principles on pasteurization values

for groups of foods

Product	Additional information; Remarks	Pasteurization value F or P	Source
	If finished equilibrium pH = 4.3 - 4.4	$F^{8.3}_{93.3}$ = 10 min.	different sources have been reported in FDA report)
	If finished equilibrium pH = 4.3 - 4.4	$F^{8.3}_{100}$ = 10 min.	
	If finished equilibrium pH = 4.5 - 4.6	$F^{8.3}_{100}$ = 10 min.	
	If finished equilibrium pH = 4.5 - 4.6	F^{10}_{110} = 1.6 min.	
Acid foods, or Acidified foods	If finished product pH < 3.7	F_{65} = 17 min.	Taylor, K.; Crosby, D. (2006) p. 7-9
	If finished product pH = 3.7 - 4.0	F_{85} = 5 min.	
	If finished product pH = 4.01 - 4.20	F_{95} = 5 min.	
	If finished product pH = 4.21 - 4.40	F_{95} = 10 min.	
	If finished product pH = 4.41	$F^{10}_{121.1}$ = 0.5 min.	
	High acid foods which do NOT require heat processing		
High acid foods **(pH < 3.3)**, acidified by addition of acetic acid	"Products with acetic acid as the primary acidulent and a pH below 3.3 do not require a heat process, but do require a temperature dependent holding time to assure safety (Breidt et al (2007)). *E. coli* O157:H7 has been found to be the most acid resistant pathogen of concern for these products (Breidt et al (2007)). To achieve a five log reduction at 25 ºC, a holding time of 48 hours is needed. However, at 10 ºC, a holding time of six days is required for a five log reduction. Interestingly, *L. monocytogenes,* a psychrotro-phic organism, which can grow at refrigeration temperatures at neutral pH, does not survive as well as *E. coli* O157:H7 under similar cold and acidic conditions" (Breidt et al (2007)).		Breidt et al (2010); Breidt et al (2007).
	A holding time of 48 hrs at pH < 3.3 (caused by acetic acid), and at 25 ºC, causes 5D reduction of *E. coli* O157:H7. The same storage conditions cause > 5 log reductions of *L. monocytogenes.*		
	A holding time of 6 days at pH < 3.3 (caused by acetic acid), and at 10 ºC, causes 5D reduction of *E. coli* O157:H7. The same storage conditions cause > 5 log reductions of *L. monocytogenes.*		

3. DECISION SCHEME: PASTEURIZATION OR STERILIZATION?

DECISION SCHEME: PASTEURIZATION OR STERILIZATION?
(based on destruction of micro-organisms)



PASTEURIZATION aims to sufficiently destruct **<u>vegetative micro-organisms</u>**.
Usually, bacterial spores survive pasteurization.
If such spores can NOT germinate to vegetative micro-organisms, sterilization is not required!

* Germination of spores to vegetative micro-organisms can be considerably **slowed down** by refrigerated storage, after rapidly cooling of the product immediately after pasteurization. (Rapid cooling prevents (thermophilic) spoilage spores to germinate during the cooling stage.)
* Germination of spores can be completely **blocked** by either:
  - reduction of water activity a_W to $a_W < 0.92$;
  - reduction of water activity $a_W < 0.95$ and at the same time pH reduction to pH < 5.6;
  - reduction of pH to pH < 3.7 [1]);
  - addition of ≥ 150 p.p.m. nitrite NO_2^-, mixed with salt NaCl.

STERILIZATION is a heating process aimed at destruction of bacterial **spores**.
Vegetative micro-organisms, present in the food, are considerably less heat resistant than bacterial spores. Thus, due to the intense heat dose of sterilization, all vegetative micro-organisms will be killed completely during sterilization.
Immediately after sterilization, sterilized products marketed in moderate climate countries such as N.W.-Europe, must be cooled down rapidly to a core temperature below 35 ºC. Such rapid cooling prevents germination of thermophilic spoilage spores to spoilage vegetatives, which still could spoil the sterilized foods during ambient storage.

[1]) ***Exception***: In pasteurized acid fruit products (pH ≤ 4.5), *Alicyclobacillus acidoterrestris*, a thermo-acidophilic (pH 3.5–4.5; temperature 35–53 ºC), non-pathogen, spore-forming bacterium sometimes produces spoilage aromas and tastes (bromophenol; guaiacol) in shelf-stable juices (apple, orange, pear), juice blends, canned diced tomatoes, and ice tea, if these were cooled slow, or stored at relatively high temperatures (Silva et al (2014), p. 583-584; Silva & Gibbs (2008), section 2.4.2). Sufficient destruction of *A. acidoterrestris* in acid fruit products requires pasteurization temperatures of 95 ºC, so an exceptionally heavy pasteurization.

4. Use of F to calculate the sterilization time Pt of a packaged food

Example 4.1: Use of F value to calculate the sterilization time Pt
Calculate the sterilization time Pt of milk in a glass bottle in a rotating retort.
Sterilization temperature = retort temperature T_R = 124 °C.
Come up time of retort L = 3 min.
Initial temperature of the milk in the bottle: Tih = 4 °C.
Heat penetration factor of bottle with liquid milk in rotating retort: fh = 5 min.
Lag factor at heating of bottle with liquid milk in rotating retort: jh = 1.0.
Lag factor at cooling of bottle with liquid milk in rotating retort: jc = 1.0.

Use C.R. Stumbo's (1973) calculation method. For "how-to-proceed": see **Appendix A**.

Worked answer 4.1:

***Step 1**: Calculate, or find in tables, the required F value for sterilization of milk in a bottle.*

Table "**STERILIZATION VALUES F**", in subsection "*Dairy products*", shows:

STERILIZATION VALUES ($F_0 = F^{10}_{121.1}$) FOR SOME COMMERCIAL FOOD PROCESSES			
Product	**Can name**; size DxH mm; ml	Approx. sterilizing value $F^{10}_{121.1}$	Source
Dairy Products			
Milk; in bottle or can		5 - 8 min.	Reichert (1985); Shapton (1994)

Thus: required $F_0 = F^{10}_{121.1}$ = 5 - 8 min. Let us choose a $F_0 = F^{10}_{121.1}$ = 7 min.

***Step 2**: Convert F value to U; U = F at retort temperature T_R* (**Appendix A**).

Retort temperature T_R = 124 °C; so U = F at retort temperature, or $U = F^{10}_{124}$.
Conversion formula from $F_{121.1}$ to U_{124} : $U = F^{10}_{124} = F^{10}_{121.1} \cdot 10^{(121.1 - 124)/10}$.
Or $U = 7 \cdot 10^{(121.1 - 124)/10} = 7 \cdot 10^{-0.29} = 7 \cdot 0.513 = 3.59$ min. So $U (= F^{10}_{124})$ = 3.59 min.

***Step 3**: Find value of g in Stumbo table fh/U versus g for z = 10 °C, at jc = 1.0*

The Stumbo table "fh/U versus g for of z = 10 °C" can be found in **Appendix C**.
For a small part of that table: see below.
First calculate fh/U.

fh = 5 min. (given)
U = 3.59 min. (calculated at step 2)

So fh/U = 5/3.59 = 1.39.

Unfortunately, in Stumbo table fh/U versus g for z = 10 °C, **no** row fh/U = 1.39 is listed.
So an interpolation between row fh/U = 1.00 and fh/U = 2.00 is required.

Values of fh/U versus g for z = 10 °C

fh/U	Values of g [in °C] at following jc of cooling section: jc = 0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00 = jc
.....									
1.00	0.227	0.248	0.269	0.291	0.312	0.333	0.354	0.376	0.397
2.00	0.850	0.922	1.00	1.07	1.15	1.23	1.30	1.38	1.45

At jc = 1.00, and fh/U = 1.00 (see table above), the value of g = 0.291 °C;
At jc = 1.00, and fh/U = 2.00, the value of g = 1.07 °C.
Interpolation: at fh/U = 1.39, g = 0.291 + [(1.39 - 1)/(2-1)]·(1.07 - 0.291) =
= 0.291 + 0.304 = 0.595 °C = g.
So if fh/U = 1.39, then the value of g = 0.595 °C.

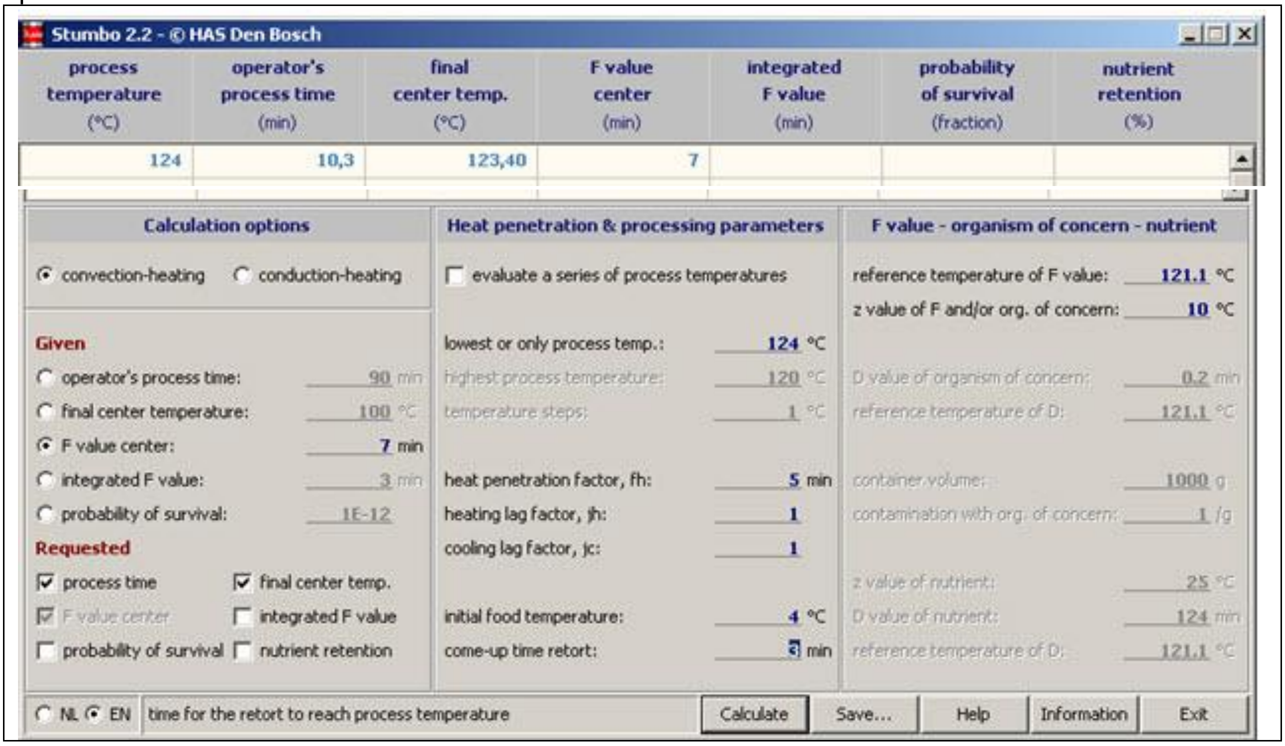
***Step 4*: Calculate the sterilization time Pt from equation**

$Pt = fh \cdot {}^{10}\log[jh \cdot (T_R - Tih)/g] - 0.4 \cdot L$ (see **Appendix A**)

fh = 5 min. (given)
jh = 1.0 (given)
T_R = 124 °C (given)
Tih = 4 °C (given)
g = 0.595 °C (calculated at step 3)
L = 3 min. (given)
Substitution of these values in the Pt equation results in:
Pt = 5·log[1·(124 - 4)/0.595] - 0.4·3 = 5·log201.7 - 0.4·3 = 11.52 - 1.2 = 10.3 min.
So Pt = 10.3 min.

Conclusion: To receive a required $F^{10}_{121.1}$ = 7 min., the milk bottles should be rotating sterilized during **Pt = 10.3 min.** at retort temperature T_R = 124 °C.

Computer program ***STUMBO 2.2.exe*** also finds a sterilization time Pt = "operator's process time" of 10.3 min. if the F value center should be 7 min.:



Example 4.2: Use of required $F^{10}_{121.1}$ = 7 min. to calculate the nutrient retention
Calculate which % of the originally 100% thiamine (with $D^{28.8}_{120}$ = 127.5 min.), present in the raw unheated milk, is retained after the sterilization process of Example 4.1.

Worked answer 4.2:

For "how-to-proceed": see **Appendix B**.

In example 4.1 above, the left hand part of the calculation procedure of Appendix B has already been executed. At step 3 of example 4.1, the value of g = g_X = g_N = 0.595 °C was found. So in Appendix B, now proceed from g = g_N (in the page centre) to the required % b_N at the bottom right of Appendix B.

***Step 1*: In the fh/U versus g table of thiamine (z = 28.8 °C), find the heat dose U which was received by thiamine during the sterilization process**

C.R. Stumbo's (1973) book does NOT have a fh/U versus g table of z = 28.8 °C. So let us use the fh/U versus g table for z = 27.8 °C (see **Appendix D**; selection at next page). The required g value has been calculated in Example 4.1: g = 0.595 °C.

The fh/U versus g table of z = 27.8 °C, at jc = 1.0, does NOT show a value of g = 0.595 °C; only g = 0.484 °C and g = 0.676 °C are listed. So interpolation is required:

Values of fh/U versus g for z = 27.8 °C

fh/U	Values of g [in °C] at following jc of cooling section: jc = 0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00 = jc
0.80	0.339	0.388	0.436	0.484	0.533	0.582	0.630	0.678	0.727
0.90	0.472	0.540	0.608	0.676	0.743	0.811	0.878	0.946	1.014

As can be seen from the above selection of table fh/U versus g for z = 27.8 °C:
At jc = 1.00 and g = 0.484 °C (see small table above), fh/U = 0.80;
at jc = 1.00 and g = 0.676 °C, fh/U = 0.90.

Interpolation:
If g = 0.595 °C, then fh/U = 0.80 + [(0.595 - 0.484)/(0.676 - 0.484)]·(0.90 - 0.80)
or: fh/U = 0.80 + 0.0578 = 0.858.

As fh = 5 min., and fh/U = 0.858, the value of U = 5/0.858 = 5.83 min. = U = $F^{28.8}_{124}$.

N.B.: For nutrients, some authors use symbol C instead of F. They will write: $C^{28.8}_{124}$ = 5.83 min.

***Step 2**: Recalculate U (at retort temperature T_R = 124 °C), to 120 °C;*
120 °C is the reference temperature of the decimal reduction time D of thiamine

U = F_{124} =5.83 min. at z = 28.8 °C of thiamine (step 1). So U = $F^{28.8}_{124}$ = 5.83 min.
Conversion equation: $F^{28.8}_{120} = F^{28.8}_{124} \cdot 10^{(124 - 120)/28.8} = 5.83 \cdot 10^{0.139} = 5.83 \cdot 1.38$;
So $F^{28.8}_{120}$ = 8.03 min.

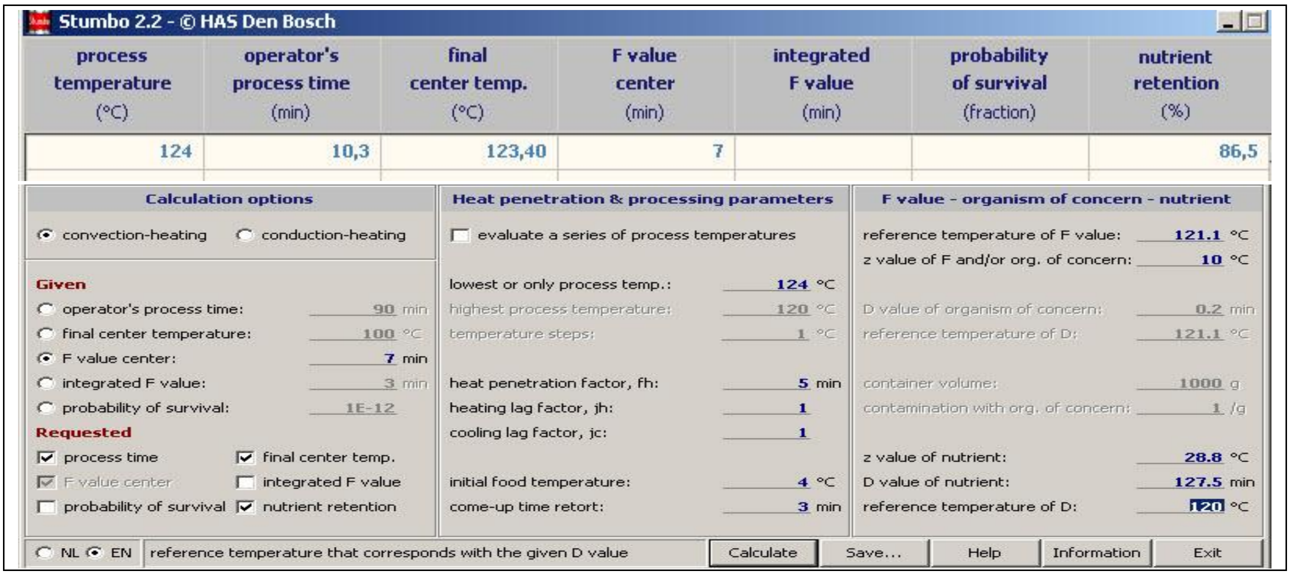
***Step 3**: Calculate the thiamine retention b% from equation*

$$F^{28.8}_{120} = D^{28.8}_{120} \cdot ({}^{10}\log \text{initial\%} - {}^{10}\log \text{retention\%})$$

$F^{28.8}_{120}$ = 8.03 min. = U (calculated at step 2)
$D^{28.8}_{120}$ = 127.5 min. (given)
initial % of thiamine = 100% (given)
Let thiamine retention % = b

Substitution in retention equation $F^{28.8}_{120} = D^{28.8}_{120} \cdot ({}^{10}\log \text{initial\%} - {}^{10}\log \text{retention\%})$,
results in: 8.03 = 127.5 · (log100 - logb); or: 8.03/127.5 = log100 - logb;
so logb = log100 - 8.03/127.5 = 2 - 0.063 = 1.937.
If logb = 1.937, then the % thiamine retention b = $10^{1.937}$ = 86.5%.
After the sterilization process of the milk, about **86.5% of the original amount of thiamine** is left in the sterilized milk. Some 13.5% of thiamine is lost during sterilization.

Computer program ***STUMBO 2.2.exe*** also finds a **nutrient retention (%) of 86.5%:**



Computer program ***STUMBO 2.2.exe***, including converted Stumbo tables, worked examples, validation, and help files, can be obtained at a CD-ROM by sending your name and postal address to j.w.mrouweler@freeler.nl.

Example 4.3: Use of F to calculate the spoilage rate and the nutrient retention
A can, containing 315 grams of carrot purée of pH = 5.9, has to be sterilized in a still, steam retort at retort temperature T_R = 123 ºC.
Carrot purée behaves as a solid, conduction heating food
4.3.1) Find the required F value in the tables of section 1 and 2 above, and calculate:
4.3.2) the sterilization time Pt;
4.3.3) the spoilage rate of the sterilized cans by pathogenic *Clostridium botulinum*;
4.3.4) the % thiamine (vitamine B1) retained after sterilization of carrot purée.
Use the additional process and product information below, and apply computer program Pham.xls, down-loadable from:
https://www.researchgate.net/profile/Janwillem_Rouweler/contributions
or from **https://hasdenbosch.academia.edu/JanwillemRouweler**

Additional process and product information:
Carrot purée is heated in A1 cans; size Diameter x Height = 65 mm x 101 mm; can volume = 315 ml.
Initial product temperature after filling of can, at "steam on" of retort: Tih = 4 ºC.
Retort temperature = sterilization temperature T_R = 123 ºC.
Come up time CUT of the still retort L = 5 min.
Heat penetration factor of A1 cans with carrot purée: fh = fc = 37.0 min.
(see Holdsworth (1997), p. 188, cited in Rouweler (2014)).
Heating lag factors of carrot purée in still retort: jh = jc = 2.0 (estimation).
Cooling water temperature Tw = 23 ºC.
Clostridium botulinum spores: $D^{10}_{121.1}$ = 0.2 min.
Initial *C. botulinum* spore load = 1 spore per gram of carrot purée; so the can, containing 315 grams of carrot purée, will initially have 315 x 1 = 315 spores of *C. botulinum.*
Thiamine (vitamin B1) in carrot purée of pH = 5.9: $D^{25}_{121.1}$ = 158 min.; initially 100%.
(Source: Feliciotti, E.; Esselen, W.B. (1957): Thermal destruction rate of thiamine in puréed meat and vegetables. *Food Technol.* **11** (1957), 77-84).

Worked Answer 4.3:

Step 1: Find the required heat process F value of carrot puree in A1 cans at sterilization.
In this document, **Section 1** Sterilization Values, subsection Vegetables, it says:
Carrot purée; A1 can; **$F^{10}_{121.1}$ = 5.5 min.** (in core). ***This is answer 4.3.1)***

Step 2: Download the most recent version of the Excel file "*HEAT PROCESS CALCULATIONS ACCORDING TO PHAM FOR CONDUCTION-HEATED CANNED FOODS - Sterilization Time, Heat Process Value F, Microbial Spoilage Rate and Nutrient Retention Calculations by Q.T. Pham and C.R. Stumbo's Formula Methods.xls*". See download links above.

Step 3: In the red-outlined section of Excel file Pham.xls, fill in all pale yellow cells (see the print screen of Pham.xls at the next page.) This results in a sterilization time (see "**CALCULATION RESULTS a-1)**" of **Pt = 56.47 min**. ***This is answer 4.3.2).***

Step 4: To find the "**CALCULATION RESULTS b)** Microbial spoilage rate by micro-organism *C. botulinum*", first two iterations are required. Use Excel's "Goal Seek". For help: see row 100, explaining how to do a "Rapid iteration by using Excel's Goal Seek". The number of surviving *C. botulinum* spores per can, thus **the spoilage rate, will be 3.13×10^{-28} per can**. ***This is answer 4.3.3).***

This "spoilage rate" of 3 cans per 10^{28} cans is extremely much lower than the minimum required "botulinum cook" of 10^{-12} per can, which is 1 "poison" can per 10^{12} cans. So the sterilized cans of carrot purée are safe ("commercially sterile"): only about 3 cans per 10^{28} cans may develop botulinum poison.

Step 5: To find the "**CALCULATION RESULTS c)** % Nutrient retention of thiamine", again two iterations are required. Result: **% nutrient, retained in the whole can = 56.1%**. ***This is answer 4.3.4).*** So 56% of vitamin B is still in the can after sterilization.

HEAT PROCESSING CALCULATIONS ACCORDING TO PHAM FOR CONDUCTION-HEATED CANNED FOODS

Protected. **Version 1.0** Janwillem Rouweler

6 worked examples: see row 121 and tab pages **July 2014** j.w.mrouweler@freeler.nl

Yellow cell	= input	Pink cell	= iteration requided; **use Goal Seek!**
Blue cell	= calculation results		(for help: see from row 100)

Select the required calculation, by typing either P or F:

If you want to calculate the pasteurization or sterilization time $\mathbf{P_t}$: type **P** in the yellow cell: ↓ **P or F**

If you want to calculate the heat process value **F**: type **F** in the yellow cell: **p**

Heat penetration properties during heating and cooling	Heat penetration factor for heating f_h =	37	min.
	Lag factor for heating j_h =	2	
	Heat penetration factor for cooling f_c =	37	min.
	Lag factor for cooling j_c =	2	
Retort properties during process	Initial product temperature at "Steam On" T_{ih} =	4	°C
	Come up time of retort C.U.T. L =	5	min.
	Sterilization temperature of retort T_R =	123	°C
	Temperature of cooling water T_W =	23	°C
Known F value:	Known heat process value F =	5.5	min.
Reference temp. of F	Reference temperature of F value is: $T_{ref,F}$ =	121.1	°C
and z of F value	z value of F value is: z_F =	10	°C

Micro-organism	Decimal reduction time of micro-organism: D_M =	0.2	min.
of concern M	Reference temperature of microbial D_M is: $T_{ref,M}$ =	121.1	°C
to be killed	z value of the microbial D is: z_M =	10	°C
is:	Initial number of micro-organisms **in whole can** =	315	

Nutrient N, or	Decimal reduction time of the nutrient: D_N =	158	min.
food component N	Reference temperature of nutrient D_N is: $T_{ref,N}$ =	121.1	°C
(initially 100%)	z value of the nutrient D_N is: z_N =	25	°C

CALCULATION RESULTS a-1) Sterilization time or Pasteurization time P_t:

Sterilization Time or Pasteurization Time, P_t =	**56.47**	**min.**
ΔT between centre of food and retort at start of cooling, g =	**6.25755345**	°C
Product temperature at center of food at start of cooling, T_{ic} =	**116.7424466**	°C

CALCULATION RESULTS a-2) Heat process value F in slowest heating point:

0.0831506	**<-Do NOT change**

Heat process value in center of can, F =	**5.50**	min.
at reference temperature $T_{Ref,F}$ = 121.10 °C	and z_F =	10 °C

CALCULATION RESULTS b) Microbial spoilage rate by micro-organism M:

1st ITERATION REQUIRED for microbial spoilage rate:

CHOOSE a value (0.04 < WMλ < 1) in this YELLOW WMλ cell: WMλ =	0.19817789	**<-Use Goal Seek**
and adapt that WMλ value, until the value in this PINK cell = 0.000	**0.0000**	3.12880
		3.12878

2nd ITERATION REQUIRED for microbial spoilage rate:

CHOOSE a value (0.04 < WM < 1) in this YELLOW WM cell: WM =	0.09596628	**<-Use Goal Seek**
and adapt that WM value, until the value in this PINK cell = 0.000	**0.0004**	6.25791
		6.25755
Number of surviving organisms M per whole can =	**3.13E-28**	per can
Mass average lethal heat value U_S for M, at T_R, integrated over can, U_S =	**3.87**	123
Mass average lethal heat value F_S for M, at $T_{Ref,F}$, integrated over can, F_S	**6.00**	121.1
		↑**reference Temp**

CALCULATION RESULTS c) % Nutrient retention of nutrient N:

1st ITERATION REQUIRED for % retention of nutrient N:

CHOOSE a value (0.04 < WNλ < 1) in this YELLOW WNλ cell: WNλ =	0.491556233	**<-Use Goal Seek**
and adapt that WNλ value, until the value in this PINK cell = 0.000	**0.0002**	3.12894
		3.12878

2nd ITERATION REQUIRED for % retention of nutrient N:

CHOOSE a value (0.04 < WN < 1) in this YELLOW WN cell: WN =	0.353301372	**<-Use Goal Seek**
and adapt that WN value, until the value in this PINK cell = 0.000	**0.0000**	6.25756
		6.25755
% nutrient, retained in the whole can =	**56.1093**	**%**
Mass average lethal heat value U_S for N, at T_R, integrated over can, $U_{S,N}$ =	**33.29**	**min.**

5. Use of F value to calculate the pasteurization holding time Pt in a heat exchanger

Example 5: Calculate the holding time in the holding tube of a plate heat exchanger, used to pasteurize freshly extracted apple juice of pH = 3.3.
After heat treatment, the juice is packed in laminated cartons of 1000 grams.
The packed juice should be shelf-stable at ambient storage temperatures.
Also calculate the spoilage rate by a mold (*Byssochlamys fulva*) and by a yeast (*Saccharomyces cerevisiae*), and calculate the % retention of 2 vitamins (folic acid and vitamin C), and of an enzyme (pecterinase). For details of nutrients: see table 5.2.
Pasteurization temperature T_R = 90 °C (see temperature in "holding tube" in table 5.1).
Use computer program ***Build-Heat-Exchanger.xls***.

Table 5.1: Given details of the heat exchanger:

Sections of heat exchanger↓	Juice temperatures		Average residence time in the section ↓
	Temperature section **IN**	Temperature section **OUT**	
Regenerative (heating)	20 °C	80 °C	120 s = 2 min.
Heating section	80 °C	90 °C	20 s = 0.33 min.
Holding section	90 °C	90 °C	***?? To be calculated***
Regenerative (cooling)	90 °C	30 °C	120 s = 2 min.
Pasteurization temperature			90 °C (see holding section)
Correction factor for residence time distribution:			Vav/Vmax = 0.80
Multiplication factor for initial fluid flow rate through all sections:			1

Table 5.2: Details about thermo-labile components in the fresh apple juice:

Component	Comment	Decimal reduction time D	Initial number in the raw juice
Byssochlamys fulva	Pathogenic mold. Produces mycotoxin patulin	$D^{7.8}_{93}$ = 5 min. = 300 s	0.001 per gram
Saccharomyces cerevisiae (ascospore)	Spoilage yeast	$D^{5.5}_{60}$ = 22.5 min. = 1350 s	100 per gram
Folic acid	Important vitamin	$D^{35}_{121.1}$ = 492 min. = 29 520 s	100%
Pecterinase	Enzyme	$D^{16.5}_{96}$ = 0.58 min. = 35 s	100%
Vitamin C	Important vitamin	D^{110}_{80} = 1200 min. = 72 000 s	100%

Worked answer 5:

Step1: Find the required F value for apple juice from the section 2 table "Pasteurization values F", at subsection "Fruit and Vegetables".

PASTEURIZATION VALUES FOR SOME COMMERCIAL FOOD PROCESSES			
Product	Approx. pasteurization value F or P	Additional information; Remarks	Source
Fruits and vegetables			
Apples; stored at ambient temperature	$F^{8.9}_{93.3}$ = 0.2 - 0.6 min.	pH 3.3	Eisner (1988) in Tucker (2011: 68)

According to section 2, the $F^{8.9}_{93.3}$ = 0.2 - 0.6 min. Choose **$F^{8.9}_{93.3}$ = 0.6 min. = 36 s**.

Step 2: Download program *Build-Heat-Exchanger.xls, and insert information*

Excel file Build-Heat-Exchanger.xls is available from :
https://www.researchgate.net/profile/Janwillem_Rouweler/contributions
or from **https://hasdenbosch.academia.edu/JanwillemRouweler**

First include, in the pale yellow cells of the top input table of Build-Heat-Exchanger.xls, all information about the F to be calculated, the micro-organisms, the vitamins and the enzyme (see **table 5.2**).
When inserting the "initial number in **whole** pack", please realize that the apple juice, after heating, will be packed in 1000 g laminated cartons.
The "Correction factor for residence time distribution" should be: Vav/Vmax = 0.8.
Assume the "Multiplication factor for initial fluid flow rate through all sections" = 1.

This results in the following top input table:

BUILD-HEAT-EXCHANGER

Compose your own heat exchanger and make calculations

	Initial number in **whole** pack	D value [in **SEC**]	Reference temp [°C]	z value [°C]
F value to be calculated:	XXX	XXX	93.3	8.9
Byssochlamys fulva	1	300	93	7.8
Saccharomyces cerevisiae	100000	1350	60	5.5
Folic acid	100%	29520	121.1	35
Pecterinase	100%	35	96	16.5
Vitamin C	100%	72000	80	110

Correction factor for residence time distribution:	0.8	**= Vav/Vmax**
Multiplication factor for initial fluid flow rate through all sections:	1	**x initial fluid**

Next, in the second input table, type the names of each of the sections (= "stages") of the heat exchanger in the correct order. Include the IN and OUT temperatures of the apple juice in each stage; and insert the average residence time in each stage. Initially, choose the residence time in the holding section to be = 0 s.
(See **table 5.1** for information about the stages of the heat exchanger.)

Thus, the second input table will look as follows:

Name the stages in the heat exchanger in the correct order	Temp [°C] In	Temp [°C] Out	**Average** residence time [s]
Regenerative (heating)	20	80	120
Heating section	80	90	20
Holding section	90	90	0
Regenerative (cooling)	90	30	120

Step 3: Stepwise change the average residence time of the holding section, until the "(Corrected) Total F value for this and previous stages" of the apple juice after leaving section "Regenerative (cooling)", is equal to the required F value of 36 s.

After some trial and error, the "(corrected) total F" = 36 s will be obtained if the average residence time of the juice = 90.3 s. This 90.3 s is the required average holding time.
(Instead of "trial and error", you could use the Excel function "Goal Seek").

For calculation results of ***Build-Heat-Exchanger.xls***, and conclusions: see next page.

Name the stages in the heat exchanger in the correct order	Temp [°C] In	Out	Average residence time [s]	Av. residence time, corrected for flow [s]	F per stage [s]	F, per stage, corrected for residence time distribution [s]	(corrected) Total F value for this and previous stages [s]
							0
Regenerative (heating)	20	80	120	120	0.247919145	0.198335316	0.198335316
Heating section	80	90	20	20	3.047461932	2.437969546	2.636304861
Holding section	90	90	**90.3**	90.3	38.45043288	30.7603463	33.39665116
Regenerative (cooling)	90	30	120	120	3.295380524	2.636304419	**36.03295558**

Name the stages in the heat exchanger in the correct order	(corrected) Total F value for this and previous stages [s]	Spoilage rate **b** by *Byssochlamys fulva*	Spoilage rate **b** by *Saccharomyces cerevisiae*	Retention Folic acid [%]	Retention Pecterinase [%]	Retention Vitamin C [%]
	0	1	100000	100	100	100
Regenerative (heating)	0.198335316	0.99910315	5.39127E-08	99.98441585	90.37615455	99.78146129
Heating section	2.636304861	0.982968965	**0**	99.96962842	66.45961616	99.71041467
Holding section	33.39665116	0.782021698	#GETAL!	99.87866096	5.078522936	99.35605223
Regenerative (cooling)	**36.03295558**	**0.768703059**	#GETAL!	**99.84861137**	**3.375406529**	**99.08843059**

Conclusions: After some "trial and error" of the average residence time in the holding section, it was found:

* To obtain the required $F^{8.9}_{93.3}$ = 0.6 min. = 36 s, a **holding time of about 90.3 s** in the holding tube at 90 °C is needed.

After the heat processing:

* ... the number of cells of mold *Byssochlamys fulva* per juice carton of 1 kg was reduced from 1/carton to 0.77/carton. **So almost no destruction!** This means: if the mold *Byssochlamys fulva* can grow in pasteurized apple juice of pH = 3.3, the heat process should be much more severe; or the initial load of the mold (at present 0.001 per gram = 1 per kg) should be reduced at least a million-fold by much better selection of the fruits, better fruit cleaning, etc.

* ...the spoilage rate by *Saccharomyces cerevisiae* will be **extremely low**; "0" in Excel means: < 1 spoiled carton per 10^{307} cartons.

* ...of the original 100% enzyme pecterinase, after pasteurization only **about 3.4% is over**; about 96.6% pectinase is destructed.

* .. both vitamins folic acid and vitamin C will be **retained for over 99%**. So less than 1% of these vitamins is destructed by heating.

6. Calculation of the required F value for moderate and for tropical climate countries, based on a microbial analysis; restrictions

Example 6: A solid food in 1 kg cans should be sufficiently heated. The food has to be both safe and shelf-stable for some years when stored at ambient temperature (so no refrigeration). Food-pH = 6.7. Food-a_W = 0.995. No preservatives added.

Microbial and chemical analysis of the raw food shows:

Table 6.1: Microbial and chemical analysis of the raw solid food

Name organism or food component	Comments	Decimal reduction time and z	Initial load per gram of raw material
Clostridium botulinum	Pathogen. Produces exo-toxins inside the canned food, in absence of oxygen. Spores germinate at T >10 °C. Acceptable "spoilage" rate after heating: ≤1 can per 10^{12} cans.	$D^{10}_{121.1}$ = 0.2 min.	1 per gram
Listeria monocytogenes	Infectious pathogen (acts in intestines). Grows at T > 0 °C. Acceptable "spoilage" rate after heating: < 1 organism per can at the last day of the shelf life.	$D^{6.7}_{70}$ = 0.3 min.	1 per gram
Clostridium sporogenes (PA 3679)	Spoilage organism. Causes "putrid swell", being a **p**utrefactive **a**naerobe (PA). Spores germinate at T >10 °C (mesophilic). Acceptable spoilage rate after heating: ≤1 can per 10^5 cans.	$D^{12}_{121.1}$ = 1.0 min.	100 per gram
Clostridium nigrificans	Spoilage organism. Spores germinate at T > 35 °C (thermophilic). Acceptable spoilage rate after heating: ≤ 1 can per 10^2 cans in moderate climate countries. ≤ 1 can per 10^5 cans in tropical climate countries.	$D^{9.5}_{121.1}$ = 3.3 min.	0.01 per gram
Pseudomonas fluorescens	Spoilage organism. Grows at T > 0 °C. Acceptable "spoilage" rate after heating: < 1000 organism per can at the last day of the shelf life.	$D^{7.5}_{60}$ = 3.2 min.	100 per gram
Vitamin B1 = Thiamine	Essential vitamin.	$D^{25}_{121.1}$ = 124 min.	100%
Betanin	Red food color (from beetroot).	$D^{36.5}_{100}$ = 21.3 min	100%

Initial temperature of the solid food in the can prior to heating: Tih = 20 °C.
Heat penetration factors: fh = 83 min.; fc = 83 min.
Lag factors: jh = 2; jc = 2.
Come up time of steam retort: L = 5 min.
Cooling water temperature: Tw = 20 °C.

6.1) Decide about the type of heating process: pasteurization or sterilization. Explain.

6.2a) Name **all** micro-organisms, listed in **table 6.1** which may be the target organisms (= "organisms of concern") for the type of heating process of answer 6.1. Explain.

6-2b) Calculate the F_{90} (pasteurization) or $F_{121.1}$ (sterilization) values for **each** of the target organisms for sale (and storage) in moderate climate countries.

6.2c) Select the best of either the F_{90} (pasteurization) or the $F_{121.1}$ (sterilization) values for sale (and storage) in moderate climate countries. Explain.

6.3) The food company plans to export the solid food in 1 kg cans also to a country with a tropical climate, to be stored without refrigeration, with a shelf life of about 1 year. Frequently the storage temperature (in warehouses, shops, houses) is $T_{STORAGE} > 35$ ºC.

6.3a) Which of the F values, calculated for moderate climate countries in answer 6.2b), is NOT valid for export to tropical countries? Explain.

6.3b) Calculate the required $F_{121.1}$ value for export to tropical areas.

6.3c) Using the required F value for tropical countries of answer 6.3b), calculate the resulting sterilization time Pt, the spoilage rate by *C. nigrificans*, and the vitamin B1 retention if the 1 kg food is sterilized in a retort at a retort temperature of T_R = 127.1 ºC. Use Excel program Pham.xls, down-loadable from:
https://www.researchgate.net/profile/Janwillem_Rouweler/contributions
or from **https://hasdenbosch.academia.edu/JanwillemRouweler**

For help in using Excel sheet Pham: see **Worked Answer 4.3**.

6.4a) Calculate, for storage in a **moderate climate country**, so $T_{STORAGE} < 35$ ºC, the sterilization time Pt at retort temperatures T_R = 117.1 °C to 127.1 °C step 2 °C, based on **each** of the target micro-organisms. At the same time calculate the vitamin B1 retention. Use computer program Stumbo.exe [1]).

[1]) Computer program ***STUMBO.exe***, including converted Stumbo tables, worked examples, validation, and help files can be obtained at a CD-ROM by sending your name and postal address to **j.w.mrouweler@freeler.nl**

6.4b) Consider the calculated sterilization times of answer 6.4a. Which is the most appropriate sterilization time Pt at sterilization temperature T_R = 117.1 °C? Explain.

6.4c) Consider the calculated sterilization times of answer 6.4a. Which is the most appropriate sterilization time Pt at sterilization temperature T_R = 127.1 °C? Explain.

Worked Answers 6:

Answer 6.1: *Pasteurization or Sterilization?*
Use "**DECISION SCHEME: PASTEURIZATION OR STERILIZATION**" of Chapter 3.
- Shelf life, at ambient temperature (= no refrigeration), should be long ("some years").
- pH = 6.7; so NOT pH < 3.7.
- a_W = 0.995; so NOT a_W < 0.95.
- No preservatives added; so NOT 150 ppm Nitrite NO_2^- + NaCl.

Conclusion: Sterilization required; $F^{10}_{121.1} \geq 3.0$ min.

Answer 6.2a: *Target organisms?*
- When sterilization takes place (according to answer 6.1), bacterial spores are the target organisms (= organisms of concern).
  During sterilization, the numbers of vegetative organisms will be reduced to extremely small numbers, so they are NOT the target organisms at sterilization.
- Which of the organisms in **table 6.1** are spores?
  Spores are very heat resistant, and thus spores can be recognized by their high reference temperature (see subscript) of D: usually $T_{REFERENCE} >> 100$ °C for the decimal reduction time D of spores.
  So *Clostridium botulinum* (T_{REF} = 121.1 °C), *Clostridium sporogenes* (T_{REF} = 121.1 °C), and *Clostridium nigrificans* (T_{REF} = 121.1 °C) will be microbial spores, and thus are the target organisms at sterilization.

Note that Vitamin B1 and Betanin (**table 6.1**) too are more or less heat resistant, but these food components are nutrients, not micro-organisms.

Answer 6.2b: *Calculate F values of **all** target organisms for moderate climate countries*:
Equation: $F = D \cdot [{}^{10}\log(\text{total initial number in can}) - {}^{10}\log(\text{spoilage rate after heating})]$.

*** *Clostridium botulinum*** (see **table 6.1**):
Initial number 1 per gram, so total number of 1000 spores per can of 1 kg.
"Spoilage" rate after heating should be 1 spore per 10^{12} cans, $= 1/10^{12} = 10^{-12}$.
$D^{10}_{121.1} = 0.2$ min.
(Why 1 pathogenic survivor per 10^{12} cans is acceptable: see Teixeira (2007), p. 419).
Substitution in F equation: $F^{10}_{121.1} = 0.2 \cdot [{}^{10}\log 1000 - {}^{10}\log 10^{-12}] = 0.2 \cdot [3 - (-12)] =$ 3.0 min. Such a process, with $F^{10}_{121.1} = F_0 = 3.0$ min., is called the "**botulinum cook**".
So to sufficiently destruct *Clostridium botulinum*, $F^{10}_{121.1} \geq 3.0$ min. is required.

*** *Clostridium sporogenes*** (see **table 6.1**):
Initial number 100 per gram, so total number of 100 000 spores per can of 1 kg.
Spoilage rate after heating should be 1 spore per 10^5 cans, $= 1/10^5 = 10^{-5}$
(Why 1 spoilage survivor per 10^5 cans is acceptable: see Teixeira (2007), p. 419).
$D^{12}_{121.1} = 1.0$ min.
Substitution in F equation: $F^{12}_{121.1} = 1.0 \cdot [{}^{10}\log 100\,000 - {}^{10}\log 10^{-5}] =$
$= 1.0 \cdot [5 - (-5)] = 10.0$ min.
So to sufficiently destruct *Clostridium sporogenes*, $F^{12}_{121.1} \geq 10.0$ min. is required.

*** *Clostridium nigrificans*** (see **table 6.1**):
Initial number 0.01 per gram, so total number of 10 spores per can of 1 kg.
Spoilage rate after heating in moderate climate countries should be 1 spore per 10^2 cans, $= 1/10^2 = 10^{-2}$.
(Why 1 thermophilic spoilage survivor per 10^2 cans is acceptable in moderate climate countries: see Teixeira (2007), p. 419).
$D^{9.5}_{121.1} = 3.3$ min.
Substitution in F equation: $F^{9.5}_{121.1} = 3.3 \cdot [\log 10 - \log 10^{-2}] = 3.3 \cdot [1 - (-2)] = 9.9$ min.
So to sufficiently destruct *Clostridium nigrificans*, $F^{9.5}_{121.1} \geq 9.9$ min. is required.

Answer 6.2c) *Select the best of these F values.*
Some microbiologists would suggest: "If F values are all at same reference temperature, select the highest F value". They thus would select $F^{12}_{121.1} = 10.0$ min.
However: although for each F the reference temperature 121.1 °C is the same, the z value of each F is different. This difference in z may have considerable influence on the microbial destruction.
Better: Select the highest sterilization time Pt at the intended retort temperature T_R.
See answer 6.4a and answer 6.4b, in which sterilization times are calculated.

Answer 6.3a) *Which of the F values, calculated in answer 6.2b) for moderate climate countries, is **NOT** valid for export to tropical countries? Explain*
The F value, in answer 6.2b) calculated for *C. nigrificans*, is valid for moderate climate countries: countries where $T_{STORAGE} < 35$ °C. Spores of this thermophilic spoilage (= NOT pathogenic!!) organism will not germinate in such moderate climate countries. Thus it is generally agreed upon that, for sale in moderate climate countries, the acceptable number of thermophilic spoilage spores surviving sterilization, should be ≤ 0.01 per can ($\leq 10^{-2}$ per can). So if such cans, unintentionally, will be stored at temperatures of $T > 35$ °C, then about 1 can per 100 cans will spoil.
However, if cans containing *C. nigrificans* spoilage spores are stored in tropical countries ($T_{STORAGE} > 35$ °C), these thermophilic spores can germinate. So it is generally agreed upon that for use in tropical areas the acceptable number of thermophilic spoilage spores surviving sterilization should be $\leq 10^{-5}$ per can. Thus only one can per 100 000 cans may be spoiled by a thermophilic organism during storage in a tropical region.

Answer 6.3b) *Calculate the $F_{121.1}$ value, required for export to **tropical** areas.*
Equation: F = D · [^{10}log(total initial number in can) - ^{10}log(spoilage rate after heating)].
For *C. nigrificans* (see **table 6.1**):

Decimal reduction time D: $D^{9.5}_{121.1}$ = 3.3 min. (see **table 6.1**)
Total initial number in of *C. nigrificans* in 1000 g can: 0.01 spore per gram = 1000 g • 0.01 spores/g = 10 spores/can (see **table 6.1**).
Spoilage rate after heating ≤ 10^{-5} spores/gram in tropical climate countries (**table 6.1**).

(Why 1 thermophilic spoilage survivor per 10^5 cans is acceptable in tropical countries: see Teixeira (2007), p. 419).

Substitution in the equation above results in:
$F^{9.5}_{121.1}$ = 3.3 • [^{10}log10 - ^{10}log10^{-5}] = 3.3 • [1 - (-5)] = 3.3 • 6 = 19.8 min. = $F^{9.5}_{121.1}$.

The required F value of F = 19.8 min. for *C. nigrificans* in tropical countries is considerably larger than the F values for sufficient destruction of the other spore species in the can, e.g. $F^{10}_{121.1}$ = 3.0 min. for *Clostridium botulinum*, and $F^{12}_{121.1}$ = 10.0 min. for *Clostridium sporogenes*; see answer 6.2b.
So for sale in tropical countries, $F^{9.5}_{121.1}$ = 19.8 min. is applicable.

(Compare the $F^{9.5}_{121.1}$ = 19.8 min. for tropics to the $F^{9.5}_{121.1}$ = 9.9 min., required to sufficiently destruct *Clostridium nigrificans* for sale in moderate climate countries. Due to the high heat resistance of thermophilic spores such as *C. nigrificans*, F values for products to be sold in tropical countries usually are considerably larger than F values for products, sold in moderate climate countries).

Answer 6.3c) *Using the required F value of answer 6.3b) for tropical countries, calculate the resulting sterilization time Pt, the spoilage rate by C. nigrificans, and the vitamin B1 retention, if the 1 kg food cans are sterilized at a retort temperature of T_R = 127.1 ºC. Use Excel program Pham.xls.*

For a print-screen of the calculation by the Pham Excel file: see the next pages.

Summary of the findings of the Pham calculation are in the middle column of **table 6.2**:

Table 6.2: Process and product properties of the 1 kg cans of solid food after sterilization at retort temperature T_R = 127.1 ºC, intended either for sale in tropical countries or for sale in moderate climate countries:

Process parameters	**Tropical** countries: storage temperature $T_{STORAGE}$ > 35 ºC; (calculations by **Pham.xls**; answer 6.3)	**Moderate climate** countries: storage temperature $T_{STORAGE}$ < 35 ºC; (calculations by **Stumbo.exe**; answers 6.2 and 6.4)
Required $F_{121.1}$ value	$F^{9.5}_{121.1}$. = 19.8 min. (**answer 6.3b**)	$F^{9.5}_{121.1}$ = 10 min. (**answer 6.2c** and **table 6.3**)
Calculated sterilization time Pt	Pt = 117.3 min. (Pham, **Pt** next pages)	Pt = 95.3 min. (Stumbo; **answer 6.4c**)
Calculated spoilage rate after sterilization during storage; spoilage organism	1 can per 10^7 cans by *C. nigrificans* **[1])** (Pham: number of **surviving mo** at next pages)	1 can per 10^5 cans by *C. sporogenes* (Stumbo; **fig. 6.2**)
Calculated nutrient Vitamin B1 retention	18 % (Pham, **% nutrient** next pages)	35.9 % (Stumbo; **fig. 6.2**)

[1]) The required spoilage rate in the **whole** can should be 1 can per 10^5 cans.
The Pham calculation method assumes that the input F is the F in the coldest core; thus the Pham Excel spreadsheet calculates the spoilage rate in the **1 cm^3 coldest core**. The actual spoilage rate for the **whole** can (in this example: 1000 cm^3) will be considerably higher, and will be close to the required 1 spoiled can per 10^5 cans!

HEAT PROCESSING CALCULATIONS ACCORDING TO PHAM FOR CONDUCTION-HEATED CANNED FOODS

Protected. **Version 1.0** **July 2014**

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Yellow cell	= input	Pink cell	= iteration requided; **use Goal Seek!**
Blue cell	= calculation results		(for help: see from row 100)

Select the required calculation, by typing either P or F:

If you want to calculate the pasteurization or sterilization time $\mathbf{P_t}$: type **P** in the yellow cell: ↓ **P or F**

If you want to calculate the heat process value **F**: type **F** in the yellow cell: **p**

Heat penetration properties during heating and cooling	Heat penetration factor for heating f_h =	83	min.
	Lag factor for heating j_h =	2	
	Heat penetration factor for cooling f_C =	83	min.
	Lag factor for cooling j_C =	2	
Retort properties during process	Initial product temperature at "Steam On" T_{ih} =	20	°C
	Come up time of retort C.U.T. L =	5	min.
	Sterilization temperature of retort T_R =	127.1	°C
	Temperature of cooling water T_W =	20	°C
Known F value:	Known heat process value F =	19.8	min.
Reference temp. of F	Reference temperature of F value is: $T_{ref,F}$ =	121.1	°C
and z of F value	z value of F value is: z_F =	9.5	°C
Micro-organism	Decimal reduction time of micro-organism: D_M =	3.3	min.
of concern M	Reference temperature of microbial D_M is: $T_{ref,M}$ =	121.1	°C

to be killed	z value of the microbial D is: z_M =	9.5	°C
is:	Initial number of micro-organisms **in whole can** =	10	
Nutrient N, or	Decimal reduction time of the nutrient: D_N =	124	min.
food component N	Reference temperature of nutrient D_N is: $T_{ref,N}$ =	121.1	°C
(initially 100%)	z value of the nutrient D_N is: z_N =	25	°C

CALCULATION RESULTS a-1) Sterilization time or Pasteurization time P_t:

Sterilization Time or Pasteurization Time, P_t =	**117.35**	**min.**
ΔT between centre of food and retort at start of cooling, g =	**7.81472665**	°C
Product temperature at center of food at start of cooling, T_{ic} =	**119.2852734**	°C

CALCULATION RESULTS a-2) Heat process value F in slowest heating point:

	0.0831506	**<-Do NOT change**
Heat process value in center of can, F =	**19.80**	min.
at reference temperature $T_{Ref,F}$ = 121.10 °C	and z_F =	9.5 °C

C

CALCULATION RESULTS b) Microbial spoilage rate by micro-organism M:

1st ITERATION REQUIRED for microbial spoilage rate:

CHOOSE a value (0.04 < WMλ < 1) in this YELLOW WMλ cell: WMλ =	0.135556501	**<-Use Goal Seek**
and adapt that WMλ value, until the value in this PINK cell = 0.000	**-0.0001**	3.90727

		3.90736
2nd ITERATION REQUIRED for microbial spoilage rate:		
CHOOSE a value (0.04 < WM < 1) in this YELLOW WM cell: WM =	0.055717456	**<-Use Goal Seek**
and adapt that WM value, until the value in this PINK cell = 0.000	**0.0001**	7.81487
		7.81473
Number of surviving organisms M per whole can =	**1.06E-07**	per can
Mass average lethal heat value U_S for M, at T_R, integrated over can, U_S =	**6.15**	127.1
Mass average lethal heat value F_S for M, at $T_{Ref,F}$, integrated over can, F_S	**26.32**	121.1
		↑**reference Temp**

CALCULATION RESULTS

c) % Nutrient retention of nutrient N:

1st ITERATION REQUIRED for % retention of nutrient N:		
CHOOSE a value (0.04 < WNλ < 1) in this YELLOW WNλ cell: WNλ =	0.407581786	**<-Use Goal Seek**
and adapt that WNλ value, until the value in this PINK cell = 0.000	**-0.0006**	3.90674
		3.90736
2nd ITERATION REQUIRED for % retention of nutrient N:		
CHOOSE a value (0.04 < WN < 1) in this YELLOW WN cell: WN =	0.278398498	**<-Use Goal Seek**
and adapt that WN value, until the value in this PINK cell = 0.000	**-0.0001**	7.81466
		7.81473
% nutrient, retained in the whole can =	**17.9848**	**%**
Mass average lethal heat value U_S for N, at T_R, integrated over can, $U_{S,N}$ =	**53.17**	**min.**

Answer 6.4a: *Calculate the **sterilization** time Pt at retort temperatures T_R = 117.1 to 127.1 °C step 2 °C, based on each of the target micro-organisms of table 6.1. At the same time calculate the vitamin B1 retention.* Use computer program Stumbo.exe.

General considerations when using computer program STUMBO.exe (see **fig. 6.1** - **6.3**):

Left hand column: "calculation options":
"conduction heating" food. Place a (•).
"Given": "probability of survival"; is different for each target organism.
"Requested": place a tick at each option.

Middle column: "Heat penetration and processing parameters":
Tick at "evaluate a series of process temperatures".
"lowest or only process temperature": 117.1 °C
"highest process temperature": 127.1 °C.
"temperature steps": 2 °C.
"heat penetration factor, fh": 83 min.
"heating lag factor, jh": 2.
"cooling lag factor, jc": 2.
"initial food temperature": 20 °C.
"come-up time retort": 5 min.

Right hand column: "F value - organism of concern - nutrient"
"reference temperature of F value": 121.1 °C.
"z value of F and/or org. of concern": is different for each target organism.
"D value of organism of concern": is different for each target organism.
"reference temperature of D": in this case each time 121.1 °C.
"container volume": 1000 g.
"contamination with org. of concern": is different for each target organism.
BE AWARE: contamination to be inserted in organisms **per gram**!
"z value of nutrient": 25 °C (for vitamin B1).
"D value of nutrient": 124 min. (for vitamin B1).
"reference temperature of D": 121.1 °C (for vitamin B1).

The 3 print screens of computer program STUMBO.exe for each of the 3 micro-organisms of concern, and for nutrient Vitamin B1, can be found in **fig. 6.1**, **fig. 6.2**, and **fig. 6.3**.

Table 6.3 summarizes the Stumbo.exe calculation results:

Table 6.3: Overview of calculated sterilization times Pt for each of the target organisms for **moderate climate countries**, calculated by computer program Stumbo.exe.
(See **fig. 6.1**, **fig. 6.2**, and **fig. 6.3** for details.)

Micro-organism of concern (= target organism)	Required F value for moderate climate countries	Sterilization time Pt at (lowest) retort temperature T_R = 117.1 °C	Comment	Sterilization time Pt at (highest) retort temperature T_R = 127.1 °C	Comment
C. botulinum (**fig. 6.1**)	$F^{10}_{121.1}$ = 3.0 min.	Pt = 116.1 min.		Pt = 87.2 min.	
C. sporogenes (**fig. 6.2**)	$F^{12}_{121.1}$ = 10.0 min.	Pt = 132.8 min.		**Pt = 95.3 min.**	***highest Pt***
C. nigrificans (**fig. 6.3**)	$F^{9.5}_{121.1}$ = 9.9 min.	**Pt = 138.8 min.**	***highest Pt***	Pt = 93.5 min.	

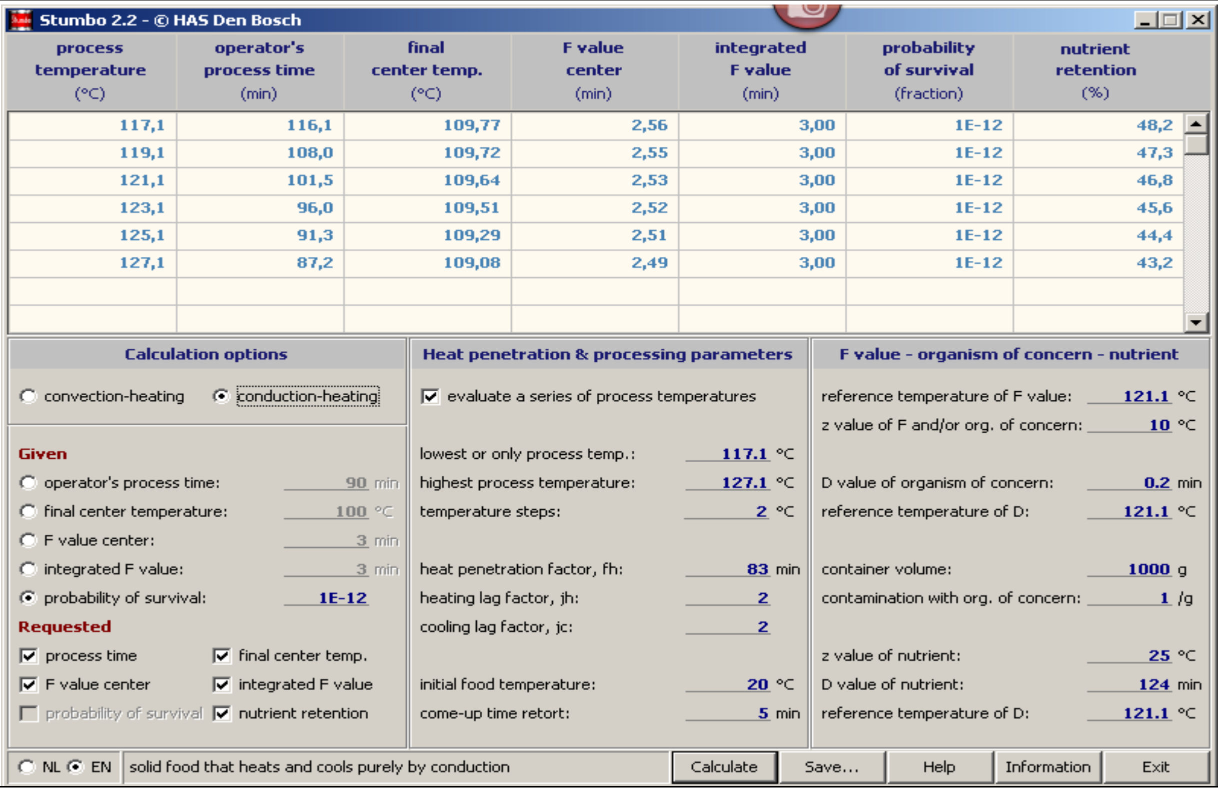


Fig. 6.1: Calculation of operator's process time (= sterilization time), final center temperature, F value in center, integrated F value, and nutrient retention, if **organism of concern** is ***Clostridium botulinum***. **Nutrient = vitamin B1.**

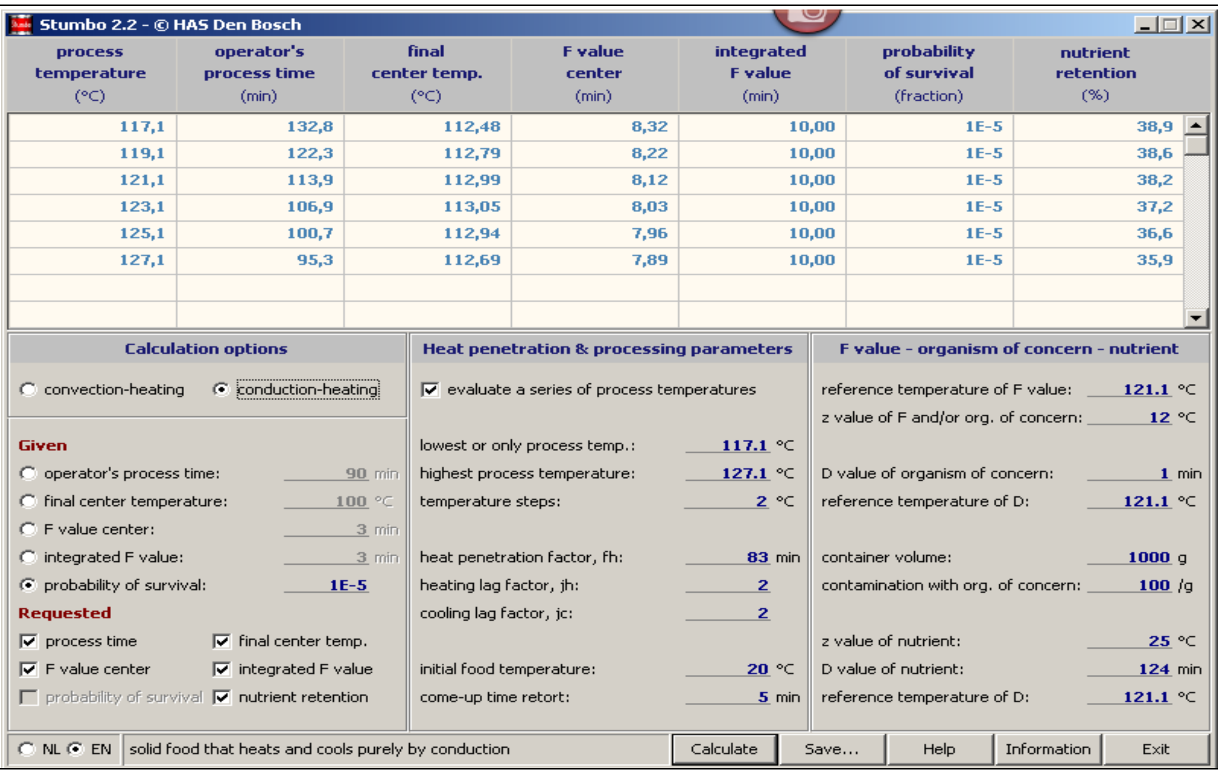


Fig. 6.2: Calculation of operator's process time (= sterilization time), final center temperature, F value in center, integrated F value, and nutrient retention, if **organism of concern** is ***Clostridium sporogenes***. **Nutrient = vitamin B1**.

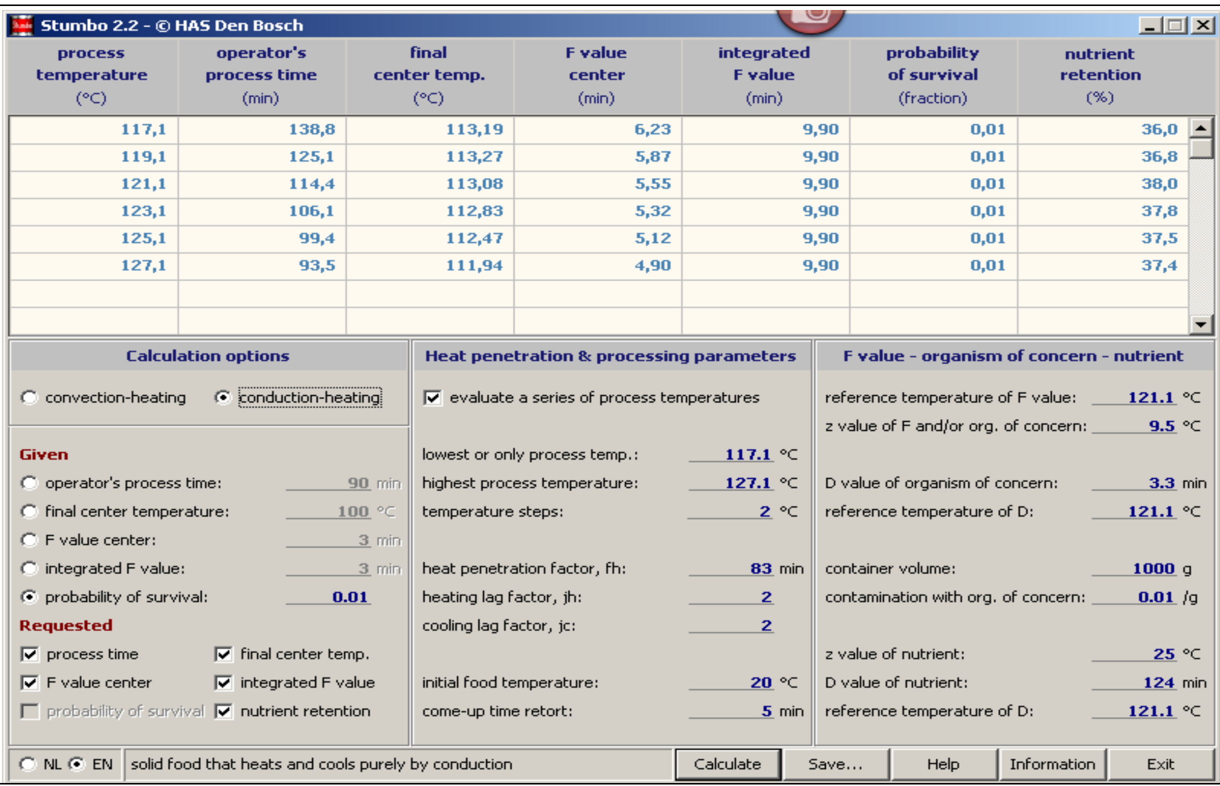


Fig. 6.3: Calculation of operator's process time (= sterilization time), final center temperature, F value in center, integrated F value, and nutrient retention, if **organism of concern** is ***Clostridium nigrificans***. **Nutrient = vitamin B1.**

Answer 6.4b: *Consider the calculated sterilization times of answer 6.4a. Which is the most appropriate sterilization time at retort temperature T_R = 117.1 ºC?*
At retort temperature T_R = 117.1 °C, the appropriate sterilization time Pt is Pt = 138.8 min., which is the largest of the 3 Pt values (see **table 6.3**). This sterilization time is needed to sufficiently destruct *C. nigrificans*. The 2 other organisms of concern, each with lower required sterilization time Pt, then certainly will be sufficiently destructed.

Note 1: At retort temp. T_R = 117.1 °C, the largest of the 3 sterilization times, Pt = 138.8 min. causes an integrated F value of $F^{9.5}_{121.1}$ = 9.9 min. This is **NOT** the highest F value of the 3 organisms of concern!

Restriction in the use of the "largest" F value when calculating the pasteurization or sterilization time:

Calculating the pasteurization or sterilization time Pt, based on the **largest F value** at a particular reference temperature, may not always give the best result. This has been illustrated in the example above, at retort temperature T_R = 117.1 °C (**Answer 6.4b**).

Advised calculation procedure to find the best Pt:
For **each** micro-organism of concern separately, the pasteurization or sterilization time Pt should be calculated at the requested retort temperature. After that, the largest of these Pt values at a particular retort temperature should be selected. Only then you can be sure that **all** target organisms will be destructed sufficiently: the organisms requiring this largest Pt, as well as the other target organisms which require a lower Pt.

Answer 6.4c: *Consider the calculated sterilization times of answer 6.4a. Which is the most appropriate sterilization time at retort temperature T_R = 127.1 ºC?*
At retort temperature T_R = 127.1 °C, the appropriate sterilization time Pt is Pt = 95.3 min., the largest of the 3 Pt values (see **table 6.2**). This sterilization time is needed to sufficiently destruct *C. sporogenes*. The 2 other organisms of concern, each with lower required sterilization time Pt, then certainly will be sufficiently destructed.

> **Note 2**: At retort temp. T_R = 127.1 °C, the largest of the 3 sterilization times, so Pt = 95.3 min., causes an integrated F value of $F^{9.5}_{121.1}$ = 10 min. This is also the highest F value of the 3 organisms of concern!

> **Note 3**:
> **1)** The Pham Excel file uses the F in the coldest core, and thus calculates the spoilage rate in the **1 cm³ coldest core**. The actual spoilage rate for the **whole** can (= 1000 cm^3) will be considerably higher, and be close to the required 1 can per 10^5 cans!
> **2)** Computer program Stumbo.exe, however, uses the integrated sterilization value for its calculations, and thus calculates the spoilage rate of the **whole** can (= 1 per 10^5 cans).

> **Note 4:** Computer program Stumbo calculates both the **integrated F value**, AND the F value in the 1 cm^3 coldest core (**F value center**). In case of solid products these figures differ, as can be seen in **fig. 6.1** to **fig. 6.3**.
> If calculations are based on the F value in the (1 cm^3) coldest center, then the number of micro-organisms of concern in that 1 cm^3 center will have been reduced to the required number. However, in a can of 1000 cm^3, there still will be the possibility of some surviving micro-organisms in the 999 cm^3 surrounding the centre. Thus the actual spoilage rate of the can will be higher than expected!

Remark on the optimum vitamin B1 retention:
During retorting of a solid food, the nutrient retention sometimes goes through a maximum when processing at different retort temperatures. See example calculation in **fig. 6.3**, on *Clostridium nigrificans*: vitamin B1 has a maximum retention of about 38.0% at retort temperatures near T_R = 121.1 °C.

APPENDIX A: CALCULATION SCHEME STUMBO

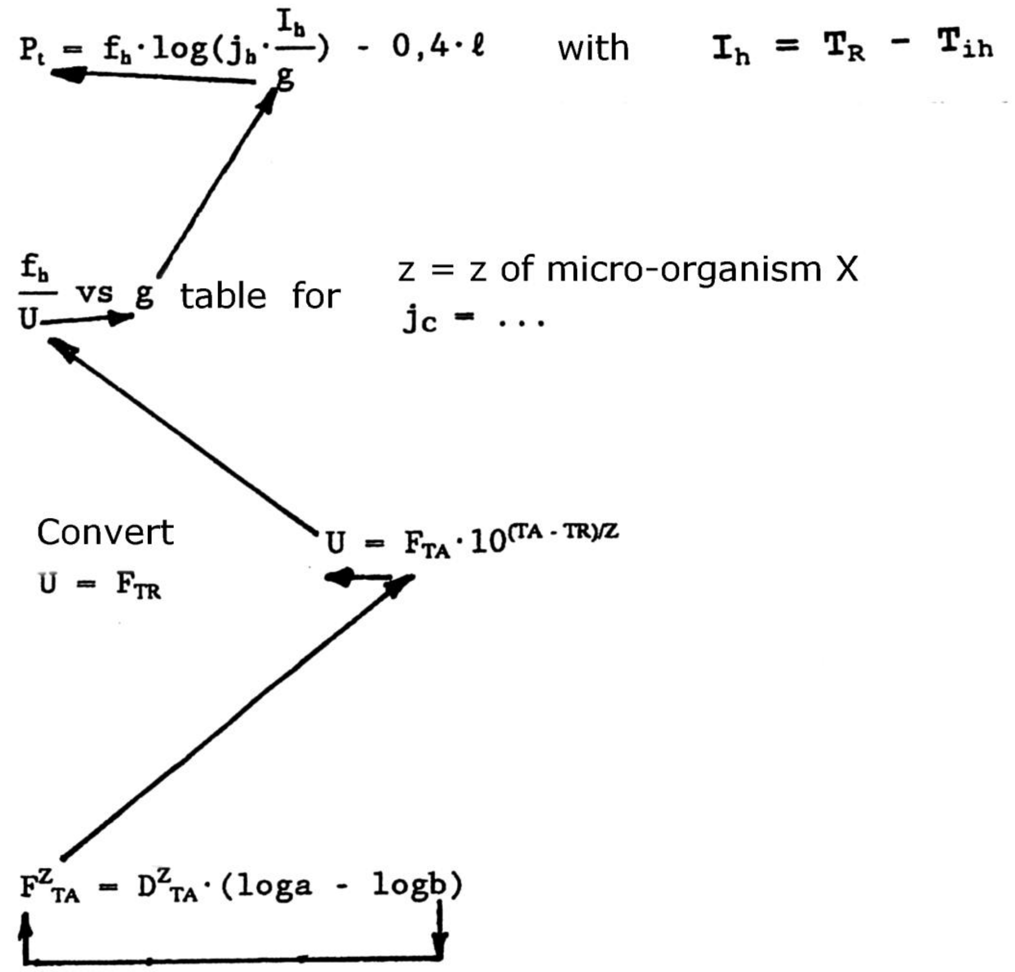
for <u>manual</u> calculation of the heating time P_t of a liquid food if microbial data (D, z, a, b) or F value are known

Follow the arrows from b at the bottom up to P_t at the top to calculate P_t of a liquid food:

LIQUID FOOD

CALCULATION OF THE STERILIZATION TIME P_t

[in case the required spoilage rate b by the micro-organism of concern X and the thermal destruction data D, z and a of micro-organism X are known; or if the F value with regard to sufficiently killing micro-organism X is known]



<u>Liquid</u> food: **a** = **TOTAL** initial number of micro-organism of concern X in the whole container, prior to heating.

COMPUTER PROGRAM: **STUMBO.exe**

APPENDIX B: CALCULATION SCHEME STUMBO

for <u>manual</u> calculation of the % nutrient retention b_N of a liquid food, if microbial data (D, z_X, a_X, b_X) or F value are known, and if nutrient data (D_N, z_N, initial % = 100) are known

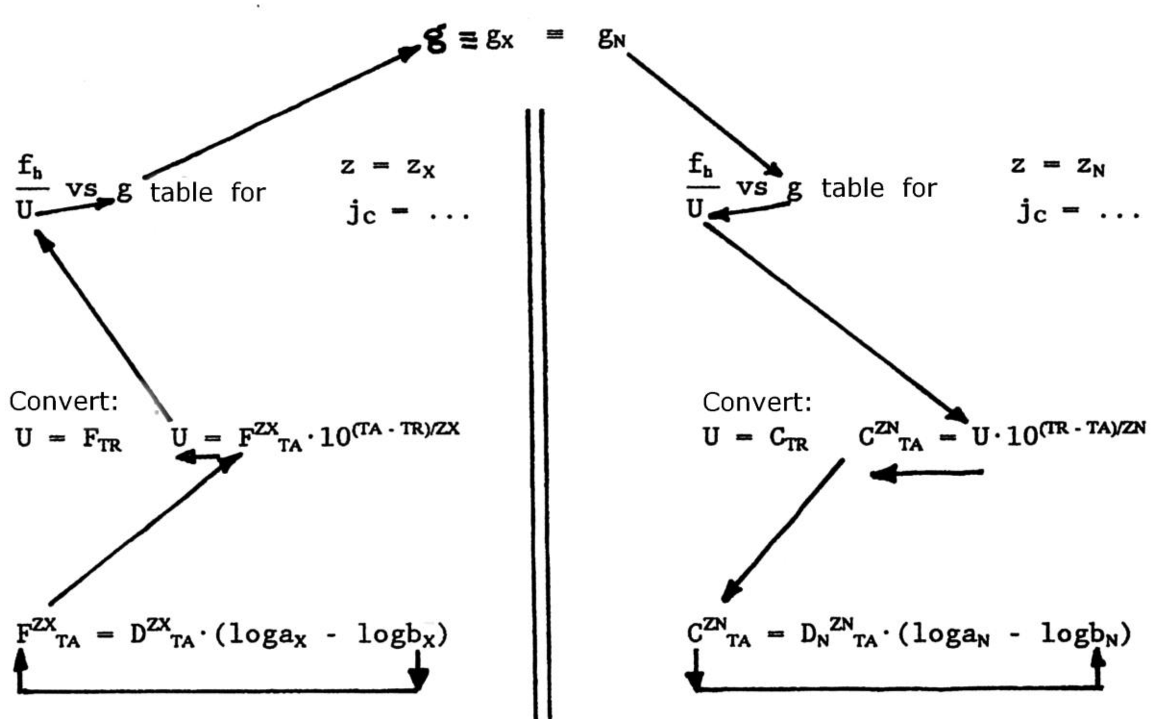
Follow the arrows from bottom **left** (micro-organism: b_X or F) via g to bottom **right** (nutrient: b_N), to calculate the % nutrient retention b_N in a liquid food after heating:

<u>LIQUID FOOD</u>

CALCULATION OF THE % NUTRIENT RETENTION b_N

[in case the required spoilage rate b_X by the micro-organism of concern X and the thermal destruction data D, z_X and a_X of micro-organism X are known; or if the F value with regard to sufficiently killing micro-organism X is known]

$$P_t = f_h \cdot \log(j_h \cdot \frac{I_h}{g}) - 0{,}4 \cdot \ell \qquad \text{with} \qquad I_h = T_R - T_{ih}$$



Liquid product:
a_X = **total** initial number of micro-organisms X in the whole container, prior to heating.

For a_N = **initial** % of nutrient N in food, please substitute a_N = 100%; then the calculated nutrient retention b_N will be the % nutrient left after heating.

For nutrients, some authors use C instead of F

Micro-organism of concern X | **Nutrient N**

COMPUTER PROGRAM: **STUMBO.exe**

<u>N.B.</u>: For nutrients, some authors use symbol C instead of F. Thus $C^{ZN}_{TA} = F^{ZN}_{TA}$.

APPENDIX C: Stumbo Table fh/U versus g for several jc values if z = 10 ºC

Values of fh/U versus g for z = 10 ºC

Values of g [in ºC] at following jc of cooling section:

fh/U	jc = 0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00 = jc
0.20	0.000023	0.000025	0.000026	0.000028	0.000030	0.000032	0.000034	0.000036	0.000038
0.30	0.00112	0.00119	0.00126	0.00133	0.00140	0.00148	0.00155	0.00163	0.00170
0.40	0.00739	0.00794	0.00844	0.00900	0.00950	0.0100	0.0106	0.0111	0.0116
0.50	0.0228	0.0246	0.0263	0.0281	0.0299	0.0317	0.0334	0.0352	0.0369
0.60	0.0483	0.0524	0.0567	0.0606	0.0644	0.0683	0.0728	0.0767	0.0806
0.70	0.083	0.0906	0.0978	0.105	0.112	0.119	0.127	0.138	0.142
0.80	0.126	0.137	0.148	0.159	0.171	0.182	0.194	0.205	0.217
0.90	0.174	0.190	0.206	0.222	0.238	0.254	0.271	0.287	0.302
1.00	0.227	0.248	0.269	0.291	0.312	0.333	0.354	0.376	0.397
2.00	0.850	0.922	1.00	1.07	1.15	1.23	1.30	1.38	1.45
3.00	1.46	1.58	1.69	1.81	1.93	2.04	2.16	2.28	2.39
4.00	2.01	2.15	2.30	2.45	2.60	2.74	2.89	3.04	3.19
5.00	2.47	2.64	2.82	3.00	3.17	3.35	3.53	3.71	3.88
6.00	2.86	3.07	3.27	3.47	3.67	3.88	4.08	4.28	4.48
7.00	3.21	3.43	3.66	3.89	4.12	4.34	4.57	4.80	5.03
8.00	3.49	3.75	4.00	4.26	4.51	4.76	5.01	5.26	5.52
9.00	3.76	4.03	4.30	4.58	4.85	5.13	5.41	5.68	5.96
10.00	3.98	4.28	4.58	4.88	5.18	5.48	5.77	6.07	6.37
15.00	4.85	5.24	5.64	6.04	6.44	6.84	7.23	7.63	8.03
20.00	5.46	5.94	6.42	6.89	7.37	7.84	8.32	8.79	9.27
25.00	5.94	6.50	7.06	7.56	8.11	8.67	9.17	9.72	10.22
30.00	6.39	6.94	7.56	8.11	8.72	9.33	9.89	10.50	11.06
35.00	6.72	7.39	8.00	8.61	9.28	9.89	10.50	11.11	11.78
40.00	7.11	7.72	8.39	9.06	9.72	10.39	11.06	11.72	12.39
45.00	7.39	8.11	8.78	9.44	10.17	10.83	11.56	12.22	12.83
50.00	7.67	8.39	9.11	9.83	10.56	11.28	12.00	12.67	13.39
60.00	8.22	8.94	9.72	10.50	11.22	12.00	12.72	13.50	14.28
70.00	8.67	9.44	10.22	11.06	11.83	12.61	13.39	14.22	15.00
80.00	9.06	9.89	10.72	11.56	12.33	13.17	14.00	14.83	15.61
90.00	9.44	10.28	11.17	12.00	12.83	13.67	14.50	15.33	16.22
100.00	9.77	10.67	11.56	12.39	13.28	14.11	15.00	15.83	16.72
150.00	11.2	12.1	13.1	14.0	14.9	15.8	16.8	17.7	18.7
200.00	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1
250.00	12.7	13.8	14.8	15.9	16.9	18.0	19.1	20.1	21.2
300.00	13.2	14.3	15.4	16.6	17.7	18.7	19.8	20.9	22.1
350.00	13.6	14.8	15.9	17.1	18.2	19.4	20.6	21.7	22.8
400.00	13.9	15.1	16.3	17.5	18.7	19.9	21.1	22.3	23.5
450.00	14.2	15.4	16.7	17.9	19.2	20.4	21.6	22.9	24.4
500.00	14.4	15.7	17.0	18.3	19.6	20.8	22.1	23.4	24.7
600.00	14.9	16.2	17.6	18.9	20.2	21.6	22.9	24.2	25.6
700.00	15.3	16.7	18.1	19.4	20.8	22.2	23.6	24.9	26.3
800.00	15.6	17.1	18.5	19.9	21.3	22.7	24.2	25.6	27.0
900.00	15.9	17.4	18.9	20.3	21.8	23.2	24.7	26.1	27.6
999.99	16.3	17.7	19.2	20.7	22.2	23.7	25.2	26.6	28.1

Adapted from C.R. Stumbo (1973). Original g values [in ºF] converted to ºC.

How to use this table:

If fh/U = 5.00 (left hand column), and jc = 1.20 (top row), then value of g = 3.17 ºC.

[g in middle section of table, at intersection of row fh/U = 5.00 and column jc = 1.20].

If jc = 1.00 (top row) and g = 4.58 ºC (middle section of table), then fh/U = 9.00 (left hand column).

[In column jc = 1.00, find g = 4.58 (in middle section of table); row of g leads to fh/U = 9.00 at left side].

APPENDIX D: Stumbo Table fh/U versus g for several jc values if z = 27.8 ºC

Values of fh/U versus g for z = 27.8 ºC

Values of g [in ºC] at following jc of cooling section:

fh/U	jc = 0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00 = jc
0.20	0.000058	0.000066	0.000074	0.000083	0.000917	0.000100	0.000108	0.000117	0.000125
0.30	0.00267	0.00307	0.00346	0.00386	0.00425	0.00464	0.00504	0.00543	0.00583
0.40	0.0184	0.0211	0.0237	0.0264	0.0291	0.0317	0.0343	0.0370	0.0397
0.50	0.059	0.067	0.076	0.084	0.092	0.101	0.109	0.117	0.126
0.60	0.128	0.146	0.164	0.182	0.200	0.218	0.237	0.254	0.273
0.70	0.223	0.254	0.286	0.318	0.349	0.381	0.413	0.444	0.476
0.80	0.339	0.388	0.436	0.484	0.533	0.582	0.630	0.678	0.727
0.90	0.472	0.540	0.608	0.676	0.743	0.811	0.878	0.946	1.014
1.00	0.62	0.71	0.79	0.88	0.97	1.06	1.15	1.24	1.33
2.00	2.22	2.54	2.88	3.21	3.54	3.87	4.20	4.53	4.86
3.00	3.64	4.19	4.75	5.30	5.86	6.41	6.96	7.51	8.07
4.00	4.84	5.58	6.32	7.06	7.80	8.54	9.28	10.02	10.76
5.00	5.8	6.8	7.7	8.6	9.4	10.3	11.3	12.2	13.1
6.00	6.7	7.8	8.8	9.8	10.9	11.9	12.9	14.0	15.1
7.00	7.5	8.7	9.8	10.9	12.1	13.3	14.4	15.6	16.8
8.00	8.2	9.4	10.7	11.9	13.2	14.5	15.8	17.1	18.3
9.00	8.8	10.1	11.5	12.9	14.2	15.6	16.9	18.3	19.7
10.00	9.3	10.8	12.2	13.7	15.2	16.6	18.1	19.5	20.9
10.25	9.4	10.9	12.4	13.9	15.3	16.8	18.3	19.8	21.3
10.50	9.6	11.1	12.6	14.1	15.6	17.1	18.6	20.1	21.6
10.75	9.7	11.2	12.7	14.3	15.8	17.3	18.8	20.3	21.8
11.00	9.8	11.3	12.9	14.4	15.9	17.5	19.1	20.6	22.1
12.00	10.3	11.9	13.5	15.1	16.7	18.3	19.9	21.6	23.2
13.00	10.7	12.4	14.1	15.8	17.4	19.1	20.8	22.4	24.2
14.00	11.2	12.9	14.6	16.3	18.1	19.8	21.6	23.3	25.1
15.00	11.6	13.3	15.1	16.9	18.7	20.5	22.3	24.1	25.9
16.00	11.9	13.7	15.6	17.4	19.3	21.2	23.0	24.8	26.7
17.00	12.3	14.2	16.1	17.9	19.8	21.7	23.6	25.6	27.4
18.00	12.6	14.6	16.4	18.4	20.3	22.3	24.2	26.2	28.1
19.00	12.9	14.9	16.9	18.9	20.8	22.8	24.8	26.8	28.8
20.00	13.2	15.2	17.3	19.3	21.3	23.3	25.4	27.4	29.4

Adapted from C.R. Stumbo (1973). Original g values [in ºF] converted to ºC.

How to use this table:

If fh/U = 10.00 (left hand column), and jc = 1.00 (top row), then value of g = 13.7 ºC

[g in middle section of table, at intersection of row fh/U = 10 and column jc = 1.00].

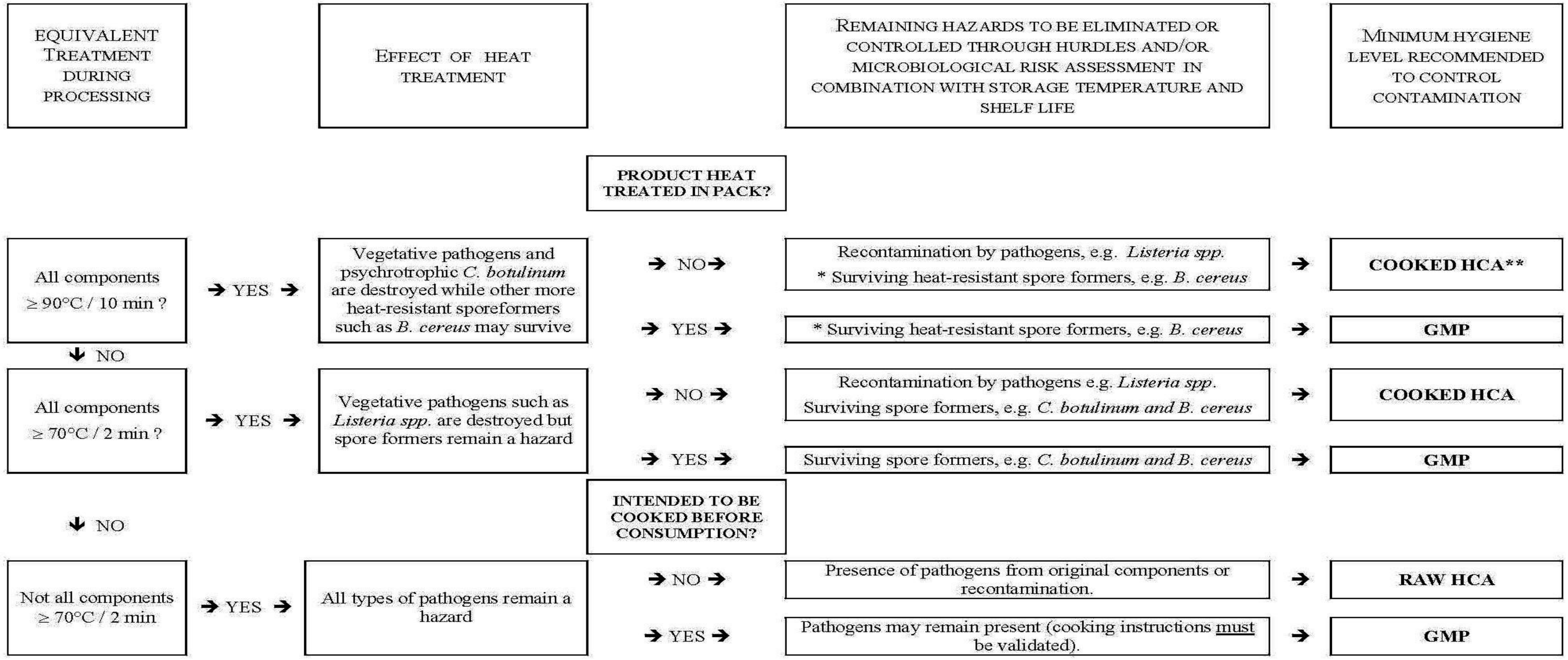
If jc = 1.40 (top row) and g = 8.54 ºC (middle field), then fh/U = 4.00 (left hand column).

[In column jc = 1.40, find g = 8.54 (in middle section of table); row of g leads to fh/U = 4.00 at left side].

APPENDIX E:
DECISION TREE TO DETERMINE THE MINIMUM HYGIENIC STATUS FOR CHILLED PRODUCTS

ECFF Recommendations December 2006

Figure 1: Decision tree to determine the minimum hygienic status required for chilled products



* *B. cereus* is managed in all cases by controlling raw materials, compositional factors (see Table 1), rapid chilling, storage temperature and shelf life

Note: This decision tree does not take into account the use of hurdles other than heat treatment and chilled storage. Refer to section 1.2 and the examples of usage of the Decision Tree in Appendix B.

** GMP conditions are sufficient if the product is mildly pasteurised in pack to inactivate any recontamination that may have occurred

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