GENERAL INDEX

1. FRAMEWORK	1
2. INTRODUCTION	5
2.1 HIGH NUTRITIONAL FOOD: FRUIT JUICE-MILK BASED PRODUCTS	6
2.2 THERMAL TREATMENT	6
2.2.1 Influence of thermal treatment on fruit juices quality	7
2.2.2 Methods for thermoresistance measurement	7
2.2.2.1 TDT tubes/disks	8
2.2.2.2 Capillary tubes	9
2.2.2.3 Industrial scale-up	9
2.3 NONTHERMAL PRESERVATION TECHNOLOGIES	10
2.4 HIGH HYDROSTATIC PRESSURE (HHP)	11
2.4.1 HHP treatment system	11
2.4.1.1 One step treatment	15
2.4.1.2 Multi-step treatment	15
2.4.1.3 Step-wise treatment	16
2.4.2 HHP technology related factors	16
2.4.2.1 Pressure level and treatment time	16
2.4.2.2 Temperature: adiabatic heating	17
2.4.2.3 Presurization/depresurization time	19
2.4.3 Food and packaging related factors	19
2.4.3.1 Type of packaging	19
2.4.3.2 Presence of air	20
2.4.3.3 Water activity	20
2.4.3.4 pH	21
2.4.4 HHP microbial inactivation	21
2.4.4.1 Spore inactivation	21
2.4.4.2 Vegetative cells inactivation	22
2.4.5 HHP enzyme inactivation	22
2.4.6 HHP advantages and disadvantages	24
2.4.6.1 Advantages	24
2.4.6.2 Disadvantages	24
2.5 PULSED ELECTRIC FIELD (PEF)	25
2.5.1 PEF treatment system	27
2.5.1.1 Treatment chambers	29
2.5.2 PEF technology related factors	30

2.5.2.1 Electric field strength (E)	30
2.5.2.2 Pulse waveform and polarity	31
2.5.2.3 Temperature (T)	33
2.5.2.4 Treatment time (t)	33
2.5.2.5 Pulse width (w)	34
2.5.3 Product related factors	34
2.5.3.1 Electrical conductivity	35
2.5.3.2 pH	35
2.5.3.3 Viscosity (particulate food)	36
2.5.3.4 Water activity	36
2.5.4 PEF microbial inactivation	36
2.5.4.1 Microorganism type	38
2.5.4.2 Microorganism inoculum size	38
2.5.4.3 Growth phase	39
2.5.5 PEF enzyme inactivation	39
2.5.6 PEF advantages and disadvantages	40
2.5.6.1 Advantages	40
2.5.6.2 Disadvantages	40
2.6 ORANGE JUICE ENZYME ACTIVITY	41
2.6.1 Pectins	41
2.6.2 Pectolytic enzymes: pectin methyl esterase (PME)	41
2.7 ORANGE JUICE MICROBIAL CHARACTERIZATION	42
2.7.1 Salmonella typhimurium	42
2.7.2 Lactobacillus plantarum	44
2.7.3 Orange juice microbial safety	45
2.8 INACTIVATION KINETIC MODELS	46
2.8.1 Microbial inactivation kinetic models	47
2.8.1.1 Bigelow	47
2.8.1.2 Hülsheger	47
2.6.1.3 Weibull	48
2.8.2 Enzyme inactivation kinetic models	49
2.8.2.1 Primary models	49
2.8.2.2 Secondary models	51
2.8.3 z parameter	51
2.8.4 Model fit validity	53
2.8.5 Goodness of fit	53
3 OBJETIVES	55

RESULTS	58
1 DEVELOPMENT OF A NEW PRODUCT BASED ON ORANGE JUICE A	ND MILK
DEAL FOR PEF TREATMENT	59
1.1 ABSTRACT	60
1.2 INTRODUCTION	61
1.3 MATERIAL AND METHODS	62
4.1.3.1 Composition and physicochemical product characterization	62
4.1.3.2 PEF treatment	62
4.1.3.3 Escherichia coli	63
4.1.3.4 Sensory analysis	64
4.1.4 RESULTS AND DISCUSSION	64
4.1.4.1 Elaboration methodology and physicochemical characterizat	ion 64
4.1.4.2 Effect of food composition on PEF inactivation of E. coli	65
4.1.4.3 Sensory analysis	65
4.2 EFFECT OF PEF, HHP AND THERMAL TREATMENT	ON PME
INACTIVATION AND VOLATILE COMPOUNDS OF AN ORAN	GE JUICE-
MILK BASED BEVERAGE	68
4.2.1 ABSTRACT	69
4.2.2 INTRODUCTION	70
4.2.3 MATERIAL AND METHODS	71
4.2.3.1 Beverage preparation	71
4.2.3.2 Thermal treatment	71
4.2.3.3 PEF treatment	72
4.2.3.4 HHP treatment	72
4.2.3.5 Analysis of headspace volatile compounds	73
4.2.3.6 PME activity measurement	73
4.2.3.7 Experimental design and statistical analysis	74
4.2.4 RESULTS AND DISCUSSION	74
4.2.4.1 Effect of treatment on PME activity in the orange	
juice-milk based beverage	74
4.2.4.2 Effect of treatment on the volatile compounds	
concentration in the orange juice-milk based beverage	77
4.3 INACTIVATION KINETICS OF PECTIN METHYL ESTERASE	UNDER
COMBINED THERMAL-HIGH PRESSURE TREATMENT IN AN O	RANGE
JUICE-MILK BEVERAGE	83
4.3.1 ABSTRACT	84
4.3.2 INTRODUCTION	85

4.3.3 MATERIAL AND METHODS	87
4.3.3.1 Orange juice and beverage preparation	87
4.3.3.2 PME activity measurement	87
4.3.3.3 Experimental design	87
4.3.3.4 Thermal inactivation at atmospheric pressure	88
4.3.3.5 Combined thermal and high-pressure inactivation	88
4.3.3.6 Orange PME purification	89
4.3.3.7 Data analysis and parameter estimation	89
4.3.3.8 Effect of food matrix	92
4.3.4 RESULTS AND DISCUSSION	92
4.3.4.1 Thermal inactivation of the PME in the orange	
juice-milk based beverage	92
4.3.4.2 Combined thermal and high-pressure inactivation of	
PME in the orange juice-milk based beverage	95
4.3.4.3 Effect of orange matrices	96
4.4 PULSED ELECTRIC FIELDS INACTIVATION OF Lactobacillus	olantarum
IN AN ORANGE JUICE-MILK BASED BEVERAGE: EFFECT OF P	ROCESS
PARAMETERS	101
4.4.1 ABSTRACT	102
4.4.2 INTRODUCTION	103
4.4.3 MATERIAL AND METHODS	104
4.4.3.1 Food sample	104
4.4.3.2 Lactobacillus plantarum	105
4.4.3.3 PEF treatment	105
4.4.3.4 Statistical analysis	106
4.4.4 RESULTS	107
4.4.4.1 Effect of electric field strength	107
4.4.4.2 Effect of temperature	108
4.4.4.3 Effect of pulse width	111
4.4.5 DISCUSSION	114
4.5 EFFECT OF TEMPERATURE AND SUBSTRATE	ON PEF
INACTIVATION OF Lactobacillus plantarum IN AN ORANGE JUI	CE-MILK
BEVERAGE	119
4.5.1 ABSTRACT	120
4.5.2 INTRODUCTION	121
4.5.3 MATERIAL AND METHODS	122
4.5.3.1 Food sample	122

4.5.3.2 Lactobacillus plantarum	123
4.5.3.3 PEF treatment	123
4.5.3.4 Mathematical models	124
4.5.3.5 Statistical analysis	125
4.5.4 RESULTS AND DISCUSSION	126
4.6 EFFECT OF pH AND PECTIN CONCENTRATION	ON PEF
INACTIVATION OF Salmonella typhimurium IN AN ORANGE J	UICE-MILK
BEVERAGE	132
4.6.1 ABSTRACT	133
4.6.2 INTRODUCTION	134
4.6.3 MATERIAL AND METHODS	136
4.6.3.1 Food sample	136
4.6.3.2 Salmonella typhimurium	136
4.6.3.3 PEF treatment	137
4.6.3.4 Mathematical models	137
4.6.3.5 Statistical analysis	137
4.6.4 RESULTS AND DISCUSSION	139
4.6.4.1 Effect of pH	143
4.6.4.2 Effect of pectin concentration	145
4.7 SHELF-LIFE STUDY OF AN ORANGE JUICE-MILK BASED B	BEVERAGE
AFTER COMBINED PEF AND THERMAL PROCESSING	148
4.7.1 ABSTRACT	149
4.7.2 INTRODUCTION	150
4.7.3 MATERIAL AND METHODS	151
4.7.3.1 Beverage preparation	151
4.7.3.2 Thermal treatment	151
4.7.3.3 PEF treatment	152
4.7.3.4 Packaging and storage	152
4.7.3.5 Analysis of headspace volatile compounds	153
4.7.3.6 PME activity measurement	153
4.7.3.7 Physical property measurements	154
4.7.3.8 Color measurement	154
4.7.3.9 Microbiological assay	155
4.3.7.3.10 Statistical analysis	155
4.7.4 RESULTS AND DISCUSSION	155
4.7.4.1 Effects of processing and storage on physical	
properties	155

	4.7.4.2 Effects of processing and storage on microbial flora	156
	4.7.4.3 Effects of processing and storage on PME activity	159
	4.7.4.4 Effects of processing and storage on color	
	measurement	160
	4.7.4.5 Effects of processing and storage on volatile	
	compounds content	162
5. GENERAL	DISCUSSION	167
6. CONCLUS	IONS	175
7. REFEREN	CES	178
8. ANNEXES		192
8.1 CC	DMMUNICATIONS BASED ON THESIS WORK	193
8.2 ST	ATISTICAL ANALYSIS	198

TABLES INDEX

TABLES INDEX	
Table 2.4.1: Adiabatic heating in different food (Toepfl, et al., 2006)	18
Table 4.1.1: Physicochemical characterization of different formulations	67
Table 4.1.2: Sample ranking based on aspect, flavor, viscosity and global appreciation.	67
<i>Table 4.2.1</i> : PME residual activity after combined PEF and thermal treatment in the juice milk based beverage	e orange- 76
<i>Table 4.3.1</i> : Biphasic and fractional conversion kinetic parameters estimate \pm stand describing isothermal inactivation of PME in the orange juice-milk based bevatmospheric pressure	
<i>Table 4.3.2</i> : Biphasic kinetic parameters estimate \pm standard error describing the thermal and high pressure inactivation of PME in the orange juice-milk based beverage	
<i>Table 4.4.1</i> : Effect of electric field strength on the inactivation of <i>L. plantarum</i> in the j beverage	uice-milk 109
<i>Table 4.5.1</i> : Kinetic parameters and <i>Af</i> and <i>MSE</i> values of Bigelow, Hülsheger and models for <i>L. plantarum</i> survivor curves at initial treatment temperature of 35°C	Weibull 131
<i>Table 4.5.2</i> : Kinetic parameters of Weibull model for <i>L. plantarum</i> in orange-ca (Rodrigo et al., 2001), peptone water (Rodrigo et al., 2003) and the beverage studied	rrot juice 131
<i>Table 4.6.1</i> : Kinetic parameters and <i>Af</i> and <i>MSE</i> values of Bigelow, Hülsheger and models for <i>S. typhimurium survivor</i> curves	l Weibull 142
<i>Table 4.6.2</i> : Comparison of \overline{tcw} values for <i>S. typhimurium</i> , <i>L. plantarum</i> (Samper 2006) and <i>E.coli</i> (Rivas et al., 2006) in the orange juice-milk beverage	lro et al., 142
<i>Table 4.6.3</i> : Effect of pH and electric field on the \overline{tcw} Weibull parameter	143
<i>Table 4.6.4</i> : Effect of pectin concentration and electric field on the \overline{tcw} Weibull parameters.	neter 145
<i>Table 4.7.1</i> : Effect of thermal and PEF processing on different parameters of an orar milk beverage	nge juice- 157
<i>Table 4.7.2</i> : Effect of thermal and PEF processing on volatile compounds content of a juice-milk beverage	an orange 164
Table 8.2.1: Effect of juice content on PEF inactivation of <i>E.coli</i> at 40 kV/cm	199
Table 8.2.2: Effect of temperature on volatile compounds concentration after thermal tr	eatment 199
<i>Table 8.2.3</i> : Effect of electric field strength on volatile compounds concentration a treatment at 25, 45 and 65°C	after PEF 200
<i>Table 8.2.4</i> : Effect of temperature on volatile compounds concentration after PEF tre 15, 20, 25 and 30 kV/cm	atment at 201

Table 8.2.5: Effect of pressure level on volatile compounds concentration after HHP t at 30 and 50° C	reatment 202
<i>Table 8.2.6</i> : Effect of temperature on volatile compounds concentration after HHP trea 450, 500, 550, 600 and 650 MPa	atment at 202
<i>Table 8.2.7</i> : Effect of treatment time on survivors fraction of <i>L. plantarum</i> after PEF t at 35 and 40 kV/cm and 35°C	reatment 204
<i>Table 8.2.8</i> : Effect of electric field strength on survivors fraction of <i>L. plantarum</i> a treatment at 40, 60, 80 and 130 μ s and 35°C	fter PEF 205
<i>Table 8.2.9</i> : Effect of temperature on survivors fraction of <i>L. plantarum</i> after PEF trea 35 and 40 kV/cm	atment at 205
<i>Table 8.2.10</i> : Effect of treatment time on survivors fraction of <i>L. plantarum</i> after PEF t at 35 and 40 kV/cm and 55°C	reatment 206
<i>Table 8.2.11</i> : Effect of pulse width on survivors fraction of <i>L. plantarum</i> after PEF trea 40 and 35 kV/cm and 35°C	atment at 207
<i>Table 8.2.12</i> : Effect of pulse width on survivors fraction of <i>L. plantarum</i> after PEF trea 40 and 35 kV/cm and 55°C	atment at 207
Table 8.2.13: Effect of electric field strength on D value of Bigelow model for L. planta	erum 208
<i>Table 8.2.14</i> : Effect of electric field strength on \overline{tCW} value for <i>L. plantarum</i>	208
<i>Table 8.2.15</i> : Effect of temperature on \overline{tcw} value for <i>L. plantarum</i>	208
Table 8.2.16: Effect of electric field strength on D value of Bigelow model for S. typhin	urium 209
Table 8.2.17: Effect of electric field strength on tc value of Hülsheger model for S. typh	imurium 209
<i>Table 8.2.18</i> : Effect of electric field strength on \overline{tcw} value for <i>S. typhimurium</i>	209
<i>Table 8.2.19</i> : Effect of type of microorganism on \overline{tcw} value	210
<i>Table 8.2.20</i> : Effect of pH on \overline{tcw} value at 15 and 40 kV/cm	211
<i>Table 8.2.21</i> : Effect of pectin concentration on \overline{tcw} value at 15 and 40 kV/cm	211
<i>Table 8.2.22</i> : Effect of electric field strength on. \overline{tcw} value at 0.1, 0.3 and 0.6%	212
Table 8.2.23: pH value after PEF and thermal treatment	212
Table 8.2.24: pH value during storage of PEF, thermal and untreated sample	213
Table 8.2.25: Brix degrees after PEF and thermal treatment	214

Table 8.2.26: Brix degrees during the storage of PEF, thermal and untreated sample	214
Table 8.2.27: Microbial inactivation after PEF and thermal treatment	215
Table 8.2.28: PME activity after PEF and thermal treatment	215
Table 8.2.29: PME activity during the storage of PEF, thermal and untreated sample	216
Table 8.2.30: L* value after PEF and thermal treatment	217
Table 8.2.31: L* value during the storage of PEF, thermal and untreated sample	217
Table 8.2.32: a* value after PEF and thermal treatment	218
Table 8.2.33: a* value during the storage of PEF, thermal and untreated sample	218
Table 8.2.34: b* value after PEF and thermal treatment	219
Table 8.2.35: b* value during the storage of PEF, thermal and untreated sample	220

FIGURES INDEX

<i>Figure 2.2.1</i> -TDT tube with an inner thermocouple (A). Instituto de Agroquímica y Te de Alimentos, Valencia (Spain). TDT disk (B). Eastern Regional Research Center, US (USA)	
<i>Figure 2.2.2</i> -Capillary tubes (200 μ L). Instituto de Agroquímica y Tecnología de Al Valencia (Spain)	limentos, 9
Figure 2.2.3-Plate heat exchanger. Eastern Regional Research Center, USDA, PA, (USA	A) 10
<i>Figure 2.4.1</i> -Number of HHP equipment installed in Europe by Hyperbaric [®] versus (A instalment and (B) industrial sector for the instalment (Urrutia-Benet, 2005)) year of 12
<i>Figure 2.4.2-</i> HHP lab-scale equipment: (A)-Laboratory of Food Process, Ka Universiteit Leuven, (Belgium), (B)-Instituto de Agroquímica y Tecnología de Al Valencia, (Spain)	
Figure 2.4.3-HHP industrial-scale equipment (Hyperbaric S.A., Burgos, Spain)	13
<i>Figure 2.4.4</i> -Illustration of direct pressurization (A) and indirect pressurization (B) 2002)	(Rovere, 14
Figure 2.4.5-One step treatment	15
Figure 2.4.6-Multi-step treatment (2 steps)	16
Figure 2.4.7-Step-wise treatment	16
<i>Figure 2.4.8</i> -T-P combination to obtain 1 log reduction of different microorgani enzymes (Ludikhuyze et al., 2002)	sms and 17
<i>Figure 2.4.9</i> -HHP common variables: temperature, pressure and treatmen (Balasubramaniam et al., 2004)	nt time 19
Figure 2.5.1-Fruit juices treated by PEF. Genesis Juice Corp. (Prof. H. Zhang)	26
<i>Figure 2.5.2-</i> Treatment chambers-(A). PEF industrial-scale equipment-(B). Oh University, OH, (USA). (Prof. H. Zhang)	io State 26
Figure 2.5.3-PEF industrial-scale equipment combined with a heat exchanger (Prof. H.	
<i>Figure 2.5.4</i> : PEF laboratory equipment-(A). Main components of a PEF equipment: i treatment chambers and thermocouples-(B). Instituto de Agroquímica y Tecnol Alimentos, Valencia, (Spain)	
<i>Figure 2.5.5</i> -Scheme of treatment chambers configuration: co-field, co-axial and (Barbosa et al., 1998)	parallel 29
<i>Figure 2.5.6</i> -Components of a co-field treatment chamber. Instituto de Agroqu Tecnología de Alimentos, Valencia, (Spain)	uímica y 30
Figure 2.5.7-Exponential decay wave (Barbosa et al., 1999)	31

Figure 2.5.8-Square wave (Barbosa et al., 1999)	32
Figure 2.5.9-Bipolar square wave (Barbosa et al., 1999)	32
Figure 2.5.10-Pulse width (w) (Barbosa et al., 1999)	34
Figure 2.5.11-Effect of PEF treatment on cell membrane (Barbosa et al., 1999)	37
Figure 2.5.12-Cellular size comparison (Qin et al., 1998)	39
Figure 2.6.1-Three-dimensional structure by ions interaction (Plinik and Voragen, 1991)42
Figure 2.7.1-Electron microscopy of Salmonella typhimurium	44
Figure 2.7.2-Electron microscopy of Lactobacillus plantarum	45
Figure 2.8.1-Illustration of different nonlinear survival curves	48
Figure 4.1.1-Orange juice-milk based product	66
Figure 4.1.2-Effect of food composition on PEF inactivation of E. coli at 40 kV/cm	66
Figure 4.2.1-Isothermal inactivation of PME in the orange juice-milk based beverage	75
Figure 4.2.2-Combined HHP and thermal inactivation of PME in the orange juice-m beverage	ilk based 77
<i>Figure 4.2.3</i> -Effect of thermal treatment for 1 min on volatile compounds content in the juice-milk based beverage	ne orange 79
<i>Figure 4.2.4</i> -Effect of combined PEF and thermal treatment (25, 45 and 65 °C) or compounds content in the orange juice-milk based beverage	n volatile 80
<i>Figure 4.2.5</i> -Effect of combined HHP and thermal treatment (30 and 50°C) on compounds content in the orange juice-milk based beverage	volatile 82
Figure 4.3.1-Isothermal inactivation of PME in the beverage fitted by a biphasic model	95
<i>Figure 4.3.2</i> -Combined thermal and high-pressure inactivation of PME in the beverage a biphasic model	fitted by 98
<i>Figure 4.3.3</i> -Isothermal inactivation of purified PME, PME in the orange juice-mi beverage and PME in orange juice	ilk based 99
<i>Figure 4.3.4</i> -Pressure inactivation of purified PME, PME in the orange juice-mi beverage and PME in orange juice	lk based 100
<i>Figure 4.4.1</i> -Inactivation curves as a function of the treatment time (A) and energy ap for <i>L. plantarum</i> with T=35 °C and pulse width of 2.5 μ s	plied (B) 108
<i>Figure 4.4.2</i> -Effect of treatment temperature on the inactivation of <i>L. plantarum</i> as a fut treatment time with E=35 kV/cm (A) and E=40 kV/cm (B) and as a function of energy with E=35 kV/cm (C) and E=40 kV/cm (D) and pulse width of 2.5 μ s	

Figure 4.4.3-Influence of pulse width in the inactivation of *L. plantarum* at 35°C as a function of treatment time with E=35 kV/cm (A) and E=40 kV/cm (B) and energy applied with E=35 kV/cm (C) and E=40 kV/cm (D) 111

Figure 4.4.4-Influence of pulse width in the inactivation of *L. plantarum* at 55°C as a function of energy applied with E=35 kV/cm (A) and E=40 kV/cm (B) 113

Figure 4.4.5-Effect of treatment temperature on the inactivation of *L. plantarum* as a function of energy applied with E=35 kV/cm (A) and E=40 kV/cm (B) and pulse width of 4 μ s 113

Figure 4.5.1-Growth curve of *L. plantarum* in the orange juice-milk beverage at 37°C 127

Figure 4.5.2-Survival curves of *L. plantarum* in juice-milk based beverage at different electric field strengths at initial T of 35°C adjusted to the Weibull model. The deviation standard was expressed by error bars 128

Figure 4.5.3-Effect of T in the survive fraction of *L. plantarum* and *tcw* of the Weibull model in the beverage with E=40 kV/cm. The deviation standard was expressed by error bars 128

Figure 4.6.1-Salmonella typhimurium counts at 37°C in the orange juice-milk product 140

Figure 4.6.2-Survival curves of *S. typhimurium* in the juice-milk based beverage at (\bullet) 15 kV/cm, (\blacktriangle) 25 kV/cm, (\blacksquare) 35 kV/cm and (\bullet) 40 kV/cm at pH=4 adjusted to the Weibull model (—) 141

Figure 4.6.3-Survival curves of *S. typhimurium* in the juice-milk based beverage at 15 kV/cm at $pH=3.5(\bullet)$, $pH=4(\bullet)$ y $pH=4.5(\bullet)$ adjusted to the Weibull model (—) 144

Figure 4.6.4-Survival curves of *S. typhimurium* in the juice-milk based beverage at 40 kV/cm at $pH=3.5(\bullet)$, $pH=4(\bullet)$ y $pH=4.5(\bullet)$ adjusted to the Weibull model (--) 144

Figure 4.6.5:
$$z_{pH}$$
 estimation at $E = 15 \text{ kV/cm}$ (\blacklozenge) and $E = 40 \text{ kV/cm}$ (\blacksquare) 145

*Figure 4.6.6-*Survival curves of *S. typhimurium* in the juice-milk based beverage at 15 kV/cm at 0.1% (•), 0.3% (•) and 0.4% (•) adjusted to the Weibull model (--) 146

Figure 4.6.7-Survival curves of *S. typhimurium* in the juice-milk based beverage at 40 kV/cm at 0.1% (•), 0.3% (•) and 0.4% (•) adjusted to the Weibull model (--) 146

Figure 4.6.8- $z_{\%}$ estimation at E = 15 kV/cm (\blacklozenge) and E = 40 kV/cm (\blacksquare) 147

Figure 4.7.1- Growth of microbial flora (A) and mold and yeast counts (B) during the storage (♦) control sample, (▲) thermal sample and (■) PEF sample 158

Figure 4.7.2-Change of PME activity during the storage, (\blacklozenge) control sample, (\blacktriangle) thermal sample and (\blacksquare) PEF sample 160

Figure 4.7.3-Change of color parameters with storage time in the unprocessed sample (\blacklozenge) , thermal treated sample (\blacktriangle) and PEF treated sample (\blacksquare) 161

Figure 4.7.4-Evolution of volatile compounds content during the storage (A) control sample, (B) thermal sample and (C) PEF sample 165

EQUATIONS INDEX

Equation 2.4.1Temperature increase in adiabatic-isentropic conditions	17
Equation 2.5.1Electric field strength (E)	30
<i>Equation 2.5.2.</i> -PEF treatment time (t)	33
Equation 2.8.1Bigelow model	47
Equation 2.8.2Hülsheger model	48
Equation 2.8.3Weibull model	48
Equation 2.8.4 \overline{tcw} expression	49
Equation 2.8.5Biphasic model	50
Equation 2.8.6Fractional conversion model	50
Equation 2.8.7Temperature dependence of the labile fraction	51
Equation 2.8.8Temperature dependence of the stable fraction	51
Equation 2.8.9Pressure dependence of the labile fraction	51
Equation 2.8.10-Pressure dependence of the stable fraction	51
Equation 2.8.11z parameter estimation	52
Equation 2.8.12Af expression	52
Equation 2.8.13MSE expression	53
Equation 4.3.1Biphasic model	89
Equation 4.3.2Fractional conversion model	90
Equation 4.3.3Temperature dependence of the labile fraction	90
Equation 4.3.4Temperature dependence of the stable fraction	90
Equation 4.3.5Pressure dependence of the labile fraction	91
Equation 4.3.6-Pressure dependence of the stable fraction	91
Equation 4.3.7Corrected R ² expression	91
Equation 4.4.1Energy input (Q)	106
Equation 4.5.1-Bigelow model	124
Equation 4.5.2Hülsheger model	124
Equation 4.5.3Weibull model	125
Equation 4.5.4 \overline{tcw} expression	125
Equation 4.5.5Af expression	125
Equation 4.5.6MSE expression	126
Equation 4.6.1Bigelow model	138
Equation 4.6.2Hülsheger model	138
Equation 4.6.3Weibull model	138
Equation 4.6.4 \overline{tcw} expression	139
Equation 4.6.5Af expression	139