



UNIVERSITI PUTRA MALAYSIA

**DETERMINATION OF HEAT TRANSFER COEFFICIENT AND
QUALITY CHARACTERISTICS OF PASTEURISED PINK GUAVA
(PSIDIUM GUAJAVA L., VARIETY BEAUMONT-30) JUICE DRINK
WITH DIFFERENT BRIX**

ZAINAL BIN SAMICHO

FEP 2001 1

**DETERMINATION OF HEAT TRANSFER COEFFICIENT AND QUALITY
CHARACTERISTICS OF PASTEURISED PINK GUAVA (*PSIDIUM
GUAJAVA* L., VARIETY BEAUMONT-30) JUICE DRINK WITH DIFFERENT
BRIX**

By

ZAINAL BIN SAMICHO

**Thesis Submitted in Fulfilment of the Requirements for the Degree of
Doctor of Philosophy in the Faculty of Food Science and Biotechnology
Universiti Putra Malaysia**

September 2001



**Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in
fulfilment of the requirements for the degree of Doctor of Philosophy**

**DETERMINATION OF HEAT TRANSFER COEFFICIENT AND
QUALITY CHARACTERISTICS OF PASTEURISED PINK GUAVA
(*PSIDIUM GUAJAVA* L., VARIETY BEAUMONT-30) JUICE DRINK
WITH DIFFERENT BRIX**

By

ZAINAL BIN SAMICHO

September 2001

Chairman: Associate Professor Dr. Russly Abd. Rahman

Faculty: Food Science and Biotechnology

Heat transfer plays a key role in the production of good quality pasteurised fruit juice drink. Knowledge of heat transfer during the pasteurisation process and the necessity of analysing the data quantitatively have become increasingly important in modern pasteurisation technology. The importance of heat transfer in the production of comfort heating was readily apparent. Heat transfer was not only important in designing the pasteurisation equipment but it was also important in the optimisation of the pasteurisation process for the production of high quality fruit juice drink. Several properties of fruit juice drink such as the microbial, enzyme and sucrose contents, cloud stability and ascorbic acid are greatly affected by heat transfer during pasteurisation.

The effect of various operating conditions of pasteurisation on the thermophysical properties (density, thermal conductivity, specific heat capacity,

consistency coefficient and flow behaviour index) of pink guava juice drink was investigated. Pink guava juice drink with different total soluble solids (9^0 Brix and 11^0 Brix) at pH 3.7 with an average particle size of 0.355 mm was used in this study. The pink guava (*Psidium guajava* L.) variety Beaumont: B-30 was supplied by the Golden Hope Plantation, Kulai, Johore, Malaysia. All pasteurisation experiments were performed by using a pilot plant heat exchanger (APV tubular pasteuriser), which was operated at different temperatures and mass flow rates or holding times. During storage at 5^0 C and at room temperature, the quality of the juice drink pasteurised at different conditions, measured as pectinesterase activity, cloud stability, microbial population, sugar and ascorbic acid contents, was analysed.

The data gathered from this study were used to develop models which could be employed to describe the variation in the physical properties of pink guava juice drink with different total soluble solids as a function of the pasteurisation operating temperature. The heat transfer coefficient models which related to mass flow rate for laminar flow were also developed. Such models are useful for the simulation process, so that the rate of heat transfer to the juice drink and the quality of the pasteurised juice drink at different pasteurisation operating conditions could be predicted. The models could also be used in designing the pasteurisation set up and the optimisation of the pasteurisation process with a great reduction in the number of experimental runs to be carried out.

**Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai
memenuhi keperluan untuk Ijazah Doktor Falsafah**

**PENENTUAN ANGKALI PEMINDAHAN HABA DAN CIRI-CIRI
KUALITI TERPASTERUR JUS MINUMAN JAMBU MERAH (*PSIDIUM
GUAJAVA* L., JENIS BEAUMONT-30) YANG BERBEZA BRIX**

Oleh

ZAINAL BIN SAMICHO

September 2001

Pengerusi: Professor Madya Dr. Russly Abdul Rahman

Fakulti: Sains Makanan dan Bioteknologi

Pemindahan haba memainkan peranan penting dalam penghasilan jus minuman buah-buahan terpasteur yang berkualiti baik. Pengetahuan berkaitan dengan pemindahan haba semasa proses pempasteuran dan keperluan menganalisis data secara kuantitatif menjadi bertambah penting dalam teknologi pempasteuran moden. Kepentingan pemindahan haba dalam membantu proses pemanasan telah tersedia maklum. Pemindahan haba bukan sahaja penting dalam merekabentuk peralatan pempasteuran tetapi juga untuk mendapatkan proses pempasteuran yang optimis bagi tujuan menghasilkan jus minuman buah-buahan yang berkualiti tinggi. Beberapa ciri jus minuman buah-buahan seperti kandungan mikrob, enzim dan sukrosa, kestabilan keruh dan asid askorbik amat mudah dipengaruhi oleh pemindahan haba semasa pempasteuran.

Kajian berkaitan dengan kesan daripada pelbagai keadaan pempasteuran terhadap ciri-ciri fizikal haba (ketumpatan, keberaliran haba, muatan haba tentu, pekali kekonsistenan dan indek kelakuan aliran) jus minuman jambu merah telah dilakukan. Jus minuman jambu merah yang berlainan jumlah pepejal larut (9°Brix dan 11°Brix), pH 3.7 dan majoriti saiz zarah 0.355 mm, telah digunakan dalam kajian ini. Jambu merah (*Psidium guajava L.*) jenis Beaumont: B-30 didapati dari Estet Golden Hope, Kulai, Johor, Malaysia. Kesemua ujikaji pempasteuran dijalankan dengan menggunakan loji pandu penukar haba (alat pempasteuran tiub APV) yang beroperasi pada suhu dan kadar aliran jisim yang berlainan atau masa menahan. Semasa penstoran pada 5°C dan suhu bilik, kualiti jus minuman yang dipasteurkan pada keadaan berlainan telah dianalisis dari segi aktiviti enzim pectinesterase, kestabilan keruh, populasi mikroba, kandungan gula dan kandungan asid askorbik.

Himpunan data daripada kajian ini telah digunakan untuk menghasilkan model-model yang boleh menerangkan perubahan ciri-ciri fizikal jus minuman jambu merah berlainan jumlah pepejal larut sebagai fungsi suhu operasi pempasteuran. Model-model pekali pemindahan haba berkaitan dengan kadar aliran jisim bagi aliran lamina telah dapat dihasilkan juga. Model-model tersebut amat berguna untuk perlakuan proses dan dengan itu kadar pemindahan haba kepada jus minuman dan kualiti jus minuman pasteur pada keadaan operasi pempasteuran yang berbeza boleh diramalkan. Model-model tersebut juga boleh digunakan untuk merekabentuk alat pempasteuran yang hendak dicipta juga

dapat menghasilkan satu kaedah yang lebih optimis dalam proses pempasteuran dan dengan itu boleh mengurangkan banyak ujikaji cubaan.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Beneficient, the Most Merciful

I thank Associate Professor Dr. Russly Abdul Rahman, Associate Professor Dr. Arbakariya Ariff and Associate Professor Dr. Nazamid Saari for their encouragement and patience in supervising this work.

I am grateful to the Faculty of Food Science and Biotechnology for permission to use all of the facilities which made my project successful and meaningful.

I am indebted to Universiti Teknologi MARA, Selangor, Malaysia for providing the scholarship which made my Ph.D programme in Universiti Putra Malaysia possible.

I am deeply grateful to my late father, to my mother and to my family for their constant encouragement, advice and moral support.

And last, but not least, I would like to extend my thanks to everyone who has directly or indirectly, contributed towards the completion of this thesis such as Associate Professor Dr. Salmah Yusuf, Mr. Dzulkifli Mat Hashim, Mr. Mustafa Marzuki, Mr. Amran Suratman, Mr. Azhar Mohd. Noor, Mr. Razali Othman, Mr. Rusli Aslim and others.

TABLE OF CONTENTS

	Page
ABSTRACT	2
ABSTRAK	4
ACKNOWLEDGEMENTS	7
APPROVAL SHEETS	8
DECLARATION FORM	10
LIST OF TABLES	16
LIST OF FIGURES	19
LIST OF PLATES	21
LIST OF ABBREVIATIONS	23

CHAPTER

I GENERAL INTRODUCTION	27
II LITERATURE REVIEW	33
Guava	33
Biochemical Compositions of Guava	34
Pectinesterase	34
Mechanism for Pectinesterase Activity	37
Optimum pH for Pectinesterase Activity	39
Optimum pH and Temperature for Pectinesterase	
Activity	41
Importance of Pectinesterase on Cloud Stability	42
Fruit Juice Cloud	44
Clarification of Juice	47
Stabilisation of Cloud Juice	49
Heat Treatment	55
Pasteurisation	55
Thermostability of Pectinesterase	59
Effect of Heating	62
Vitamin	62
Physical and Chemical Changes	63
Colour and Flavour	64
Rheological Properties of Fluid Foods	65
Classification of Fluid Foods	65
Rheological Models for Viscous Foods	68
Models for Time-Independent Behaviour	68
Measurement of Flow Properties of Fluid Foods	70
Rheology of Fluid and Food Processing	71

Heat Transfer	71
Heat Transfer to Foods Flowing in Tubes	71
Heat transfer to Pseudoplastic Fluid in Laminar Flow	73
Tubular Heat Exchanger	76
Application of Tubular Heat Exchanger	78
Storage Stability of Fruit Juice Drink	79
Cloud Loss	80
Microbial Spoilage	80
Sugar Fermentation	82
Ascorbic Acid Degradation	83
 III THERMOPHYSICAL PROPERTIES OF PSEUDOPLASTIC CHARACTERISTICS OF PINK GUAVA JUICE DRINK AT TWO LEVELS OF TOTAL SOLUBLE SOLIDS	85
Introduction	85
Materials and Methods	86
Materials	86
Sample Preparation	87
Pseudoplastic Characteristic: Flow Behaviour Index and Consistency Coefficient	88
Density	89
Thermal Conductivity	89
Specific Heat Capacity	90
Results and Discussions	90
Effect of Temperature and Total Soluble Solids on Pseudoplastic Characteristic, Flow Behaviour Index and Consistency Coefficient	90
Effect of Temperature and Total Soluble Solids on Density...	98
Effect of Temperature and Total Soluble Solids on Thermal Conductivity	100
Effect of Temperature and Total Soluble Solids on Specific Heat Capacity	102
Conclusion	104
 IV LAMINAR HEAT TRANSFER TO PINK GUAVA JUICE DRINK EXHIBITED PSEUDOPLASTIC BEHAVIOUR IN TUBULAR HEAT EXCHANGER	105
Introduction	105
Mass balance	106
Heat transfer	109
Materials and Methods	111
Materials	111
Sample Preparation	111
Specific Heat Capacity	112
Density	112

Viscosity, Flow Behaviour Index and Consistency Coefficient	112
Heat Treatment of Juice Drink	113
Results and Discussion	116
Shear Rate	116
Characteristic of Juice Drink	117
Heat Transfer	120
Conclusion	124
V RELATIVE RESIDUE PECTINESTERASE ACTIVITY AND CLOUD LOSS OF PINK GUAVA JUICE DRINK PASTEURISED AT DIFFERENT HEAT QUANTITY	125
Introduction	125
Materials and Methods	128
Materials	128
Sample Preparation	128
Heat Treatment of Juice Drink	128
Determination of Pulp Content	129
Determination of PE Activity	130
Cloud Index Determination	130
Calcium Determination	131
Statistical Analysis	132
Results and Discussion	132
Effect of Pasteurisation Conditions on PE Activity	132
Effect of TSS on PE Activity	136
Effect of Storage Temperature on PE Activity	137
Effect of Pulp Content on PE Activity	138
Effect of Pasteurisation Conditions on Cloud Loss	138
Effect of TSS on Cloud Loss	141
Effect of Storage Temperature on Cloud Loss	142
Effect of Pulp Content on Cloud Loss	142
Effect of Calcium Content on Cloud Loss	143
Relationship Between PE Activity and Cloud Loss	144
Conclusion	147
VI EEFECT OF DIFFERENT HEAT QUANTITY ON MICROORGANISM POPULATION, SUGAR AND ASCORBIC ACID CONTENT IN PINK GUAVA JUICE DRINK DURING STORAGE	148
Introduction	148
Materials and Methods	153
Materials	153
Sample Preparation	153
Heat Treatment of Juice Drink	153
Microbiological Analysis	154
Determination of Sugar	155

Preparation of Sample for HPLC	156
Preparation of Standard	156
Quantification of Sugar	156
Determination of Ascorbic Acid	157
Statistical Analysis	158
Results and Discussions	158
Mesophilic	158
Yeast and Mould	161
Lactic acid bacteria	164
Properties Affecting Sucrose Concentration During Storage of Pasteurised Pink Guava Juice Drink	169
Effect of Heat Quantity on Sucrose	170
Effect of Total Soluble Solids on Sucrose	170
Effect of Storage Temperature on Sucrose	173
Properties Affecting Glucose Concentration During Storage of Pasteurised Pink Guava Juice Drink	173
Effect of Heat Quantity on Glucose	176
Effect of Total Soluble Solids on Glucose	176
Effect of Storage Temperature on Glucose	177
Properties Affecting Fructose Concentration During Storage of Pasteurised Pink Guava Juice Drink	177
Effect of Heat Quantity on Fructose	178
Effect of Total Soluble Solids on Fructose	178
Effect of Storage Temperature on Fructose	181
Effect of Heat Quantity on Ascorbic Acid	182
Effect of Total Soluble Solids on Ascorbic Acid	185
Effect of Storage Temperature on Ascorbic Acid	186
Conclusion	186
VII CONCLUSION AND RECOMMENDATION FOR FUTURE WORK	190
BIBLIOGRAPHY	193
APPENDICES	205
BIOGRAPHICAL SKETCH	230

APPENDICES

	Page
Appendix A: Total Hectarage of Guava in Peninsular Malaysia	205
Appendix B: Chemical Composition of Fruit Juices	206
Appendix C: Types and Characteristics of Guava	207
Appendix D: Nutrient Composition of Guava	211
Appendix E: Characteristics of Guavas for Juice Processing	212
Appendix F: Amount and Value of Guava Exported	214
Appendix G: Malaysia's 1991 Export and Total Value for Fresh and Processed Fruits	215
Appendix H: Biochemical Changes in Guava (cv Baladia) During Ripening	216
Appendix I: Plates	217
Appendix J: Standard Curve for Sugar	229



LIST OF TABLES

Table	Page
1: The Presence of Pectinesterase in Some Fruits	35
2: Distribution of Pectinolytic Enzymes in Some Microorganisms	35
3: The Optimum pH for Pectinesterase Activity in Some Microorganisms and Fruits	40
4: Optimum pH and Temperature of Some Fruits and Microbial Pectinesterase	42
5: Composition of Orange Juice Cloud	47
6: Effect of Heat Treatment on the Cloud Retention in Shamuti (Jaffa) Orange Juice	50
7: Influence of Calcium Ions and pH on the Retention of Cloud Particles Subjected to PE Action in Shamuti(Jaffa) Orange Juice	51
8: Pectinesterase (In)activators and Inhibitors	52
9: Effect of Added Essential Oil on Cloud Retention in Shamuti(Jaffa) Orange Juice	55
10: Enzyme Related to Food Quality and Inactivation of Pectinesterase	56
11: Flash Pasteurization Conditions for Fruit Juices	58
12: The Thermostability of Fruit Juices	61
13: The Effect of Sorbic Acid on Discoloration and Off-flavour of Guava Beverage (<i>Allahabad Safeda</i>) During Storage	65
14: Newtonian and Pseudoplastic Foods	68
15: Range of Experiment Conditions of Two Fluid Foods (CMC and Tomato Juice)	75
16: Power Law Equations for Different Temperatures and Total Soluble Solids	94
17: Equations of Thermophysical Properties for Different Total Soluble Solids	94

18: Shear Rate of Juice Drink Flowing in the Heating Section Tube During Pasteurisation at 75°C	116
19: Shear Rate of Juice Drink Flowing in the Heating Section Tube During Pasteurisation at 85°C	117
20: Characteristic of Juice Drink Flowing in the Heating Section Tube During Pasteurisation at 75°C	118
21: Characteristic of Juice Drink Flowing in the Heating Section Tube During Pasteurisation at 85°C	118
22: Summary of Parameter Characteristics of the Heat Transfer During Pasteurisation of Pink Guava Juice Drink at 75°C	121
23: Summary of Parameter Characteristics of the Heat Transfer During Pasteurisation of Pink Guava Juice Drink at 85°C	122
24: PE Activity During Storage of Pink Guava Juice Drink with TSS of 9°Brix which was Pasteurised at 75°C/12.9 sec or Heat Quantity = Q_1 and 85°C/12.1 sec or Heat Quantity = Q_3	133
25: PE Activity During Storage of Pink Guava Juice Drink with TSS of 11°Brix which was Pasteurised at 75°C/16.5 sec or Heat Quantity = Q_2 and 85°C/15.0 sec or Heat Quantity = Q_4	133
26: Cloud of Pink Guava Juice Drink TSS at 9°Brix Before Pasteurisation and During Storage, After Treatment by Different Heat Quantity	139
27: Cloud of Pink Guava Juice Drink TSS at 11°Brix Before Pasteurisation and During Storage, After Treatment by Different Heat Quantity	139
28: Concentrations of Calcium	143
29: Sucrose Content During Storage of Pink Guava Juice Drink with TSS of 9°Brix which was Pasteurised at 75°C/12.9 sec or Heat Quantity = Q_1 and 85°C/12.1 sec or Heat Quantity = Q_3	172
30: Sucrose Content During Storage of Pink Guava Juice Drink with TSS of 11°Brix which was Pasteurised at 75°C/16.5 sec or Heat Quantity = Q_2 and 85°C/15.0 sec or Heat Quantity = Q_4	172
31: Glucose Content During Storage of Pink Guava Juice Drink with TSS of 9°Brix which was Pasteurised at 75°C/12.9 sec or Heat Quantity = Q_1 and 85°C/12.1 sec or Heat Quantity = Q_3	175

32: Glucose Content During Storage of Pink Guava Juice Drink with TSS of 11°Brix which was Pasteurised at 75°C/16.5 sec or Heat Quantity = Q ₂ and 85°C/15.0 sec or Heat Quantity = Q ₄	175
33: Fructose Content During Storage of Pink Guava Juice Drink with TSS of 9°Brix which was Pasteurised at 75°C/12.9 sec or Heat Quantity = Q ₁ and 85°C/12.1 sec or Heat Quantity = Q ₃	180
34: Fructose Content During Storage of Pink Guava Juice Drink with TSS of 11°Brix which was Pasteurised at 75°C/16.5 sec or Heat Quantity = Q ₂ and 85°C/15.0 sec or Heat Quantity = Q ₄	180
35: Profile of Ascorbic Acid Content in Pink Guava Juice Drink with TSS Value of 9°Brix which was Pasteurised at 75°C/12.9 sec (Heat Quantity = Q ₁) and 85°C/12.1 sec (Heat Quantity = Q ₃) During Storage	183
36: Profile of Ascorbic Acid Content in Pink Guava Juice Drink with TSS Value of 11°Brix which was Pasteurised at 75°C/126.5 sec (Heat Quantity = Q ₂) and 85°C/125.0 sec (Heat Quantity = Q ₄) During Storage	183

LIST OF FIGURES

Figure	Page
1: Mode of Action of Pectinase	38
2: Reaction Mediated by Pectin Methyl esterase	46
3: Theory of Orange Juice Cloud Loss Via Enzyme Action	48
4: Newtonian and Time-independent Non-Newtonian Fluids	67
5: Relationship Between Shear Stress and Shear Rate for Juice Drink with TSS at 9°Brix	92
6: Relationship Between Shear Stress and Shear Rate for Juice Drink with TSS at 11°Brix	93
7: Arrhenius Plots Showing the Effect of Temperature on the Flow Behaviour Index of Pink Guava Juice Drink	95
8: Arrhenius Plots Showing the Effect of Temperature on the Consistency Coefficient of Pink Guava Juice Drink	96
9: Effect of Temperature on Density of the Pink Guava Juice Drink	99
10: Effect of Temperature on Thermal Conductivity of the Pink Guava Juice Drink	101
11: Effect of Temperature on Specific Heat Capacity of the Pink Guava Juice Drink	103
12: Side View of Several Sections of the Tubular Heat-exchanger	108
13: Experimental Equipment	114
14: Viscosity Versus Shear Rate for Juice Drinks with TSS at 9°Brix and TSS at 11°Brix at Inlet Temperature 27°C	119
15: Shear Stress/Shear Rate Relationship for Juice Drinks with TSS at 9°Brix and TSS at 11°Brix at Inlet Temperature 27°C	123
16: Relative Residue PE Activity During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	134

17: Cloud Loss During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	140
18: The Relationship Between Residue PE Activity and Cloud Loss During Storage at 5°C for Pink Guava Juice Drink which was Pasteurised at Different Heat Quantity	146
19: Mesophilic Population During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	160
20: Yeast and Mould Population During Storage for Pink Guava Drinks Juice of TS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	163
21: Lactic acid bacteria Population During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	163
22: The Change of pH During Storage of Pink Guava Juice Drink which were Pasteurised with Different Heat Quantity	165
23: Sucrose Degradation During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	171
24: Glucose Accumulation During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	174
25: Fructose Accumulation During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	179
26: Ascorbic Acid Loss During Storage for Pink Guava Juice Drinks of TSS at 9°Brix and TSS at 11°Brix which were Pasteurised with Different Heat Quantity	184

LIST OF PLATES

Plate	Page
1. Pink Guava (<i>Psidium guajava L.</i>) Variety Beaumont-30 Left: 80% Ripe, Right: Fully Ripe	217
2. Washing of Pink Guava Fruits	217
3. Pink Guava Fruits (halved)	218
4. Pink Guava Fruits During Crushing by the Coconut Grinder ...	218
5. Grinding and Separating of Crushed Pink Guava Fruits Left Pail: Puree, Right Pail: Waste	219
6. The APV Pilot Plant Tubular Heat Exchanger	219
7. Bottling of Pasteurised Pink Guava Puree	220
8. HDPE Bottles of Pasteurised Pink Guava Puree in Freezer	220
9. Defrosting of Pasteurised Pink Guava Puree in HDPE Bottles	221
10. Mixing of Puree with Water and Sugar	222
11. Centrifuge (Model Kabato)	223
12. Brookfield Rheometer (Model DV III)	223
13. Differential Scanning Calorimetry (DSC 7)	224
14. Pouring of Pink Guava Juice Drink into the Mixing Tank of the APV Tubular Heat Exchanger	224
15. Pink Guava Juice Drink in HDPE Bottles at 0 day	225
16. Pink Guava Juice Drink in HDPE Bottles Kept in 5°C After 4 Weeks Storage Times	225
17. Pink Guava Juice Drink in HDPE Bottles Kept in RT After 1 Week Storage Times	226

18.	Auto Titrator (VIT Video Titrator)	226
19.	UV- Visible Spectrophotometer (Model Shimadzu UV-1601PC)	227
20.	Atomic Absorption Spectrophotometer (Model Perkin-Elmer 5100PC)	227
21.	HPLC (Model Waters 410 Refractive Index Detector)	228

LIST OF ABBREVIATIONS

AFHP	ASEAN Food Habits Project
FAFR	Food Act Food Regulation
MAFF	Ministry of Agriculture, Fisheries and Food
MARDI	Malaysian Agricultural Research and Development Institute
PE	Pectinesterase
PG	Polygalacturonase
PMG	Polymethylgalacturonase (pectin hydrolase)
PMGL	Polymethylgalacturonate lyase (pectin lyase)
PGL	Polygalacturonate lyase (pectate or pectic acid lyase)
PPO	Polyphenoloxidase
HDPE	High density polyethylene
NaOH	Sodium hydroxide
RT	Room temperature
n, n _H	Flow behavior index
K, K _H	Consistency coefficient (Pa s ⁰)
τ	Shear stress (N m ⁻²)
τ_0	Yield stress (N m ⁻²)
γ or S	Shear rate (s ⁻¹)
ρ	Density (g ml ⁻¹)
C _p	Specific heat capacity (J kg ⁻¹ °C ⁻¹)
k	Thermal conductivity (J m ⁻¹ s ⁻¹ °C ⁻¹)

T	Temperature ($^{\circ}\text{C}$)
T'	Temperature (Kelvin)
α	Thermal diffusivity of the fluid (m^2s^{-1})
p	Moisture content (kg moisture/kg of juice drink)
TSS	Total soluble solid
a, b, γ	Constant
F	Constant (m^2N^{-1})
A'	Constant (s^{-1})
n_{∞}	Frequency factors
K_{∞}	Frequency factors (Pa s^n)
E_{ak}	Activation energy (J mol^{-1})
R	Gas constant ($8.314 \text{ J K}^{-1} \text{ mol}^{-1}$)
h_m	Mean heat transfer coefficient
ω	Mass flow of the juice drink
D	Diameter
v	Velocity of juice drink
r	Radius
A	Area
V	Volume of juice drink
μ	Viscosity of juice drink
Re	Reynolds number
Q	Total heat transfer
ΔT	Temperature different between inlet temperature and heating temperature