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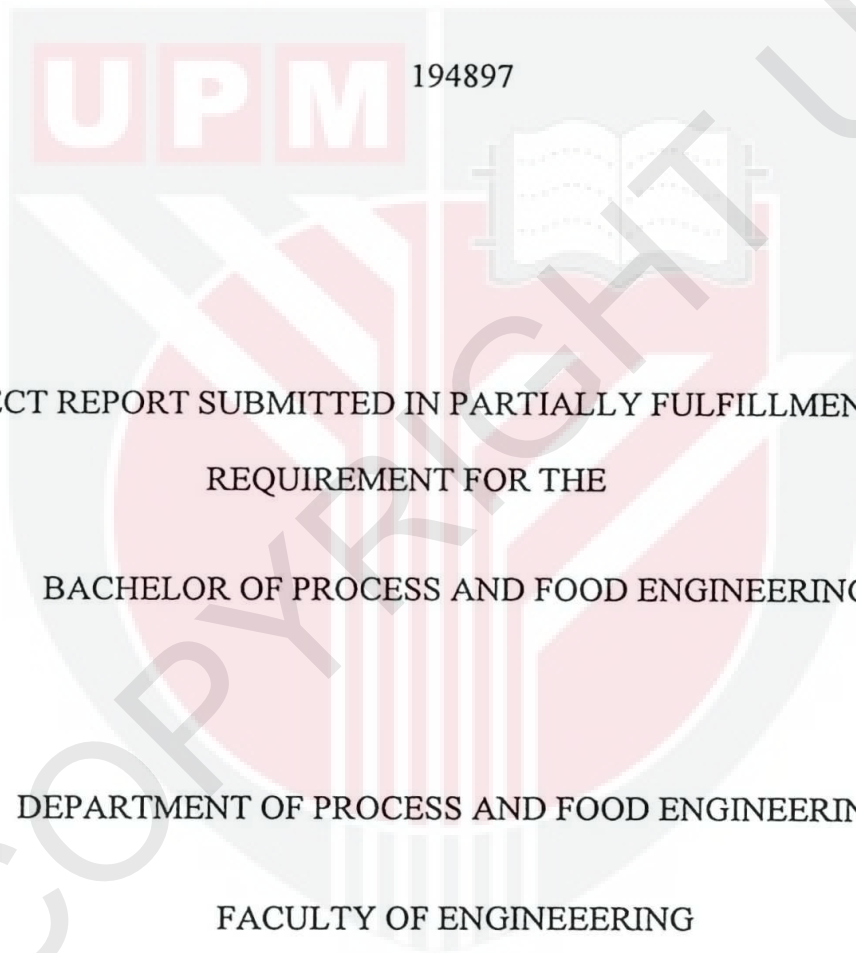
MODELLING COFFEE EXTRACTION KINETICS DURING BREWING

DIYANAH NABIHAH MOHD. SHAFEK

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MODELLING COFFEE EXTRACTION KINETICS DURING BREWING

DIYANAH NABIHAH BINTI MOHD. SHAFEK



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ABSTRACT

Coffee drink is a famous beverage worldwide. Brewing is an important step in the making of coffee beverages. This research aimed to model coffee extraction kinetics during an infusion method brewing. The quality of coffee brew depends on the coffee extraction rate during coffee brewing. The extraction kinetic can be used to predict the coffee extraction rate. This study used *Coffea Arabica* and Robusta ground with particle size of 500 μm , an infusion method brewing time of 30 to 150 seconds, 90°C of water temperature and mass of coffee in the range of 10 to 50 g. The parameters studied are concentration of coffee brewed, total dissolve solid and extraction yield. From the study shows 50g Arabica at longest brewing time (150s) has highest concentration and total dissolved solid which is 18.15 g/L and 1.87% respectively. Besides, between Arabica and Robusta, proved that Arabica has higher concentration and total dissolved solid where concentration and total dissolved solid of Robusta is 17.33 g/L and 1.79% respectively. Experimental data were analysed using Unsteady-state Diffusion Model and Hyperbolic Model. The results showed 50 gram Arabica has fitted to both, Unsteady-state Diffusion Model and Hyperbolic Model with R-squared value is 96.58% and 92.53% respectively. The root mean square error is low, 0.0095% for Unsteady-state Diffusion Model and 1.12% in Hyperbolic Model. The conclusion is, brewing time and type of coffee influence concentration and total dissolved solid of coffee brewed. Besides, Unsteady-state Diffusion Model and Hyperbolic Model were proven to show good fit in model 50g of coffee extraction kinetics during brewing.

ABSTRAK

Membancuh adalah langkah penting dalam membuat minuman kopi. Penyelidikan ini bertujuan untuk memodelkan kinetik pengekstrakan kopi semasa membancuh menggunakan kaedah infus pembuatan kopi. Kopi adalah minuman terkenal di seluruh dunia. Kaedah pembuatan kopi boleh mempengaruhi produk kopi. Kinetik pengekstrakan adalah salah satu mekanisme penting dalam ramalan kadar pengekstrakan. Biji kopi *Coffea Arabica* dan *Robusta* digunakan dengan ukuran zarah 500 μm . Parameter pengekstrakan yang digunakan dalam kaedah infuse ialah masa membancuh (30 hingga 150 saat) dengan 90°C air dan jisim kopi yang berbeza (10 hingga 50 gram). Parameter setelah membancuh adalah kepekatan kopi yang diseduh, jumlah larut pepejal dan hasil pengekstrakan. Dari kajian ini menunjukkan, 50g Arabica yang mempunyai tempoh masa membancuh kopi yang lama (150s), mempunyai kepekatan dan jumlah pepejal terlarut yang paling tinggi, masing-masing adalah 18.15 g/L dan 1.87%. Selain itu, Arabica membuktikan bahawa Arabica mempunyai kepekatan dan jumlah pepejal terlarut yang tinggi berbanding Robusta, dimana nilai masing-masingnya adalah 17.33 g/L and 1.79%. Data dari eksperimen telah di analisis menggunakan *Unsteady-state Diffusion Model* dan *Hyperbolic Model*. Keputusan menunjukkan, data 50g Arabica sesuai untuk kedua-dua model tersebut dimana nilai R-squared masing-masing adalah 96.58% and 92.53%. Selain itu, nilai *root mean square error* juga rendah iaitu 0.0095% untuk *Unsteady-state Diffusion Model* dan 1.12%in *Hyperbolic Model*.

TABLE OF CONTENT

DECLARATION	i
APPROVAL.....	iii
ACKNOWLEDGEMENT	v
ABSTRACT.....	vi
ABSTRAK.....	vii
TABLE OF CONTENT	viii
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF ABBREVIATIONS	xiv
CHAPTER 1 INTRODUCTION.....	1
1.1 Demand of Coffee	1
1.2 Chemical Composition of Coffee.....	2
1.3 Coffee Brewing Method.....	2
1.4 Coffee Extraction Parameter	4
1.5 Problem Statement	6

1.6	Objective	6
CHAPTER 2 LITERATURE REVIEW.....		7
2.1	Coffee Bean.....	7
2.2	Coffee Extraction	9
2.3	Modelling	11
2.4	Unsteady-State Diffusion Model.....	13
2.5	Hyperbolic Model.....	15
CHAPTER 3 METHODOLOGY.....		17
3.1	Sample Preparation.....	18
3.2	Coffee Concentration Analysis	19
3.3	Extraction Kinetic Modelling.....	21
3.4	Statistical Analysis	22
CHAPTER 4 RESULTS AND DISCUSSION		24
4.1	Concentration of Coffee	24
4.2	Modelling of Coffee Extraction Kinetic.....	31
CHAPTER 5 CONCLUSIONS AND RECOMMENDATION.....		36
5.1	Conclusion.....	36

5.2 Recommendation.....	37
REFERENCES.....	38
APPENDICES	50



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LIST OF TABLES

Table 1.1 Parameter of different coffee brewing method (Mestdagh et al., 2017).	5
Table 2.1 Different characteristic between Arabica and Robusta (Durand Faith, 2021).	8
Table 2.2 Various type of model used in solid-liquid extraction	12
Table 2.3 Application of Unsteady-state diffusion model	14
Table 2.4 Application of Hyperbolic Model	16
Table 4.1 Total dissolved solid (%) of Arabica	26
Table 4.2 Total dissolved solid (%) of Robusta	29
Table 4.3 Extraction Yield of Arabica coffee brewed	31
Table 4.4 The statistical values of various models for coffee extraction kinetic during brewing time	35
Table A.1 Brix value and Concentration of Arabica and Robusta coffee with 10 gram mass and brewing time	50
Table A.2 Brix value and concentration of Arabica and Robusta coffee with 20 gram mass and brewing	50

Table A.3 Brix value and concentration of Arabica and Robusta coffee with 30 gram mass and brewing.....	50
Table A.4 Brix value and concentration of Arabica and Robusta coffee with 40 gram mass and brewing.....	51
Table A.5 Brix value and concentration of Arabica and Robusta coffee with 50 gram mass and brewing.....	51

LIST OF FIGURES

Figure 2.1 Infusion Method (Drip Filter Brewing) (Moroney et al., 2016).....	10
Figure 2.2 Coffee solubles concentration profiles for JK standard drip filter grind (•) and Cimbali #20 grind (▪) (Moroney et al., 2015).....	11
Figure 3.1 Process flow chart of the study of modelling coffee extraction kinetic during brewing of Arabica and Robusta bean.....	18
Figure 3.2 Equipment for brewing coffee infusion method.....	19
Figure 3.3 Coffee concentration profile for JK standard drip filter grind (Moroney et al., 2015).....	20
Figure 3.4 Atago Poket Refractometer PAL- α	20
Figure 4.1 Extraction kinetic curve for different mass of Arabica during brewing.....	26
Figure 4.2 Total dissolved solid of Arabica at 30s and 150s brewing time.....	27

Figure 4.3 Total dissolved solid of Arabica at 10g and 50g of mass	28
Figure 4.4 Extraction kinetic curve for different mass of Robusta during brewing	29
Figure 4.5 Total dissolved solid of Arabica and Robusta at 150s and 50g	30
Figure 4.6 Unsteady-State diffusion model of 50-gram Arabica.....	32
Figure 4.7 Unsteady-State diffusion model of 50-gram Robusta	32
Figure 4.8 Hyperbolic Model of 50-gram Arabica	33
Figure 4.9 Hyperbolic Model of 50-gram Robusta.....	34

LIST OF ABBREVIATIONS

RMS	Root Mean Square
TDS	Total dissolved solid
q	Content of coffee
q_0	Initial content of coffee
k	Slow extraction coefficient (Unsteady-state Diffusion Model)
b	Washing Coefficient (Unsteady-state Diffusion Model)
t	Time
K_1	Initial Extraction Rate (Hyperbolic Model)
K_2	Constant related maximum extraction yield (Hyperbolic Model)
\bar{q}	Extraction yield
σ	Standard deviation
N	Total number of data
x_i	Value of each data
μ	Population mean
R^2	Coefficient determination

CHAPTER 1

INTRODUCTION

1.1 Demand of Coffee

Coffee is a second most highly traded commodity after oil. Arabica and Robusta are two type of coffee that are traded internationally. Columbians Mild, Brazilians Naturals and Other Milds are the three subcategories of Arabica (Ghoshray, 2010; Ponte, 2002). However, in 2019 coffee is imported globally 2.4 million 60 kg bags and become fourth most traded commodity (Corwin et al., 2021). In the same year of 2019, Global Coffee Market, (2020) was valued at \$102.15 billion and expected to grow to \$155.64 billion by 2026. In Malaysia coffee is forecasted 800 thousands 60 kg bags will be consumed in 2022 (Hirschmann R, 2021). Thus, Indonesia is one the largest producer of coffee. In the period of 2018 to 2019, they produced around 12 million 60 kg bags (Bashiri et al., 2021). Fact that Indonesia is leading global supplier of green coffee bean to the United Kingdom, behind Vietnam and Brazil which is 15%, 22 % and 21 % respectively (International Coffe Organization, 2019). Corwin et al., (2021) studied that coffee demand will grow 2% annually and by 2050, coffee demand is expected to triple.

1.2 Chemical Composition of Coffee

Arabica has nearly 70% while Robusta has 30 % of the global coffee production (Killeen & Harper, 2016). Both coffee has different physiochemical characteristic and different sensory properties (del Campo et al., 2010). Consumers prefer Arabica because it has greater commercial rather than Robusta, besides Arabica has an aromatic composition (Toledo et al., 2016). Coffee is a product that has rich of caffeine, trigonelline, chlorogenic acids, diterpenes and antioxidants. Roasting Brazilian coffee (100% Arabica) can cause formation of acetic, formic, and lactic acid (dos Santos & Boffo, 2021). The colour and flavour of coffee changed due to different process parameters of roasting (Diana et al., 2008). By consuming coffee, consumer can reduce hepatocarcinoma, lipid oxidation, provide a balance in total cholesterol and it the presence natural chemical components act as biological activities for Alzheimer's disease (Arendash et al., 2009; Butt & Sultan, 2011; Cano-Marquina et al., 2013; Johnson et al., 2011). According to Kornman, (2017a), extracted coffee has caffeine, acid, lipids, sugars and carbohydrates.

1.3 Coffee Brewing Method

As mentioned, coffee is globally consumed beverages and more 47 countries exported the coffee including Brazil as leading producer (dos Santos & Boffo, 2021). Every year, about 500 billion cups of coffee are made around the world (Parikh Anish, 2013). Extraction method of coffee is one of the factors that influence the chemical composition of coffee brewed and produce different qualitative and quantitative characteristics, starting from the same raw material (Angeloni et al., 2019). There are three

main categories extraction method of coffee brew which is pressure method, decoction method and infusion method (Cordoba et al., 2020a; Moroney et al., 2015). The coffee brewing method is depending on consumer preferences, the mode is impacted by a variety of factors such as lifestyle, culture, and flavour preferences (Illy Andrea, 2005).

Even though there are various brewing method, the most popular is pressure method. Plunger, Moka and Espresso are in pressure method categories. Espresso is one the pressure method usually use espresso machine which consist rotational pump, heat exchanger and extraction chamber (Parenti et al., 2014). To extract the soluble material from coffee packed bed in preparing espresso coffee, pressure gradient ($90^{\circ}\text{C} \pm 5^{\circ}\text{C}$) of hot water is required (Corrochano et al., 2015). Since this method has almost double yield compare to other method, this method is categories as most efficient recovery of chlorogenic acid and caffeine recovery (Angeloni et al., 2019).

Filter method is gravity infusion method that use hot water to pass through medium ground roasted coffee. In term of chlorogenic acid, filter method has higher amount compare to pressure method (espresso) (Pérez-Martínez et al., 2010). Filter method is one of the most popular brewing coffee method but during past decade, espresso consumption has increase. This method is traditional method using filter paper. Where the roasted medium ground size coffee put into the holder that contain filter paper. Thus, filter paper has various size and shape and material (Mestdagh et al., 2017).

Next category is decoction method which is Turkish boiled coffee is in this category. This method is need heat up and boiling process. An amount of coffee ground and water with room temperature are put in brewing pot known as “cersve” and the coffee

stirred before boiling. The extraction is mostly based on solute diffusion at high temperatures. This method is happened where water is forced through the grinds with high pressure and heat, like how espresso process (Sunarharum et al., 2014). The less water-soluble chemicals that create the usual strong, bitter, and dark-chocolate flavours are also extracted at these high temperatures (Turan Ayseli et al., 2021).

1.4 Coffee Extraction Parameter

In coffee extraction, the parameters can influence the coffee flavour quality. For the example, changing grind size in espresso can change brewing pressure and contact time. Besides, parameter can influence chemical and flavour characteristic. Extraction time is time between water interact with roasted coffee ground. More than 70% of antioxidant are extracted for 8 seconds brewing time of espresso. (Cordoba et al., 2020b). Thus, in filter coffee brewing, extraction begin after 75 seconds where higher efficiency and less polar antioxidant compound (Ludwig et al., 2012).

The kinetic energy of water molecules increases as the temperature rises due to the driving force behind the extraction of chemical components found in coffee grounds is temperature (Mestdagh et al., 2017). Water temperature can affect the sensory of coffee brew and affect saturated vapour pressure of aromatic compound. Beverages with the lowest concentration, extraction percentage, and total solids are produced at low temperatures. (Angeloni et al., 2019).

Pressure is most likely use in espresso method and the range pressure of espresso brewing method is between 7 to 9 bar to get the most efficient extraction and influence bioactive compound in coffee (Caprioli et al., 2014). Besides, high foam consistency and

aroma intensity can be achieved by using 9 bar pressure during espresso method brewing (Ndueza et al., 2002). But more lipid can be extract by higher pressure such as 11 bar (Parenti et al., 2014).

The taste and quality of coffee is depending on coffee and water ratio which is relationship is mass of coffee ground and mass of water used in brewing coffee (Coelho et al., 2007). By using more water during brewing, the titratable acidity/total polyphenol concentration (TA/TPP) ratio concentration decrease, and coffee flavour may change (Wang et al., 2016). Parameter coffee/water ratio need to be considered to perform the best on coffee brew quality (Corrochano et al., 2015).

Table 1.1 shows the extraction parameter from previous study in different coffee brewing method.

Table 1.1 Parameter of different coffee brewing method (Mestdagh et al., 2017).

Parameter	Preparation method					
	Boiling Coffee Turkish	Pour Over (Drip Filter)	French Press	Espresso	Moka Pot	Cold Brew (Pour Over)
Water to coffee ratio (mL/g)	~20	~13-20	~15-20	3.5-6	~9-15	~4-15
Particle size	Fine	Medium	Coarse	Medium	Medium	Coarse
Compaction	No	No	No	Yes	No	No
Pressure (bar)	0	0.1	0	8-19	1-2	0-0.1
Brewing Time	-	3-10 min	2-5 min	25-30 s	3-5 min	2-24 h

1.5 Problem Statement

In Malaysia, there are less information suitable temperature and brewing time, and extraction time of coffee brewed that sustain the quality and taste of coffee. Quality of coffee used for consumer such as percentage dissolve coffee in final beverage (Korhonen, 2019). Furthermore, coffee brewing method is important because it give direct result to final product and different brewing method give different taste (Kelly, 2018).

Thus, extraction kinetic is important because of mechanism in extraction will allow the prediction of enhancement extraction rate. Besides, it important in estimation system in industry (Aly & Daoud, 1996). While model coffee extraction is needed because will help brew perfect cup.

1.6 Objective

The objectives of this study are,

- i. To study the coffee extraction parameters such as water temperature, coffee and water ratio, and brewing time.
- ii. To evaluate the difference between coffee Arabica and Robusta brewed concentration.
- iii. To investigate the extraction kinetic models suitable for the infusion method of coffee brewing.

CHAPTER 2

LITERATURE REVIEW

2.1 Coffee Bean

Coffee is the second most popular beverage in the world after water, and millions of people drink it every day (Butt & Sultan, 2011; Cano-Marquina et al., 2013; Esquivel & Jiménez, 2012). According to Davis et al., (2012), the two most common species to make coffee are Arabica coffee (*Coffea arabica L.*) and Robusta coffee (*C. canephora Pierre ex A.Froehner*). In world coffee production, Arabica coffee (*Coffea arabica L.*) has 60 % of current global coffee production and often marketed higher price Robusta due to their superior beverage quality (van der Vossen et al., 2015). Thus, Robusta coffee (*C. canephora Pierre ex A.Froehner*) accounts for up to 40% of global coffee production and is a vital export for many tropical developing countries (Kath et al., 2021). Three categories (types and defect, bean size, beverage quality) of coffee are important to set a price (Brighenti & Cirillo, 2018).

Leroy et al., (2006) state that coffee has different type of quality and biochemical compound is one of the different variations between coffee species. Caffeine, sugars, chlorogenic acids and lipids are biochemical compound that related to coffee quality. In

terms of characteristic of polysaccharide of Arabica and Robusta, Fischer et al., (2001) studied that there are no different of polysaccharide content, but the study shows difference of solubility so that Robusta bean is easier to extract compare to Arabica bean. Table 2.1 shows common differences between Arabica bean and Robusta bean.

Table 2.1 Different characteristic between Arabica and Robusta (Durand Faith, 2021)

Characteristic	Arabica	Robusta
Taste	Sweeter, Softer Taste	Stronger, Harsher Taste
Acidity	Higher	Less
Caffeine	Low	High (twice as much caffeine as arabica bean)

Quality of coffee beans is depending on different phase of development, harvesting, preparation, transport, and storage (Batista et al., 2003). All of this can cause contamination of coffee bean. However, Silva et al., (2000) state that, coffee bean has natural contaminants come from field to production warehouse called toxigenic fungal genera (*Aspergillus*, *Penicillium* and *Fusarium*). In order to brew coffee using pour over method, Greene, (2019) recommend grind the coffee bean to medium-course grind size.

In this study, coffee has been selected because it is most popular beverage and has high production of coffee. Besides, coffee in Malaysia has been growing for centuries. By

modelling coffee extraction kinetics, will help to produce quality of coffee by identifying the strength of coffee concentration.

2.2 Coffee Extraction

Wang et al., (2016) state that three different method involves in coffee extraction to produce the brew. The methods involve are water absorption by coffee grinds, mass transfer of soluble compounds from the ground coffee into the hot water and separation of the resulting extract from coffee solids. Besides, decoction methods, infusion methods and pressure methods are classification of main categories of coffee extraction method (D'Agostina et al., 2004; Moroney et al., 2015). In addition, infusion method can apply in extraction kinetic model because these kinds of coffee brew is quite commonly used (Cordoba et al., 2020a).

In infusion brewing method, coffee grinds are placed in a filter, which is frequently conical in form, and hot water is poured over them. Under the effect of gravity, hot water travels down through the coffee bed, leaching soluble material. The resistance supplied by the porous bed and filter is the only hindrance to the coffee flow (Moroney et al., 2016). Figure 2.1 shows the schematic of infusion method (drip filter brewing) where hot water pours over the coffee ground in the filter. Soluble coffee components are leached from the grain once the water runs through the bed. As the liquid leaves the filter, any undissolved particles in the fluid are filtered out of the extract (Moroney et al., 2016; Pictet, 1987).

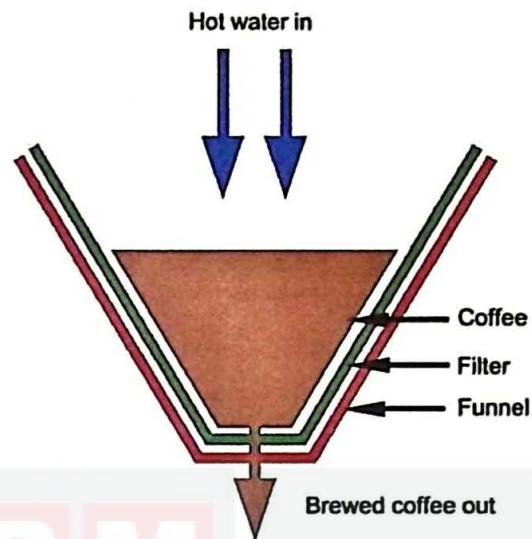


Figure 2.1 Infusion Method (Drip Filter Brewing) (Moroney et al., 2016).

K. M. Moroney et al., (2015) studied coffee extraction kinetics during batch-wise brewing to measured concentration of coffee brewed as a function of time that can be determined by measure the °brix using a refractometer ($1^{\circ}\text{brix} = 8.25 \text{ g/l}$ of coffee brewed) by mixing 60-gram different size of coffee (coarse and fine) at 80°C to 90°C of hot water with fixed volume, 0.5 liter. Even though there are variety of methods have developed for coffee brewing, most of them use high-temperature of water (near boiling) and short period of time which is less than 5 minutes (Cordoba et al., 2019). Espinoza-Pérez et al., (2007) state that extraction carried out at natural and forced convection when at a constant temperature of 90°C of hot water. Hot water is used to increase the extraction yield and usually constant in temperature of boiling water (Angeloni, Guerrini, Masella, Innocenti, et al., 2019). Figure 2.2 shows the result study from K. M. Moroney et al., (2015) with different size of coffee, which is fine grind, called Jacobs Krönung (JK) standard drip filter coffee grind and coarse grind, called Cimbali #20 (Cimbali burr grinder with setting #20).

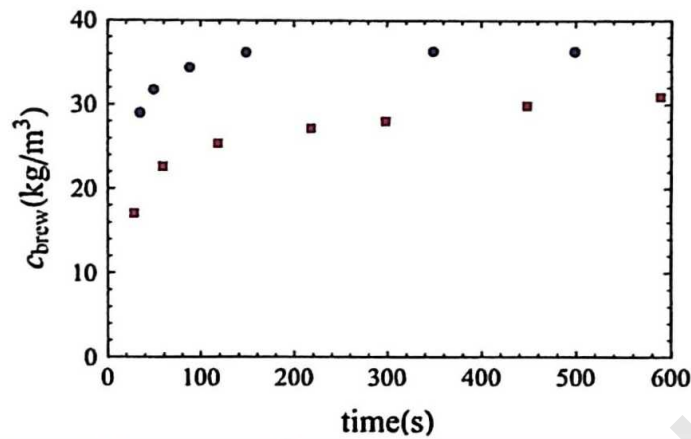


Figure 2.2 Coffee solubles concentration profiles for JK standard drip filter grind (•) and Cimballi #20 grind (▪) (Moroney et al., 2015).

Gloess et al., (2013) examined nine different coffee extraction method to present analytical and sensory aspects for four espresso and five *lunghe*. On the other hand, this study state that one of the methods which is *lungo* method that filter coffee using a paper filter and a coffee machine from Hapag Aarau use temperature 90°C hot water and 1 bar pressure. Coffee extraction determine percent of dry coffee has been dissolved in the hot water of brewing coffee and extraction yield (%) can be calculated using Equation 3.2 (Korhonen, 2019). Thus, McKeon Aloe (2020) state that percent total dissolved solid (TDS) of coffee can be find by multiplying 0.85 of convert °brix.

2.3 Modelling

Kevin M. Moroney et al., (2016) state that solid-liquid extraction is used in the coffee brewing process. Various model proposed to fit any experimental data of solid-liquid extraction and many research done by researcher to predict solid-liquid extraction

from various plant components with steady state mass transfer model (Handayani et al., 2008), kinetic model (Rakotondramasy-Rabesiaka et al., 2007) and unsteady state model (Simeonov et al., 1999; Wongkittipong et al., 2004). Besides, Table 2.2 shows various model involved in solid-liquid extraction studies.

Table 2.2 Various type of model used in solid-liquid extraction

Food / Material Extract	Model	References
Extraction of soybean oil using ethanol and mixtures with alkyl esters (biodiesel) as co-solvent.	First- Order Model	(Dagostin et al., 2015)
	Second-Order Model	
	Mass Transfer Kinetic Model	
Extraction of vanillic acid from pumpkin seeds.	Unsteady-State Diffusion Model	(Ickovski, 2020)
	Film Theory Model	
	Ponomarev Model	
	Hyperbolic Model	
	Second-Order Model	
	Elovich Model	

Extraction of Ursolic Acid from Leaves of vitex Negundo Linn.	Unsteady-State Diffusion Model	(Taralkar & Ashta, 2014)
Solid-liquid extraction kinetics of total polyphenols from grape seeds.	Peleg's Model	(Bucić-Kojić et al., 2007)

From all the previous studies in Table 2.2, Dagostin et al., (2015) state that the kinetic model that has better correlated the overall extraction yields were the second-order kinetic model and the mass transfer model for an infinite slab. Thus, Ickovski, (2020) analysed the root mean square, standard deviation, and correlation coefficient in experimental kinetic data and state that from all the six kinetics models tested, Ponomarev model has been found to be the most suited and accurate model. Previous study, Taralkar & Ashta, (2014) estimated diffusion coefficient from unsteady-state diffusion model for various extraction experiment because it can account dynamicity of extrusion process. Bucić-Kojić et al., (2007) identified high correlation coefficient and low root mean square deviation in Peleg's model.

2.4 Unsteady-State Diffusion Model

Unsteady-state diffusion is taking place at the function of time and in this state, the rate of diffusion is not constant. Besides, this Unsteady-state diffusion is determined by Fick's first law and second law (Madhusa, 2018). The origin of this Fick's first law

and second law is when a physiologist named Adolf Fick inspired an experiment from Thomas Graham which is measure concentration and fluxes of salt and at that time, Fick's focus on diffusion in solid (Vendom et al. 1998). Besides, it is important to textile industry, pharmaceutical, extraction from solvent and membrane separation process (Karimi, 2011). The general equation relates in Unsteady-state diffusion model is described from Fick's second law shown in Equation 2.1 (De Meijer et al., 1996; Karimi, 2011; Kupiec & Gwadera, 2013; Park et al., 1992; Shi, 2007). The equation stands for concentration (C) change at certain element of system respect to time (t) in the x -direction D is diffusion coefficient.

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \left[D - \frac{\partial c}{\partial x} \right] \quad \text{Equation 2.1}$$

Various application of Fick's Law of Unsteady-state diffusion model such as polymer, chemical, food, fabricated, biological and semiconductor. Table 2.3 shows the previous study applied Unsteady-state diffusion model.

Table 2.3 Application of Unsteady-state diffusion model

Application	References
Methanol in Douglas-fir Heartwood	(De Meijer et al., 1996)
Cryoprecipitate Formation	(Kukharenko & Kolgatin, 1992)
Cesium through Granite	(Park et al., 1992)

Liquid Surfactant Membrane	(Goswami et al., 1993)
Hydrocarbon	
Gas in Coal Matrix	(Guo et al., 2014)
Osmotic Dehydration of	(Alakali et al., 2006)
Mango	

2.5 Hyperbolic Model

Hyperbolic model is applied as Peleg's Model in food engineering science (Agu et al., 2021). Peleg developed an equation that show in Equation 2.2 to predict the accuracy during water vapour adsorption of milk powder and rice (Peleg, 1988; Turhan et al., 2002). The equation shows M represent moisture content %, t is time, M_0 is initial moisture content (%), K_1 is Peleg rate constant ($\%^{-1}$) and K_2 is capacity constant ($\%^{-1}$). Application of Hyperbolic Model as Peleg's Model are in food application shows in Table 2.4.

$$M = M_0 \pm \frac{t}{K_1 + K_2 t}$$

Equation 2.2

Table 2.4 Application of Hyperbolic Model

Application	References
Solvent extraction of <i>Irvingia gabonensis</i> kernel oil	(Agu et al., 2021)
Extractive synthesis of oil from <i>Terminalia catappa</i> L. kernel	(Menkiti et al., 2017)
Extraction of protopine from <i>Fumaria officinalis</i> L	(Rakotondramasy-Rabesiaka et al., 2007)
Extraction kinetics of total polyphenols from grape seeds	(Bucić-Kojić et al., 2007)
Extraction of vanillic acid from pumpkin seeds	(Ickovski, 2020)

CHAPTER 3

METHODOLOGY

This study investigated the extraction kinetic for two different types of coffee beans: *Coffea Arabica* and *Coffea Robusta* during brewing. The commercial coffee bean for both Arabica and Robusta are from Mister Coffee from Petaling Jaya, Selangor. Figure 3.1 shows summary of the experimental design where Arabica and Robusta Coffee Beans is ground sieved. After coffee brewing, the concentration, extraction yield and total dissolve solid were measured. Then, the experimental data was used to model the extraction kinetics. Detailed methods will be explained in the subsequent sub-topics.

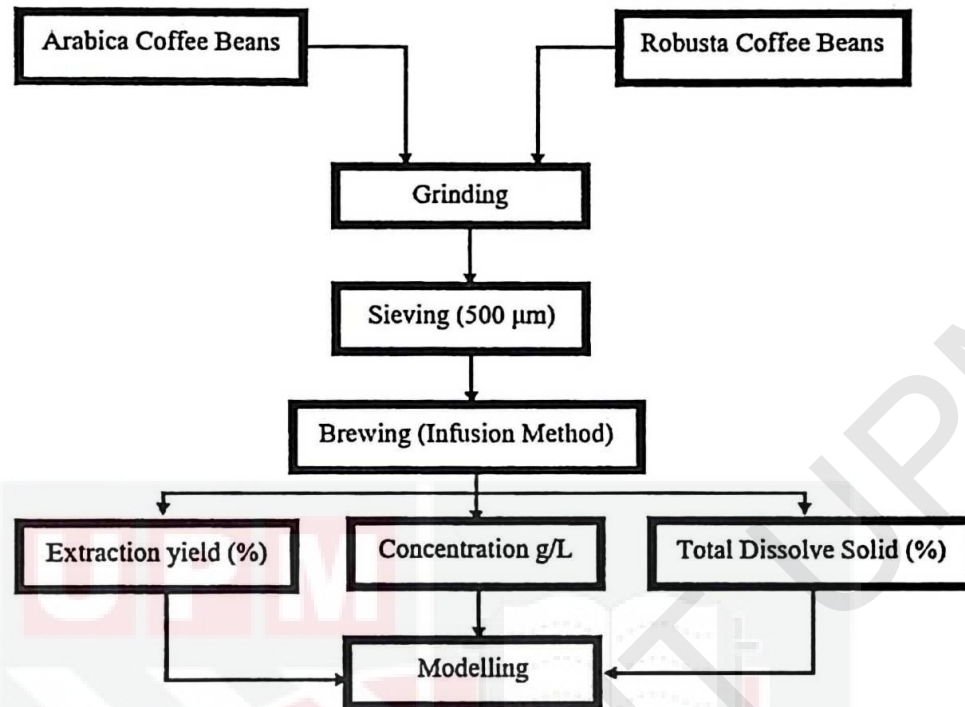


Figure 3.1 Process flow chart of the study of modelling coffee extraction kinetic during brewing of Arabica and Robusta bean.

3.1 Sample Preparation

Roasted Arabica and Robusta coffee beans from Mister, Malaysia were ground using a coffee grinder. The coffee ground then sieved through a 500 μm sieve to get a uniform particle size. After that, the sieved coffee ground was weighed of 10, 20, 30, 40 and 50 gram. The temperature of water used during coffee extraction was 90°C that was heated using a water bath. Although, there are many methods for brewing coffee, we had selected the infusion method for this experiment. The main equipment used for infusion method brewing is filter paper, coffee dripper and coffee server as shown in Figure 3.2.



Figure 3.2 Equipment for brewing coffee infusion method

3.2 Coffee Concentration Analysis

Coffee concentration is known as strength of coffee that refer to the dissolved coffee (Haare, 2017). The reading of the concentration of extraction coffee is taken every 30 seconds during brewing using a refractometer (PAL- α ATAGO Digital Hand-held “Pocket” Refractometer) as shown in Figure 3.4 to measure the value of Brix. Parameter Brix indicates the concentration of coffee brewed after extraction. The Brix value was taking every 30 seconds, 60 seconds, 90 seconds, 120 seconds, and 150 seconds for both types of coffee ground (Arabica and Robusta) during brewing to complete the extraction kinetics. According to previous study from Moroney et al., (2015), 1 °Brix is equivalent to 8.25 g/l. So, every Brix value in this experiment needs to multiply by 8.25 g/l to get the concentration of coffee brewed. In addition, Brix values are valuable to get the Total Dissolved Solid (TDS) by using Equation 3.1.

$$\text{TDS (\%)} = 0.85 \times \text{Brix}$$

Equation 3.1

From the experimental data, which is concentration coffee brewed of both types of coffee ground (Arabica and Robusta), extraction curves were made using Microsoft Excel 2019 to find the best pattern of concentration of coffee brewed against brewing time. The pattern of the graph from experimental data was determined in Figure 3.3 that refers to the previous study (Moroney et al., 2015).

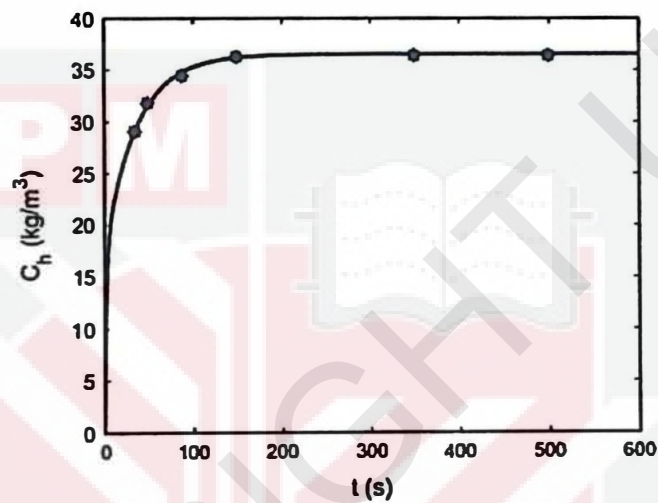


Figure 3.3 Coffee concentration profile for JK standard drip filter grind (Moroney et al., 2015)

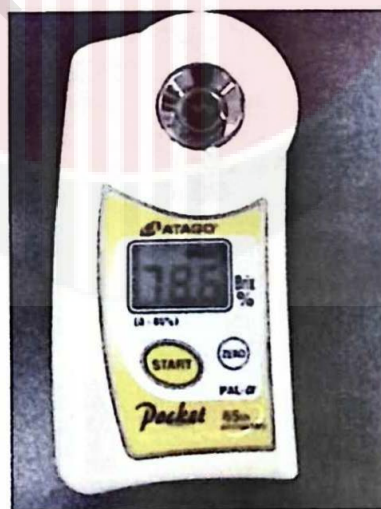


Figure 3.4 Atago Poket Refractometer PAL- α

Extraction yields also known as the percentage of extracted dry coffee ground mass into the water (Manzocco & Lagazio, 2009). In this experiment, extraction yield was calculated from the mass of coffee brewed, total dissolved solid, and the mass of dry coffee ground. The extraction yield was calculated using Equation 3.2

$$\text{Extraction Yield (\%)} = \frac{\text{Coffee brewed (g)} \times \text{TotalDissolved Solid}}{\text{Dry Coffee Ground}} \quad \text{Equation 3.2}$$

3.3 Extraction Kinetic Modelling

Extraction kinetic model is important for industrial application because in industrial process usually scale -up the laboratory scale from process that developed (da Porto & Natolino, 2018). Data with the best pattern was chosen to do modelling coffee extraction kinetic. From a previous study, Ickovski (2020) applied six types of kinetic models, physical models (unsteady-state diffusion model, film theory model) and empirical models (hyperbolic model, second-order model, Elovich model, and Ponomarev model). But, in this analysis, there are only two types of kinetic models involved. The coffee extraction kinetics was investigated using the physical models (unsteady-state diffusion model) and empirical models (Hyperbolic model)

The first model is the unsteady-state diffusion model that is expressed in Equation 3.3 and can be rearranged in Equation 3.4 as a linear equation.

$$\frac{q}{q_0} = (1 - b)e^{-kt} \quad \text{Equation 3.3}$$

$$\ln\left(\frac{q}{q_0}\right) = \ln(1 - b) - kt \quad \text{Equation 3.4}$$

From the linear Equation 3.4, q is representing the content of coffee in the coffee brewed during the extraction (g/mL), q_0 is the initial content of coffee in the coffee brewed during the extraction (g/mL), k is the slow extraction coefficient of the model ($1/s$), and b is the washing coefficient of the unsteady-state diffusion model.

The second model is Hyperbolic model. The Equation 3.5 expressed as linear equation of the model.

$$\frac{t}{\bar{q}} = \frac{1}{K_1} + \frac{K_2}{K_1}t \quad \text{Equation 3.5}$$

The equation shows K_1 ($1/s$) value that represent as initial extraction rate, K_2 represent the constant related to the maximum extraction yield ($1/s$), K_1 / K_2 represent Peleg capacity constant representing the maximum extraction yield and \bar{q} represent as extraction yield. Based on these two models, all the unknown parameters or statistical values of various kinetic models for extraction can be identified by plotting the graph and solving the Equation 3.4 and Equation 3.5.

3.4 Statistical Analysis

Statistical analysis can be used to find the best fitted model of coffee extraction kinetics. Root mean square (RMS) and standard deviation (σ) were calculated using Equation 3.6 and Equation 3.7, respectively. The RMS and σ were used to show the performance of regression model fits of the experimental data.

$$\text{RMS} = \sqrt{\frac{1}{N} + \sum_i x_i^2} \quad \text{Equation 3.6}$$

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

Equation 3.7

RMS and standard deviation have same represented value where N is total number of data and x_i is each value of data. Thus, in standard deviation μ represent the population mean.



CHAPTER 4

RESULTS AND DISCUSSION

The result of this study shows the concentration of coffee which is related to total dissolved solid (TDS) value. The concentration shows from different extraction parameter which is different mass of coffee and brewing time. Besides, two different types of coffee beans: *Coffea Arabica* and *Coffea Robusta* during brewing to find the differences of concentration and total dissolved solid (TDS). The optimum concentration and total dissolved solid (TDS) were chose to be modelled using two types of models: Unsteady-state Diffusion Model and Hyperbolic Model to find the fitted data of the model. Detail methods will be explained in the subsequent sub-topics.

4.1 Concentration of Coffee

Concentration of coffee is soluble concentration or dissolved solid that represent exact strength of final coffee brewed (Bodnariuc, 2017). In coffee brewed, concentration is important, this is because it can determine the coffee strength, taste, and flavour (Bodnariuc, 2017) . Effect of mass on concentration of coffee for different brewing time of Arabica and Robusta are shown in

Figure 4.1 and Figure 4.4 respectively. There show significant different in concentration of different mass of Arabica and Robusta coffee when brewing at different time. Besides, Table 4.1 shows total dissolved solid (TDS) that related to concentration of coffee. The graph in

Figure 4.1 shows increase in concentration with brewing time for 50 g, 40 g of Arabica coffee so where show the total dissolved solid (TDS) is higher at 50g and 40g at every time. Meanwhile, the concentration of 10 g of coffee decreases in range 15.68 g/l to 0.8 g/l at 30 s and 60 s respectively so it shows the TDS value is 1.62% and 0.09%. For 20 gram shows same pattern of concentration with 10g of coffee which is decrease in range 10.73 g/l to 5.8 g/l at 30 s and 60 s respectively. So the TDS at 60s lower than 30s brewing time which is 0.6% and 1.11% respectively. For 30 g of coffee show gradually increase in concentration from 14.85 g/l to 21.54 g/l at 30 s and 150 s respectively, so the TDS in brewed coffee shows 1.53% and 2.21% respectively.

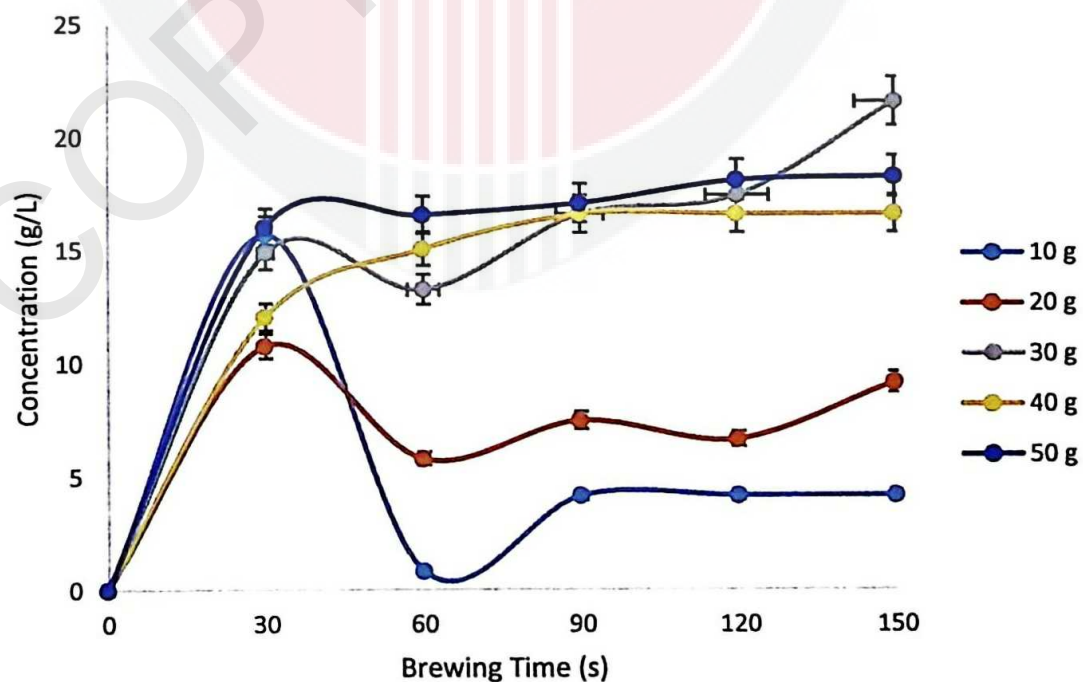


Figure 4.1 Extraction kinetic curve for different mass of Arabica during brewing

Table 4.1 Total dissolved solid (%) of Arabica

Time (s)	10g	20g	30g	40g	50g
0	0	0	0	0	0
30	1.62	1.11	1.53	1.45	1.66
60	0.09	0.6	1.36	1.53	1.70
90	0.43	0.77	1.70	1.70	1.76
120	0.43	0.68	1.79	1.70	1.87
150	0.43	0.94	2.21	1.62	1.87

From the discussion above shows the different concentration and TDS value in different condition. Correspond to the discussion above, Figure 4.2 shows TDS value of Arabica at different brewing time and constant mass. The initial brewing time 30s where the concentration was measured and 150s where the final time of concentration was measured in constant 50g of mass. From the graph shows at 30s, Arabica has 1.66% of TDS and 1.87% at 150s. It show that, higher brewing time will have high total dissolved solid of coffee in coffee brewed at 50g.

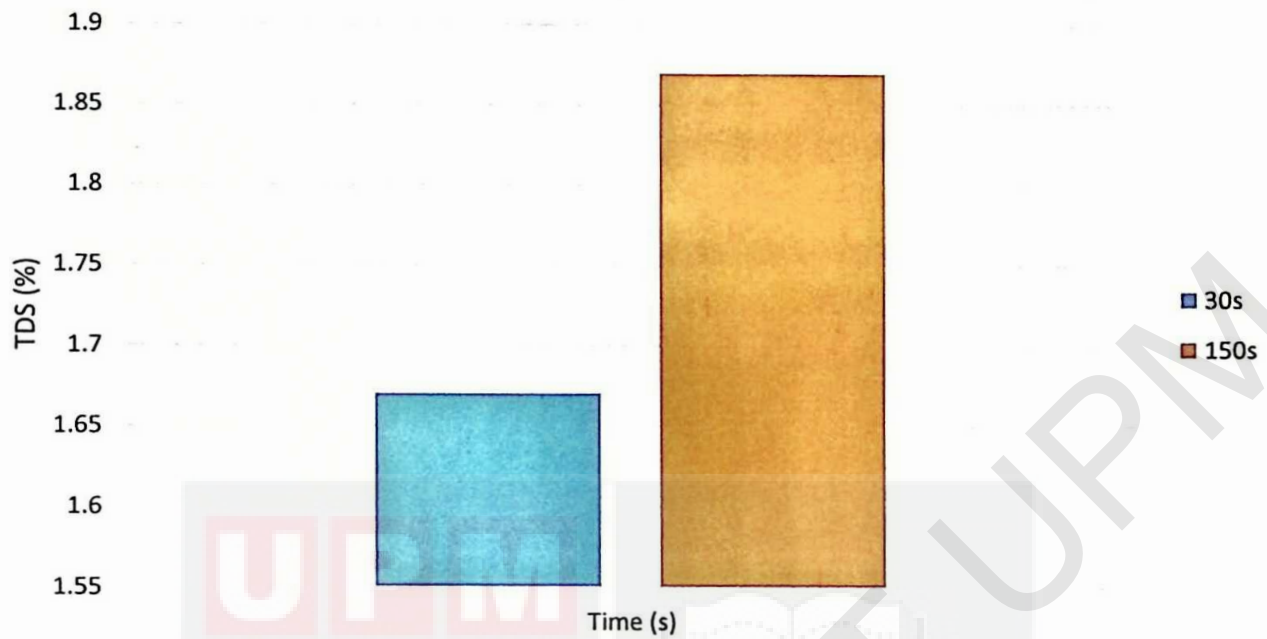


Figure 4.2 Total dissolved solid of Arabica at 30s and 150s brewing time

Since discussion in Figure 4.2 shows 150s has higher TDS value, so Figure 4.3 shows TDS value of Arabica at different mass and constant brewing time. Where shows TDS value of Arabica at 150s in different mass which is 10g and 50g. The figure shows that 10g has 0.43% of TDS value where 50g has 1.87 TDS value. It shows that in this study, higher mass will have high total dissolved solid of coffee in coffee brewed at 150s.

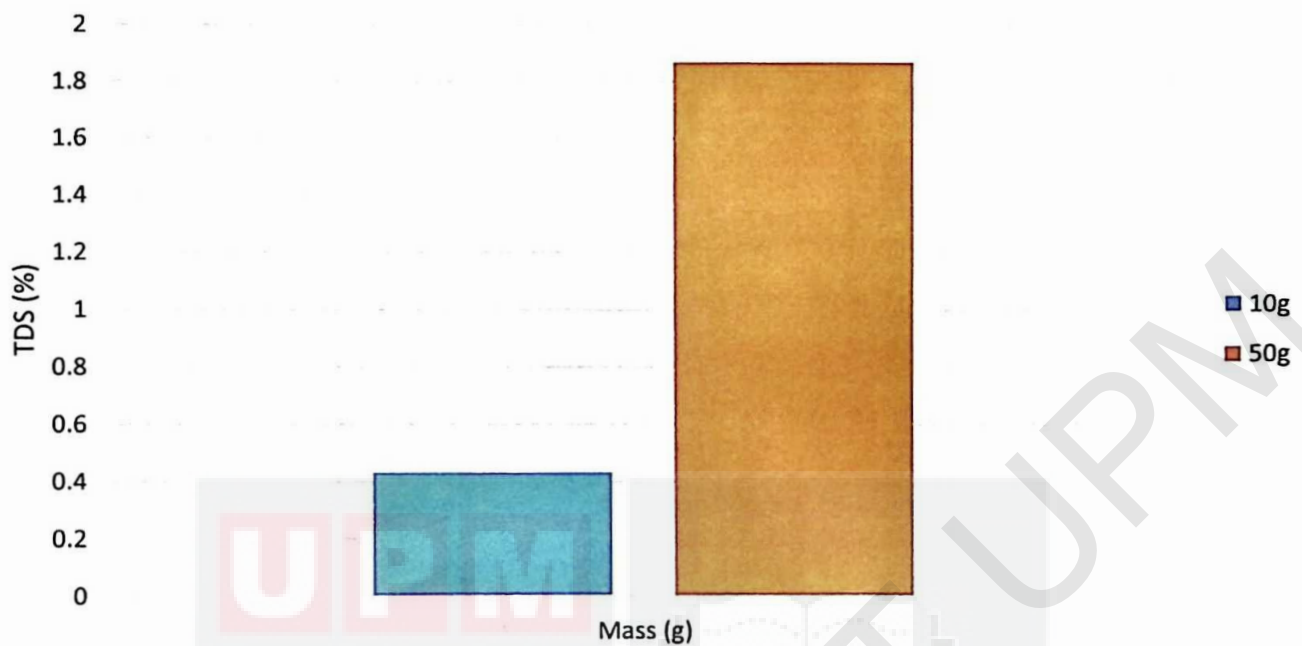


Figure 4.3 Total dissolved solid of Arabica at 10g and 50g of mass

For Robusta coffee type, there were significant different in concentration of coffee during different brewing time and mass. The graph in Figure 4.4 shows that at 10g the concentration decreases at 30s and 60s from 4.95 g/l to 1.65 g/l. It means the total dissolved solid (TDS) that shows in Table 4.2 is decrease from 0.51% to 0.17%. Furthermore, the concentration and TDS slightly increase to 2.48 g/l and 0.26% at 150s. At 20g of Robusta coffee show lower concentration which is 1.65 g/l at 60s compared to 5.78 g/l at 30 s. Meaning that the TDS is lower which is 0.17% at 60s and 0.6% at 30s initial concentrated time. For 30 g show the concentration slightly drop to 6.6 g/l at 60s but gradually increase to 13.2 g/l at 150s. 40g show decreased number of concentrations from 11.5 g/l for the first 30s to 9.9 g/l at 60s. The concentration increases to 15.68 g/l at 120 s but at 150 s it decreases to 11.55 g/l. For 50g shows the same pattern as 10g which is slightly decrease at

60s and 90s from 18.15 g/l to 16.5 g/l then increase to 19.8 g/l but decrease at 17.32 g/l at 120 s and 150 s respectively. Based on the pattern of the Figure 4.4, it shows fluctuating data. Besides, the TDS values also show the same trend as concentration shown in Table 4.2.

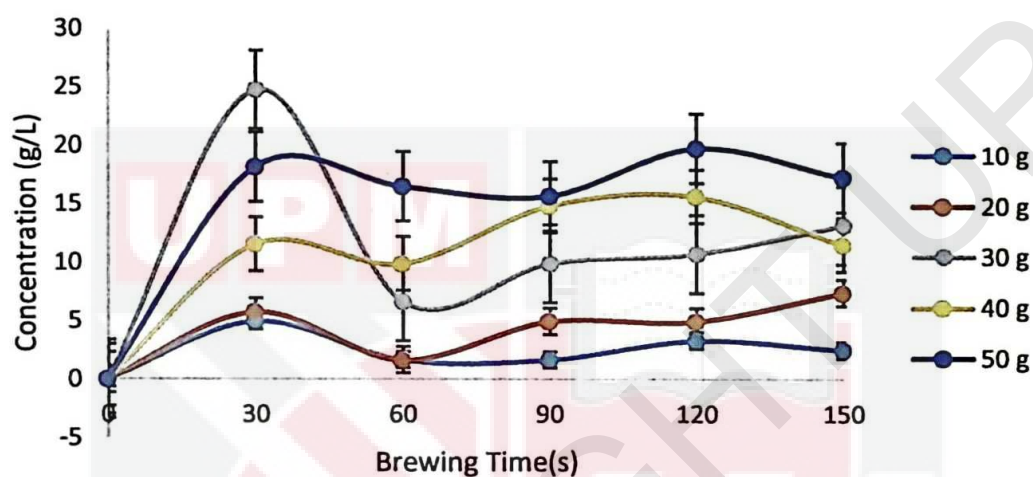


Figure 4.4 Extraction kinetic curve for different mass of Robusta during brewing

Table 4.2 Total dissolved solid (%) of Robusta

Time (s)	10g	20g	30g	40g	50g
0	0	0	0	0	0
30	0.51	0.60	2.55	1.19	1.87
60	0.17	0.17	0.68	1.02	1.70
90	0.17	0.51	1.02	1.53	1.62
120	0.34	0.51	1.11	1.62	2.04
150	0.26	0.77	1.36	1.19	1.79

Based on discussion above, Figure 4.5 shows differences TDS value of Arabica and Robusta at constant mass and different mass brewing time. It shows TDS value of Arabica is higher which is 1.87% and Robusta is 1.79%. That shows where Arabica has

better total dissolved solid in coffee brewed compared to Robusta. In other word, in this study shows Arabica has high concentration of coffee brewed.

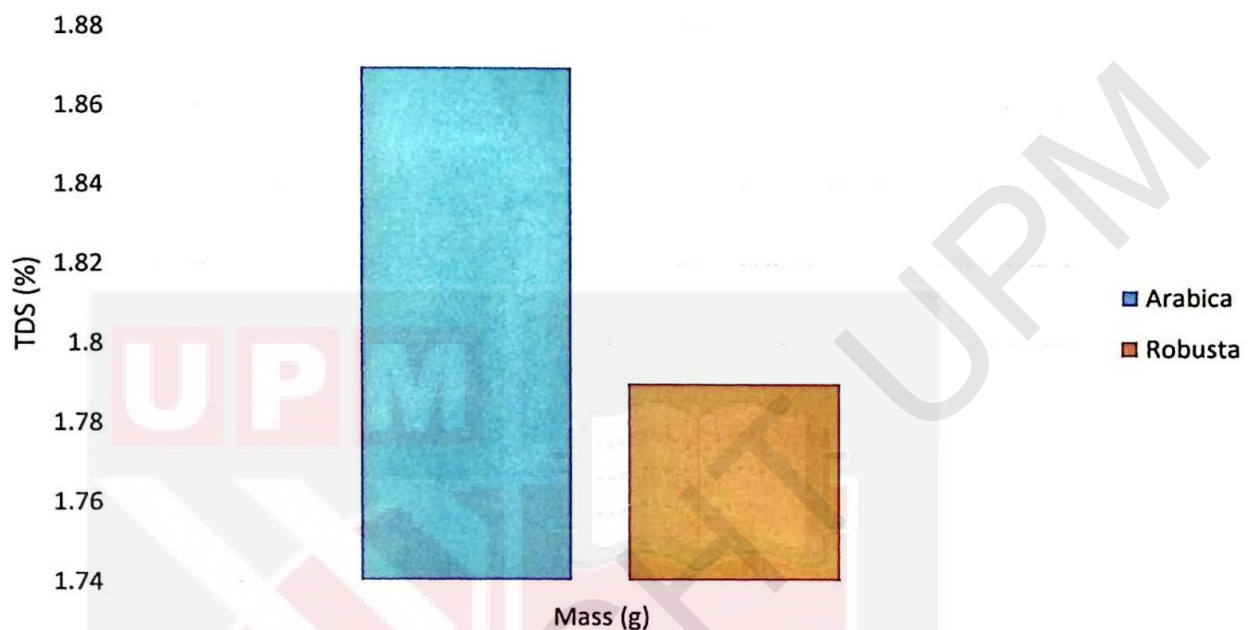


Figure 4.5 Total dissolved solid of Arabica and Robusta at 150s and 50g

Since 50g of Arabica has highest total dissolved solid, it chose to calculate the extraction yield by using Equation 3.2 and the result shows in Table 4.3. In the table shows extraction yield of 150s brewing time has highest value which is 6.73% compared to the lowest at 30s brewing time is 0.93%. Even though 150s has highest value of extraction yield, in term of flavour, it is not a has balance flavour of coffee brewed because according to (Frost et al., 2020), to get the balance flavour, extraction yield value is in a range between 18% to 22%. TDS value higher when brewing time increase because, if more coffee relation or contact to water, the coffee brewed has stronger taste means that higher TDS.

Table 4.3 Extraction Yield of Arabica coffee brewed

Brewing Time (s)	Extraction Yield (%)
0	0
30	0.93
60	1.83
90	3.34
120	4.84
150	6.73

4.2 Modelling of Coffee Extraction Kinetic

Modelling of coffee extraction kinetics during brewing involved many types of models as shown in section 2.3. In this study, which is Unsteady state diffusion model and Hyperbolic Model chose to be analysed. Data from brewing 50 gram Arabica and 50 gram Robusta coffee are selected because based on previous discussion both of the coffee have highest total dissolved solid.

Figure 4.6 and Figure 4.7 shows the graph of Unsteady-State Diffusion Model of Arabica and Robusta that plotted using Equation 3.4. Slow extraction coefficient, k and washing coefficient, b are calculated based Equation 3.4 and developed Equation 4.1 for Arabica and Equation 4.2 for Robusta from the graph.

$$y = 0.0011x + 0.0347$$

Equation 4.1

$$y = 0.0003x + 0.0671$$

Equation 4.2

Gradient from the graph represent slow extraction coefficient k of Arabica and Robusta, which is 0.0011 and 0.0003 respectively. Same goes to washing coefficient, b calculated and the value is -0.035 and -0.069 respectively.

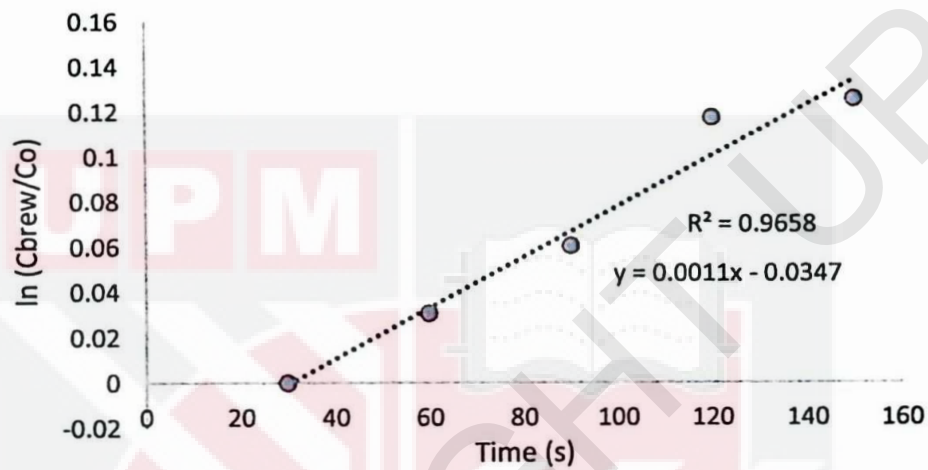


Figure 4.6 Unsteady-State diffusion model of 50-gram Arabica

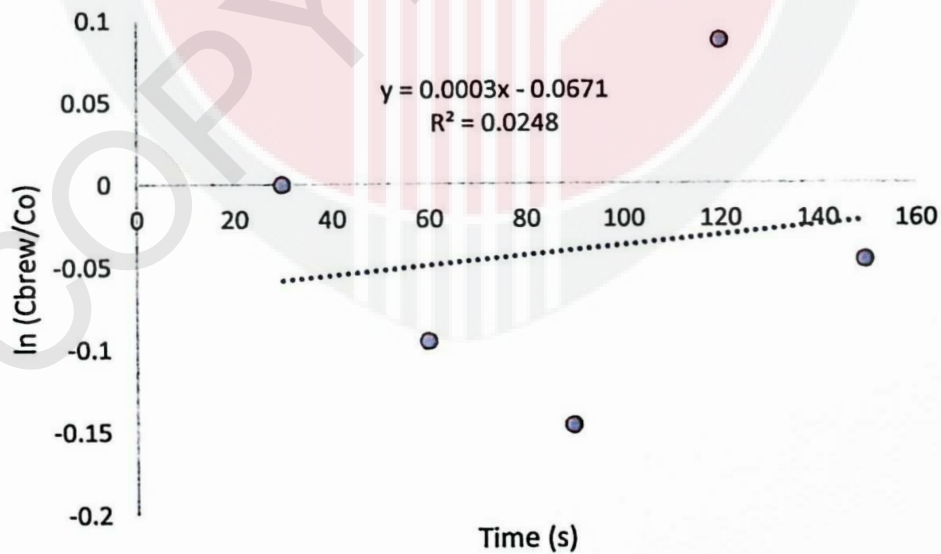


Figure 4.7 Unsteady-State diffusion model of 50-gram Robusta

Figure 4.8 shows the graph of Hyperbolic Model that plotted using Equation 3.5. Initial extraction rate, K_1 , constant related to the maximum extraction yield, K_2 , Peleg capacity constant representing the maximum extraction yield, K_1 / K_2 , and extraction yield \bar{q} are calculated based Equation 3.5 and developed Equation 4.3 for Arabica and Equation 4.4 for Robusta from the graph.

$$\dot{y} = -0.0932x + 36.28 \quad \text{Equation 4.3}$$

$$y = 0.2237x + 23.317 \quad \text{Equation 4.4}$$

Gradient from the graph represent K_2/K_1 , where initial extraction rate, K_1 and K_2 calculated as K_1 is 0.027, K_2 is -2.57×10^{-3} and K_2/K_1 , is -0.0932 . Thus, for Robusta, K_1 is 0.042, K_2 is 9.4×10^{-3} and K_2/K_1 , is 0.2237

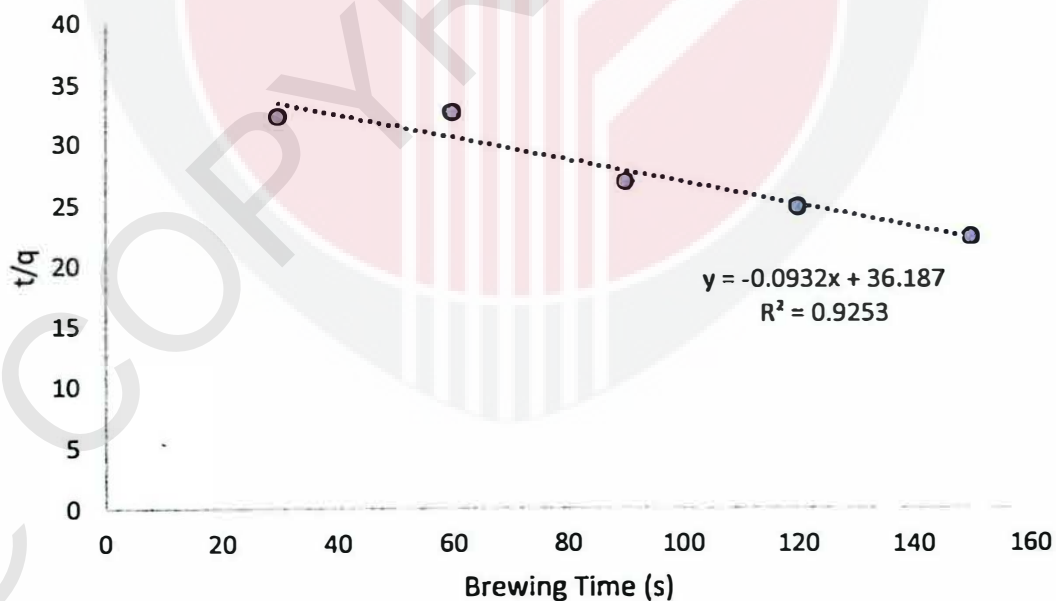


Figure 4.8 Hyperbolic Model of 50-gram Arabica

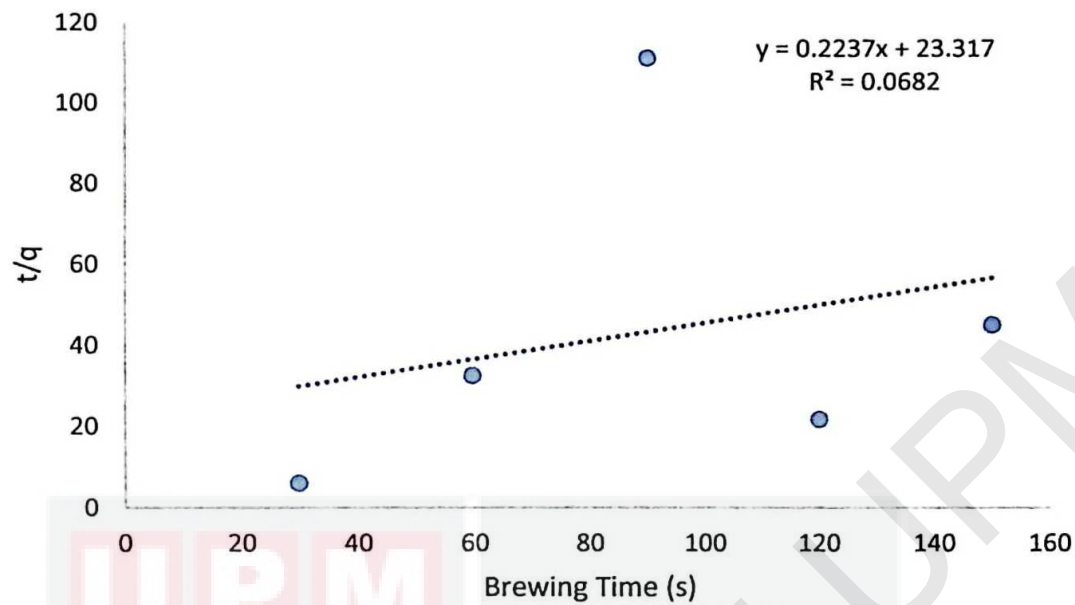


Figure 4.9 Hyperbolic Model of 50-gram Robusta

From these two models, statistical value in Table 4.4 shows the differences parameter between the model. The table show the washing coefficient of Unsteady- state Diffusion Model, b of 50g Arabica and Robusta have -0.035 and -0.069 respectively. According to Ickovski, (2020) washing coefficient will increase by increasing the temperature. Same goes to slow extraction coefficient. For root mean square (RMS), it calculated by using Equation 3.6. Unsteady-state Diffusion Model of Arabica shows the lowest value of 0.0095%, while Robusta shows 0.07%. While standard deviation is calculated using Equation 3.7 and Robusta shows high standard deviation which is 0.1%. Thus, Arabica show lower value, 0.055%. Regression coefficient, R^2 for these two coffees in Unsteady-state Diffusion Model shows Arabica has highest value of R^2 which is 96.58 %, compare to Robusta only 2.48%. It is show that, Arabica has lowest RMS, standard deviation and R^2 near to 1 so Unsteady-state Diffusion Model has good fit in modelling the Arabica coffee extraction kinetics.

For Hyperbolic Model, Arabica has lowest value of K_1 and K_2 which is 0.027 and -2.57×10^{-3} respectively. Thus, Robusta has higher value which 0.042 and 9.4×10^{-3} respectively. The RMS value of Robusta also higher compared to Arabica which is 35% and 1.12%. It shows that Robusta has big error. Standard deviation of Arabica is better which is 4.59% compare to Robusta that has almost 10 times bigger from Arabica. R^2 near to 1. Hyperbolic Model is 92.53%. The, Arabica shows high value 92.53% which is near to 100 % where Robusta is 6.82%. It shows that, Arabica has lowest RMS, standard deviation and R^2 near to 100% so Hyperbolic Model has good fit in modelling the Arabica coffee extraction kinetics.

Table 4.4 The statistical values of various models for coffee extraction kinetic during brewing time

Model	Parameters	Arabica 50g	Robusta 50g
Unsteady-State Diffusion Model	b	-0.035	-0.069
	k (1/s)	0.0011	0.0003
	RMS (%)	0.0095	0.07
	SD (%)	0.055	0.1
	R^2 (%)	96.58	2.48
Model	Parameters	Arabica 50g	Robusta 50g
Hyperbolic Model	K_1 (1/s)	0.027	0.042
	K_2 (1/s)	-2.57×10^{-3}	9.4×10^{-3}
	K_2/K_1	-0.095	0.2237
	RMS (%)	1.12	35.1
	SD (%)	4.59	40.6
	R^2 (%)	92.53	6.82

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

The time of brewing coffee related determine the end of concentration of coffee at the end of brewing process. In conclusions, the coffee Arabica and Robusta extraction kinetics during brewing were investigated. We also study extraction kinetic model that suitable in this infusion method of coffee extraction.

In a conclusion, Arabica and Robusta coffee subjected to investigate the concentration at different brewing time and different type of coffee. In term of different brewing time, we found out that concentration of 50g Arabica at 150s brewing time is 1.87% total dissolved solid which is higher from 30s brewing time that has total dissolved solid 1.66%. It shows that brewing time influence the concentration and total dissolved solid of coffee brewed. For the difference type of coffee, this studied found that Arabica has easier to dissolved because, the concentration and total dissolved solid of 50g Arabica at 150s is 18.15 g/L and 1.87% respectively, which is higher than Robusta that has concentration and total dissolved solid 17.3 g/L and 1.79% respectively. It proved that different type of coffee influences the concentration at final coffee brewed.

The data from Arabica and Robusta at 50 g applied in modelling of coffee extraction kinetics. Unsteady-state Diffusion Model and Hyperbolic Model are two types of kinetic model for the experimental data. From this model can generate kinetic parameter. The result proves that experimental data of 50g Arabica coffee extraction kinetics has good fit in Unsteady-state Diffusion Model because, it has R^2 almost to 100%, smaller standard deviation and less value root mean square error which is 96.58%, 0.055% and 0.0095% respectively. Hyperbolic Model was proven to show good fit in 50g of coffee extraction kinetic because has highest value of linear coefficient, low standard deviation and root mean square error value which is 92.53%, 4.59% and 1.12% respectively.

5.2 Recommendation

To improve this study in future, it is recommended to determine the chemical composition of Arabica and Robusta coffee after brewing. This is because, the chemical composition in coffee brewed show the final quality and taste of coffee. Furthermore, analysis on cold brew coffee can be consider since it is made without heat will give different quality or impact to chemical composition and.

Besides, the experimental must improve in a way to get desire temperature and maintain the temperature because it heats easy to release surrounding. Besides improve the equipment such as refractometer because it will affect the Brix reading. Moreover, the brewing time should be in wide range to see more interval and accurate reading. Lastly, it will be better doing caffeine concentration modelling to get the stronger or bitter taste of coffee.

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APPENDICES

Table A.1 Brix value and Concentration of Arabica and Robusta coffee with 10 gram mass and brewing time

Time	Arabica			Robusta		
	Brix	Concentration (g/L)	TDS (%)	Brix	Concentration (g/L)	TDS (%)
0	0	0	0	0	0	0
30	1.9	15.675	1.62	0.6	4.95	0.51
60	0.1	0.825	0.09	0.2	1.65	0.17
90	0.5	4.125	0.43	0.2	1.65	0.17
120	0.5	4.125	0.43	0.4	3.3	0.34
150	0.5	4.125	0.43	0.3	2.475	0.26

Table A.2 Brix value and concentration of Arabica and Robusta coffee with 20 gram mass and brewing

Time	Arabica			Robusta		
	Brix	Concentration (g/L)	TDS (%)	Brix	Concentration (g/L)	TDS (%)
0	0	0	0	0	0	0
30	1.3	10.725	1.11	0.7	5.775	0.6
60	0.7	5.775	0.6	0.2	1.65	0.17
90	0.9	7.425	0.77	0.6	4.95	0.51
120	0.8	6.6	0.68	0.6	4.95	0.51
150	1.1	9.075	0.94	0.9	7.425	0.77

Table A.3 Brix value and concentration of Arabica and Robusta coffee with 30 gram mass and brewing

Time	Arabica			Robusta		
	Brix	Concentration (g/L)	TDS (%)	Brix	Concentration (g/L)	TDS (%)
0	0	0	0	0	0	0
30	1.8	14.85	1.53	3	24.75	2.55
60	1.6	13.2	1.36	0.8	6.6	0.68
90	2	16.5	1.7	1.2	9.9	1.02

120	2.1	17.325	1.79	1.3	10.725	1.11
150	2.6	21.45	2.21	1.6	13.2	1.36

Table A.4 Brix value and concentration of Arabica and Robusta coffee with 40 gram mass and brewing

Time	Arabica			Robusta		
	Brix	Concentration (g/L)	TDS (%)	Brix	Concentration (g/L)	TDS (%)
0	0	0	0	0	0	0
30	1.7	14.025	1.45	1.4	11.55	1.19
60	1.8	14.85	1.53	1.2	9.9	1.02
90	2	16.5	1.7	1.8	14.85	1.53
120	2	16.5	1.7	1.9	15.675	1.62
150	1.9	15.675	1.62	1.4	11.55	1.19

Table A.5 Brix value and concentration of Arabica and Robusta coffee with 50 gram mass and brewing

Time	Arabica			Robusta		
	Brix	Concentration (g/L)	TDS (%)	Brix	Concentration (g/L)	TDS (%)
0	0	0	0	0	0	0
30	1.95	16.0875	1.66	2.2	18.15	1.87
60	2	16.5	1.67	2	16.5	1.7
90	2.07	17.0775	1.76	1.9	15.675	1.62
120	2.189	18.05925	1.87	2.4	19.8	2.04
150	2.2	18.15	1.87	2.1	17.325	1.79