HYDRODYNAMICS OF TWO IMMISCIBLE LIQUID FLOW SYSTEM: BIODIESEL SYNTHESIS

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ABSTRACT

The hydrodynamic study of two immiscible liquids-liquid flow system is essential, especially in the liquid-liquid extraction process during biodiesel synthesis. This work aims to determine variable hydrodynamic parameter such as the liquid holdup fraction and dispersibility factor in two immiscible liquid-liquid flow system (*namely palm oil and ethanol employed during biodiesel synthesis*). A hindrance, which is the mass transfer limitation coexisted within the liquid-liquid flow system. The formation of emulsion layer which occurred when the organic phase expanded and the polar phase inversion occurs under vigorous stirring, resisted the upwards flow of ethanol to the decanter top and subsequently, inhibits the formation of FAEE. An agitated column with 6-bladed impellers was employed under a counter-current flow condition where the heavier palm oil phase was filled in the bottom decanter whereas the lighter ethanol was filled from the top decanter. Different feed flow rate and stirring speed were tested to identify the hydrodynamic variables. The ratio of feed flow (*ethanol to palm oil*) includes 1:1, 1:3, 3:1, 1:5 and also 5:1 whereas the stirring speed experimented were 300 and 500 RPM. It was observed that the lighter phase liquid holdup decreased along the number of stages for palm oil-to-ethanol flow ratio of 1:1, 1:3, 3:1, 1:5 and 5:1 with stirring speed 300 RPM. Similar trend can be observed with stirring speed 500 RPM. The distribution of these two phases were identified by determining the dispersibility value, wherein it was found that the dispersibility decreased along the stages together with increasing stirring speed. Noted also that the dispersibility decreased as the palm oil-to-ethanol flow ratio increased.

Keywords: Hydrodynamics, liquid-liquid extraction, liquid holdup fraction, dispersibility

ABSTRAK

Kajian hidrodinamik bagi dua cecair-cecair yang tak boleh campur dalam sistem aliran adalah penting, terutama dalam proses pengekstrakan cecair-cecair dalam sintesis biodiesel. Kerja ini bertujuan untuk menentukan parameter hidrodinamik ubah seperti pemegangan pecahan dan penyuraian faktor cecair tak boleh campur dalam dua sistem aliran cecair-cecair (*iaitu minyak sawit dan etanol yang bekerja dalam sintesis biodiesel*). Satu halangan, yang merupakan had pemindahan jisim wujud bersama dalam sistem aliran cecair-cecair. Pembentukan lapisan emulsi yang berlaku ketika fasa organik berkembang dan fasa penyongsangan kutub berlaku di bawah kacau bertenaga, menentang aliran ke atas etanol ke atas penyiring dan seterusnya menghalang pembentukan FAEE. Satu turus gelisah dengan pendesak 6-bilah telah bekerja di bawah keadaan aliran balas semasa di mana fasa minyak sawit yang lebih berat telah diisi penyiring bahagian bawah manakala etanol yang lebih ringan dipenuhi dari penyiring atas. Kadar aliran makanan yang berbeza dan kelajuan kacau telah diuji untuk mengenal pasti pembolehubah hidrodinamik. Nisbah aliran makanan (etanol kepada minyak sawit) termasuk 1: 1, 1: 3, 3: 1, 1: 5 dan juga 5: 1 manakala kelajuan kacau yang bereksperimen 300 dan 500 RPM. Ia adalah diperhatikan bahawa lebih ringan cecair fasa pemegangan menurun bersama-sama bilangan peringkat untuk nisbah aliran kelapa sawit ke etanol daripada 1: 1, 1: 3, 3: 1, 1: 5 dan 5: 1 dengan kelajuan kacau 300 RPM. Aliran yang sama boleh diperhatikan dengan kelajuan kacau 500 RPM. Pengagihan ini dua fasa telah dikenal pasti dengan menentukan nilai penyuraian, di mana didapati bahawa faktor penyuraian menurun di sepanjang peringkat bersama-sama dengan peningkatan kelajuan kacau. Diperhatikan juga bahawa faktor penyuraian menurun sebagai nisbah aliran kelapa sawit ke etanol meningkat.

Kata Kunci: Hidrodinamik, pengekstrakan cecair-cecair, cecair pecahan pemegangan, penyuraian

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LIST OF ABBREVIATIONS

ϕ	Liquid holdup
χ	Dispersibility
μ	Viscosity
ρ	Density

Subscript

$_L$	Lighter phase
$_H$	Heavy phase

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
Av	Average
FAEE	Fatty acid ethyl ester
FFA	Free fatty acid
R.P.M	Rotation per minute
RDC	Rotating disc contactor
S.D	Standard deviation

1.0 INTRODUCTION

1.1 Background

Hydrodynamics study in liquid-liquid extraction process to produce biodiesel is essential to determine variable parameter such as the liquid hold up fraction and dispersibility factor in various liquid-liquid flow system (*two immiscible liquids, namely palm oil and ethanol for this case of study*). The term 'immiscible' occurs when two substances are not capable of combining to form a homogenous solution and thus, two layers will be formed in which the lighter phase will be on top whereas the heavy phase will be in the bottom. Flows of two immiscible liquids are encountered in diverse range of processes and equipments, particularly in petroleum and biodiesel industry where mixtures of oil, ethanol and oil are transported in columns and pipes of certain height and length respectively. Therefore, hydrodynamics enables the behavioural study of the two immiscible liquids, wherein it provides a greater insight on the flow characteristic of ethanol and palm oil during the production of fatty acids ethyl ester (FAEE) in an extractive column.

In this study, the liquid-liquid extraction employed is a process for separating components in solution by their distribution between two immiscible liquid phases in which this extraction process is a function of difference in densities between the two phases. Not only that, the liquid-liquid extraction can be defined as a counter-current separation process for isolating the constituents of a liquid mixture. The counter-current flow of palm oil and ethanol in the extractive column enables the dispersed phase to be observed in the continuous phase in the form of liquid droplets, where ethanol is filled in the bottom decanter whereas the palm oil is filled in the top decanter. The dispersed phase of palm oil and ethanol in the top and bottom decanter respectively enables a throughout mixing along the extractive column, producing FAEE overtime together along with certain emulsion layer. In order to achieve higher yield of FAEE, it is necessary to operate the extractive column with multiple stages (*extractive column with 9 stages)* and with the liquids flowing counter-currently.

1.2 Motivation

Twin crises of fossil fuel depletion and environmental degradation are currently experienced today. Excessive use of fossil fuel has led to global degradation effects such as greenhouse effect and ozone depletion which have to be minimized, especially during globalization. The search for alternative fuels such as biodiesel promises a harmonious correlation with sustainable development and energy conservation as well as environmental preservation has become highly pronounced in the present context (Shahabuddin et.al., 2012). In terms of biodiesel's energy efficiency, for every one unit of energy needed to produce biodiesel, 5.5 units of energy are gained (Khan, 2013). Therefore, the search for an appropriate and concise experimental activities for the synthesis of biodiesel are actively seen in present as the world crude oil stock is continuously diminishing. Biodiesel synthesis have been sought after by researchers as it is one of the main alternative energy source that can replace the current energy source that are derived from natural resources. One of the current progressive way to produce biodiesel includes the liquid-liquid extraction, in which it operates under mild conditions (*under atmospheric pressure and low temperature condition*) Hence, liquid-liquid extraction for biodiesel synthesis is one of the revolutionary ways which should be explored in-depth as compared to other conventional methods such as supercritical and enzymatic method which are not economical feasible.

The liquid-liquid extraction used to synthesis biodiesel requires hydrodynamic variables such as the fraction liquid hold up and dispersibility of the two immiscible liquid to be made known. This is to estimate the formation of emulsion phase which usually occur when the organic liquid holdup is almost all unity. In contrast, the dispersibility is used to determine whether there is any back mixing which usually have a detrimental effect on multistage columns. Dispersibility also enables the identification of phase inversion due to the condition where either ethanol or palm oil can be a dispersed phase. Not only that, by studying the effect of flow ratio of oil and ethanol in the extractive column, the dispersed form of the organic phase can be maintained. The stirring effect will also be analysed to observe the change in fraction liquid hold up when the stirring speed alters and thus, prevent the formation of emulsion which hinders the mass transfer of the biodiesel components in the extractive column.

Therefore, by studying these hydrodynamics variables of two immiscible liquids, the optimum conditions (stirring speed and feed flow rate) can thus be identified for the synthesis of FAEE in a liquid-liquid extractive column, providing useful information on its operational condition.

1.3 Problem Statements

Mass transfer limitation, which is a form of hindrance is expected to coexist within the liquid-liquid flow system (Sha'piee, 2013). One of the hindrance includes the formation of emulsion layer which occurs when the organic phase expands and the polar phase inversion occurs under vigorous stirring (Mahmud, 2011). The emulsion phase generated would be dominant, hindering the upwards flow of ethanol to the decanter top and subsequently, inhibits the formation of FAEE.

The unidentified operational conditions for the liquid-liquid extractive column also will lead to mass transfer limitation in the flow system. The stirring speed of the impellers can indirectly influence the flow system as the mechanics of flow for the solvent extraction are closely related to the interfacial area, compromising the fraction hold up, dispersibility and physical properties of the liquid phases (Chong, 2013). Not only that, different feed ratios (*ethanol and palm oil)* will cause the properties of the two-phase flows to vary in the extractive column. For instance, increasing the palm oil flow rate would increase the emulsion formation (Mahmud, 2011)

1.4 Research Objectives

There are several purpose to conduct this research: These include:

1.) To determine the fraction liquid hold up for the two liquid phases (*ethanol and palm oil)* along the extractive column stage at different flow rates.
2.) To investigate the effect of stirring speed on the dispersibility of the two liquid phases (*ethanol and palm oil*)

Commentary: Although it seems that the objectives are many, they are all obtained from the sample experimental works.

1.5 Scope of Study

During this analysis, ethanol will be employed instead of methanol whereas palm oil will be the source of triglycerides for the synthesis of biodiesel (FAEE). An agitated extractive column with impellers will be employed under a countercurrent flow condition where the heavier palm oil phase is filled in the bottom decanter whereas the lighter ethanol is filled from the top decanter. Different feed flow rate and stirring speed are tested to identify the hydrodynamics variable. The ratio of feed flow (ethanol to palm oil) includes 1:1, 1:3, 3:1, 1:5 and also 5:1 whereas the stirring speed experimented will be 300 and 500 RPM. Initially, the flow meters of the palm oil and ethanol have to be calibrated as there tend to be cavitation in the pump along the flow meter which causes the pumping rate to differ from its actual condition. To check whether the flow system have achieve a steady state, a torque reading indicator above the stirrer will show a constant value in terms of percentage of its maximum value.

1.6 Thesis Organization

To acquire a better insight and understanding on the hydrodynamic study, this research involves a prominent literature survey, designing experimental works and a thorough discussion on the results, in which these can be outlined in the subsequent chapters of this thesis:

Chapter 2: To review on the various aspects of liquid-liquid extractive column and the hydrodynamics behavioural of two immiscible liquids.

Chapter 3: To identify the materials and methods available to conduct the research and also not forgetting the experimental set-up strategies.

Chapter 4: To represent the raw data obtained and elaborate the findings from the analysed results.

Commentary: The last section of this thesis basically summarizes and the conclusions drawn from this research, and subsequently re-addressing the key objectives introduced in the review based on the findings in the investigations. Recommendations are then given to pursue more intensive research and thus, improvise this biodiesel study. Finally, the attached appendices provide a thorough account of tabulated data and calculations that are referred to in the textual chapters.

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2.0 LITERATURE REVIEW

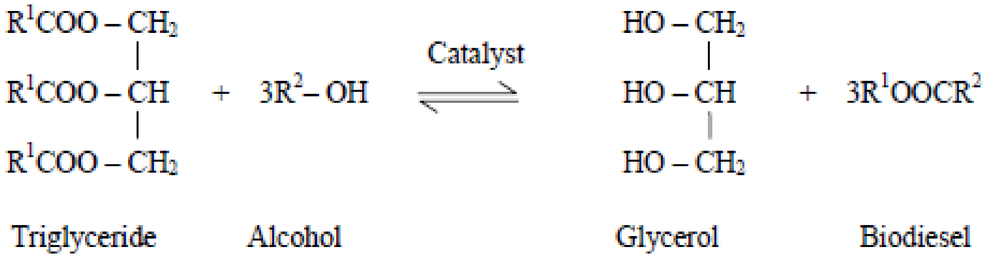
2.1 Chapter Overview

This chapter consists of the reviews on literature related to the hydrodynamics study of two immiscible liquid in an agitated column, particularly for biodiesel synthesis. The reviews can be organized into seven main sections. The first section will be a general review on the biodiesel where there will be explanation on its classification and synthesis. The second section will be reviewing on the reasons ethanol is used instead of methanol for biodiesel synthesis. Next, the third section will be a general overview on liquid-liquid extraction along with certain conventional configurations. The fourth section will be touching on the extractive reaction in the column. The fifth section will include the different type of agitated column used previously. The following section will be reviews on disturbance such as inverse phase emulsification and the final section will be reviewing on the hydrodynamics properties in liquid-liquid flow system.

2.2 Biodiesel

Biodiesel (ASTM 6751), in accordance with the US Standard Specification, is defined as a fuel comprising of mono-alkyl esters of long chain fatty acids derived particularly from vegetable oils or animal fats (Vicente et.al., 2007). Biodiesel has similar physico- chemical properties as conventional fossil fuel and can consequently, entirely or partially substitute fossil diesel fuel in compression ignition engines (Pasqualinoa, 2006).

Vegetable oil consists of complex esters of fatty acids and these are the fats naturally present in oil seeds, known as tri-glycerides of fatty acids. Due to the high molecular weights of these tri-glycerides (*of order of 800* kg/m^3 *or more*), these fats have high viscosity causing major problems in their use as fuels in engine (Jaichandar & K.Annamalai, 2011). These molecules have to be split into simpler molecules so that they have viscosity and other properties similar as to that of standard diesel oils and therefore, modifying the vegetable oils (*to make them lighter*), can be achieved via transesterification where it is the most commonly used commercial process to produce biodiesel. Via transesterification, animal or vegetable oil is converted into biodiesel when one mole of triglyceride reacts with three moles of alcohol to produce a mole of glycerol and three moles of mono-alkyl esters. The following equation is a reversible transesterification reaction:



The hydrocarbon chains of biodiesel produced do not contain sulphur or any aromatics compounds in its composition and thus, biodiesel is classified as an alternative fuel that is obtained from renewable resources that burns in diesel engines with less environmental pollutants (Demshemino et.al., 2013).

2.3 Choosing Ethanol Over Methanol for Biodiesel Synthesis

Many studies were recently focusing on using methanol to synthesize fatty acid esters as their price is relatively cheap and abundantly available. However, in this research, ethanol will be used to synthesize biodiesel due to several reasons. The first reason includes ethanol being less toxic as compared to methanol. Vapours of methanol are irritating to the lungs and can damage the eyes, even in small doses in which it is metabolized by the body to formaldehyde (which is also very toxic) and then to formic acid. Not only that, ethanol has excellent fuel property where it would not dissolve tubing materials and corrode gasket. Furthermore, ethanol is produced a more environmentally benign fuel. The systematic effect of ethyl alcohol differs from that of methyl alcohol as ethyl alcohol is rapidly oxidized in the body to carbon dioxide and water, and in contrast to methyl alcohol no cumulative effect occurs. Ethanol is also a preferred alcohol in the transesterification process compared to methanol because it is derived from agricultural products such as corn and it is renewable and biologically less objectionable in the environment (Demirbas, 2005)

2.4 Liquid-Liquid Extraction

Liquid-liquid extraction can be used in biodiesel production. The conventional esterification way to produce biodiesel can be replaced with liquid-liquid extraction where methanol do not only serve as a reactant but also as a solvent to extract the oil from the feedstock for biodiesel production. This concept was investigated on cottonseeds to generate cottonseed meal and biodiesel products where it was found that an extraction rate of 98.3% could be achieved for cottonseed oil while the free fatty acids (FFAs) and water content of cottonseed were reduced to 0.20% and 0.037% respectively, meeting the requirements of base-catalyzed transesterification (Qian et.al., 2010).

Liquid-liquid extraction for biodiesel is a type of diffusional process, wherein phase composition equilibria are reached by mass transfer of molecules across the interface from one phase to the other. If the phases are not in equilibrium, net accumulation of components in one phase and depletion of the other in the direction of equilibrium will occur. Given that the densities of the phases are different, the multistage effect can be obtained by introducing the solvent and feed at opposite ends of a vertical tower. Denser phase will flow counter-currently to the lighter phase across the extractive column. Consequently, the concentration of the components in the two liquid phases in contact will not be in equilibrium, and mass transfer will take place, concentrating the more soluble materials in the extract phase and the less soluble ones in the raffinate phase (Pratt, 1953)

Liquid-liquid extraction involves the combination of chemical reaction to achieve synergistic effect in terms of its final product’s selectivity, productivity and conversion (Rivera, 2004). To maximize the interfacial area available for mass transfer, liquid-liquid extraction column with multiple stages will be employed as it promotes the contact between a dispersed phase (*in droplet form*) and a continuous phase. This interfacial area depends on the coalescence process generated within the extractor and also on the dispersion device at the feed entry. Previous experimental work to synthesize biodiesel includes Gutierrez’s work, in which a biodiesel-enriched liquid phase (65% of ethyl esters) and a glycerol-enriched liquid phase (44% of glycerol) are continuously removed from the multi-stage liquid-liquid extractor (Gutierrez, 2008) with palm oil and ethanol as the reactants.

The figure below represents the conventional configuration involving liquid-liquid reactive extraction:

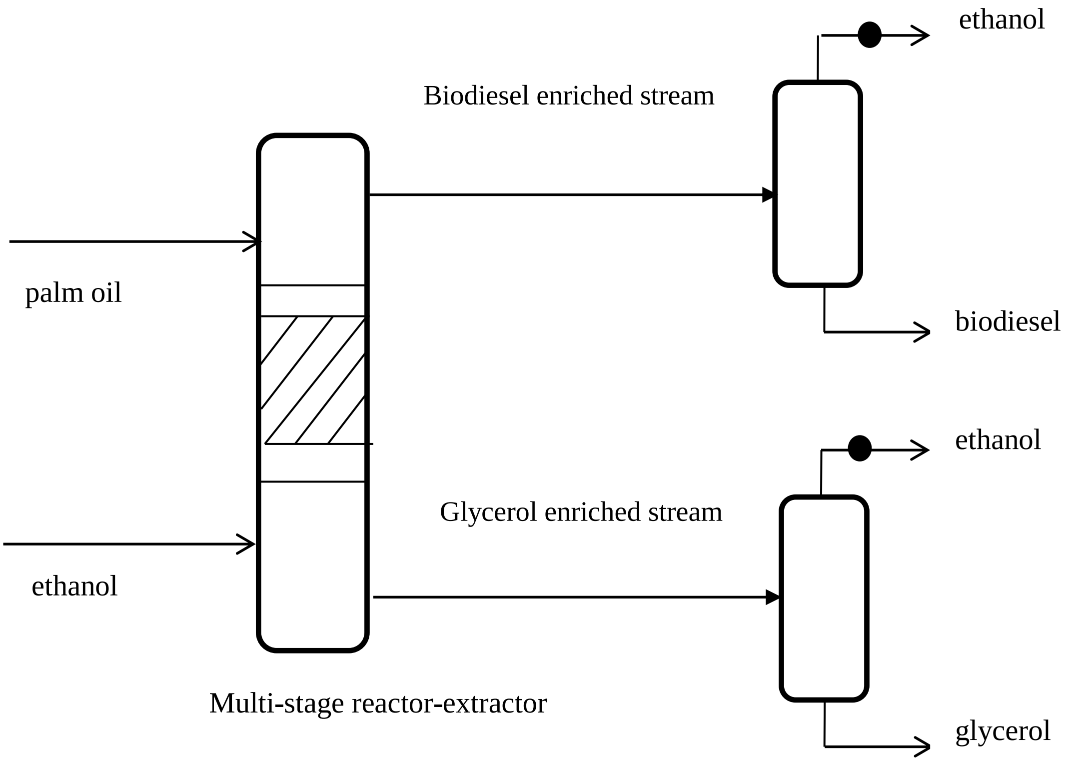


Figure 2-1: Liquid-liquid reactive extraction

Not only that, a novel of continuous process is proposed in the present work of Garcia Jurado’s which suggest the use of a single column liquid-liquid extraction with two zones : a reactive-extractive zone and another extractive only (Figure 2.2)

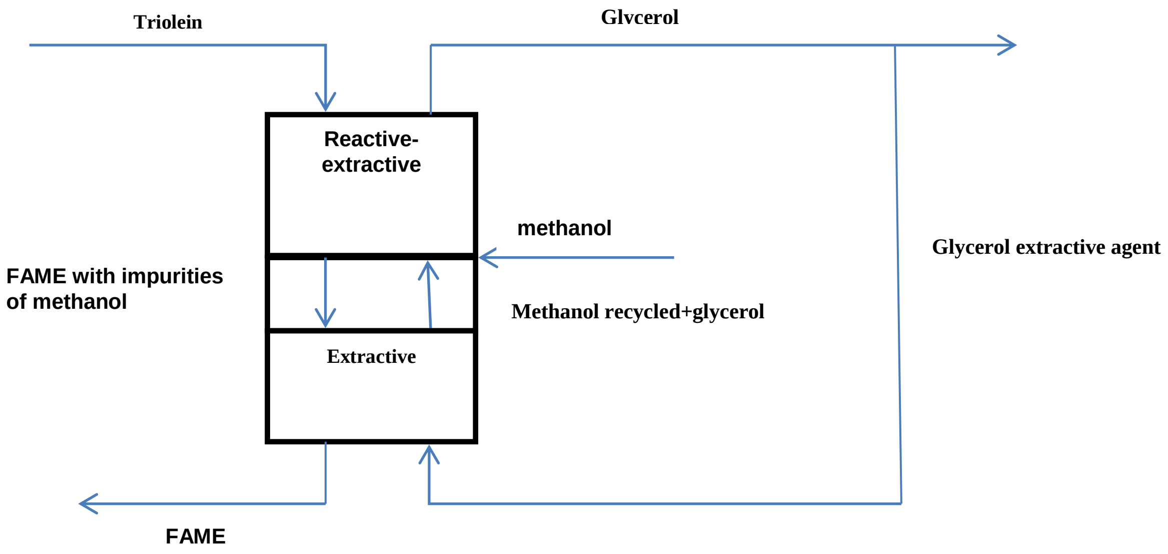


Figure 2-2: A reactive-extractive zone and another extractive

All along the column, the reactants flow in countercurrent. In this way, at one end of the reactive section, an excess of methanol is assured for high conversion of triglycerides and in the other end the excess of triglycerides assures a high conversion of methanol. Thus, an excess of reactant can be achieved at both reactive section ends while the overall reactant feeds to the two immiscible liquid flow system can be in stoichiometric ratio. A synergy effect is created between the reaction and liquid-liquid separation where this process utilizes the advantage of the affinity between methanol and glycerol, having a non reactive extractive section useful to recover the methanol present in the FAME stream (Juradoa, 2013).

2.5 Extractive reaction

To improve the reaction yield of reversible reactions specifically in biodiesel production, extraction process together along with the shifting of physicochemical equilibrium must be employed (Perry & Green, 2008). This in turn decreases the capital investment due to high yield and selectivity towards the main product (Samant & Ka, 1998b). A second immiscible liquid phase which independently appears may be generated due to the accumulation of a co-product (Mahmud, 2011), in which by introducing solvents, the simultaneous liquid-liquid phase separation will facilitate extraction of an intermediate or a product. This prevents futher reaction or leading to beneficial equilibrium shift (Rydberg et.al., 2004a)

Notions of an extraction-driven reaction in a single column were implemented in the late 20th century (Bart, 2003) where application of this type of column was believed to begin in the nuclear field and later in the chemical industries. Examples of extractive reaction includes extractive reaction of fatty acid ethyl esters (biodiesel) from palm oil distinctively using inorganic catalyst resin (Gutierrez, 2008), continuous production of N-(benzyloxycarbonyl)-l-lglycyl-l-phenylalanine methyl ester in aqueous organic biphasic medium (Murakami et.al., 2000), alcoholic extraction of vegetable oils (Rao & Arnold, 1956) and many more. However, not all extraction reaction can benefit from this technique and thus, it is necessary to formulate a systematic framework for developing potential processes (Mahmud, 2011). Therefore, a procedure based on equilibrium thermodynamics was developed for synthesis of single- and multistage extractive reaction in order to facilitate the idea of extractive reaction (Samant & Ka, 1998) where several key features such as the reactive equilibria in the multicomponent feed and the hydrodynamic parameters in the column model (Bart, 2003) have to be taken into consideration.

2.6 Agitated extractive columns

The agitated extraction is unanimously appropriate for all kind of extracting applications following the limiting condition, which is a minimal density difference of 0.05kg/m^3 between both phases and also having a strong tendency to resist the formation of emulsion in order to allow a smooth agitation (Sulzer.com ,2014). Some of the advantages of using an agitated extraction column include its adaptation of the compartments and agitator geometry to the specific product and operation process conditions, the adjustable optimal droplet size by varying the agitator speed, insensitive to solids and also its alternatively heavy or light phase dispersed.

The initial models of extraction column were simple in nature as both the phases were assumed to be in differential contact with each other (*a continuum*). The dispersed phased was categorized as pseudo-homogenous and backflow was accounted for by the axial dispersion coefficient. In the subsequent models, the dispersed phase was epitomized by monodispersed drops without undergoing breakage or coalescence. However, in later models, the coalescence was taken into consideration by introducing a coalescence height and the concentration of the dispersed phase was assumed to be constant throughout a given cross-section of the column due to sufficiently intensive redispersion. In the recent modeling of the extractive column, population balance models have been established to predict hold-up profiles along the length of the column taking into consideration the drop breakage and coalescence (Mohanty, 2000).

There are various types of agitated extractive columns present today such as the RDC, Scheibel's, Karr's, and also Kuhni or Kuehni's extractor column. Each of these agitated extractive column has its own different characteristics. As early as 1940, contactors attached with mixing mechanisms have been used in countercurrent liquid-liquid extraction systems (Rydberg et al., 2004). An example of a mixer-settler column which constitutes multiple stages arrayed in series includes the Scheibel's column. This particular column has a high efficiency due to internal baffling and it is best suited when many stages are required. However, this column is not recommended for highly fouling systems or rather systems that tend to emulsify (Modularprocess.com, 2014).

Agitated extractor can be divided into two main categories based on the mechanical motion pattern which is either a circular rotation or axial reciprocation. These different types of circular extractors differ in terms of the design of the mixer and stator plates or baffles which compartment the column into successive stages (Mahmud, 2011). For example, the Scheibel's column have a turbine impeller with horizontal inner and outer baffle but, however do not have any stator plates. In contrast, the rotating disk contactor (RDC) system utilizes horizontal disks as the agitating elements which aids in the shearing of the dispersed liquid, along with stator rings above and below which have a larger aperture than the diameter of the agitating disk (Mahmud, 2011). The RDC is suitable for viscous and fouling materials unlike the Scheibel column and also sensitive to emulsion due to high shear mixing. However, it has a limited efficiency due to axial backmixing (Modularprocess.com, 2014). On the other hand, the Karr column has perforated plates which moves vertically with tie rods and spacers in between the column. Baffle plates are located below the perforated plates and it essentially has a pulse-driven sieve tray mounted onto the central shaft by means of reciprocal force located at the top of the column. This type of column has a uniform shear mixing and thus suitable for systems that emulsify (Modularprocess.com, 2014). In comparison, the Kuhni or Kuehni column has perforated partition plates with customizable aperture arrangement and size which allows flexibility of the column to suit a variety of application (Mahmud, 2011). The dimension of Kuhni extraction column includes three spacer rods and a Teflon bearing together with perforated plates (Kumar, 1986). This typical column is for high mass transfer or changing fluid physical properties along the column as the geometry of the agitated compartments can be adapted for changing hydrodynamic conditions. Also, it can be used for various components with widely differing boiling points (Sulzer.com, 2014).

2.7 Phase inversion emulsification

Phase inversion is a phenomenon where the dispersed phase becomes the continuous phase and vice versa, in which emulsion will usually form. Emulsions are fluid systems composed of at least two immiscible phases. This system present a dispersed phase, usually in the form of droplets, surrounded by a continuous matrix where in some conditions, the dispersed phase can be the one present in smaller quantitiy. The “oil phase” is usually considered as organic whereas the aqueous can be presented as inorganic (Preziosi et.al., 2013).

2.8 Hydrodynamic Properties in Liquid-Liquid Flow System

Liquid holdup

The above hydrodynamic parameter can be used to gauge the efficiency of unit operations and process by computing the hydrostatic head losses in the two-phase. It is defined as the fraction volume of a phase over the total contacting volume (Mahmud, 2011) where

$$\emptyset = \frac{volume\ of\ a\,phase}{total\ contacting\ volume}$$

This liquid holdup equation is a function of dimensionless liquid where its value varies from zero to one for single-phase liquid flow. The liquid holdup can be measured experimentally by various methods such as by using an injection syringe to measure the volume of liquid trapped extracted from the septum along the column. Previous works include the measurement of pressure gradient.

Dispersibility

The dispersibility factor, χ is a function of stirring speed and the height of the column by means of stage numbers. As the stirring speed increases, there is a probability that a phase flow disperse slowly and changes from organic phase to aqueous phase from the upper stages to the lower stages of the column (Mahmud, 2011). This trend can be depictured by the figure below where these data were obtained from the experimental works of Dr Sabri bin Mahmud:

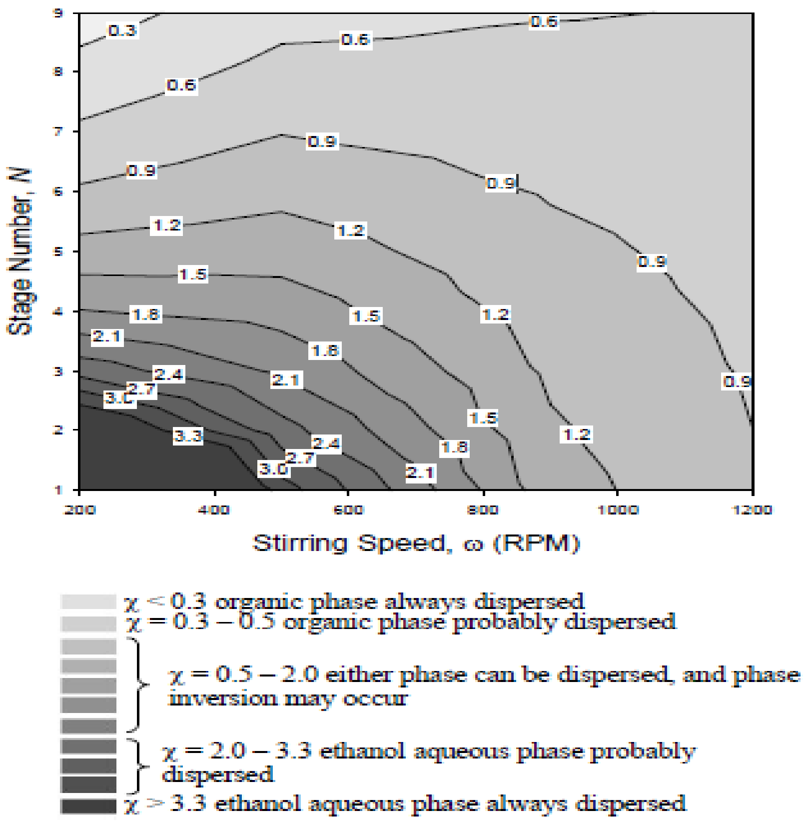


Figure 2-3: Dispersibility measure of organic phases in stages of the column

(Mahmud, 2011)

The dispersibility factor (Frank et al, 2008; Hooper, 1997; Penney, 1987) for a liquid-liquid flow system can be calculated using the following formulae:

$$X = \frac{\phi_L}{1 - \phi_L}\left(\frac{\rho_L \mu_H}{\rho_H \mu_L}\right)^{0.3}$$

where ϕ_L denotes the volume fraction of the light organic phase, ρ_L and μ_L as the density and viscosity of the light phase liquid respectively. One of the significance in finding the dispersibility factor includes the detection for any possible phase inversion due to back mixing which is an adverse effect in a multistage column.