Increasing Protein Concentration in Soymilk Using Ultrafiltration Membrane Process

Shnonn Eamdee

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Accepted by the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering (Petrochemical Engineering).

Thesis Committee

_____ Chairman

(Asst. Prof. Dr. Pornsawan Assawasaengrat)

_____ Committee

(Asst. Prof. Dr. Santi Wattananusorn)

_____ Committee

(Dr. Pattranit Wongpromrat)

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Abstract

The research is aimed to increase the concentration of protein in soymilk and to study the effects of parameters on protein concentrated in soymilk using ultrafiltration membrane process including quantity of round and feed flow rate of membrane. The protein concentration was determined by Kjeldahl method. The result shown that the protein concentration of raw material soymilk was 2.37% (w/v). After, filtered by ultrafiltration membrane, the result shown that the protein concentration in soymilk was increased to 4.66% (w/v) with 7.5 millileter per second of feed flow rate at the fifth round of membrane process.The feed flow rate affect directly to permeate flux, it means that water was separated better in high flow rate but the higher feed flow rate get more risk to increase occurrence of concentration polarization and fouling. The quantitiy of round affect directed variation to percentage of protein concentration in retentate. In conclusion, indication that protein concentration in soymilk was increased using ultrafiltration membrane process which is a alternative method to increase the value of soymilk in milk industry.

Keywords: Ultrafiltration, Soymilk, Membrane

เรื่อง	การเพิ่มความเข้มข้นของโปรตีนในน้ำนมถั่วเหลืองด้วยกระบวนการอัลตราฟิวเตรชันเมมเบรน
โดย	นาย ชนน เอี่ยมดี
อาจารย์ที่ปรึกษา	ผศ. ดร. พรสวรรค์ อัศวแสงรัตน์, ดร. พงษ์เสริฐ ศรีพรหม
สาขาวิชา	วิศวกรรมปิโตรเคมี
สังกัด	ภาควิชาวิศวกรรมเคมี คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาการเพิ่มปริมาณความเข้มข้นของโปรตีนในน้ำนมถั่วเหลืองด้วยกระบวนการอัลตราฟิวเตรชันเมมเบรน (Ultrafiltration Membrane Process) และศึกษาปัจจัยที่มีผลต่อความเข้มข้นของโปรตีนที่ผ่านกระบวนการอัลตราฟิวเตรชันโดยปัจจัยที่ใช้ในการออกแบบกระบวนการอัลตราฟิวเตรชันเมมเบรน ได้แก่ จำนวนรอบและอัตราการป้อนเข้าของระบบเมมเบรน ซึ่งปริมาณโปรตีนในน้ำนมถั่วเหลืองถูกทดสอบด้วยวิธีคเจลดาห์ล (Kjeldahl Method) โดยการวิเคราะห์ปริมาณไนโตรเจนที่มีอยู่ในตัวอย่าง ปริมาณโปรตีนในน้ำนมถั่วเหลืองมีประมาณร้อยละ 2.33 โดยมวลต่อปริมาตร ผลการศึกษาพบว่าอัตราการป้อนเข้าของน้ำนมถั่วเหลืองอยู่ระหว่าง 7.5 มิลลิลิตรต่อวินาทีที่จำนวน 5 รอบ ซึ่งจากภาวะที่กล่าวมาจะสามารถเพิ่มความเข้มข้นของโปรตีนในน้ำนมถั่วเหลืองได้เป็นร้อยละ 4.66 โดยมวลต่อปริมาตร อัตราการป้อนเข้าของระบบเมมเบรนส่งผลโดยตรงกับเพอร์มีเอตฟลักซ์ เมื่ออัตราการป้อนเข้าสูงขึ้นจะส่งผลให้แยกน้ำออกจากน้ำนมถั่วเหลืองได้ดีขึ้น แต่ในขณะเดียวกันหากอัตราการป้อนเข้าสูงเกินไปจะส่งผลให้เกิดคอนเซนเตรชันโพลาไรเซชัน (Concentration polarization) และฟาวลิ่ง (Fouling) จำนวนรอบมีผลโดยตรงกับปริมาณของโปรตีนในรีเทนเทต (Retentate) ถ้าจำนวนรอบสูงขึ้นจะส่งผลให้แยกน้ำออกจากน้ำนมถั่วเหลืองได้มากขึ้น จากการศึกษาจะเห็นได้ว่าการเพิ่มโปรตีนในน้ำนมถั่วเหลืองเป็นการเพิ่มช่องทางในการเพิ่มมูลค่าของน้ำนมถั่วเหลืองในท้องตลาด

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Shnonn Eamdee

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NOMENCLATURE

NF	Nanofiltration
MF	Microfiltration
UF	Ultrafiltration
V_s, V_b	Volume of HCl titrant used for sample and blank (ml), respectively
M	Molarity of HCl solution
W	Weight of sample (g)
F	Factor for converting nitrogen to protein, for milk use 6.38

CHAPTER I

INTRODUCTION

1.1 Background

Soymilk is one kind of milk that is obtained from soybean. There are various of soymilk benefits such as containment of antioxidants and increasing strength of blood vessels. It is known as an alternative source of protein apart from cow milk. The further advantage comparing to other protein sources is the high ratio between protein and fat (Soymilk 1.86, Cow milk 1.27) *[S. Van Dyck, 2010]*. Protein also consists of amino acid connected to each other in different forms and arrangements. Any cell in the human body consists of protein which aims to fix, improve and develop our body.

The common ways to dispart protein from soymilk are extraction, separation and thermal treatments. Yet, their bad flavor from the enzymatic oxidation of unsaturated fatty acids catalyzed by lipoxygenase *[Axelrod, 1981]* seems to be inevitable. The bad flavor was gotten rid by a blanch treatment to soybean. However, the amount of protein in soymilk was low compared with other kinds of milk. Soymilk contains only 2-3% protein and particles in diameter of >40 nm *[Ono, Choi, Ikeda, & Odagiri, 1991]*. Protein concentration in soymilk was increased and separated by a membrane. As it seems to be a faster and effective way to extract protein from water in soymilk, it keeps the fouling composite low at the medium's surface. Ultrafiltration (UF) is one of the membrane separation processes. The range of particle size is around 20 Nanometer to 0.1 Micrometer. The driving force is pressure and concentration. The materials which are used to create UF are ceramic *[Marta, 2016]*, carbon *[Zhang, 2018]*, zeolite *[Xuehong, 2018]*, and polymer [*Nanwen, 2018*] membrane. Most popular membrane for protein separation is made from a certain polymer such as a polysulfone or polyethersulfone *[Cui, 2005]*. Protein concentration in soymilk was concentrated by Ultrafiltration, water is separated into the permeate while concentrated protein is transferred into the retentate. The research has shown that the parameters which affect protein concentration are the flow of velocity, the temperature and the transmembrane pressure *[Cassini, 2010]*. However, the concentration polarization and the fouling on the membrane surface still limit the UF process. Both lead to a decrease in permeate flux over time.

Finally, this project aims to increase the protein concentration in soymilk using membrane separation along with study the effect of variables which affect protein concentration.

1.2 Objective

1.2.1 To increase protein concentration in soymilk using by Ultrafiltration membrane process

1.3 Scopes of Work

1.3.1 Study the effects of the parameter in protein concentration by using Ultrafiltration membrane process

1.3.3.1 Study the feed flow rate of soymilk between 5 – 10 ml/s to optimize the increment of protein concentration in soymilk by using Ultrafiltration membrane process

1.3.3.2 Study the round number of membrane process between 1 – 5 round(s) to optimize the increment of protein concentration in soymilk by using Ultrafiltration membrane process

1.3.2 Evaluating protein concentration in soymilk by using nitrogen equivalent called Kjeldahl method

1.4 Expected Outputs

1.4.1 The increment of protein concentration in soymilk

1.4.2 To use ultrafiltration membrane process to separate concentration protein in soymilk

1.4.3 An alternative to increase protein concentration in soymilk for any industrial

CHAPTER II

LITERATURE REVIEW

2.1 Protein

Protein is one of macronutrient which is vital for human utilizing mainly to fix the human body. Protein can be found in meats, milk, and nuts, protein consists of amino acids that connecting in various forms and arrangement in the polypeptide chain. There are plenty of cells in the human body and protein is needed for cell maturation. Protein size varies between 1-100 nanometer, so it called nanoparticles. There are many physical properties of protein for instance, colorless, tasteless, homogeneous and low diffusion rate. Globular and Fibrillar are both patterns of protein. Globular is long, narrow and has a structural use while fibrillar is round and has a functional use. *[Xingyun, 2016]*

2.1.1 Soy protein

Soy protein can be found in soybean which is one of ingredient in tofu, soymilk, and animal meat substitute for Vegetarianism. In term of nutrition, soy protein consists of Manganese, Copper, Potassium, Phosphorus, Selenium, Calcium, Iron and lots of Vitamin that all good for human health. In term of the quality of the protein source, soy protein is better than other plant protein and has protein and fat ratio better than animal meat. Most essential amino acids which found in soy protein are leucine, isoleucine, threonine, tryptophan, valine methionine, phenylalanine, lysine and histidine. The diameter of protein particle is more than 400 Angstroms. *[Xingyun, 2016]*

2.2 Soymilk

Soymilk is a beneficial protein beverage which comprises of 2-3% proteins, 2% fat and 2% non-lactose carbohydrates (i.e. sucrose, statchyose, rhamose) *[Giri & Mangaraj, 2012].* Soymilk is free of cholesterol and contains no lactose. Comparing to cow's milk, the quantity of calories is lower.

2.2.1 Preparing soymilk

2.2.1.1 Traditional method

Soymilk is obtained by extraction, separation and thermal treatments. The process starts with mixing soybean seeds with water then blends it in a grinding machine. Afterwards, separate Okara (the insoluble extraction) then heat the soluble extraction until boiling and cool it down. *[Xingyun, 2016]*

2.2.1.2 Blanching method

For industry production of the traditional method, soymilk flavor is unpleasant as the result of the unsaturated fatty acid enzymatic oxidation catalyzed by lipoxygenase *[Axelrod, 1981]*. To eliminate those flavors, blanching is operated. Started with a denaturation temperature of lipoxygenase, it causes inhibition the distasteful flavor. *[Xingyun, 2016]*

2.3 Membrane

The equipment used to separate substance is called "Membrane". Some matters are allowed to pass through, yet some are not. Its operation has occurred between medium, Membrane, and the membrane's driving force factors, which are concentration, pressure and electric power (for ion membrane). Furthermore, this process also has no change in phase, consumes low energy, and be able to concentrate and purify the product. At any rate, a proper membrane should firstly meet these requirements which are high chemical resistance, high flux and selectivity, low fouling rate at the membrane's surface, and inexpensive. *[Zhanfeng, 2005]*

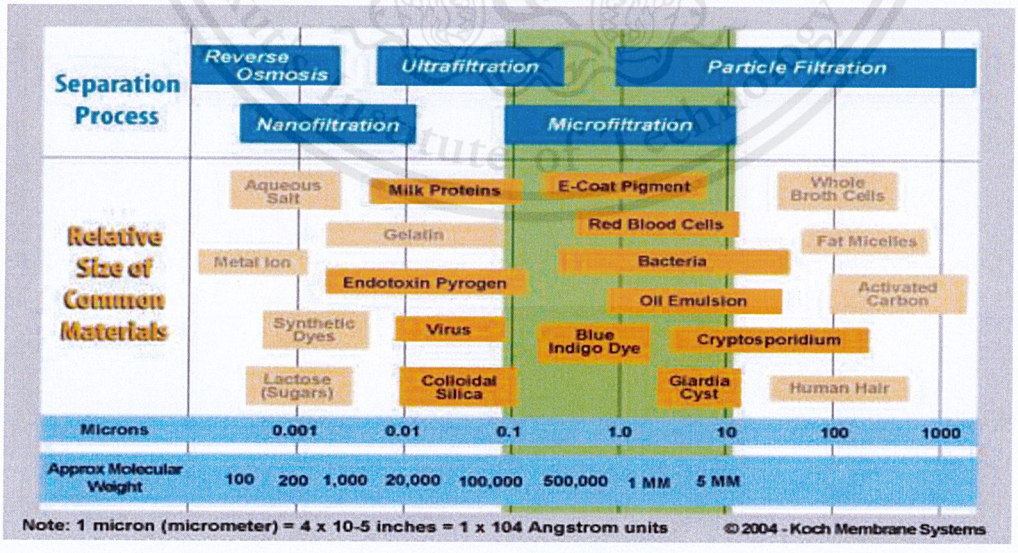

Figure 2.1 Classification of membrane filtration as a function of molecular weight cut off and pore size *[Koch, 2004]*

2.3.1 Microfiltration (MF)

Microfiltration separates particles between 500 to 20000 Angstrom and operates at 15 to 500 kPa. It is used to remove bacteria in water and used in pre-treatment for the reverse osmosis. It consists of two types of pores screen filter, and depth filter. *[Kulozik, 2019]*

2.3.2 Nanofiltration (NF)

Nanofiltration separate particles between 10 to 50 Angstrom and operate at 500 to 1400 kPa. It is used in wastewater treatment and pre-treatment before reverse osmosis to prevent fouling and concentration polarization. *[Ahsan, 2019]*

2.3.3 Ultrafiltration (UF)

Ultrafiltration separates particles between 30 to 1000 Angstrom and operate at 200 to 1400 kPa. The popular application of UF is protein concentration, desalting and purification. The main driving force is pressure gradient. Most important things to concern when operating ultrafiltration are concentration polarization and fouling. Ultrafiltration membranes are produced from metallic materials, ceramic and polymers. The latter is the most popular one for UF application. The important parameters in the process are permeate flux, membrane rejection and membrane selectivity. Membrane modules were categorized into 4 kinds, which are flat sheet, tubular, hollow fiber and spiral wound. The advantage and disadvantage of these modules, flat sheet and tubular, were designed to minimize concentration polarization and fouling by controlling feed rate. While hollow fiber and spiral wound frequently found concentration polarization and fouling but provide more surface area. *[Zhanfeng, 2005]*

2.4 Kjeldahl method

Kjeldahl is the method that used to determine protein in food such as milk, rice and nuts. Consisting of 3 steps, digestion, distillation and titration. The process started with digesting a sample in sulfuric acid using copper as a catalyst then boil it to release nitrogen from protein and retain nitrogen as the ammonium salt. The concentrated sodium hydroxide is used for releasing ammonia. The distillate is mixed with boric acid and then titrated with hydrochloric acid. *[Compendium of methods for food analysis, 2003]*

2.4.1 Calculation

$$\text{Nitrogen, (\%)} = \frac{1.4\times(Vs-Vb)\times M}{W}$$

Where

V_s and V_b = volume of HCl titrant used for sample and blank (ml), respectively

M = molarity of HCl solution

W = weight of sample (g)

Protein, (%) = %nitrogen x F

Where

F = factor for converting nitrogen to protein, for milk use 6.38

2.5 Literature Review

In the past, membrane technology is in many applications such as purification of drinking water, but the disadvantages are slow operation and high costs. Nowadays, membrane technology is used on a larger scale in many industries and have a variety of membrane types such as an organic and inorganic membrane. The study is mainly about the protein separation and the effect of the parameter, for instance, feed rate, pressure, temperature, and initial protein concentration using ultrafiltration membrane. Cassini studied about the performance of three ultrafiltration membranes treating the wastewater. The 20-kDa shown the best results because of the highest percentage of protein in permeate. Gavazzi studied about high-protein milk concentration produced by ultrafiltration. To maximize protein percentage in the retentate, polymer membrane is used. Baldasso studied about purification of whey protein using ultrafiltration and obtained protein concentrate more than 70% by weight (dry basis).

Table 2.1 Literature review of ultrafiltration membrane process

Membrane	Pore size	Condition	% Permeate	% Retentate	Reference
Monotubular ceramic	5 kDa	6 bar 48 °C	31	52	Cassini, 2009
	20 kDa		18	74	
	50 kDa		39	52	
Spiral-wound Polyethersulfone	10 kDa	4.65 bar 50 °C	9.8	79.7	Gavazzi, 2018
Spiral Polyethersulfone	10 kDa	2 bar 50 °C	-	71	Baldasso, 2011

CHAPTER III

RESEARCH METHODOLOGY

3.1 Apparatus

1. Beaker, (Duran, Germany)
2. Titration burette, (Duran, Germany)
3. Pipette, (Duran, Germany)
4. Flask, (Duran, Germany)
5. Weight scale, (Shimadzu, Japan)
6. Digestion block, (with adjustable temperature control and device for measuring block temperature), (Gerhardt, Germany)
7. Distillation block tubes, (Duran, Germany)
8. Distillation unit for steam distillation, (Gerhardt, Germany)
9. Membranes module, (Hollow fiber and Polyethersulfone synthetic), (Dora, China)
10. Feed tank
11. Valve
12. Pump, (Seaflo, Thailand)

3.2 Chemicals and Reagents

1. Sulfuric acid, 95 – 98 %, (reagent grade, SIGMA-ALDRICH)
2. Copper catalyst solution, $CuSO_4$: KSO_4 = 1: 10, (reagent grade, SIGMA-ALDRICH)
3. Boric acid solution, 2%, (reagent grade, SIGMA-ALDRICH)
4. Sodium hydroxide 40% (w/v), (reagent grade, SIGMA-ALDRICH)
5. Hydrochloric acid 0.1N, (reagent grade, SIGMA-ALDRICH)
6. Soymilk
7. Shear indicator consists of 0.016% methyl red, 0.083% bromocresol green in ethanol, (AR grade, RCI LABSCAN)

3.3 Experimental Procedure

1. Preparation of soymilk

Start with soak the clean fresh 500 g soybean seeds in water for 10-12 hours, then the bean was grounded with 4.5 liters of water by blending machine, after that separate milk from residue using fine cloth, then boiled it at 100 degree Celsius for 15 minutes and stirring simultaneously. Finally, the sample was kept in freezer to keep it fresh until the use.

2. Determination of protein using Kjeldahl method

Start with weigh the 10 ml sample, then put the sample in a digestion tube, then weigh 10 g of catalyst and pour it in the digestion tube and pour 25 ml of sulfuric acid in digestion tube and sway it softly till it is completely mixed. Put the sample tube and blank the tube in a digestion block then turn on the hood. Heat the sample up until it become thicker, then stop the heater when the liquid become blue (often around 2 hours). Put the digestion tube in the distillation unit and pour 100 ml of 50% Sodium hydroxide in a digestion tube, then pour 60 ml of Boric acid in a 250 ml flask. Drop a shear indicator to make boric acid become pink and put it in the unit. The sample was distilled for 5 minutes until getting 100 ml of distillate. The sample was titrated with sulfuric acid until it becomes pink (the same color before distillation). Then calculate the percentage of nitrogen and protein content.

3. Study the effect of feed flow rate and quantity of round

The sample in the feed tank were fed to the pump at 10 ml/s feed flow rate. The temperature of the sample was kept constant at room temperature. Then pass it through pre-filter to filtrate others solid particle. The sample was fed into the membrane module. After the membrane process, collect the sample of permeate and retentate. Repeat the process above and collect the sample at round 3 and 5. Determine protein concentration by using Kjeldahl method and change the feed flow rate to 7.5 and 5 ml/s then repeat the process again.

4. Membrane

The UF membrane was Dora H Series Hollow Fiber Dialyzer B-18H: BMH0318, made of polyethersulfone, in a hollow fiber module manufactured by BAIN Medical. The filtration surface was 1.8 m^2 and diameter of inner fiber was 200 microns with 30 microns of thickness.

5. Utrafiltration membrane equipment

Experiment were performed in a lab scale, shown schematically in Fig. 3.1.

The lab scale comprises the following equipment:

(1) feed tank, polypropylene, with a volume of 10 L;

(2) pump, water pressure pump, model SFDP1-011-070-21, with pressure setting 4.8 bar;

(3) prefilter, manufactured by USAriya, produced from pure polypropylene with a nominal pore size of 1 micron;

(4), (6) pressure gauge, manometer, with 30 cm in length.

(5) housing for module hollow fiber membrane, polycarbonate, with 30 cm in length.

(7), (8) sample test point, for permeate and retentate

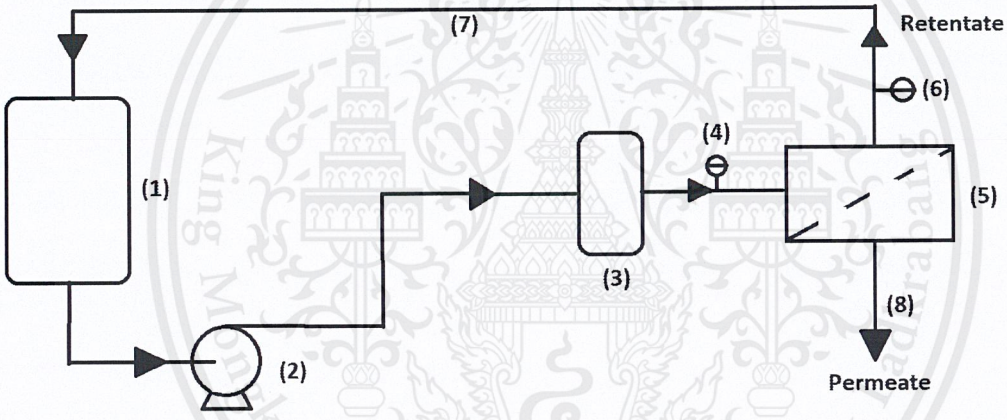

Figure 3.1 Schematic of the membrane unit that was used for the experiment (1) tank, (2) pump, (3) pre-filter, (4) and (6) pressure gauge, (5) membrane module, (7) and (8) sample test point

CHAPTER IV

RESULTS AND DISCUSSION

This research aims to study the effects of the parameter in protein concentration and optimize the conditions for Ultrafiltration membrane process to increase protein concentration in soymilk. The effects on the number of round and feed flow rate were tested by membrane module. The amount of protein in feed, retentate, and permeate were determined by Kjeldahl method. To clarify the optimum conditions for increasing protein concentration in soymilk, the effects of these condition were investigated.

4.1 Ultrafiltration membrane process and protein analysis

Figure 4.1 show the picture of permeate sample, retentate sample, and feed sample. The sample of feed and retentate show the general milk color but retentate sample shows a little thicker color. The sample of feed shows a clear color which means that ultrafiltration membrane can separate water from soymilk excellently.

Figure 4.1 Sample of (a)Permeate, (b)Retentate, (c)Feed

Table 4.1, 4.2, 4.3 show the protein percentage in feed, permeate, and retentate in different feed flow rate consist of 5, 7.5, 10 ml/s. The samples were collected at the first, third, and fifth round of the membrane process. The protein percentage was determined by Kjeldahl method, the amount of HCl that was used to titrate the sample after distillation was specified. The amount of HCl was used to calculate percentage of nitrogen and protein which are also specified in the table.

Table 4.1 The sample data at 10 ml/s feed flow rate in ultrafiltration membrane process with 10 ml of sample.

Sample	% Nitrogen	% Protein
Feed	0.3654	2.33
Retentate 1st	0.3836	2.45
Retentate 3rd	0.4914	3.14
Retentate 5th	0.5782	3.69
Permeate	0.0154	0.10

Table 4.2 The sample data at 7.5 ml/s feed flow rate in ultrafiltration membrane process with 10 ml of sample.

Sample	% Nitrogen	% Protein
Feed	0.3724	2.38
Retentate 1st	0.4620	2.95
Retentate 3rd	0.5670	3.62
Retentate 5th	0.7308	4.66
Permeate	0.0224	0.14

Table 4.3 The sample data at 5 ml/s feed flow rate in ultrafiltration membrane process with 10 ml of sample.

Sample	% Nitrogen	% Protein
Feed	0.4256	2.72
Retentate 1st	0.4354	2.78
Retentate 3rd	0.4914	3.14
Retentate 5th	0.6244	3.98
Permeate	0.0140	0.09

According to the tables above, the result shows that the amount of protein at 10 ml/s feed flow rate was increased by around 1.3%, at 7.5 ml/s feed flow rate was increased by around 2.3%, and at 5 ml/s feed flowrate was increased by around 1.2% comparing feed and retentate at fifth round of each feed flow rate. The amount of protein in permeate for every feed flow rate are 0.09%, 0.14%, and 0.09% which is very low compare to retentate. It means that ultrafiltration membrane process shows marvelous results of concentrate protein in soymilk and separate water from soymilk.

4.2 Effect of quantity of round

The percentage of initial protein mass in all experiments was about 2.33-2.72%. Fig 4.2 shows the comparison in graph between percentage of protein and quantity of round of all the experiment in different feed flow rate. It shows that with 7.5 ml/s feed flow rate has the highest protein concentration at the fifth round with 4.66% of protein which means that the protein concentration in soymilk was increased by 2.28%, in other word, the concentration was doubled. While at 5 ml/s feed flow rate, the concentration of protein was increased by 1.26% and 10 ml/s feed flow rate, the concentration of protein was increased by 1.36%. At 5 and 10 ml/s feed flow rate, the retentate at fifth round have increased in protein concentration. All the result show significantly increasing of protein concentration using ultrafiltration membrane process.

The concentration of protein increased in the retentate in ultrafiltration membrane process. The initial concentration of protein was around 2.3-2.7% and was around 2.4-2.9% at the first round, 3.1-3.6% at the third round, and 3.6-4.6% at the fifth round. The results show that the concentration of protein in retentate is directed variation to quantity of round. While the concentration of protein in permeate still low at any time. To conclude, the concentration of protein in retentate will be increasing when the quantity of round is increased until there is nothing left to concentrate in the feed.

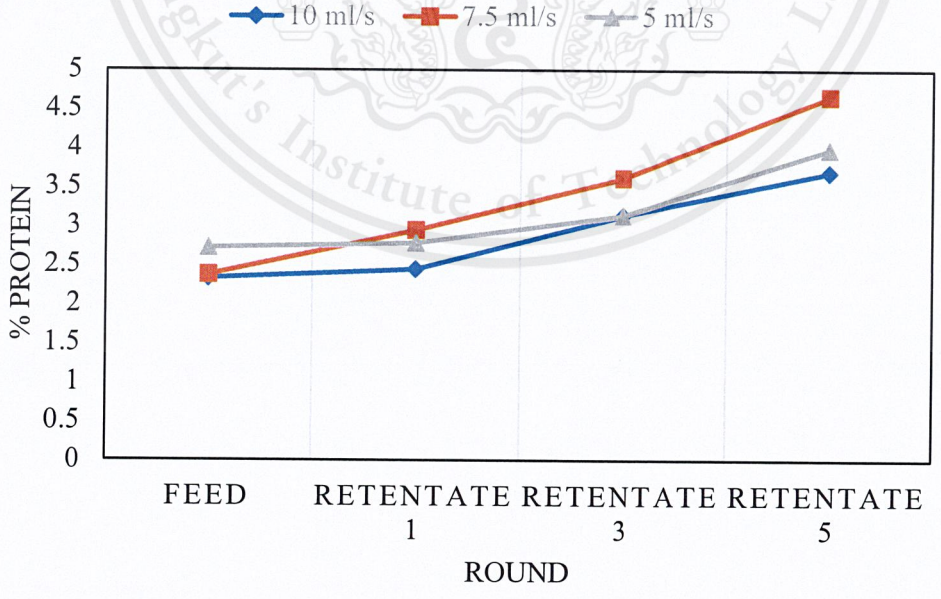

Figure 4.2 Graph plotted between percentage of protein and quantity of round

4.3 Effect of feed flow rate.

In figure 4.3, the result show that 7.5 ml/s feed flow rate is the best alternative because it gives the highest yield at 96.62%. Comparing the feed flow rate at 5 and 7.5 ml/s, the first one has lower permeate flux at all time, it means that it will give lower permeate flow rate and separate water from soymilk worse than the latter. But when compare feed flow rate at 7.5 and 10 ml/s, the result shown that 7.5 ml/s feed flow rate still doing better that 10 ml/s because of the effect of concentration polarization and fouling. These two may result in decreasing the permeate flux and process efficiency. The increasing of feed flow rate causes the higher risk of concentration polarization and fouling occurrence.

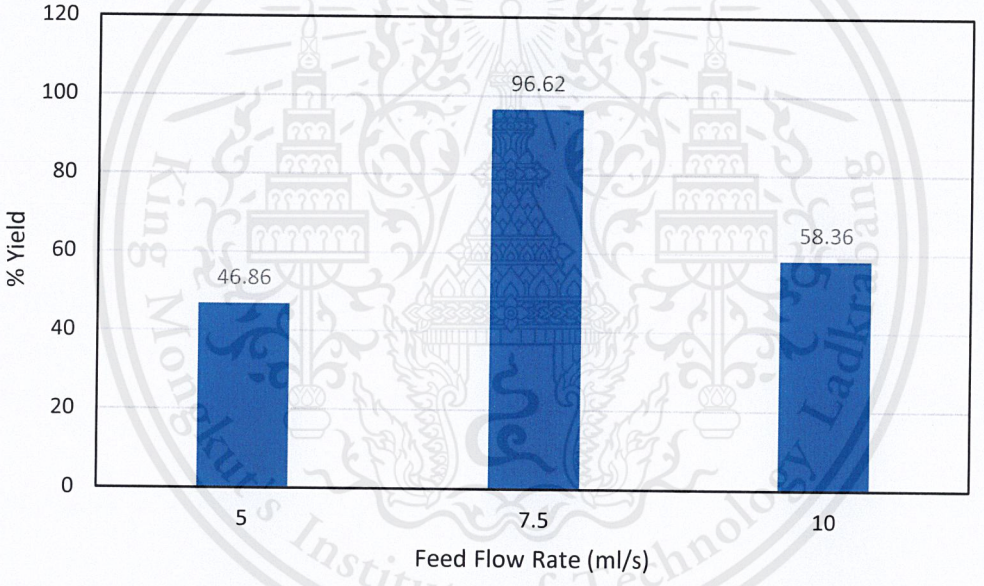

Figure 4.3 Graph plotted between % yield and feed flow rate

CHAPTER V
CONCLUSION

5.1 Conclusion

Based on the results of this study, the application for concentrate protein in soymilk of ultrafiltration membrane is very promising due to the increasing of protein concentration of retentate. The parameter that was studied and controlled including feed flow rate of membrane and quantity of round of membrane process. The 7.5 ml/s feed flow rate presented the highest increasing of protein concentration in retentate due to the lowest permeate flux, which mean that the feed flow rate beyond 7.5 ml/s does not affect to protein concentration in permeate and retentate in a positive way. The quantity of round that affect the result the most is fifth round, which has the highest protein concentration in retentate. The optimum condition from the results of this study is 7.5 ml/s feed flow rate at the fifth round of membrane process, which give the 4.66% of protein concentration in retentate and 0.14% of protein concentration in permeate and also give 96.62% yield.

5.2 Recommendation

The recommendation for further study, researcher recommends to study more about other parameter that also affect to the membrane performance and efficiency, such as pressure, initial concentration, and temperature, which mean that the upscale of experiment is needed. The further analysis another composition, such as fat and carbohydrate should be also analyzed to verify the information of other macronutrient.

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APPENDIX

1. Calculation of Kjeldahl Method

Nitrogen, (%) $= \frac{1.4\times(Vs-Vb)\times M}{W}$

Where

V_s and V_b = volume of HCl titrant used for sample and blank (ml), respectively

M = molarity of HCl solution

W = weight of sample (g)

Protein, (%) = %nitrogen x F

Where

F = factor for converting nitrogen to protein, for milk use 6.38

Example 1 Calculate amount of nitrogen and protein in retentate 1 from table 4.1, V_b = 0.4 ml and M = 0.1N

Table 4.1 The sample data at 10 ml/s feed flow rate in ultrafiltration membrane process with 10 ml of sample.

Sample	HCl (ml)	% Nitrogen	% Protein
Feed	26.5	0.3654	2.3313
Retentate 1st	27.8	0.3836	2.4474
Retentate 3rd	35.5	0.4914	3.1351
Retentate 5th	41.7	0.5782	3.6889
Permeate	1.5	0.0154	0.0983

Nitrogen, % $= \frac{1.4\times(27.8-0.4)\times 0.1}{10} = 0.3836\%$

Protein, % = 2.4474%

Table A1 Conversion factors used for certain foods *[Compendium of methods for food analysis, 2005]*

Foods	Conversion factor
Milk	6.38
Barley	5.83
Rice	5.95
Wheat flour, refined	5.7
Wheat, Whole-kernel	5.83
Almonds	5.18
Peanuts	5.46
Soybean	5.71
Nut and seeds	5.3

2. The operation time of each experiment

Table A2 The operation time of each round at 10 ml/s feed flow rate with 4.5 L initial feed soymilk.

Round	Time (mins)
1	7.4
2	7.1
3	6.4
4	5.5
5	4.1

Table A3 The operation time of each round at 5 ml/s feed flow rate with 4.5 L initial feed soymilk.

Round	Time (mins)
1	11.2
2	10.05
3	8.24
4	7.5
5	7.08

Table A4 The operation time of each round at 7.5 ml/s feed flow rate with 5.4 L initial feed soymilk.

Round	Time (mins)
1	10.2
2	9.3
3	7.25
4	5.54
5	5.07

3. Picture of Kjeldahl equipment

Figure A1 Distillation Unit, Vapordest 30S, Gerhardt

Figure A2 Digestion Unit, Gerhardt

BIBLIOGRAHPY

Name: Shnonn Eamdee

Date of Birth (DD/MM/YY): 31/03/1997

Address: 332 Rama 9 Soi 17, Rama 9, Bangkapi, Huaykwang, Bangkok 10310

E-mail: nonshn@gmail.com

Academic Background:

King Mongkut's Institute of Technology Ladkrabang
Bangkok, Thailand, 2015 - Present
Bachelor's degree in engineering
Major: Petrochemical, Cumulative GPA: 3.04

Chitralada School
Bangkok, Thailand. 2010 - 2015
Mathematics-Science Program

Working Experience: Internship with Thainamthip