# CHAPTER IV
# RESULTS AND DISCUSSION

## 4.1 Ultrafiltration Performance

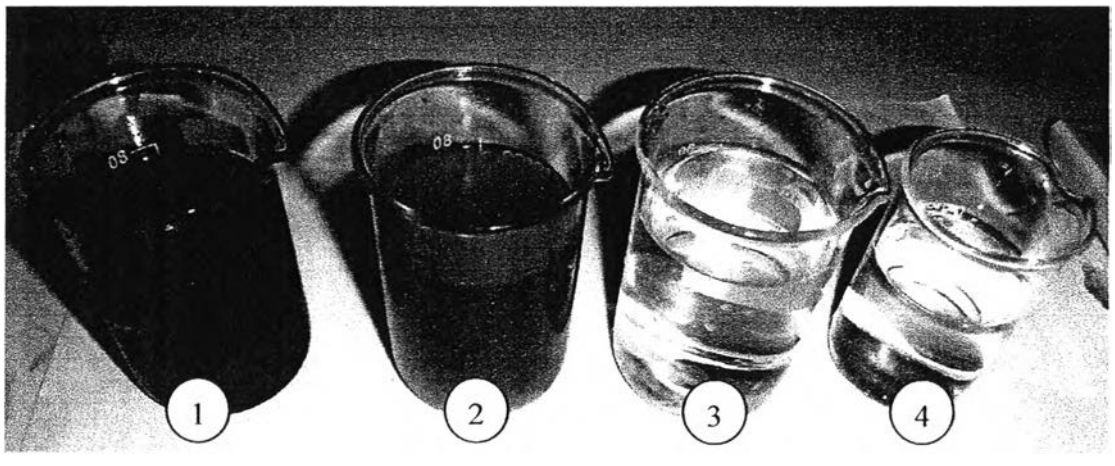


**Figure 4.1** Appearance comparison; (1) Crude glycerol, (2) Crude glycerol diluted to 70% of water, (3) Crude glycerol after treated by UF, (4) Deionized water for reference.

Glycerol was diluted and pumped through the UF membrane. The transparency was measure by turbidity meter to determined how much MONG can be removed by UF. The turbidity of tap water and refined glycerol were also measured for reference.

The result show that, after mixed with water, turbidity of solution clearly increased. This is because the MONG which are mainly fatty acid and glycerides, did not dissolve in water, this can be clearly seen as show in figure 4.1. So when the water content increase, these MONG dissociate from the glycerol and is suspendible in the solution. The turbidity reached maximum point at 60% that all MONG appeared, and at 70% of water, water completely acted as solvent instead of glycerol, so the turbidity was significantly dropped.

**Table 4.1** Turbidity value of each sample

| Sample | | Turbidity (NTU) | | |
|---|---|---|---|---|
| | | **Before treatment** | **After treatment** | **Mix treated** |
| **Diluted glycerol (% of water)** | **0%** | 20.90 | N/A | - |
| | **30%** | 29.83 | 9.98 | - |
| | **40%** | 31.80 | 11.00 | 15.00 (30% & 50%) |
| | **50%** | 35.00 | 11.20 | - |
| | **60%** | 49.20 | 11.03 | 13.87 (50% & 70%) |
| | **70%** | 44.97 | 10.43 | - |
| **Tap water** | | 0.41 | - | - |
| **Refined glycerol** | | less than 0.01 | - | - |

UF membrane can make the solution clearly transparent. but there are some leakage of MONG that why the turbidity of treated solution still not so low as showed in table 4.1. This is estimated because of the UF which were used in this experiment are household membrane and their perfomance is not as good as industrial grade that was tested previous and can drove the turbidity to 0.7NTU which was very close to the tap water. In this experiment, the flowrate of treated product extremely dropped after hundreds litre of glycerol were treated. According to Abdul Wahab Mohammad, et al. (2013) who studied the fouling of ultrafiltration membrane during adsorption of long chain fatty acid in glycerol solutions, flux decline is depend on the composition of MONG and can be retain longer with the larger molecular weight cut-off membrane.

## 4.2 Electrodeionization Performance

### 4.2.1 Salt Distribution in Each Stream in Different Water Content

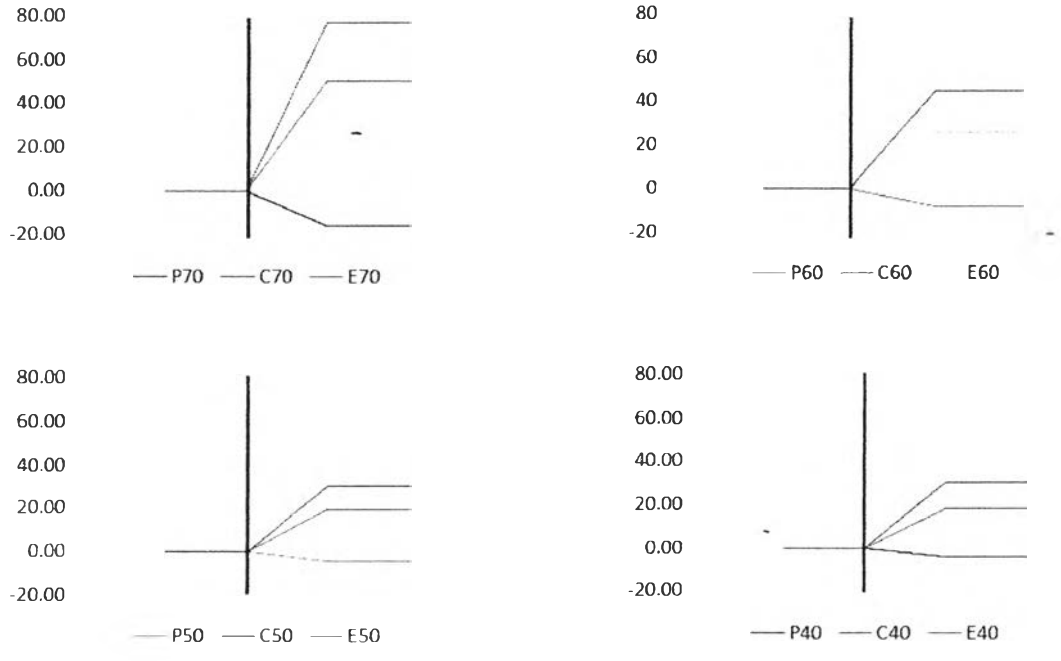


**Figure 4.2** The conductivity changes of each stream in different water content.

The distribution of salt from product stream to the concentrate and electrode stream were investigated by the change of conductivity. Every pictures showe the same trend. The top are concentrate stream, electrode are in the middle and the bottom line are the product. The result show that the concentrate stream has highest concentration at about 60% higher than the electrode stream in every %, while the flow rate of concentrate stream was also 60% lower than the electrode stream. These result show that the salt is almost equally distributed from the product stream to the others. Since the flow rate of electrode is independent of product stream, if the feed flow rate is increased, the salt content of electrode stream will be raised so much, while the content of salt in concentrate stream will be lower, this can be calculated by doing the mass balance.

4.2.2 Effect of Salt Concentration to the %Desalination of Glycerol Solution

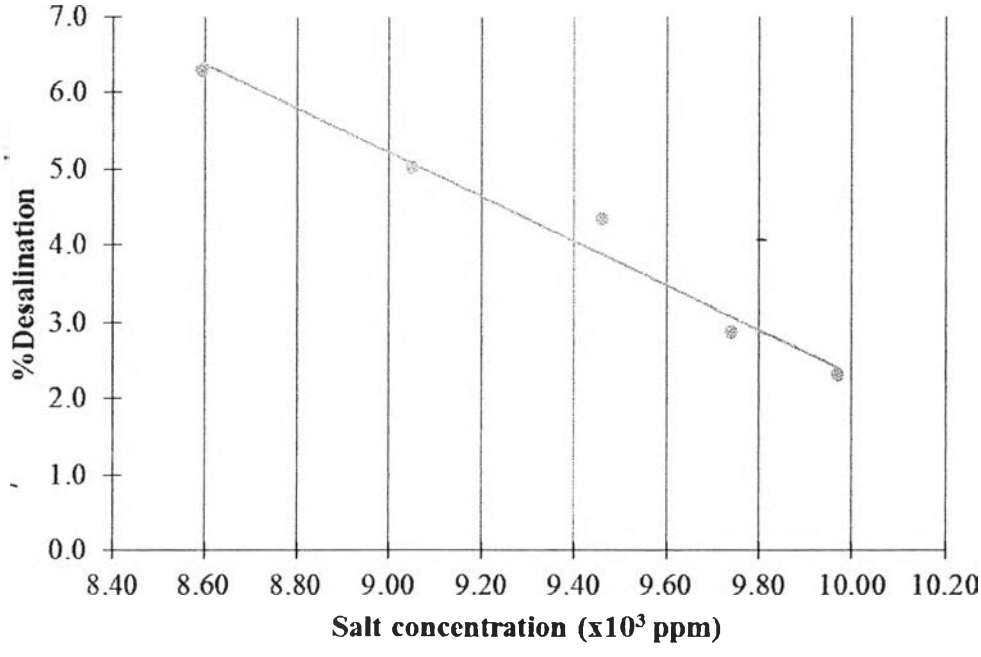


**Figure 4.3** Effect of salt concentration to the %desalination in 50% water concentration at the current of 1.6A.

To study the effect of salt centration to the desalination capability, 50% water concentration with constant current was investigated

The result show that the %desalination increases when the salt concentration decrease. This phenomenon is estimated to be due to the membrane permselectivity loss. The membranes used in EDI are essentially consisted of sheets of ion exchange polymeric resins. In the membrane space are mobile counterions. The resin cation exchange membrane would have negatively charged groups chemically attached to the polymer chains as showed in figure 4.4. Ions with a charge opposite to the fixed charge (cations) are freely exchanged at these sites. An ideal permselective cation exchange membrane would transmit positively charged ions only. That mean all of the negative ion must be repeled to get into the membrane, but this efficiency can be loss. Normally the concentration of fixed ion is very high compared to the concentration of ion in electrolyte solution, when the salt concentration in the solution is also high, these fixed ions can not repel all of ions in the solution anymore. Result

in the leakage of anion in the cations exchange membrane. So, the %desalination increase for later cycle that amount of salt decrease because the membrane permselectivity approach the ideal as proved by the equation in the literature review section.

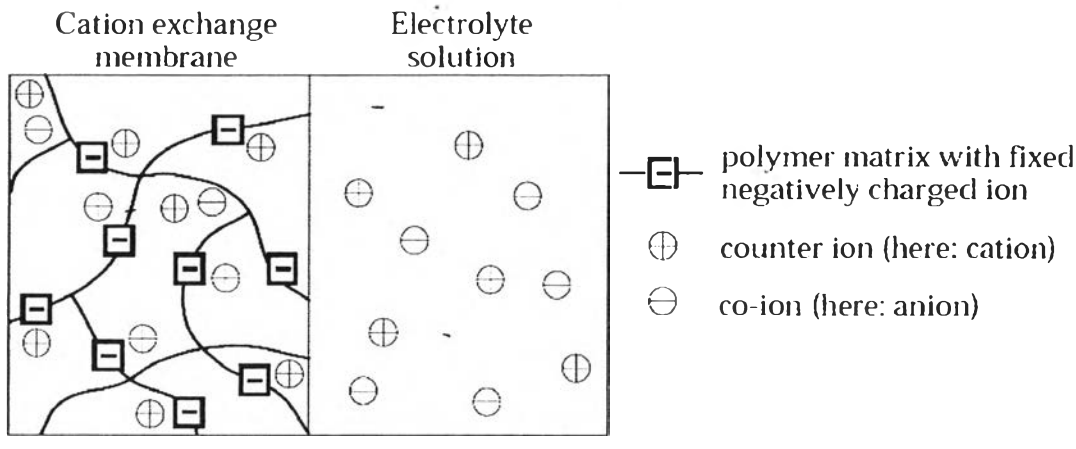


**Figure 4.4** The mechanism of ion exchange of the membrane in the EDI module.

4.2.3 Effect of Water Concentration to the Salt Removal

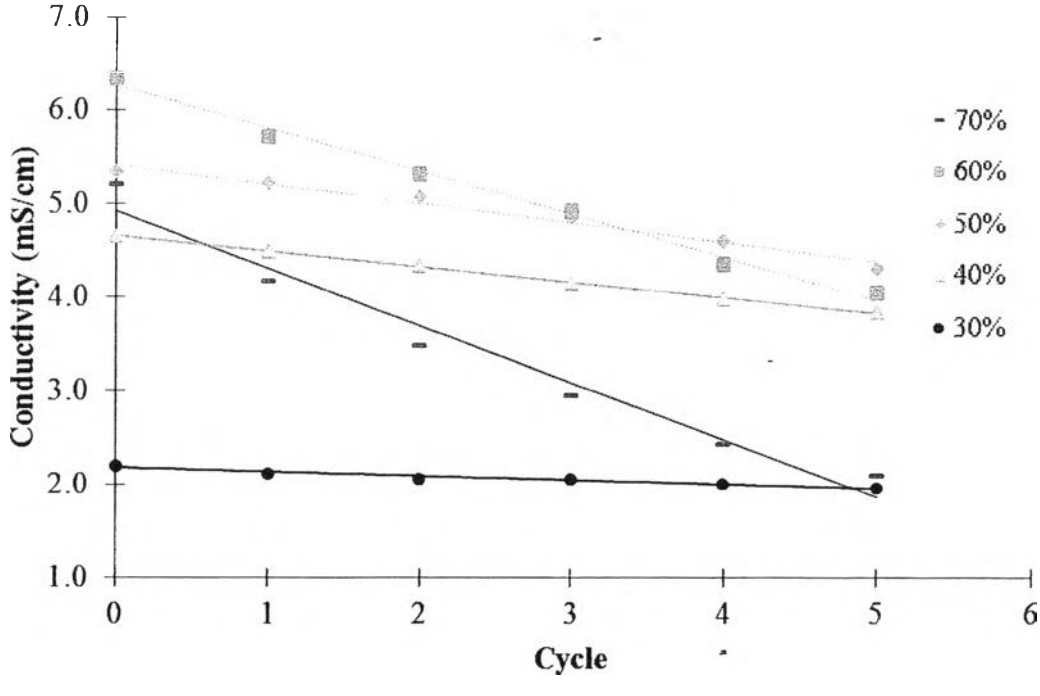


**Figure 4.5** Change of the conductivity along the experiment of different water concentration.

Change of salt concentration in term of conductivity of each % water concentration were plotted on the same graph for comparison.

The result show that, the initial conductivity increase when the % of water increase because the glycerol has high electricity resistance. Water provide better movement of salt ions resulting in higher electrical conductivity and reach the maximum at 60% water content and decrease when the % water was added to 70%. This trend seem the same as of the turbidity, because at this stage, water completely act as the solvent and the glycerol is the smaller portion compared to the water.

The viscosity is also an important factor since high viscosity increase the resistance of the salt transfer. According to figure 4.5, high %water has higer slope which mean the salt ions can be transferred more in higher water content at the same residence time which mean higer desalination rate because of the lower viscosity and higher electrical conductivity of the solution, and table 4.2 show that the viscosity decrease about 40% lower for each 10% water increase.

4.2.4 Effect of Water Concentration to the Power Consumption

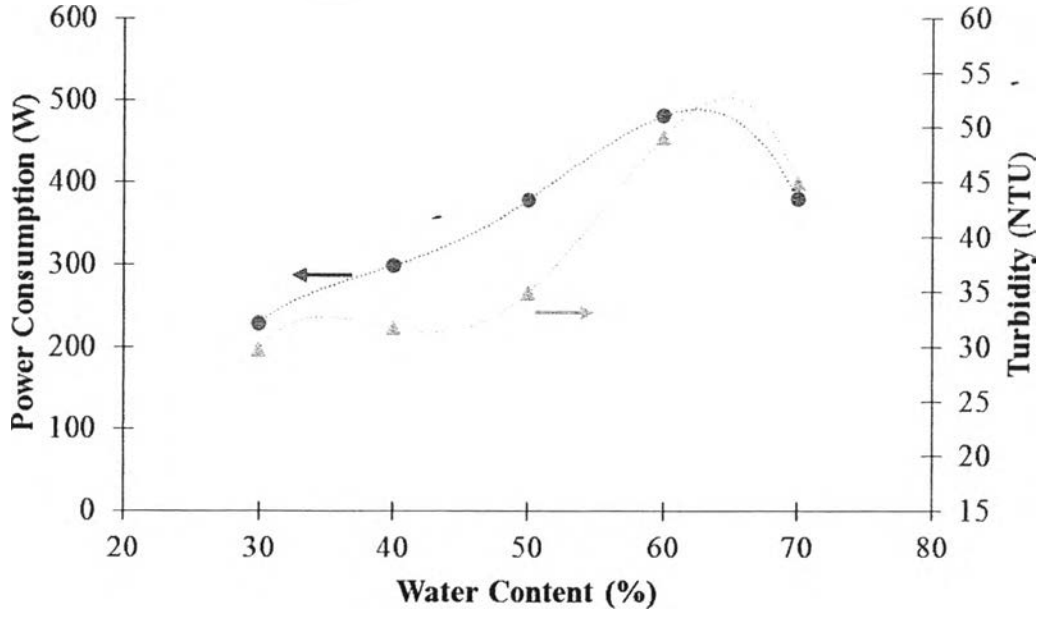


**Figure 4.6** Comparison of power consumption to the turbidity at different water concentration.

**Table 4.2** Salt removal after 5 cycles treatment, total power consumption and calculated power consumption to achieve 10,000ppm salt removal with EDI in different water concentration

| %Water (by volume) | Simulated Dynamic viscosity(cP) | Power consumption for 10,000ppm salt removal (Wh/L of pure glycerol) |
|---|---|---|
| **30** | 18.99 | 29.71 |
| **40** | 11.42 | 37.40 |
| **50** | 6.794 | 67.23 |
| **60** | 3.976 | 74.88 |
| **70** | 2.514 | 83.13 |

The current is automatic varied by the module, %salt and power consumption are different in each %water. Power consumption to achieved 10,000ppm salt removal in term of Wh/L of pure glycerol was calculated in order to compare with the previous work.

According to figure 4.5 and 4.6, the desalination rate, turbidity and power consumption have the same trend. Even though the water content had a large influence on desalination rate. A solution diluted twice from 30% to 60% water content led to a desalination rate 16% higher with the same residence time as showed in table 4.2. But if consider the total amount of glycerol that was treated, the result were inversed. A solution diluted twice from 30% to 60% water content led to the power consumption more than 150% higher at the same amount of glycerol treated.

Compared to the electrodialysis, Schaffner et al. (2004) studied the desalination of 35% of water in glycerol solution by electrodialysis and found that the energy consumption is a linear function of the desalination rate. Desalination by conventional electrodialysis required power for 10,000 ppm salt removal at 19Wh/kg of pure glycerol (calculated value) in approximately 24 minutes batch process. While from the table 4.2, the EDI use 35.71Wh/L (calculated value) to do the same at very much lower residence time due to the help of ion-exchange resin.

### 4.3 Economic Evaluation

The energy consumption and energy cost were evaluated by the help of HYSYS V.7.1 simulation software. The condition and variable were described in the experimental section.

**Table 4.3** The energy cost comparison between the conventional distillation and EDI

| Process | Energy consumption per month | | Energy cost (THB/Month) | |
|---|---|---|---|---|
| | EDI | Distillation | EDI | Distillation |
| **Desalination** | 81,106 kWh = 69,738 Mcal | 317,088 MCal | ฿288,736 | ฿943,725 |
| **Water removal** | 784,080 MCal | 904,320 MCal | ฿2,333,599 | ฿2,691,460 |
| **Concentrate purification** | 127,217 MCal | - | ฿378,626 | - |
| **Total** | **0.91 MMCal** | **1.22 MMCal** | **฿3,000,961** | **฿3,635,186** |

The calculation is based on 24hrs/day and 30days/month operation, feed rate is 3,400 $m^3$/h, the electricity have to buy from the Provincial Electricity Authority.

The result show that, the desalination energy consumption by EDI technic is about 25% lower than the distillation. The total energy cost of EDI is approximately 17% lower than the distillation. However, the energy cost of EDI is on the assumption that the plant have to buy the electricity. If the glycerol plant can produced electricity itself, the total energy cost can be significantly lower than the distillation. Nevertheless, the energy cost of EDI is directly affected by the salt content in the solution, and the regeneration cost of UF membrane aren't included in this calculation. So these number can be varied so much due to the diversity of feed composition of each biodiesel plant.