Laboratory Study: Biopolymer from Extraction Seeds of Kluwih and Jackfruit for Enhanced Oil Recovery

Ganesha Gajah[1],*, Ihsan Arifin[1], Rahmad Hidayat[1]

[1]Bandung Institute of Technology, Indonesia

Abstract. Polymer injection is a tertiary recovery that lowering the injection-oil water mobility ratio thus more efficient to produce oil. The increase in the polymer used for injection requires a large number of suitable polymers. Laboratory studies are necessary to develop new polymer produced domestically, with easily available materials, do not damage the environment, not harm the environment, and are economical. Seeds of Kluwih and Jackfruit contain the starch as a biopolymer for polymer injection because competent to act as a viscosifying agent thus repair the water-oil mobility ratio. Laboratory study is carried out through a series of processes. From starch extraction to polymer screening. The pure starch extraction is done by the wet method through a series of experiments carried out repeatedly. Observation with polymer screening was carried out on five tests. The rheology of polymers examined at two different polymer concentrations and temperatures to determine the viscosity at varying shear rate. Compatibility tests are reviewed to determine the homogeneous and the solubility of the polymer by the solvent. Filtration test is an entrapment test, know the relation between polymer molecule sizes and pore size distribution. The static polymer test is an adsorption test to know the polymer retention in the core caused by chemical interaction between core and polymer. The polymer flooding procedure is to know polymer performance to pushes remaining oil after waterflooding. The results show a pure starch without impurity content. In liquid, the starch acts as a viscosifying agent. Both of the two polymers degrade by shear rate and (polymer chain) broken at higher temperatures. Kluwih and Jackfruit starch dissolve homogeneously without a lumping. Polymer trapping and adsorption not dominantly occur by Jackfruit and Kluwih. The native polymer can enhance oil recovery but sensitive to the core and polymeric conditions.

Keywords: Enhanced Oil Recovery, polymer injection, Kluwih, jackfruit, starch

1. Introduction

Polymer injection is one of the EOR (Enhanced Oil Recovery) techniques that has been proven to increase oil recovery and has been used in more than 50 fields in the world. One polymer injection that has been carried out is at Tanjung Field. Polymer injection is based on reservoir temperature, reservoir fluid and geological conditions. The injection pilot design is made with a requirement of 70 tons of polymer, the volume of injected polymer solution is 200 thousand barrels with a concentration of 2,000 ppm and an injection rate of 1,000 barrels per day. As a result, oil production in Tanjung Field reached 3,254 BOPD and gas reached 1,098.99 MMSCFD (Usman, 2018).

There are two kinds of polymer; synthetic polymer such as polyacrylamide, and biopolymer such as a polysaccharide. Starch is a carbohydrate that is spread in plants, especially chlorophyll plants. For plants, starch is a food reserve found in seeds, stems and the tubers (Ben, Zulianis, & Halim, 2007). Starch is composed of two kinds of carbohydrates; amylose and amylopectin, in different compositions. Amylose gives hard properties while amylopectin causes stickiness (Wikipedia, Amilum, 2018). The amount of starch content in plants depends on the origin of the starch, for example, starches derived from rice seeds containing 50-60% starch and starches derived from cassava tubers contain 80% starch (Winarno, 1986). Starch for polymer injection application is must not from a human primary

---

consumption source, not harm the environment, and economical. The starch is researched for polymer injection because can act as a viscosifying agent.

The high content of carbohydrate is an initial reference to this laboratory study initiation. Kluwih (*Artocarpus camansi*) has a carbohydrate content of 64.96% (Sukatiningsih, 2005) and Jackfruit (*Artocarpus heterophyllus*) has carbohydrate content 36.7% (Fadilah, Wijaya, & Antara, 2018). Kluwih (seeded breadfruit, breadnut) is the name of a type of tree plant whose fruit is similar to Sukun, but this fruit has a more prominent thorny seed and skin. Jackfruit has a delicious taste and strong aroma depending on the level of maturity. Jackfruit seeds are oval-shaped and covered in a thin layer of chocolate called spermoderm. Spermoderm covers white cotyledons. These cotyledons contain high starch (Mukprasirt & Sajjaanantaku, 2004). Kluwih and Jackfruit are shown in Figure 1.

An important part is the seed of Kluwih and Jackfruit. The older seed cannot use because it contains more impurity such as the rotten one. Seed used from the fruit 3-6 months old because the flesh is ripe yet and the seed not to brown compared to the ripe one. This laboratory study is run to observe these two polymer performances. The analysis is done through polymer rheology, polymer retention, and polymer injection process.

(a)   (b)

Figure 1. (a) Kluwih (*Artocarpus camansi*) and (b) Jackfruit (*Artocarpus heterophyllus*).

Starch from the seed of Kluwih and Jackfruit is a polymer, can repair the water-oil mobility ratio and enhanced oil recovery. This is due to the viscosity of the polymer that greater than the viscosity of the formation-water causing a smaller value of the injection-oil water mobility ratio making it more efficient to produce oil and increasing the recovery factor. The polymer injection process needs a bulk quantity of polymer for field application. In this time, the polymer still dominantly depends on the abroad product. Because of this, a laboratory study needs to do about new polymer development that domestically produced, by material that easy to get and economically.
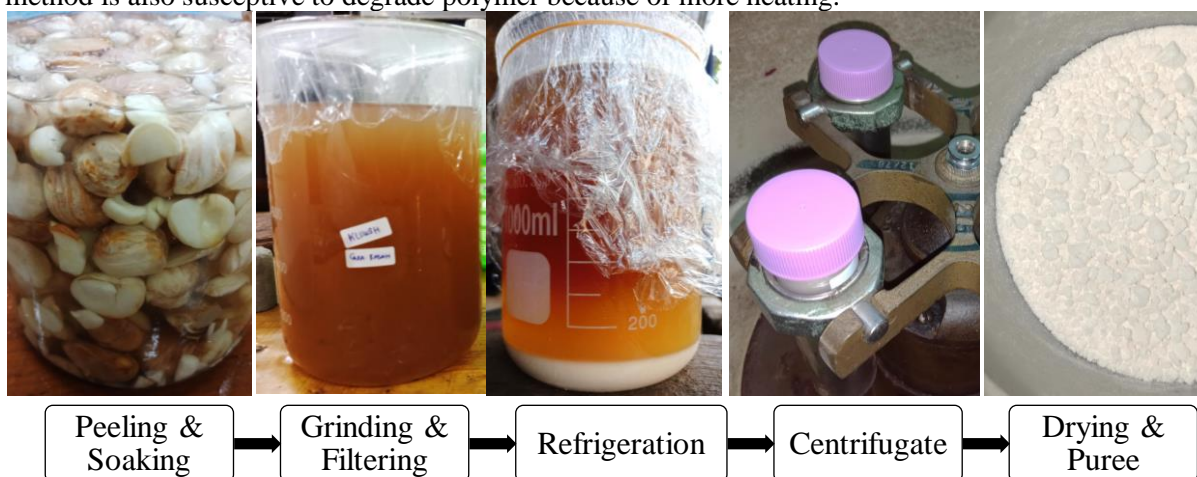
2. Methodology

2.1 Starch Extraction

Extraction is the first step and the most important in this research because determines how the polymer quality will be obtained. There are two kinds of extraction common to do, wet method and dry method. The dry method does by drying the seed first in the oven or under the sun's heat until low water content, then grind and the extraction process started by adding water. The powder that settles then drying, it is the main starch. The wet method does by grind the seed with some water, precipitation process, the powder that settles then centrifuges to speed up a deposition, the wet powder then dry.

The gained starch from these two methods is different since for polymer injection needs pure starch without any impurity because can plug the oil pathway in the core. The dry method result is not good

for this extraction because the starch powder contains more impurity from the seed that dry first. This method is also susceptive to degrade polymer because of more heating.

| Peeling & Soaking | → | Grinding & Filtering | → | Refrigeration | → | Centrifugate | → | Drying & Puree |

**Figure 2.** Starch Extraction Method.

The extraction method is shown in Figure 2. Take the seed from the fruit and separate from the flesh, peel the epidermis seed because it is the impurity for the starch. This is quite difficult to do since the epidermis is slippery because of the mucus of seed. This mucus has a phenol compound that worsens the starch extraction results since containing the browning effect. Brown color in powder starch will not solute and the solution cannot use. Because of that, the seed must soak in sodium chloride solution to easier peeling epidermis and prevent the browning process. The difference between sodium chloride use or not is shown in Figure 3.

(a)   (b)
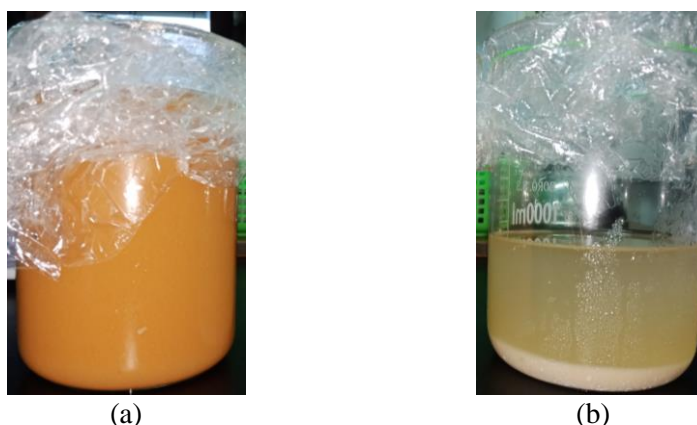
Figure 3. (a) Brown enzyme effect and (b) Sodium chloride effect.

The seeds added some water to the easier grinding process. Make sure the seed porridge not too soft to prevent the lost when filtering. After that filter seed porridge with batiste, separate the liquid phase of the seed pulp. Place the liquid one in the refrigerator in one night to an easier precipitation process. The white one settle in the bottom of the container is the probable starch because the impurity is also settling mix with the starch

To separate the starch from the impurity need centrifugation process. Place the probable starch in the cone and add aqua demineralization as a media to separation. Centrifuge the cone at 600 RPM- 900 RPM. The result of centrifugation is shown in Figure 4. In Figure 4 (b) the settled part shows 2 layers. The bottom part has pure white color which means this is the truly starch and the top part has a brown color that is the impurity. Clean the brown part then take the pure white by spatula.

(a)   (b)
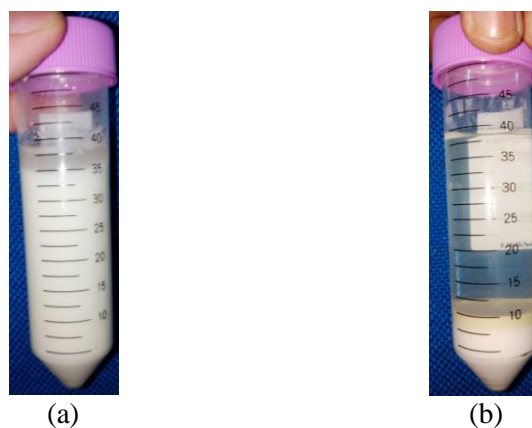
Figure 4. (a) Before Centrifugation and (b) After Centrifugation.

The pure white part then dries in the oven. This process does carefully because a longer time will scorch the starch. Periodic checks are recommended while this process. After the powder is dry, the lump of starch must puree. Next, these starches are the polymer each of Kluwih and Jackfruit are ready to use.

2.2 Materials

Crude oil used is light oil type as density 43.7 API and viscosity 2.5 cSt. The formation-water is synthetic brine that represents the real formation-water in the field. Synthetic brine by density 1.003 gr/cc made of solute sodium chloride at a certain concentration with demineralization aqua. Viscosity and density measured at ambient temperature (28°C).

Polymer used is starch from the seed of Kluwih and Jackfruit respectively, extracted by the wet method. The polymer that commonly used for polymer injection applications such as Xanthan Gum and Guar Gum is compared by Kluwih and Jackfruit. The reason uses those polymers as a comparison because these polymers grouped into a biopolymer too. As together extracted from a natural source. The difference is Xanthan Gum and Guar Gum have become commercial polymer which is undergone a modification process so that more resist degradation and better result. While Kluwih and Jackfruit is a native polymer that not given any modification so susceptible to degradation and lower rheology quality result.

The core samples used are the Berea core that suits the porous media to do a polymer injection test. Berea Sandstone is a sedimentary rock whose grains are predominantly sand-sized and are composed of quartz held together by silica (Berea Sandstone, 2019). Every core has the same size. From petrophysics measurement, cores have porosity range 20-26% with permeability 400-850 mD and have pore volume not as far as different. Core A and B respectively use for Guar Gum and Xanthan Gum, while core C and D used for Kluwih and Jackfruit. The difference permeability between core A B and C D is too far thus will affect the injection result. The petrophysics data of the Berea core is shown in Table 1.

Table 1. Core Data.

Name	Porosity (%)	Permeability (mD)	Pore Volume (ml)
A	26.1	841.5	2.6
B	25.8	771.3	2.4
C	20.3	423.1	3.4
D	20.1	425.2	3.5

2.3 Polymer Screening

The polymer rheology tested by measure the viscosity of Xanthan Gum, Guar Gum, Kluwih, and Jackfruit to the difference of shear rate at different concentrations and temperatures. The viscosity to

shear rate graph shows fluid type such as Newtonian or non-Newtonian. The polymer viscosity measurement use Viscometer Brookfield LVDV3T Spindle CV40. That tool worked by measure the liquid performance restrains the spin (shear rate) that makes a velocity gradient (shear stress). The torsion will legible and used for polymer viscosity calculation at each testing condition.

Viscosity measurement at different concentrations has a purpose to know viscosity increment effect, at the same polymer and as the performance comparison for another polymer. The commercial polymer such as Xanthan Gum and Guar Gum, measurement is done at 2,000 ppm and 4,000 ppm. It is the usual concentration to do inject application. But for the native polymer such as Kluwih and Jackfruit, measurement is done at 10,000 ppm and 20,000 ppm. It needs a higher concentration to get higher viscosity. On the contrary the polymer viscosity measurement at different temperatures to know viscosity decrement effect at the same polymer and as the performance comparison for another polymer, especially for the higher temperature. At this measurement, polymer concentration is 20,000 ppm. The same concentration may result in different viscosity, moreover different polymer. For the commercial and native polymer, viscosity measurement is done at two temperatures. First, at an ambient temperature about 28°C represents surface temperature and second at a higher temperature of about 60°C that represents a reservoir temperature. The higher temperature is chosen by reservoir temperature where the crude oil from. The polymer viscosity measurement repeatedly does at a different time to prove the same value at the same condition before. This is to make sure polymer performance consistency.

Before injecting, the four polymers in powder form. The polymer must dissolve by a solvent. It is to make polymer can enter and optimally push the oil that remains in the core. Dissolved polymer marked by there is no granule of powder that exists in a solvent. Granule that undissolved will retain in core and potentially close the oil pathway. A compatibility test is a periodical observation by a long time to seeing a change of powder granule to be a liquid form. After that, the polymer increases the solvent viscosity and worked as a viscosifying agent. After the polymer in liquid form, observation does time by time. To know the polymer is still homogenous with solvent or not, it marked by there is polymer settle in the bottom of the container. The settles part has different colors and ranked by value. This test observes polymer at the three different concentrations there are 2,000 ppm, 10,000 ppm, and 20,000 ppm.

Polymer retention occurs in two ways, entrapment, and adsorption (Mishra, Saurabh, Bera, & Mandal, 2014). In this study, the polymer retention is simply explained with polymer trapping analogous by filtration test and polymer adsorption by static polymer test. The polymer that injected will flow from the top to bottom of the core. The core is a porous media because has pores with vary size. Pore size can interact with a liquid that flows inside, especially polymer. There is pore that has a lower size than polymer molecule, as the known polymer also called a giant molecule. Filtration test is an initial entrapment test to know how much polymer can pass the core without oil contain at the increased time. The little polymer trapped between core and polymer will increase the amount of polymer flow.

The static polymer test is an initial adsorption test to know how much polymer retention in the core without oil contains. Because the core mostly composed of material Silica (SiO_2), the lower chemical interaction between core and polymer will lower the amount of polymer adsorbed to the core.Observation is done by soak a core in different polymer concentrations. This test measures the core mass before and after the soaking process. The data represent the percentage of polymer that adsorbed to the core.

Figure 5 shows the polymer flooding procedure. The polymer flooding is done at each of the cores by each of Xanthan Gum, Guar Gum, Kluwih, and Jackfruit. Polymer flooding is done at ambient temperature at a velocity of 0.3 cc/minute. Polymer injected into core up to stable pressure with assuming core and polymer get equilibrium. Berea core carried out brine saturation, to make the core contain formation-water. Next, the core carried out oil saturation, to make the core contain crude oil that will inject. Next, the core is done polymer flooding as secondary recovery. The last, core is done polymer flooding to know polymer performance pushes oil.
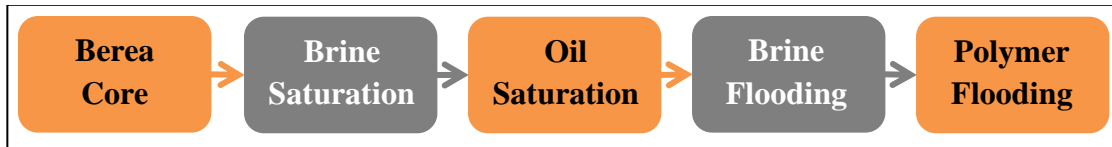
Figure 5. Polymer Flooding Procedure.

3. Result

3.1 Polymer Rheology

The first polymer rheological testing is done by measure the polymer viscosity at changes in the shear rate. In Figure 6 polymer viscosity measurements are done from shear rates of 15 s^{-1} to 225 s^{-1}. Each of the polymer dissolved at a concentration of 20,000 ppm. From the measurement results (orange and black dash line) in an increase in shear rate results in a decrease in the viscosity of the Kluwih and Jackfruit. From this measurement, it observed that each polymer was a non-Newtonian fluid, type pseudoplastic. Jackfruit viscosity decreased by about 30 cp, and Kluwih viscosity decreased by about 25 cp. The decrease in viscosity is greater in Jackfruit than in Kluwih. This indicates that Jackfruit is more sensitive to shear rate changes.

The second polymer rheological test is done by measure the polymer viscosity at changes in the shear rate at different polymer concentrations. Each of the polymer dissolved at a concentration of 10,000 ppm. From the measurement results (orange and black full line) in an increase in shear rate results in a decrease in the viscosity value of the Kluwih and Jackfruit, although the value is lower than higher concentration. Jackfruit viscosity decreased by about 0.5 cp, and Kluwih viscosity decreased by about 7 cp. The decrease in viscosity is greater in Kluwih than in Jackfruit. This indicates that Kluwih is more sensitive to shear rate changes.

This phenomenon described by the relation between molecular weight and polymer chain. Higher polymer concentration and bigger molecular weight cause higher viscosity. Higher viscosity formed by a stronger or longer polymer chain, and vice versa. It gives three indications of Kluwih and Jackfruit, compared at the same concentration. First, Jackfruit has a bigger molecular weight and in higher concentration has long
er polymer chain but weaker, it caused by a higher viscosity get but easier to degrade by shear rate. Second, lower Jackfruit concentration has a shorter polymer chain but stronger, it caused by a lower viscosity get but harder to degrade by shear rate. Third, Kluwih more stable about viscosity change if refer to shear rate and lower concentration quite increase viscosity. These indications must prove by another method to determine polymer molecular weight or polymer chain tendency.
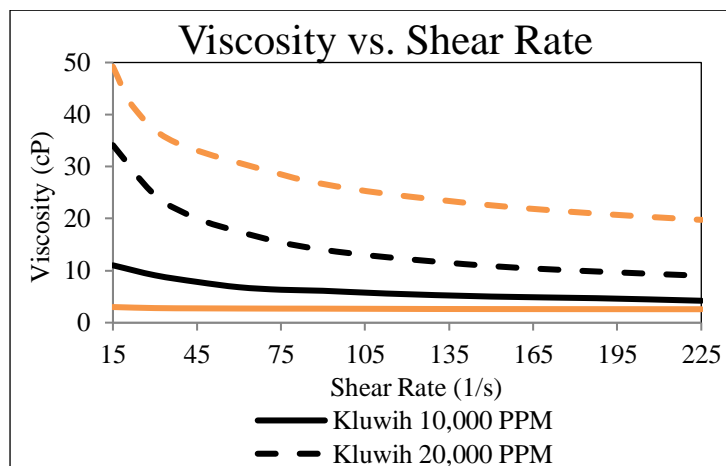

Figure 6. Kluwih and Jackfruit Viscosity at Variation Shear Rate.

The third polymer rheological testing is done by measure the polymer viscosity at a 7 s^{-1} shear rate. It assumed the shear rate at the reservoir. Commercial polymer at concentrations of 2,000 ppm and 4,000 ppm, whereas native polymer at concentrations of 10,000 ppm and 20,000 ppm. The commercial polymer has modified to give higher viscosity at a lower concentration. Contrary to native polymer, it needs more concentration to get higher viscosity. The results are shown in Figure 7. Proven that commercial polymer has higher viscosity (Xanthan Gum). This result also gives the same behavior that higher concentration and higher viscosity for all polymers. But there is an anomaly from the Guar Gum that has lower viscosity and not explained in this research.
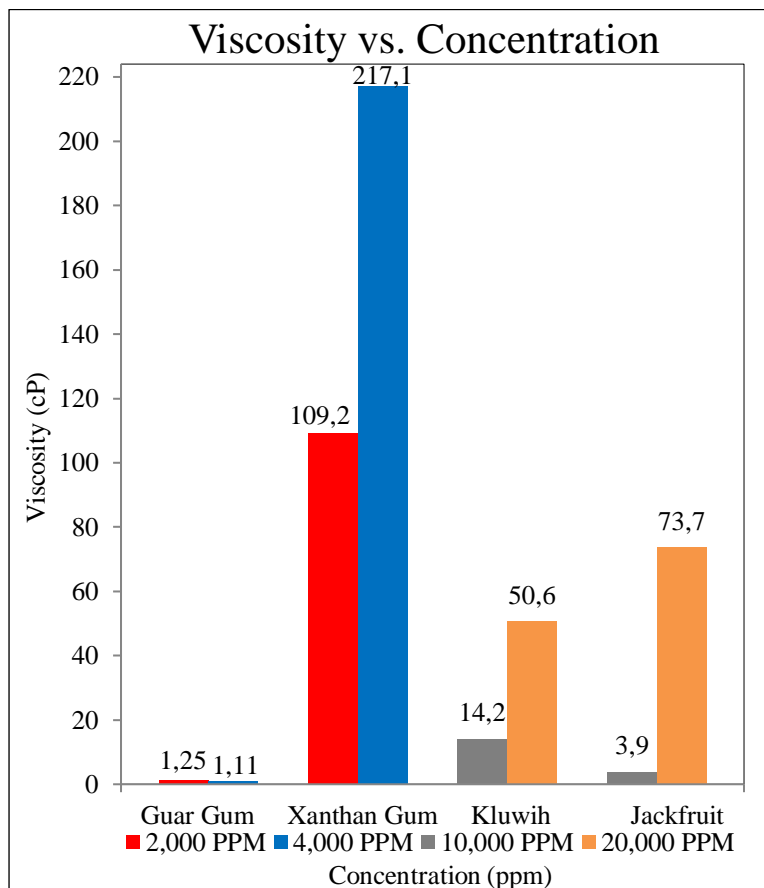

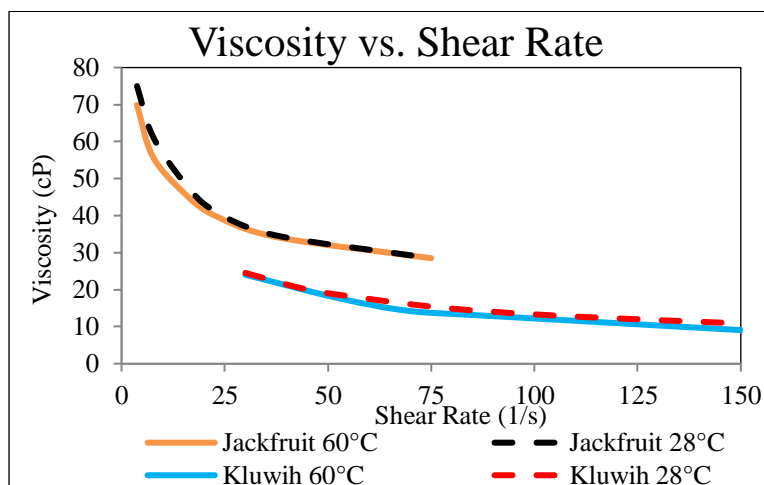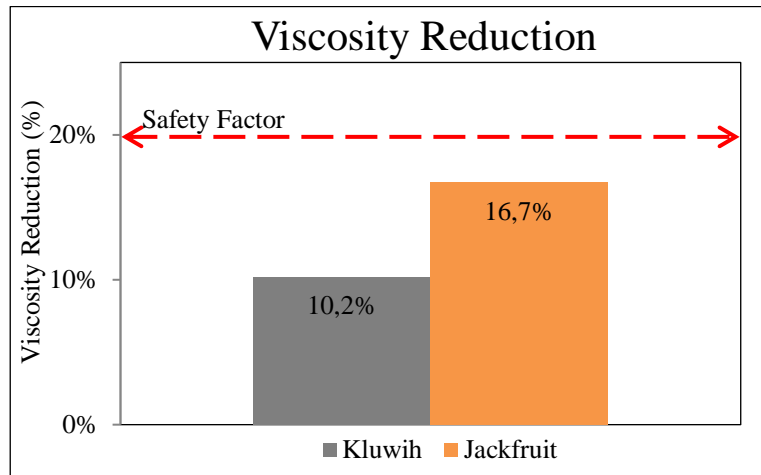**Figure 7.** Polymer Viscosity.

Figure 8. Kluwih and Jackfruit Viscosity Reduction at Variation Shear Rate.

The fifth polymer rheological testing is done by measure the polymer viscosity at a 7 s^{-1} shear rate and different temperatures. It assumed the shear rate at the reservoir. Jackfruit viscosity reduction by about 16.7%, and Kluwih by about 10.2 %. The viscosity reduction is greater in Jackfruit than Kluwih. This result still bellows the safety viscosity reduction for polymer injection that is 20%. The results are shown in Figure 9.

Figure 9. Kluwih and Jackfruit Viscosity Reduction.

This phenomenon describes the relationship between temperature and polymer chain. Higher temperatures cause lower viscosity that formed by a weaker or shorter polymer chain. Compare to Kluwih, Jackfruit easier causes a polymer chain to break at a higher temperature. It can happen by a polymer that has a linear chain or branch chain than a cross-link. If the polymer chain break, the polymer will degrade and viscosity is lower. This statement support indication before that Jackfruit is easier degrade by shear rate. Kluwih more stable about viscosity reduction if it refers to a higher temperature. But degrade is still occurs to this polymer. This will affect when an injection is done at a higher temperature because friction from the inner apparatus also reduces the viscosity, and these two factors will affect injection performance in the core. Some polymer may harden when applied at a higher temperature because solvent evaporates and leaving a higher concentration of polymer. Further research at 100°C condition is the need for these two polymers.
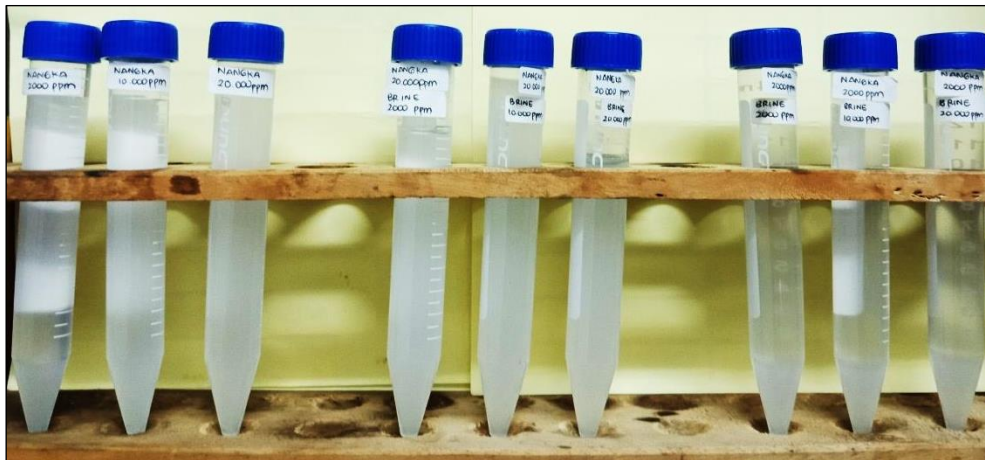
3.2 Polymer Compatibility Test

Starch from extraction gets in powder form, dry and granules texture. The dissolution of starch powder becomes the liquid phase use aquadest as the solvent. The changing process of this phase called hydrolysis. Hydrolysis is a chemical reaction that splits water molecules (H_2O) into hydrogen cations (H+) and hydroxide anions (OH−). In solution, cations and anions react with ions of other compounds which cause the hydrogen cation (H+) and hydroxide anion (OH−) to lag or excess so that the solution is acidic or basic (Wikipedia, Hidrolisis, 2019).

Starch does not dissolve in cold water, but in hot water the starch molecule absorbs water (hygroscopic) so that the starch molecule swells and breaks, mixing with the solvent to form a viscous solution. This is because the hydrogen ions (H+) and hydroxyl ions (OH-) resulting from the split of water molecules are substituted into amylose and amylopectin compounds, thus breaking the glucoside bonds and freeing glucose that is bound in amylose compounds. In this research, pure hydrolysis is done because starch just reacts with H_2O, without acid, alkali, or enzyme.

In this research, two factors affect the dissolution of polymer, temperature, and mixing. This factor is run together. Temperature is set at 30°C - 45°C and mixing at 100 RPM - 500 RPM, mixing until all of the granules is combine as a solution. Kluwih and Jackfruit mixing temperatures are quite low compared to starch from yam and corn that need 100°C and 160°C (Agra, Warnijati, & Pujianto, 1973). Mixing

is needed so that the molecule can collide with each other as well as possible and be homogenous fluid. Thes results of dissolution are shown in Figure 10.

Figure 10. Observation of Compatibility Test.

Observation results are shown in Figure 11. The commercial polymer has a different appearance to the native polymer. Commercial polymer solution still in a transparent liquid after hydrolysis process, while the native polymer into an opaque liquid. An opaque color occurred by native polymer, proves the existence of glucose content in the solution. Shows that the complete hydrolysis of starch occurs when heating. Starch granules break and straggling (Lehninger & Albert, 1982). The color range value state by 0 - 6 represents from transparent to opaque.
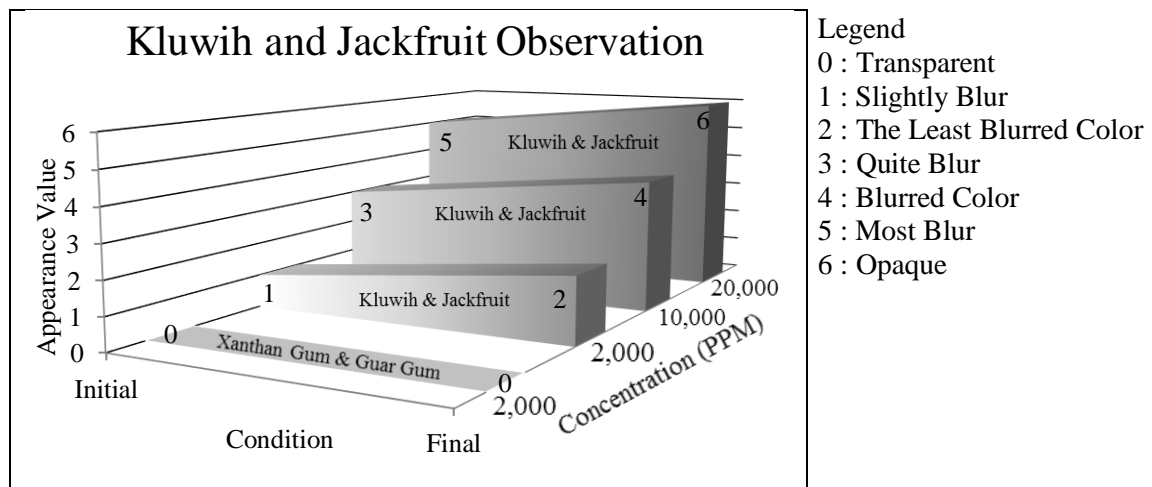
**Figure 11.** Polymer Compatibility Test.

Native polymer shows the inclination that higher concentration produces higher opaque color. As the observation after a long time, the final condition of liquid shows more opaque than initial. It caused of polymer settling at the bottom of the cone, change the homogenous liquid after a long time. The liquid is no longer combine, separate from the transparent part at the top and opaque at the bottom. It indicates that the transparent part is solvent dominant and the settle is polymer.
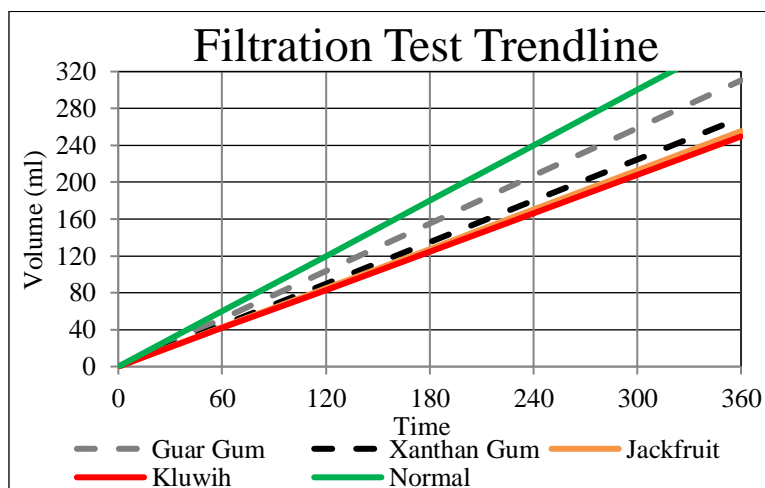
3.3 Filtration Test

In this study, the filtration test is to explain polymer trapping. The analysis is based on an indication of the interaction between polymer molecule size and pore size distribution. This means that the observation is specific. Specific means based on the effect caused by each polymer on each different core.

Polymer entrapping occurs in porous media due to pass by the polymer. So assumed that the polymer solution has physical contact with all parts of the core. The main thing in calculating the filtration test knows the amount of polymer that passes through the porous media in increased the time. If there is a change in the volume of the polymer between before and after, there is a certain amount of polymer retention. The measurement results of the test in Figure 12. The passed polymer volume data at a time shown Figure 12 (a) shows the amount of accommodated polymer after injecting to the core. This data redraw to easier analyze by trendline and shown in Figure 12 (b).

The green full line shows normal trendline, the amount of passed volume is the same at all the time. There is no fluid retention in the core, the pore size is suitable to polymer molecule size. The trendline shows commercial polymer is closer to the normal line than native polymer. The closer is Guar Gum then Xanthan Gum respectively shown by the grey and black dash line. The orange and the red full line show Jackfruit and Kluwih respectively. Further the trendline from normal means the amount of passed polymer volume is reduced at all the time. The cause has two indications. First, the core native polymer used tends more absorbent or second is polymer molecule size is bigger than pore size so that close the smaller size pore pathway along with adding the time.
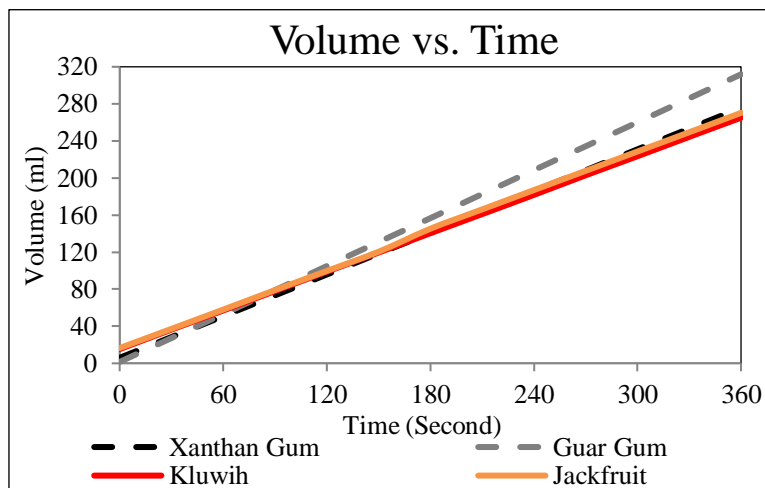
(a)

(b)

Figure 12. Filtration Test Result; (a) The polymer volume that passes, and (b) Trendline analysis.

If viewed from cores that have the same rock type and composition that is sandstone, then it is assumed that each core has the same characteristics (absorbent ability and pore size distribution). It means that the phenomenon in the polymer filtration test is purely caused by differences in the size of the polymer molecule, so the first indication does not apply. The amount of passed polymer volume is reduced at all

the time means there is polymer remain in the core. It can thicken the pore wall inside and reduce the passed fluid. This affects the permeability reduction of rocks, called residual resistance factors (RRF). This further causes a reduction in polymer mobility.
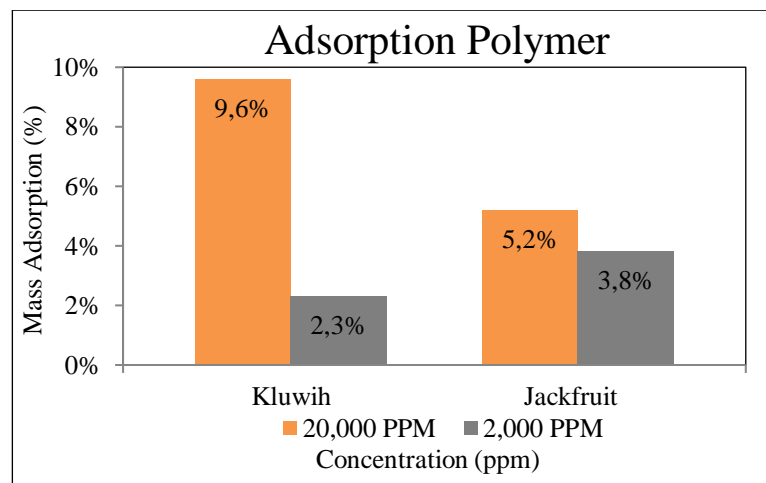
3.4 Static Polymer Test

In this study, the static polymer test is to explain polymer adsorption simply. The analysis is based on an indication of the chemical interaction between polymer and rock sand grains. The observation is based on the effect caused by each polymer on each different core.

The main thing in calculating the static polymer test knows the amount of polymer that adsorbed to porous media after an observation time at water bath temperature. If there is a change of the polymer mass against core, between before and after, there is a certain amount of polymer retention caused by adsorption. There is no force to inject the polymer, except chemical interaction. The measurement results of the test in Figure 13. The percentage of adsorbed polymer mass at two far different concentrations has a purpose to know the significant effect.

The results of the two polymers show as higher concentration gives higher adsorption than the lower concentration. The comparison of two polymers at 20,000 ppm concentration shows Kluwih adsorption is higher than Jackfruit. But reverse with 2,000 ppm that Jackfruit adsorption is higher than Kluwih. The differences in adsorption percentage at Jackfruit are not as far as Kluwih, Jackfruit just 1.4% but Kluwih is 7.3%.

Physical adsorption occurs when polymer molecules are adsorbed to the rock surface due to lower free energy. This lower free energy contributes to entropy and enthalpy. An increase in entropy occurs when water molecules that previously bound to a polymer or rock surface, become released because the polymer is adsorbed. The reduction of polymer concentration in a liquid will increase entropy. The contribution of enthalpy occurs for ionic polymers. This contribution results from the electrostatic attraction or repulsion of the polymer depending on the surface ion charge. Initial conclusion Jackfruit is better about adsorption.

Figure 13. Static Polymer Test Results.

As a result of the hydrolysis process that explained before, Figure 14 shows the nature of the solution acidic or base, at initial and final static polymer test. The initial pH of the polymer is measured when the solution has just dissolved and not contact the core yet. At 20,000 ppm these two polymers have pH 5 that is an acid solution. This is normal to biopolymer because have acid pH. But at 2,000 ppm Kluwih in base condition, while jackfruit still in an acid condition. The acidic solution occurs caused by hydrogen cation (H+) lag or excess in the solution, and the basic solution caused by hydroxide anion (OH−) lag or excess in the solution.

A final observation, the acidity of the polymer is measured. Data show two polymer's solution becomes a basic solution. It caused some amount of polymer is retention in porous media. Refer to adsorption and pH data, Jackfruit lower to adsorb but higher pH change, and vice versa to Kluwih. It concludes Kluwih is more hygroscopic and acidic than Jackfruit. Kluwih is a higher polymer adsorb, but the final pH is lower.
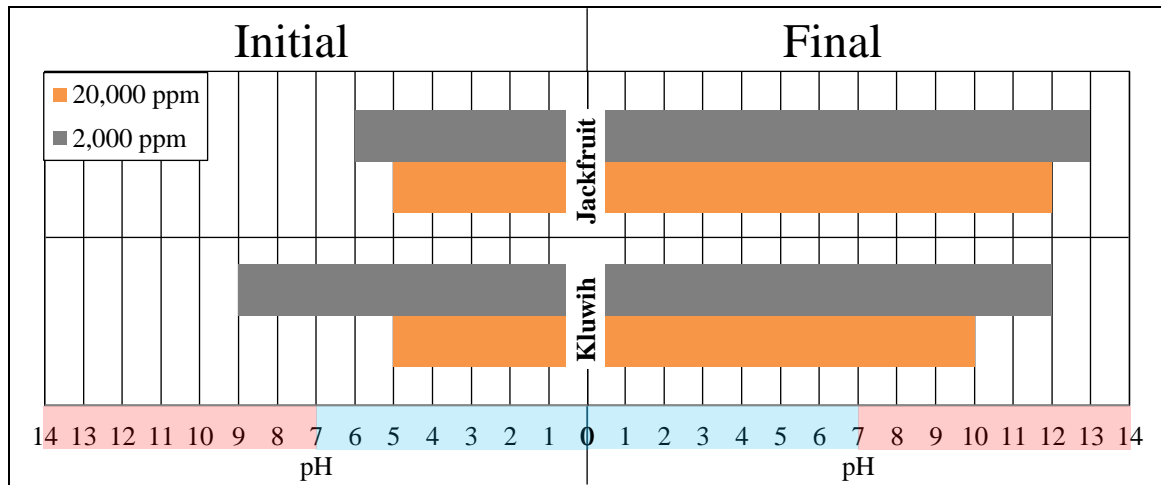

Figure 14. pH Change of Static Polymer Test.

3.5 Dynamic Polymer Test

In the tertiary recovery process, polymer injection can improve the mobility ratio of water-oil in porous media filled with oil. Polymer injection is done after the waterflooding process. The goal is to increase oil production that remains after secondary recovery. The results of the oil recovery from the injection are shown in Figure 15. There are two aspects of analysis from this result, the core, and the polymer.

In the secondary recovery (water flooding), the same synthetic brine is injected into each core. The difference is the core characteristics that have a wide permeability range. The core for commercial polymer injection uses permeability above 700 mD, while the original polymer uses permeability below 500 mD. The results show lower permeability giving lower oil recovery, which means there is still a large amount of oil left. The distribution of diverse rock grains, rock pores getting smaller so that rock permeability is also getting smaller. Support by low porosity which has lower permeability as shown in Table 1. This characteristic also influences polymer injection performance.
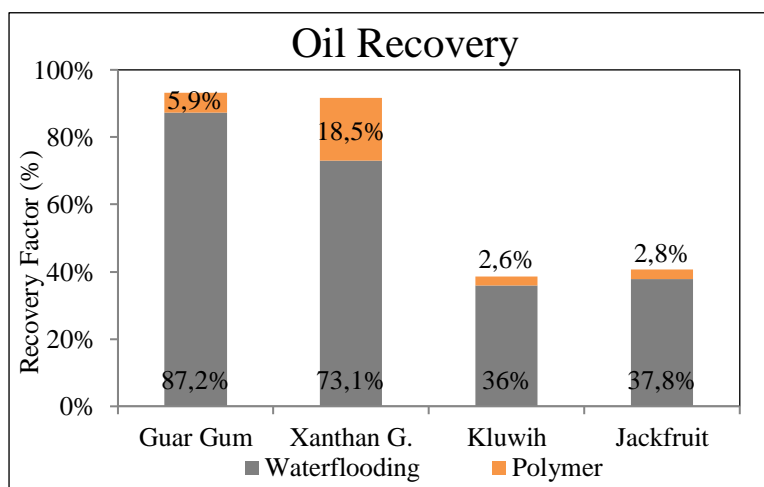

Figure 15. Oil Recovery Result.

At the tertiary recovery process (polymer flooding), the four different polymers are injected to each of the core. The results show native polymer gives lower recovery factors than commercial polymer. This caused of polymeric conditions such as lower viscosity due to unmodified polymer and viscosity reduction in porous media due to retention (entrapment and adsorption) and shear degradation. The lower polymer viscosity results in a greater mobility ratio of water-oil injection so that it is inefficient to produce oil or increase the value of the Recovery Factor. The result is a reduced efficiency of polymer injection to increase oil production thereby reducing the value of Recovery Factor.

4. Potential Utilization of Kluwih and Jackfruit for Polymer Injection

Economic studies that can be done are comparing the capital of making each native polymer with the price of commercial polymers. This is because analytical studies are only carried out in laboratory sizes and not in field applications. For field applications, certain geological conditions are required. From the results of laboratory studies obtained the economic value of each of the native polymers and commercial polymers as in Table 2. In the native polymer compared to the seeds content of whole fruit and the starch yield weight of the seeds. In native polymers and commercial polymers compared to the price of polymer products.

Table 2. Polymer Price.

Aspect	Xanthan Gum	Guar Gum	Kluwih	Jackfruit
Seed Price (Rp)	-	-	1,000	1,000
Seed Weight (per Kg fruit)	-	-	20%	15%
Starch	-	-	39%	16%
Price ($/lb)	3.2	2	0.4	1.4

Native polymers have lower prices than commercial polymers. This is because the main material of native polymer, the seeds of Kluwih and Jackfruit, is a waste material that is not major human consumption, so the price is very cheap. Observe from the ability to produce oil, native polymers have less performance than commercial polymers. It takes ten times the concentration of native polymer to commercial polymer to increase viscosity. Native polymer viscosity has not exceeded commercial polymers. The native polymer oil recovery factor is still lower than the native polymer. This indicates starch modification is needed to have a stronger ability. The modified Kluwih and Jackfruit starches are further laboratory study prospects for cheap, environmentally friendly and economically based polymers.

5. Conclusion

The starch is proven contained in the seed of Kluwih and Jackfruit. By a correct extraction method, a pure starch is getting without any impurity content. In liquid, the starch acts as a viscosifying agent. An increase in shear rate results in a decrease in the viscosity shows each of the polymers was a non-Newtonian fluid, type pseudoplastic.

Compared to Kluwih, Jackfruit easier degrade by shear rate and (polymer chain) easier to broke at higher temperatures. Kluwih is more stable about viscosity reduction at a higher temperature, 10.2% in kluwih and 16.7% in Jackfruit. But degrade is still occurred to this polymer. The starch powder of Kluwih and Jackfruit homogeny solute without any granule agglomeration. The appearance of the native polymer is opaque liquid (shown by above 0 appearance value), which proves the existence of glucose content in the solution and the complete hydrolysis of starch occurs when heating.

Polymer trapping is not dominantly occurred by Jackfruit and Kluwih. It explained by getting further the trendline from normal line means the amount of polymer volume is reduce at the time. Caused by polymer molecule size is bigger than the pore size. The adsorption of Kluwih is higher than the Jackfruit, 9.6% in kluwih and 5.2% in Jackfruit. Because polymer molecules are adsorbed to the rock surface,

when water molecules that previously bound to a polymer or rock surface, become released because the polymer is adsorbed. Kluwih is also more hygroscopic and acidic than Jackfruit by pH change, maximum change of 5 pH in kluwih and 7 pH in Jackfruit.

The native polymer has lower recovery factors than commercial polymer, 5.9% & 18.5% by Guar Gum & Xanthan Gum and 2.6% & 2.8% by Kluwih & Jackfruit, indicated by two causes. First, lower permeability and porosity, caused by rock sand grains distribution are diverse. Second, polymeric conditions such as lower viscosity and viscosity reduction because of retention (entrapment and adsorption) and shear degradation. Laboratory studies show native polymer prices are cheaper than commercial polymers, 0.4 $ / lb & 1.4 $ / lb by Kluwih & Jackfruit and 2 $ / lb & 3.2 $ / lb by Guar Gum & Xanthan Gum.

References

Berea Sandstone. (2019). Retrieved August 7, 2019, from Berea Sandstone™ Petroleum Cores: https://www.bereasandstonecores.com

Agra, I. B., Warnijati, S., & Pujianto, B. (1973). Hidrolisa pati ketela rambat pada suhu lebih dari 100 C. *Forum Teknik*, 3, 115 - 129.

Ben, E. S., Zulianis, & Halim, A. (2007). Studi awal permisahan amilosan dan amilopektin pati singkong dengan fraksinasi butanol – air. *Jurnal Sains dan Teknologi Farmasi*, 12, 1-11.

Cenk, T., Dike, P., Henny, A., & Raul, M. (2017). Economic Comparison of Hydrocarbon Recovery under Injection of Different Polymers. *SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition*.

Fadilah, U., Wijaya, I. M., & Antara, N. S. (2018). Studi pengaruh pH awal media dan lama fermentasi pada proses produksi etanol dari hidrolisat tepung biji nangka dengan menggunakan Saccharomycess cerevisiae. *Jurnal Rekayasa dan Manajemen Agroindustri*, 6, 92-102.

Gajah, G. (2019). Investigasi eksperimental mekanisme transportasi HPAM pada media berpori. *Bachelor Thesis Faculty of Mining and Petroleum Engineering Institut Teknologi Bandung*.

Gajah, G., Susantry, Arifin, I., Ramas, E. W., & Hidayat, R. (2019). Indonesia local biopolymer for enhanced oil recovery from seeds of kluwih. *Proceedings Indonesian Petroleum Association Forty Third Annual Convention & Exhibition*.

Lehninger, & Albert, L. (1982). *Basics of biochemical* (Vol. 1). Jakarta: Erlangga.

Mack, J. C., & Duvall, M. L. (1984). Performance and Economics of Minnelusa Polymer Floods. *SPE Rocky Mountain Regional Meeting*.

Mishra, Saurabh, Bera, A., & Mandal, A. (2014). Effect of polymer adsorption on permeability reduction in enhanced oil effect of polymer adsorption on permeability. *Journal of Petroleum Engineering*.

Mukprasirt, A., & Sajjaanantaku, K. (2004). Physico-chemical properties of flour and starch from jackfruit eeds (Artocarpus heterophyllus Lam.) compared with modified starch. *International Journal of Food Science and Technology*, 39, 217 - 276.

Sieberer, M., Jamek, K., & Clemens, T. (2017). Polymer-Flooding Economics, From Pilot to Field Implementation. *SPE Economics & Management*.

Sukatiningsih. (2005). Physicochemical and functional properties of starch from breadnut (Artocarpus communis G.Forst) seed. *Jurnal Teknologi Pertanian*, 6, 163-169.

Usman, F. (2018, December 20). *Guna Meningkatkan Produksi, Pertamina EP Terapkan EOR Injeksi Polymer di Field Tanjung*. Retrieved August 17, 2019, from Pertamina: https://pertamina.com/id/news-room/news-release/guna-meningkatkan-produksi-pertamina-ep-terapkan-eor-injeksi-polymer-di-field-tanjung

Wikipedia. (2018, February 15). *Amilum*. Retrieved August 7, 2019, from Wikipedia: https://id.wikipedia.org/wiki/Amilum

Wikipedia. (2018, November 22). *Kluwih*. Retrieved August 7, 2019, from Wikipedia: https://id.wikipedia.org/wiki/Kluwih

Wikipedia. (2019, March 26). *Hidrolisis*. Retrieved August 7, 2019, from Wikipedia: https://id.wikipedia.org/wiki/Hidrolisis

Winarno, F. G. (1986). *Kimia pangan dan gizi*. Jakarta: Gramedia.

Zhou, K., Hou, J., Ren, X., & Yu, B. (2017). Economic Design of Surfactant-Polymer Flooding Under Low Oil Price. *SPE Oil and Gas India Conference and Exhibition*.