

# Addition of Chain Extender to Improve Flexible Polyurethane Foam Characteristics of Palm Oil Polyol

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## ARTICLE INFO

### Article History:

Received: 02 September 2022

Final Revision: 05 November 2022

Accepted: 06 November 2022

Online Publication: 07 November 2022

## KEYWORDS

Chain extender, Flexible polyurethane foam  
Palm oil polyol

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## A B S T R A C T

The use of 100% palm oil polyol without the addition of a chain extender produced foam which initially expands and then collapses so that the resulting foam has tight pores, dense texture and brittle (brittle). It was necessary to use a chain extender to improve the flexible properties of the foam. This study aimed to examine the ratio of palm oil polyols with a chain extender to produce flexible polyurethane foam with good characteristics. The treatment of this study was a combination of types and comparisons of palm oil polyols with chain extenders which were carried out 3 times, consisting of factor A = type of chain extender (diethylene glycol (DEG), diethanolamine (DEA), and polyethylene glycol (PEG)-400) and factor B = ratio of palm oil polyols. with a chain extender (80%:20%, 70%:30%, 60%:40%, and 50%:50%). The obtained foam was observed visually, foam development and foam density. The best sample for each type of extender was analyzed by FTIR. The results showed that 40% PEG-400 has succeeded in producing flexible polyurethane foam with higher expansion (291.22%), lower density (29 kg/m<sup>3</sup>), and visually has the best flexible properties. Based on FTIR analysis, the use of PEG-400 in the polyol system can increase the reactivity of palm oil polyols to isocyanates.

## 1. INTRODUCTION

### 1.1. Research Background

Conventional polyurethane flexible foams use polyols from petroleum derivatives having a hydroxyl number of less than 100 mg KOH/g. Petroleum is non-renewable causing its availability to dwindle, so it is necessary to look for an alternative to renewable polyols. Renewable sources of polyols are widely distributed in nature, such as lignin, starch, sucrose, maltose, fructose, glucose, glycerol, dextrin, and vegetable oils. However, many researchers have developed vegetable oil as a source of bio-polyol. According to Ref. [1] vegetable oil as a source of bio-polyol has advantages, namely low price, widely available and renewable. Vegetable oil which is quite potential to be developed as a source of polyols is palm oil because it contains unsaturated fatty acids that can be converted into polyols.

Ref. [2] stated that vegetable oil polyols were obtained from the oxidation of unsaturated fatty acids by peracid acids into epoxidized oils. Then, the epoxide ring was opened using a ring-opening compound to form a polyol. Polyols determine the type

of polyurethane produced. Polyols having a hydroxyl number of less than 100 mg KOH/g are polyols used to produce flexible polyurethane foam, while polyols having a hydroxyl number of more than 100 mg KOH/g can produce rigid polyurethane foam.

In a preliminary study, foam synthesis was carried out using palm oil polyol with a hydroxyl number of 99.37 mg KOH/g without the use of a chain extender. Palm oil polyols have more secondary O-H groups than primary O-H groups. This causes palm oil polyols to be less reactive when reacted with isocyanates. This reaction contributes to the formation of cross-links in the foam. This cross-linking can strengthen the foam cell so that it can withstand CO<sub>2</sub> gas produced from the reaction of the blowing agent with the isocyanate. According to [3] it is necessary to add a chain extender that can react with isocyanates to form urethane or cross-links in the hard segment. This hard segment serves as a reinforcing filler that can strengthen the cell wall. According to [4], the use of a chain extender is a way to improve the flexible properties of the foam.

### 1.2. Literature Review

Polyurethanes are polymers formed from the reaction of polyols and isocyanates. Polyurethanes have been widely applied

as coatings, adhesives, sealants, foams, elastomers and are used to produce various products such as furniture, cars, wall and roof insulation, shoes, and clothing [5]. According to Ref. [1] the largest market share of polyurethane products is polyurethane foam with 65%. Polyurethane foam consists of flexible and rigid polyurethane foam. The demand for flexible polyurethane foam which has an open cell structure is increasing along with the rapid growth of the furniture, mattress and automotive industries.

Polyurethanes are usually formed by the reaction of long chain glycols (polyols) and low molecular weight chain extenders, such as glycols or diamines, which are composed of soft and hard segments [6]. The properties of polyurethane are determined by the composition of the soft and hard segments. The hard segment is formed by the reaction of a diisocyanate with a low molecular weight glycol chain extender or diamine, while the soft segment is formed by a polyol. According to Ref. [7] the hard segment provides a rigid structure that is physically cross-linked while the soft segment gives polyurethane elastic properties. If the ratio of soft and hard segments is the same, then the hard segment structure will have more influence on the mechanical properties of polyurethane [8].

There are also chain extenders that have high molecular weights such as PEG-400. Ref. [9] stated that PEG-400 can increase the reactivity of biopolyols by adjusting the hydroxyl number and viscosity of the polyol system, besides that PEG-400 also functions as a chain extender in the synthesis of polyurethane foams and plays an important role in improving structural homogeneity and mechanical properties. polyurethane foam. PEG-400 is also a non-toxic crosslinking agent [10][11].

The use of chain extenders in the synthesis process of flexible polyurethane foam has an optimal limit. If the use of a chain extender exceeds the optimal amount, the resulting foam will affect the flexibility, expansion and density of the foam. Therefore, it is necessary to conduct research that aims to examine the ratio of palm oil polyols with a chain extender to produce flexible polyurethane foam with good characteristics.

### 1.3. Research Objective

This study aims to evaluate the ratio of palm oil polyols with a chain extender (80%:20%, 70%:30%, 60%:40%, and 50%:50%) and type of chain extender to produce flexible polyurethane foam with good characteristics.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The materials used in this study were palm oil polyol with a hydroxyl number of 99.37 mg KOH/g [12], Sari Murni commercial palm oil, 50% H<sub>2</sub>O<sub>2</sub> from Bratachem, 100% acetic acid from Merc, 98% sulfuric acid from Smart Lab, ethylene glycol from Bratachem, sodium bicarbonate from Merc, HBr from Merc, KOH from Merc, DABCO BLV catalyst from Shandong Tonglan Chemical Co., Ltd., DABCO T-9 catalyst from Tianjin Hutong Global Trade Co., Ltd., silicone oil from Hubei Star Chem Co., Ltd., TDI 80 from Shandong Baovi Energy Technology Co., Ltd., aquades, methylene chloride from Dow, diethylene glycol from Merc, polyethylene glycol 400 from Subur Kimia Jaya, diethanolamine from Merc.

### 2.2. Foam synthesis

Flexible polyurethane foam is formed from the reaction of O-H and NCO functional groups. Biopolyol is obtained from palm oil which is epoxidized with 50% H<sub>2</sub>O<sub>2</sub>, 100% acetic acid, and 98% sulfuric acid as a catalyst. Then the epoxide ring of epoxidized palm oil was opened using ethylene glycol to produce biopolyol. Furthermore, foam synthesis is carried out by mixing biopolyol with additional materials (chain extender, blowing agent, catalyst, aquades and surfactants). Then the mixture was reacted with TDI 80 and stirred at 1200 rpm for 10 seconds. The reaction mixture was poured into a mold with a size of 120 x 120 x 100 mm<sup>3</sup> and put in the oven at 70°C for 1 hour. Then it was left at room temperature for 24 hours and the foam was ready to be observed. The formulation can be seen in Table 1.

**Table 1.** Flexible polyurethane foam formulation

Component (pphp)	Quantity				
Palm oil polyols	100	80	70	60	50
Chain extender:					
Diethylene glycol	-	20	30	40	50
Diethanolamine					
PEG-400					
DABCO T-9 catalyst	0.2	0.2	0.2	0.2	0.2
DABCO BLV catalyst	0.53	0.53	0.53	0.53	0.53
NIAX L-618 silicone oil	1	1	1	1	1
Aquades	1	1	1	1	1
Methylene chloride	4.2	4.2	4.2	4.2	4.2
TDI Isocyanate	51.9	51.9	51.9	51.9	51.9

Note: pphp = parts per hundred of polyol

### 2.3. Characterization

The polyurethane foam produced was visually observed, density, expansion, and Fourier Transform Infra-Red (FTIR) analysis. Foam density was determined by cutting the foam specimen into dimensions of 2.5 x 2.5 x 1 cm<sup>3</sup> and then weighed on an analytical balance. The data were taken 3 times and averaged [13].

Foam expansion is obtained by calculating (final volume/initial volume) x 100%. Observations were made 3 times and averaged.

Perkin Elmer FT-IR Spectrometer Frontier L128-0099 was used for FTIR analysis. Sample measurements were carried out after the FT-IR Tool was connected to a computer/PC using a LAN cable. Samples that have been inserted into the holder will be scanned to produce a graph.

## 3. RESULT AND DISCUSSION

### 3.1. Visual Observation of the Characteristics of Flexible Polyurethane Foam

The addition of various types of chain extenders with different ratios to biopolyols produces flexible polyurethane foams with different characteristics. According to [14] the difference in the molecular structure of the chain extender affects the initial polymerization reactivity, cell morphology, intermolecular interactions, and matrix strength in flexible polyurethane foams. Initial characterization of flexible polyurethane foam produced from palm oil biopolyol and chain extender was carried out visually (Table 2).

**Table 2.** Visual observations of flexible polyurethane foam synthesized using various types of chain extenders

Treatment		Observation result
Biopolyol : chain extender		
100	0	collapse, not soft, not flexible, very brittle, very little hollow
Biopolyol : Diethanolamine (DEA)		
80	20	collapse, somewhat soft, not flexible (brittle), a bit hollow
70	30	collapse, somewhat soft, not flexible (brittle), a bit hollow
60	40	collapse, mushy, easy to break, slightly hollow
50	50	collapse, very mushy, break easily, slightly hollow
Biopolyol : Diethylene glycol (DEG)		
80	20	collapse, not soft, not flexible, slightly hollow
70	30	collapse, slightly soft, slightly flexible, slightly hollow
60	40	collapse, soft, slightly flexible, hollow
50	50	collapse, soft, not flexible, slightly hollow
Biopolyol : Polyethylene Glycol (PEG)-400		
80	20	collapse, not soft, slightly flexible, hollow
70	30	a little collapse, a little soft, a little flexible, hollow
60	40	very little collapse, soft, flexible, hollow
50	50	shrinking, soft, flexible, hollow

The foam from biopolyol without chain extender was very brittle, stiff, not soft and crumbles when removed from the mold. Biopolyol have more secondary O-H groups than primary O-H groups which make them less reactive when reacting with isocyanates so that the hydrogen bonds formed in the gelling reaction are less strong. This condition causes the foam cell to be unable to withstand the CO<sub>2</sub> formed from the blowing reaction and eventually collapses. According to [15] low molecular weight polyols will produce stiff foam, while high molecular weight polyols will produce flexible foam. From this research, it can be concluded that the biopolyol produced has a low molecular weight. The addition of polyol molecular weight can be done by using a chain extender.

Diethanolamine (DEA) is a type of chain extender that also functions as a crosslinking agent. [14] stated that the use of DEA as a chain extender and crosslinking agent in the PPG-6000 polyol foam system increased the cross-link formation slightly in flexible polyurethane foam compared to foams that did not use a chain extender. DEA as a chain extender can form hard segments (urea bonds) or urethane bonds. This is in accordance with the results of the study that the use of DEA for all treatments resulted in foam that did not expand. However, the structure of DEA foam is somewhat stronger than foam without using a chain extender.

Biopolyol and DEA (80%:20% and 70%:30%) resulted in a slightly soft, brittle, non-flexible and non-swelling foam (Figure 1. A). At the beginning of the mixing of biopolyol, DEA and isocyanate a very fast reaction occurred so that a fairly high expansion occurred, but after a while the foam experienced shrinkage. [16] stated that the amine group of DEA reacted very quickly with the isocyanate molecule compared to the hydroxyl group of DEG and PEG-400. According to [17] this condition causes a sudden stiffening of the polymer without any covalent network formed, resulting in foam with brittle cell walls and

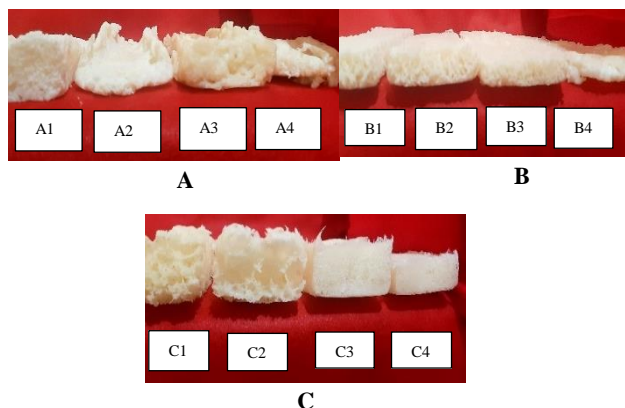
cannot withstand further foam expansion by CO<sub>2</sub> gas. Thus the cell wall becomes broken and collapse occurs so that very few open cells are formed.

The use of DEA with a concentration of 40% and 50% produces a sticky foam and contains a liquid such as mucus. This foam is very easy to break. The results of this study are in accordance with the statement of [18] that the use of DEA can disrupt the hydrogen bonding pattern in the hard domain so as to reduce the mechanical properties of the foam. The collapse condition causes the surface of the foam to be concave and very thin and brittle (Figure 3. A). Biopolyol: DEA of 50%:50% there was an extraordinary expansion and then collapse occurred. This is because DEA has a high reactivity with isocyanates so that the reaction takes place quickly. This reaction forms a hard segment in the form of urea bonds. Meanwhile, the reaction of biopolyol and isocyanate is slow and so that the reaction for the formation of CO<sub>2</sub> gas resulting from the reaction of water, methylene chloride and TDI. The CO<sub>2</sub> gas that is formed cannot penetrate into the hard cell walls. Most of the isocyanates have reacted with DEA, while the remaining isocyanates are not sufficiently reacted with biopolyols so that there are residual biopolyols that do not react.

The use of DEG of 40% produces foam with better characteristics when compared to the use of DEG of 20%, 30% and 50%. The characteristics of the foam obtained up to the optimum concentration of 40% are soft, somewhat flexible but less swell (Figure 1B and Figure 2). This is because the use of 40% DEG can form cross-links that are not too strong so that a little CO<sub>2</sub> gas is trapped in the foam cells. DEG has a higher molecular weight than DEA so it slightly lengthens the polyurethane chain and can produce a soft and slightly pliable foam. Expansion, foam flexibility is not as good as using PEG-400, but better than using DEA. The use of DEG by 50% can reduce the flexible properties of the foam (Figure 2). The less the biopolyol content that plays a role in the formation of the soft segment, the less flexible the foam.

The use of PEG-400 to 50% resulted in foam with sponge-like pores (Figure 1. B), but the expansion was not as high as that of using commercial polyols. The less PEG-400 is used the foam formed is brittle and the stiffer it is, even though foam cells have formed. PEG-400 is a solvent that can form stronger hydrogen bonds than diethylene glycol [11]. Several studies have been conducted, the polyols used to produce flexible polyurethane foam are polyether polyols [19][20][21][22]. This is because polyether polyols have primary O-H groups that are more reactive in reacting with isocyanates [16]. PEG-400 is a polyether polyol that can have strong hydrogen bonds with diisocyanates to form urethane so that it can hold CO<sub>2</sub> produced from the reaction of water and methylene chloride with isocyanate. This condition affects the flexible properties of the foam. In addition, the use of PEG-400 can increase the molecular weight of the polyol system so that it can produce a more soft and flexible foam. PEG-400 has a higher molecular weight (BM 400 g/mol) than DEA (BM 105.1383 g/mol) and DEG (BM 106.12 g/mol). [23] stated that polyols with high molecular weight when reacted with diisocyanates will form few cross-links so as to produce a flexible foam structure (Figure 2). [18] stated that the addition of a chain extender can increase the viscosity or molecular weight of the polyol system so that it can produce better foam expansion (Figure 1.C) and is resistant to cell membrane rupture.

Increasing the addition of PEG-400 as a chain extender can produce foam with smaller foam pores and tends to be homogeneous. This is in accordance with the statement of [9] PEG-400 can change the non-reactive groups and viscosity of the biopolyol as well as increase structural homogeneity and improve the mechanical properties of polyurethane foam. The use of PEG-400 more than 40% of the weight of the polyol resulted in a decrease in cross-link strength so that the foam cell wall could not retain CO<sub>2</sub> gas and CO<sub>2</sub> gas was released which resulted in decreased foam expansion [9].



**Figure 1.** The foam produced from the ratio of palm oil biopolyols with various types of chain extender compounds  
A = DEA (A1 = 20%, A2 = 30%, A3 = 40%, A4 = 50%);  
B = DEG (B1= 20%, B2=30%, B3=40%, B4=50%); C = PEG-400 (C1= 20%, C2=30%, C3=40%, C4=50%)

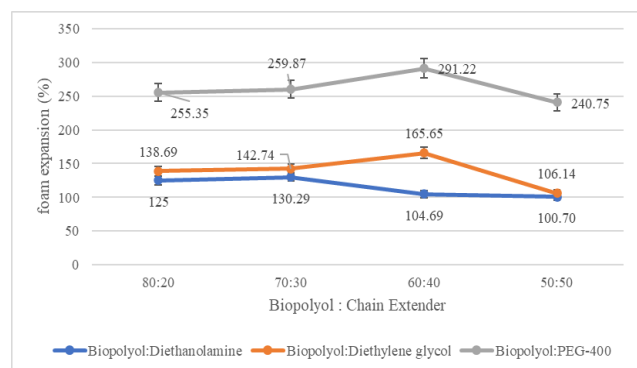


**Figure 2.** Flexibility of polyurethane foam synthesized from the ratio of palm oil polyols with a. DEG 20%; b. DEG 30%; c. DEG 40%; d. PEG 20%; e. PEG 30%; f. PEG 40%; g. PEG 50%

### 3.2. Foam expansion

Ref. [18] stated that the addition of a chain extender can increase the viscosity or molecular weight of the polyol system so that it can result in better foam expansion and resistance to cell membrane rupture. The use of different chain extenders results in different foam expansion. PEG-400 provides better foam expansion than DEG and DEA. This is because DEG and DEA are chain extenders that have a lower molecular weight [24] while

PEG-400 is a chain extender that has a high molecular weight [25]. DEG and DEA play a role in the formation of hard segments in the foam and have many closed cells so that the resulting foam is not and does not expand. PEG-400 has a long chain that plays a role in the formation of soft segments and can produce foam that expands and is flexible [25].



**Figure 3.** Graph of expansion of polyurethane foam from palm oil polyol

DEA with a concentration of 30% resulted in the highest foam expansion of around 130.29% (Figure 3). However, the expansion of DEA foam is much lower than that of DEG and PEG-400 foams. The reaction of DEA which has an amine group with an isocyanate is faster than the primary O-H group found in DEG and PEG-400 [17]. This is due to DEA also has the ability to catalyze reactions. The speed of this reaction cannot be matched by the reaction rate of CO<sub>2</sub> gas formation so that the foam cell that has been stiffened cannot accommodate more stretch due to the penetration of CO<sub>2</sub> gas into the cell and the cell wall breaks. This condition causes collapse and the resulting foam expands slightly. The use of DEA of 40% and 50% resulted in foam that tends not to expand because the reaction of formation of urea bonds in the hard segment is too fast compared to the formation of CO<sub>2</sub> gas.

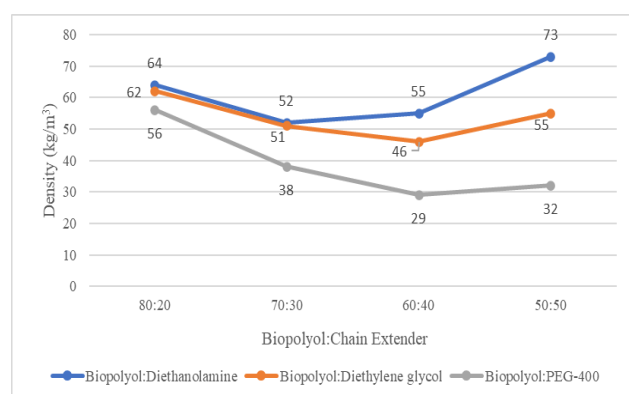
The highest foam expansion of DEG foam was at a concentration of 40%. DEG which has a primary O-H group can increase the reactivity of the polyol system to react with isocyanates. DEG foam expansion rate is better than DEA but not as good as PEG-400 foam expansion. The addition of 20% and 30% DEG resulted in a stiffer foam than 40% DEG. This shows that the 20% and 30% DEG foam contains more closed cells than open cells so that the foam expands less. The reaction for formation of urea bonds in the hard segment is still slower than the formation of CO<sub>2</sub> gas because the presence of secondary O-H groups from palm oil polyols is still contained in the polyurethane system. Thus, the 20% and 30% DEG foam produced was less swelled (138.69% and 142.74%). The formation of urea bonds in the hard segment of DEG foam with a concentration of 40% produces foam with cell walls that are more flexible than the concentration of 20%, 30% DEG so that 40% DEG foam can trap more CO<sub>2</sub> gas. However, the use of 40% DEG resulted in the formation of CO<sub>2</sub> gas faster than the urea bond formation reaction, causing less CO<sub>2</sub> gas to be trapped by the foam cells so that the resulting foam was less swelled (165.65%), somewhat softer and less flexible (Figure 2). The use of 50% DEG caused the foam expansion to decrease (106.14%). The more primary O-H group content in the polyurethane system causes the gelling reaction (polymer formation) between primary O-H and

isocyanate to be faster than the CO<sub>2</sub> gas formation reaction. This makes it difficult for CO<sub>2</sub> gas to enter the foam cells that have stiffened so that foam expansion is limited.

PEG-400 includes polyethers containing primary O-H groups which can help palm oil polyols to react with isocyanates. The addition of PEG-400 can increase the soft segment content in polyurethane foam so that the cell walls are more flexible in trapping CO<sub>2</sub> gas so that the resulting foam expands more than DEG and DEA foams. The use of PEG-400 by 40% gave the highest expansion (291.22%). However, the use of PEG-400 at 50% causes the formation of a higher soft segment so that the foam cell wall that is formed becomes weak in trapping CO<sub>2</sub> gas so that CO<sub>2</sub> gas is easily separated from the cell wall. This causes the foam expansion to be low.

### 3.3. Foam density

Foam density is an important parameter to control the mechanical properties of the foam. Polyurethane foam has low density, high porosity and high expansion rate. The results of measuring the density of polyurethane foam using various types of chain extenders at different concentration levels can be seen in Figure 4.



**Figure 4.** Graph of density of polyurethane foam from palm oil polyol

Figure 4 shows that the density of palm oil polyurethane foam with various additions of chain extenders is the addition of DEA (52 kg/m<sup>3</sup>-73 kg/m<sup>3</sup>), DEG (46 kg/m<sup>3</sup> - 62 kg/m<sup>3</sup>), and PEG-400 (29 kg /m<sup>3</sup>-56 kg/m<sup>3</sup>). The density of commercial flexible polyurethane foam is about 30 kg/m<sup>3</sup> [6]. The density of semi-flexible polyurethane foam is about 50 kg/m<sup>3</sup> -80 kg/m<sup>3</sup> [26]. This shows that polyurethane foam produced from 60% biopolyol : 40% PEG-400 produces foam with a density that is almost the same as commercial flexible polyurethane foam. According to [27] the more closed cells, the higher the foam density.

DEA tends to produce a higher foam density than DEG and PEG-400. The amine group in DEA reacts with the isocyanate more quickly than the CO<sub>2</sub> gas formation reaction, causing the urea bond in the hard segment to form first. The foam walls that have stiffened make it difficult to bind the formed CO<sub>2</sub> gas.

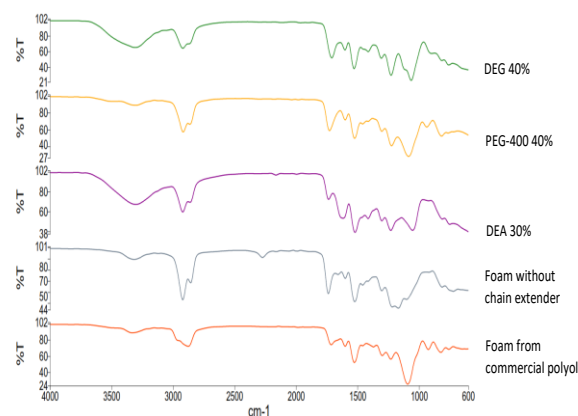
The higher of DEG (up to 40%), the more isocyanate used so that the more hard segment content can strengthen the foam cell wall [1]. The content of the hard segment formed can still be balanced by the soft segment containing hydrocarbon derivatives in the form of fatty acid chains so that the 40% DEG foam cell wall becomes somewhat flexible and can trap more CO<sub>2</sub> gas than other DEG treatments. The number of open cells affects the

density value. Foam of 40% DEG had a lower density value (46 kg/m<sup>3</sup>) than foam at 20%, 30% and 50% DEG concentrations with densities (62 kg/m<sup>3</sup>, 51 kg/m<sup>3</sup>, and 55 kg/m<sup>3</sup>). [1] [28] [5] stated that the density of polyurethane foam more than 30 kg/m<sup>3</sup> can be categorized as rigid foam.

The density of polyurethane foam with the addition of PEG-400 is lower than that of DEG and DEA. The density parameter is related to the percentage of foam expansion. This is in accordance with the statement of Ref. [29] that the decrease in density is due to the increase in the volume of polyurethane foam after the addition of PEG-400. Furthermore, [9] stated that the decrease in density is usually caused by an increase in the expansion of foam cells during the foaming process. Increasing the concentration of PEG-400 to 40% in the biopolyol can increase cell expansion and reduce foam density. The use of PEG-400 exceeding 40% causes more primary O-H groups to react in the polyurethane system. PEG-400 is classified as polyether which plays a role in forming soft segments so that the foam has flexible cell walls that can trap more CO<sub>2</sub> gas. The foam formed is more fluffy and has a lower density (29 kg/m<sup>3</sup>). So little cross-links are formed to form a strong cell wall to trap CO<sub>2</sub> gas produced during the foam formation process [9]. However, the use of PEG-400 by 50% forms a weaker foam cell wall so that the release of CO<sub>2</sub> gas from the foam cell can occur. This causes a decrease in the volume of foam expansion and a slightly higher density (32 kg/m<sup>3</sup>).

### 3.4. Fourier Transform Infra-Red (FTIR)

FTIR analysis was carried out on flexible polyurethane foam that had the best characteristics of each type of chain extender, namely foam from DEG with a concentration of 40%, PEG with a concentration of 40% and DEA with a concentration of 30%. Then the results were compared with foam from palm oil polyol without a chain extender and commercial flexible polyurethane foam. The purpose of FTIR analysis was to determine the presence of functional groups in flexible polyurethane foam from palm oil polyols.



**Figure 5.** Infrared spectrum of flexible polyurethane foam

Figure 5 shows the infrared spectrum of polyurethane foam with an addition of 40% DEG, 40% PEG-400, 30% DEA, commercial polyurethane foam and palm oil polyurethane foam without a chain extender have almost the same absorption peak patterns, but there is a slight shift in wavenumber for each treatment. In the infrared spectrum of the five foam samples, there was no absorption peak of the O-H group at a wave number of



3650  $\text{cm}^{-1}$ . Flexible polyurethane foam samples with DEG addition of 40%, PEG-400 40%, DEA 30%, commercial polyurethane foam did not have an absorption peak of free -NCO groups at wave number 2274  $\text{cm}^{-1}$ , but palm oil polyurethane foam samples without a chain extender has an absorption peak of the free -NCO group at a wave number of 2274  $\text{cm}^{-1}$ . This indicates that the O-H functional groups of polyols and DEG, PEG-400, DEA have completely reacted with the -NCO groups of TDI in forming urethane bonds [4] as well as commercial flexible polyurethane foams. However, palm oil polyurethane foam without a chain extender did not have a perfect reaction between the O-H group of the palm oil polyol and the isocyanate group of TDI. This is because palm oil polyols have many secondary O-H groups which are less reactive with isocyanate groups in forming urethane cross-links. Ref. [2] stated that the presence of free -NCO can be toxic to living body cells.

The infrared spectrum also showed that the five polyurethane foam samples contained -NH<sub>2</sub> bonds at wave numbers 3305  $\text{cm}^{-1}$  – 3335  $\text{cm}^{-1}$ . Flexible polyurethane foam using a chain extender with a concentration of 40% DEG, 30% DEA, 40% PEG and without a chain extender has absorption peaks between 2920  $\text{cm}^{-1}$  – 2923  $\text{cm}^{-1}$  which are aliphatic hydrocarbon groups such as -CH<sub>3</sub>- and -CH<sub>2</sub>-. Polyurethane foam with the addition of 40% DEG, 30% DEA and without the addition of a chain extender has a sharper absorption peak. This indicates that the foam has more cross-links in the hard segment resulting in a stiff foam. Meanwhile, commercial flexible polyurethane foam and foam with the addition of 40% PEG-400 had a non-sharp absorption peak. This indicates that the foam has fewer cross-links in the hard segment and has been compensated by the presence of the soft segment so that the resulting foam is flexible.

The wave number of about 2879  $\text{cm}^{-1}$  is that there is a symmetrical -CH<sub>2</sub>- stretching in commercial flexible polyurethane foams. The absorption peaks at 2357  $\text{cm}^{-1}$  and 2180  $\text{cm}^{-1}$  are the peaks of stretching vibrations of CO<sub>2</sub> and CO. Wave numbers 1710  $\text{cm}^{-1}$  – 1738  $\text{cm}^{-1}$  and 1523  $\text{cm}^{-1}$  -1529  $\text{cm}^{-1}$  indicate the presence of bent carbonyl and -NH groups that form polyurethane through hydrogen bonds (-NH--hydrogen bonds-C=O) [2][30]. The success of the foam synthesis reaction was indicated by the absorption of hydrogen bonded C=O urethane, meaning that hydrogen bonds were formed between the carbonyl group and the N-H group that occurred at 1601  $\text{cm}^{-1}$  – 1618  $\text{cm}^{-1}$  (owned by the five foam samples) and strengthened by the absorption of C-O urethane. which has a wave number of 1086  $\text{cm}^{-1}$  – 1093  $\text{cm}^{-1}$  (not owned by polyurethane foam samples without a chain extender). Polyurethane foam without a chain extender undergoes an incomplete reaction, because palm oil polyols have a lot of secondary O-H groups that are less reactive to TDI isocyanates. The polyurethane chain has quite strong hydrogen bonds (20 – 50 kJ/mol), which usually occurs in the N – H group, the urethane carbonyl group C = O (-NHCOO) and the urea carbonyl group C = O (-NH-CO-NH -), even formed in the polyether O – H group [31]. The presence of C, N, O absorption peaks indicates a flexible polyurethane foam component [32].

The amide absorption peak occurred at wave number 1414  $\text{cm}^{-1}$  - 1459  $\text{cm}^{-1}$ . The absorption peak at wave number 1300  $\text{cm}^{-1}$  – 1307  $\text{cm}^{-1}$  indicates the presence of a secondary amide. The peak at wave number 1220  $\text{cm}^{-1}$  -1226  $\text{cm}^{-1}$  indicates the presence of C=N absorption in the carbomide trimer. The absorption peak at 1053  $\text{cm}^{-1}$  – 1093  $\text{cm}^{-1}$  is the C-O-C stretching vibration of the ether bond.

## 4. CONCLUSION

Chain extenders also have a role as cross linkers. The right type of chain extender and concentration level can form a good covalent network that allows the cell to accommodate more strain due to the presence of CO<sub>2</sub> gas in the cell and does not burst when the polymer foam stiffens. This condition can increase foam expansion. PEG-400 as a chain extender can increase the reactivity of palm oil polyols to isocyanates. The use of PEG-400 has succeeded in improving the foam flexibility properties of palm oil polyols. The use of 40% PEG-400 can produce foam with high expansion (291.22%), lower density (29  $\text{kg/m}^3$ ), and visually has the best flexible properties. Based on FTIR analysis, PEG-400 in the polyol system can increase the reactivity of palm oil polyols to isocyanates. PEG-400 has been successful in improving the foam properties of palm oil polyols to become more pliable and flexible.

## Acknowledgment

The authors would like to thank Andalas University for providing financial support for conducting this study.

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