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SYNTHESIS BIO-BASED OIL FROM CATFISH FAT, BLENDING BIO-LUBRICANT

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ABSTRACT

Catfish fat was pre-filtered to catfish oil. Catfish oil was chemical converted to esterified catfish oil by the epoxydation reaction and ring opening reaction of epoxidized catfish oil. Base on the formula of SAE20W50 engine lubricants, bio-lubricants were blended by replacing mineral base oil (SN500) as esterified catfish oil in ratio (wt/wt) at 10/90, 20/80, 30/70, 40/60 and 50/50. FT-IR method was used to identify functional groups of samples. The oxidation resistance of samples was determinated by TGA method and Rancimat test. The biodegradability of samples was analyzed by COD test and BOD test. Properties of material and products were determined by TCVN standard and ASTM standard. From the analysis results show that, esterified catfish oil can used as bio-based oil and blend of ratio of (wt/wt) esterified catfish oil/SN500/ at 40/60 can not only meet the characteristics of SAE20W50 lubricant but also it may be high biodegradability. The synthesis esterified catfish oil from catfish fat and preparation of bio-lubricant from esterified catfish oil can develop in green chemistry.

Keywords: catfish fat, bio-lubricant, rancimat, thermogravimetric, biodegradability.

1. INTRODUCTION

Lubricants with features such as lubrication, cooling, and friction, improved engine performance and increased the engine life significantly. However, lubricant is not a sustainable product because base stocks were produced from limitted crude oil resource and the pollution of waste lubricants. Vegetables oils/animal fats can be an renewable, friendly feedstock resource [1]. In the research of Kailas M. Talkit et al, bio-lubricant was made by blending of soybean oil and olive oil [2]. Muhamad Azwar bin Azhari and partners was blended corn oil, canola oil and 2 wt.% of antiwear additive (Zinc dialkyldithiophosphate) to creat a bio-lubricant [3] nor in the research of Rozaini Abdullah et al, blend of waste cooking oil with Jatropha curcas oil can used as biolubricant [4]. It can be said that, the direct use of vegetable oils as a based oil in blending bio-lubricant can be simple and easy to do. However, some properties of vegetable oils have not yet met the technical requirement of mineral base stock because because of the presence of unsaturated compounds in vegetable oils (Lou A.T. Honary, Erwin Richter, 2011). Therefore, chemical methods have been interested by scientists to improve the properties of animal fats /vegetable oils [6]. 2015, Rajesh V. Sharma *et al*, was metabolized the unsaturated composition of canola oil by reactions and esterified product was used as bio-lubricant because it had high thermal oxidation stability and high lubricity [7]. In the research of Ebtisam K. Heikal and partners, bio-lubricant was synthesized from palm oil and jatropha oil by a two-step process of esterification. The viscosity index, thermal stability and pour point temperature of product was enhance significantly and bio-lubricant product could meet the technical requirements of lubricant ISO-VG46 [8]. In 2018, Michael Bong Alang et al, used chemical method to synthesis bio-lubricant from Cameroon palm kernel seed oil (PKSO). The process can be described by two steps. The first, it was the esterification reaction of PKSO with methanol to creat the methylester. The second, it was the esterified reaction of methylester with trimethylolpropane. The basic properties of this biological lubricant may be equivalent to those of the commercial T46 lubricant [9]. In Vietnam, the process of exporting catfish fillet increased strongly in recent years. Catfish fat is a by-product and it obtained in large quantities from catfish processing (Tran Minh Phu, Tran Thuy Tien, Nguyen Le Anh Đao, Tran Thi Thanh Hien, 2014). So the catfish fat can an abundant and available resources in Viet Nam and the process of synthesizing bio-based oil from catfish fat can be developed sustainably.

2. METHODOLOGY

2.1 Materials

Catfish fat (CFF) was bought from Phuoc Thanh Agricultural Import Export Company Limited, 12F2 Truong Chinh, My Phuoc Ward, Long Xuyen City, An Giang province, Viet Nam. Mineral base oil SN500 and some additives were provided from Đai Lam Son Lubricant Company in Dong Nai province, Viet Nam. Sodium of H_2O_2 (30 wt.%), CH_3COOH (99 wt.%) and H_2SO_4 (99 wt.%) was purchased from Chemsol company, Viet Nam. Anhydride acetic, assay ≥ 99.9 (v.%) was from Merck. Chemicals and solvents in analysis were analytical pure standard and they were procured from Merck. The IKA RW16 mechanical stirrer made in Germany.

2.2 Experimental

2.2.1 Preparing bio-based oil from catfish oil

Catfish oil (CFO) material was received from the filtration of catfish fat. The process of synthesizing bio-based oil from catfish oil consists of 2 parts. Part one is the epoxydation reaction of catfish oil and part two is the opening reaction of epoxidized catfish oil.

The epoxydation reaction of catfish oil can be described as follows:

First, volume acetic acid (98 v.%) and volume of H_2SO_4 (98 v.%) catalysis was put into the reactor- two-neck glass flask (1 L). The condenser and the magnetic stirrer was installed and the mixture stirred at room temperature for 15 minutes. Next, solution of H_2O_2 (30 wt.%) was put into reactor slowly [7]. The mixture stirred at room temperature for 30 minutes to creat the peracid acetic. After that, the reaction mixture remained in the dark bottle. Second, the condenser and the magnetic stirrer was installed in the reactor two- neck glass flask (3L), it has already contained 1000 mL of CFO. Then mixture of peracid acetic and H_2SO_4 catalysis was put into into this reactor two- neck glass flask (3 L). The epoxy reaction was carried out at fix conditions, temperature of 55 ^oC, molar ratio of H_2O_2/CH_3COOH/double bond of 4.5/1.5/1 and time reaction of 4 hours. Purify the product by washing with distilled water several times in the separating funnel [7] [11]. Final, epoxydized catfish oil product (ECFO) was dried at vacuum (0.1atm) and anhydrous substance $NaSO_4$. ECFO was tested the weight percent epoxide (E) according to the ASTM D1652 to evaluate the yield of epoxydation reaction of catfish oil.

The opening reaction of epoxydized catfish oil can be described as follows:

First, volume anhydride acetic (99.9 v.%) and volume of H_2SO_4 (98 v.%) catalysis was put into the reactor- two- neck glass flask (500 mL) slowly. The condenser and the magnetic stirrer was installed and the mixture stirred in range of (50 ^oC ÷ 60 ^oC) for 30 minutes to activate the catalyst. After that, the condenser and the magnetic stirrer was installed in the reactor two- neck glass flask (3L), it has already contained 1500 mL of ECFO. Then mixture of anhydride acetic and H_2SO_4 catalysis was put into this reactor two- neck glass flask (3L). The opening reaction of epoxidized catfish oil was carried out at fix conditions, temperature of 90 ^oC, molar ratio of $(CH_3CO)_2O$/epoxy of 2/1 and time reaction of 5 hours. Purify the product by washing with distilled water several times in the separating funnel [7] [11]. Final, esterified catfish oil product (ESCFO) was dried by microwave oven and anhydrous substance $NaSO_4$ and ESCFO was tested the ester value (EV) according to the ASTM D5558 to evaluate the yield of the opening reaction of epoxydized catfish oil.

2.2.2 Blending bio-lubricant

Blending bio-lubricant can be described as follows:

Firstly, the engine lubricant SAE20W50 was blended from the base stock oil SN500 and additives. Second, base on the SAE20W50 formular, the basestock oil (BSO) was replaced by bio-based oil (ESCFO) in ratio of ESCFO/BSO of 10/90. 20/80, 30/70, 40/60 and 50/50 and bio-lubricant blends was coded 10Bio, 20Bio, 30Bio, 40Bio and 50Bio respectively. Finally, the alternatives of bio-based oil for basestock oil was evaluated base on the results of their properties analysis.

2.3 Analysis

The characterization of samples were identified by FT-IR spectrophotometry. Oxidation stability of samples were determined by TGA method and Rancimat test. TGA was carried out in LINSEIS STA-PT 1600, under nitrogen, temperature in range of (25÷800 ^oC), heating rate at 10 ^oC/minute in Biomass Laboratory of Research Institute for Sustainable Energy, Viet Nam National University (VNU). Rancimat test was carried out in Rancimat 743. Temperature was set up at 110 ^oC with an airflow of 10 L/h. Rancimat test were carried out in the Laboratory of Petroleum Products of Quality Testing Center Standard 3, Viet Nam. Biodegradability of samples were analyzed by biochemical oxygen demand test (BOD) and chemical oxygen demand test (COD). Sample of bio-lubricant was diluted 10 times and mineral lubricant was diluted 100 times in distillated water. The properties of materials and products were determined according to the TCVN and ASTM standard in Petroleum Laboratory of HCMC University of Technology, Viet Nam National University (VNU) and Industry University HCMC (IUH).

2.4 Calculation Formulation

The yield of epoxydation reaction of catfish oil was calculated by Eq1, as follows:

$$Y=\frac{O_{exp}}{O_{theo}}\times 100\% \quad (1)$$

Here by:

Y : the yield of epoxydation reaction of CFO (%)

O_{exp} : the weight percent of experimental oxirane oxygen (wt.%)

O_{theo} : the weight percent of theory oxirane oxygen (wt.%)

O_{theo} was calculated by Eq2 [12], as follows:

$$O_{theo}=\frac{{}^{IV_0}/_{2A_I}}{100+({}^{IV_0}/_{2A_I})\times A_O}\times A_O \quad (2)$$

Here by:

IV_0 : Iod value of catfish oils (gIod/100g). Iod value determined according to TCVN 6122: 2010

A_I= 126.9 : Iodine molecular weight (đvC)

A_O = 16 : oxygen molecular weight (đvC)

According to ASTM D1652, O_{exp} was calculated by Eq3 , as follows:

$$O_{exp} = \frac{16}{43}E \quad (3)$$

E: weight percent epoxide (wt.%). E was calculated by Eq4 , as follows:

$$E=\frac{V}{W}\times C\times 4.3 \quad (4)$$

Here by:
V : Titration volume $HClO_4$ (mL)
C : Concentration of $HClO_4$ (N)
W : weight of sample (g)

The yield of opening reaction of epoxidized catfish oil was calculated by Eq5, as follows:

$$Y=\frac{EV_{exp}}{EV_{theo}}\times 100\% \quad (5)$$

Here by:
Y : The yield of opening reaction of ECFO (%)
EV_{exp} : The experimental ester value of (mgKOH/g)
EV_{theo} : The theory ester value of (mgKOH/g)

According to ASTM D5558, EV_{theo} was calculated by Eq6, as follows:

$$EV_{theo}=\frac{10E}{43}\times 56.1 \quad (6)$$

Here by:
E : weight percent epoxide of ECFO (wt.%).

EV_{exp} was calculated by Eq7, as follows:

$$EV_{exp} = {}^{EV}_{ESCFO} - {}^{EV}_{ECFO} \quad (7)$$

Here by:
${}^{EV}_{ESCFO}$: the ester value of ESCFO (mgKOH/g)
${}^{EV}_{ECFO}$: the ester value of ECFO (mgKOH/g)

According to ASTM D5558, EV_{ECFO} and EV_{ESCFO} was calculated by Eq8 , as follows:

$$EV_{ESCFO} = \frac{V_0-V_1}{w}\times C\times 56.1 \quad (8)$$

Here by:
V_0 : Blank level (mL)
V_1 : Titration volume HCl (mL)
C : Concentration of HCl (N)
w : weight of sample (g)

3. RESULTS AND DISCUSSIONS

3.1 Result of Preparing Bio-Based Oil from Catfish Oil

After pre-filtration, catfish oil is a yellow liquid. The iod value of it was 69 (gIod/100g). The O_{theo} = 4.165 (wt.%). Epoxidized catfish oil product is a colourless liquid and it was titrated according to ASTM D1652 to determine the weight percent epoxide, E and E reached at 10.08 (wt.%), the yield reached at 90.09 %.

Esterified catfish oil product is a slight yellow and high viscosity liquid. The ESCFO product and ECFO was titrated according to ASTM D5558 to determine the ester value (EV). EV_{ECFO} and EV_{ESCFO} reached at 168.30 (mgKOH/g) and 277.70 (mgKOH/g), the yield of opening reaction of ECFO reached at 82.94 %.

Result of synthesis of bio-based oil from catfish fat in this study were similar to those of other studies.

Liew Kin Hong *et al*, was optimized for the epoxydation reaction of linoleic of Jatropha oil and the conversion into oxirane was 80.4% in molar ratio of H_2O_2/HCOOH/double bond of 12/2/1, 45 Oc, 2 hours [13].In the research of Venu Babu Borugadda and colleagues, bio-based oil was synthesized by esterification reaction of castor oil and epoxydation reaction of castor oil fatty acid methylester (COFAME). The optimal of epoxydation reaction was temperature of 60 ^oC, time reaction of 10 hours, used catalyst of 15 (wt.%) of castor oil methylester, molar ratio of H_2O_2/CH_3COOH/double bond of 1.5/0.5/1 (Venu Babu Borugadda, 2014). Rajesh V. Sharma and partners was synthesized bio-lubricant by epoxydation reaction of canola oil and opening reaction of canola epoxydized oil. Temperature of 65 ^oC, time reaction of 8 hours and molar ratio of H_2O_2/double bond of 1.5/1 were the optimal conditions of epoxydation reaction. Temperature of were 130 ^oC, time reaction of 15 hours and ratio (wt/wt) of anhydride acetic/epoxy of 1.5/1 were the optimal conditions of opening reaction of canola epoxydized oil [7]. Le Thi Thanh Huong, Nguyen Hung Ha was converted catfish fat to bio-lubricant by chemical reactions. The optimal conditions of epoxydation reaction of catfish fat with peracid formic, sulfuric acid catalyst were 55 ^oC, 3 hours and molar ratio of H_2O_2:CH_3COOOH:double bond of 4.5:1.5:1. The optimal conditions of the opening reaction of epoxidized catfish oil with anhydride acetic, *p*-TSA catalyst were 80 ^oC, 5 hours and ratio (wt/wt) of acetic anhydride/epoxy of 1.5/1 [11].

3.2 FT-IR Spectroscopy

FT-IR analysis of samples are shown in Figure-1

Figure-1 shows the FT-IR analysis of CFO, ECFO and ESCFO. The main peaks of functional groups of samples were characterized, such as the ester functional group C = O (722.42, 1744.51 cm^{-1}) and C-O-C (1110 cm^{-1}), the CH_3 group (1375.92 cm^{-1}), the C-H bond (2925.41 cm^{-1}, 2854.71 cm^{-1}), the CH_2 group (1462.49 cm^{-1}) [15]. In the FT-IR spectra of ECFO, double bond C=C (3006.57 cm^{-1}, 1654.86 cm^{-1}) was disappears and the epoxy ring group (825.50 cm^{-1}) was formed. This shows that, the double bond C=C of CFO was converted to epoxy ring. Next to, the oxirane ring was not presented in FT-IR spectrum of ESCFO, it can be indicated that, the opening reaction of oxirane ring was occurred.

The results of FT-IR spectra CFO, ECFO and ESCFO in this study are similar to that of others studies.

Results of FT-IR analysis in the research of Liew Kin Hong and partners for the the epoxydation reaction of linoleic of Jatropha oil presented that, double bond of linoleic acid of Jatropha oil showed at 3009 cm^{-1} and in FT-IR spectroscopy of oxirane of linoleic acid did not

present the pick of double bond but instead is formation of typical pick for the epoxy group (822 cm^{-1} and 823 cm^{-1}) [13]. In the research of Rajesh V. Sharma and partners, double bond of canola oil showed at 3007 cm^{-1}. Oxirane ring presented at 831 cm^{-1} and the ester group was showed at 1750 cm^{-1} [7]. In the results of FT-IR analysis of samples in the study of Le Thi Thanh Huong and Nguyen Hung Ha, double bond of catfish fat showed at 1655 cm^{-1} and 3006 cm^{-1}. Epoxy ring group presented at 824 cm^{-1} and the ester group was showed at 1743 cm^{-1} [11].

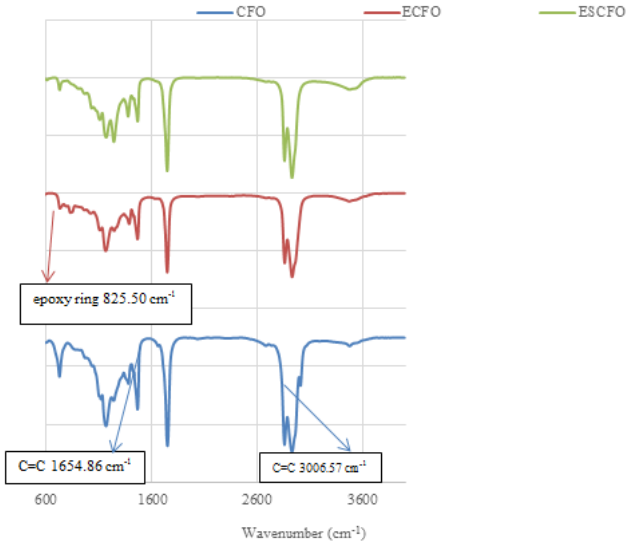

Figure-1. FT-IR spectra of catfish oil (CFO), epoxidized catfish oil (ECFO) and esterified catfish oil (ESCFO).

3.3 Determination of Properties of Catfish Oil (CFO), Esterified Catfish Oil (ESCFO) and Mineral Base Oil (SN500)

Properties of catfish oil (CFO), esterified catfish oil (ESCFO) and SN500 are shown in Table-1.

Table-1. The properties of CFO, ESCFO and SN500.

Properties	CFO	ESCFO	SN500 [16]	Analytical methods
Gravity density	0.916	0.998	0.889	ASTM D1298
Flast point (ºC)	280	254	210	ASTM D92
Pour point (ºC)	20	5	-6	ASTM D97
Kinematic viscosity (cSt) 40 ºC 100 ºC	 93.70 11.77	 116.36 16.77	 96.03 11.59	ASTM D445
Viscosity index	115.71	152.66	109.07	ASTM D2270
Stability oxidation (hour)	0.5	6	30	Rancimat EN 14112
BOD (mgO_2/mL)	-	6.3	158	TCVN 6001-1:2008
COD (mgO_2/mL)	-	15.8	700	SMEWW2012(5220-D

The data in Table-1 indicates that, the properties of ESCFO were greatly improved compared to those of CFO. This may be explained by the amount of double bond of CFO, that were converted to the ester functional group (Lou A.T. Honary, Erwin Richter, 2011). The value of BOD and COD test of SN500 mineral base oil are much higher than that of esterified catfish oil. Beside it, the value of the ratio 5BOD / COD of esterified catfish oil is 1.99, it is higher than that of mineral base oil SN500 (1.13). This can predict that, the biodegradability of esterified catfish oil may be higher than that of SN500 mineral base oil [17]. ESCFO can be used as a bio-based oil because ESCFO can not only meet the technical requirements of SN500 mineral base oil for lubrication properties, but also it have a higher biodegradability than SN500 mineral base oil.

Esterified catfish oil has a high molecular weight and the presence of oxygen atoms in the triglyceride structure may be the reason for ESCFO's higher pour point and lower oxidation resistance than SN500 mineral base oil (Lou A.T. Honary, Erwin Richter, 2011). However, the average temperature in winter of Viet Nam and Asian countries is over 10 ºC and in the blending of bio-lubricant from ESCFO, an amount of pour point depressant additive

and antioxidation additive can be added to improve these properties for bio-lubricant. So it can say that, using ESCFO as bio-based oil may be entirely possible.

The characteristics of esterified catfish oil were similar to those of other bio-base oils in others studies. Ebtisam K. Heikal *et al* synthesized esterified palm oil. The kinematic viscosity (at 40 ºC, 100 ºC) and viscosity index of esterified palm oil was 38.25 cSt , 7.28 cSt and 171 respectively. Flash point and pour point of esterified palm oil was 296 ºC và 5 ºC [8]. In the research of Rajesh V. Sharma et al, kinematic viscosity (at 40 ºC, 100 ºC) and viscosity index of esterified canola biodiesel oil was 116 (cSt), 19 (cSt) and 183.59 [7]. In the study of Rosana Maria A. Saboya and colleagues, the product of the esterification of free fatty acids contained in cotton oil was more biodegradable than that of mineral base oil [18].

3.4 Blending Bio-Lubricant

3.4.1 Blending the SAE20W50 engine lubricant

The SAE20W50 engine lubricant formular can be described in Table-2 [16] [19]. Bio-lubricants were blended base on the formular of SAE20W50 engine lubricant with the replacing basestock oil SN500 as bio-based oil (ESCFO).

Table-2. The formular of 20W-50 engine lubricant.

SN500 (wt.%)	Additives (wt.%)			
	viscosity	alkalinity	pour point depressant	Multi-function
85.938	6.218	1.854	1.255	4.735

3.4.2 Determination properties of bio-lubricant and SAE20W50 lubricant

3.4.2.1 Gravity density, flast point and pour point of bio-lubricant blends and 20W50 engine lubricant

Gravity density, flast point and pour point of bio-lubricant blends and SAE20W50 engine lubricant are shown in Table-3.

Table-3. Gravity density, flast point, pour point of samples.

Samples	Gravity density	Flast point (ºC)	Pour point (ºC)
10Bio	0.910	236	-21
20Bio	0.919	240	-18
30Bio	0.926	242	-15
40Bio	0.930	244	-12
50Bio	0.935	246	-9
SAE 20W50	0.915	239	-21
SAE20W50 standard	0.900	Min 230	Max -10
Analytical method	ASTM D1298	ASTM D92	ASTM D97

The data in Table-3 shows that, gravity density, flast point and pour point of bio-lubricant blends increased as the amount of bio-based oil increased in the formulation of bio-lubricant. This can be explained by the molecular of ESCFO can be higher than that of SN500 (Lou A.T. Honary, Erwin Richter, 2011).

3.4.2.2 Kinematic viscosity, viscosity index of bio-lubricant blends and 20W50 engine lubricant

Kinematic viscosity, viscosity index of samples are shown in Table-4.

Table-4. Kinematic viscosity, viscosity index of samples.

Samples	Viscosity (cst)		Viscosity index
	40 ºC	100 ºC	
10Bio	213.06	22.31	127.15
20Bio	215.49	23.11	131.92
30Bio	221.81	24.34	137.48
40Bio	224.63	24.92	140.07
50Bio	227.55	25.50	142.60
SAE 20W50	211.02	21.51	121.91
SAE20W50 standard	-	18÷21	min 110
Analytical method	ASTM D445		ASTM D2270

The data in Table-4 shows that, the kinematic viscosity, viscosity index of bio-lubricant blends increases in order 10Bio blend to 50Bio blend and all of bio-lubricant blends have a higher lubricity than that of SAE20W50 engine lubricant [19].

3.4.2.3 Total base number (TBN), foaming ability and ability oxidation

The long life properties can be evaluated through the foaming ability, TBN and oxidation stability [19]. The TBN, foaming ability and oxidation stability of samples are shown in Table-5 and Table-6.

Table-5. TBN and foaming ability of samples.

Samples	TBN (mgKOH/g)	Foaming ability at 93 ºC (ml/ml)
10Bio	9.3	0/0
20Bio	9.3	0/0
30Bio	8.5	0/0
40Bio	8.0	0/0
50Bio	7.0	10/0
SAE 20W50	10.2	0/0
SAE20W50 standard	min7.9	Max 10/0
Analytical method	ASTM D2896	ASTM D891-13

The foaming ability of all bio-lubricant blends is similar to that of mineral lubricants SAE20W50. TBN values of samples are reduced from 10Bio sample to 50Bio sample and TBN of 4 blends of bio-lubricant was meet the TBN requirement of the SAE20W50 standard. It can be explained by the amount of acid contained in the ESCFO (Lou A.T. Honary, Erwin Richter, 2011).

Table-6. The oxidation stability of samples in TGA and Rancimat test.

Samples	Decomposition temperature (ºC)		Oxidation stability	
	On set	50 (wt.%)	Time (h)	Conductivity (µS/cm)
10Bio	243.5	418.5	30	2.17
20Bio	239.5	409	30	2.21
30Bio	233.5	394.5	30	2.67
40Bio	230.5	386	30	3.77
50Bio	216.5	366	30	6.64
SAE 20W50	261	425	30	2.07
Analytical method	TGA			Rancimat EN 14112

Datas in Table-6 shows that, the oxidation resistance of samples increased in order 50Bio to 10Bio. The oxidation stability of 10Bio, 20Bio and 30Bio can be approximately equal to that of SAE20W50 lubricant. This may be explained by the presence of oxygen atoms in the ESCFO structure that may be the cause of the lower oxidation resistance of the bio-lubricant blends than the oxidation resistance of the mineral lubricant SAE20W50 (Lou A.T. Honary, Erwin Richter, 2011).

3.4.2.4 Determination of biodegradable ability

The biodegradable of samples were determinated by BOD test and COD test and the results are shown in Table-7.

Table-7. BOD test and COD test of samples.

Samples	BOD (mgO_2/mL)	COD (mgO_2/mL)
10Bio	47.9	164
20Bio	43.9	161
30Bio	21.6	141
40Bio	21.2	127
50Bio	17.3	122
SAE 20W50	161	712
Analytical method	TCVN 6001-1:2008	SMEWW 2012(5220-D)

The BOD value and COD value of samples in Table-7 show that, the demand of biochemical oxygen and chemical oxygen in water of mineral engine lubricant SAE20W50 are higher than that of all blends of bio-lubricant. It can be predicted, the biodegradability of all bio-lubricant blends may be easier than that of mineral lubricant SAE20W50 [17].

From the above results and discussion and with the purpose of creating a bio-lubricant that can replace the mineral lubricants and biodegradable, 40Bio was selected as the formulation of bio-lubricants in this research. The properties of bio-lubricant (40Bio) and SAE20W50 lubricant are shown in Table-8.

Table-8. Properties of bio-lubricant and SAE20W50 lubricant.

Properties	Bio-lubricant	SAE 20W50	Analytical method
Gravity density	0.935	0.915	ASTM D1298
Flah point (ºC)	244	239	ASTM D92
Pour point (ºC)	-21	-12	ASTM D97
Viscosity (cst) 40 ºC 100 ºC	 224.63 24.92	 211.02 21.51	ASTM D445
Viscosity index	140.07	121.91	ASTM D2270
TBN (mgKOH/g)	8.0	10.2	ASTM D2896
Foaming ability at 93 ºC (ml/ml)	0/0	0/0	ASTM D891-13
Oxidation stability			
Induction time (h)	30 in 3.77 (µS/cm)	30 in 2.17 (µS/cm)	Rancimat test
Decomposition temperature (ºC)			TGA
On set	230.5	261	
50 (wt.%)	386	425	
BOD (mgO_2/mL)	21.2	161	TCVN 6001-1:2008
COD (mgO_2/mL)	127	712	SMEWW 2012(5220-D)

The data in Table-8 shows that, the bio-lubricant blended from esterified catfish oil in this study can not only meet the quality requirements of SAE20W50 engine lubricant, but also it is an environmentally friendly lubricant.

When comparing the bio-lubricants in this study with some of the bio-lubricants of other studies, their properties may be similar.

In the research of Michael Bong Alang et al, bio-lubricant synthesized from Cameroon palm seed oil. The kinematic viscosity (at 40 ºC, 100 ºC) and viscosity index of esterified oil was 509.80 cSt, 30.80 cSt and 120. Flash point of it was over 210 ºC [9]. In the research of Amith Aravin, stable themal under oxygen environment of bio-lubricant from rubber tree seed oil was 250 ºC and after 300 ºC, decomposition of bio-lubricant was occured strongly [17]. The onset temperature, flash point and viscosity index of polyesters bio-lubricant from original linoleic acid was 215 ºC, 264 ºC and 192 respectively [20]. Viscosity index of canola bio-lubricant was 184.84 and TGA thermogram of it was similar to that of bio-lubricant in this study [7].

4. CONCLUSION

Catfish oil was chemical converted by epoxydation reactions and opening reaction of oxirane ring. Properties of esterified catfish oil were improved significantly. So ESCFO can be used as bio-based oil. Bio-lubricants were blended in ratio (wt/wt) of ESCFO/BSO of 10/90, 20/80, 30/70, 40/60 and 50/50. The analysis results show that, bio-lubricant blends in ratio (wt/wt) of ESCFO/BSO of 40/60 can meet the quality standards of SAE20W50 engine lubricant and it can a green lubricant. The synthesis of esterified catfish oil from catfish fat and the preparation of bio-lubricant from esterified catfish oil can be developed sustainably.

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