The Characteristics of Castor Oil as a Bio-diesel Fuel and its Effects on the Diesel Engine's Performance

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Abstract

Diesel engines have been used for more than a century, but they still need to progress in many aspects. This kind of engine is applied in many areas, due to its high efficiency, better durability and reliability. The use of conventional fuel for diesel engines has several disadvantageous, and predominantly is air pollution and particulate matters. Scarcity of such a kind of fuel in the near future could also be one of the challenges to be tackled head on.

This paper describes at length characteristics of castor oil as a bio-diesel fuel and its blending process, along with the engine performances such as engine power characteristics, specific fuel consumption, exhaust gas emissions of Nox, and its particulate matters. Several general disadvantageous of methyl ester of castor oil will also be outlined; especially its high viscosity and weak-solubility when it is mixed with diesel oil.

This paper also delivers information on the best composition of methyl ester of castor oil when it is mixed with diesel oil along with associate torque, power and specific fuel consumption for various blending compositions. Some general information on the possibility to develop the use of castor oil in the future and its obstacles are conveyed at the end of this paper.

Key words: Diesel engine, alternative fuel, bio-diesel, blending technique, engine performance.

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1. Introduction

Diesel engines are widely applied in many areas due to its high efficiency, better durability and reliability, when they compare to some other engines *(Zuhdi et-al, 1996)*. The diesel engines which use conventional fuel oil also give impact to environment, since they produce high air pollution. Furthermore, the reserve of fossil fuel oil is also very limited, and it gradually will finish. Indonesia, for instance, its petroleum reserve approximately can only be used up to the next few decades. For that reason, today it's the time to think about finding alternative fuel oil as a substitute for fossil fuel. The main problem in operating diesel engines is high NO_x and particulate matters. Therefore, the new alternative for fuel oil should be able to fulfill the operational requirements of the diesel engine as performed by the one that of using conventional fuel, and on the other hand, they must capable to reduce the exhaust gas emission. Bio-diesel fuel oil is a kind of fuel oil produced from a certain process using renewable substance. Hence, such kind of fuel is considered will never used up.

Bio-diesel term refers to the kind of renewable fuel oil produced through esterification process *(Grabosky and McCormick, 1998; Culshaw,1993)*; for example, esterification process of vegetable oil with methanol will produce methyl ester. From economic point of view, this fuel oil is still more expensive than conventional fuel oil. However, when bio-diesel is produced in big scale capacity, it will be environmental friendly and economically can be considered as a reserve for the future.

This experiment used castor oil as a substance for bio-diesel, with some reasons such as it can be developed in some regions in the east part of Indonesia, and only few people still think of using castor oil as fuel for diesel engines. In this first stage, this experiment learns the way to produce and to analyze the characteristic of castor oil as methyl ester (hereafter CME). A standard diesel engine has been utilized to assess the characteristic of the CME, associated with the resulted performance of the engine. This research also tries to describe at length how to deal with the low solubility of the CME when it is blended with the diesel oil.

2. The Production and The Characteristics of Castor Methyl Ester (CME)

The main substance of this bio-diesel is castor oil obtained from a local market in Indonesia. This CME is produced by esterification process. Firstly, we conducted a small scale production experiment to ensure the proper composition and its quantity of the castor oil, methanol, and catalyst. The subsequence process is carried out by washing and drying the substance. A small-scale production is aimed to eliminate the loss when it is fail. After trying to produce several time in a small scale and trying out the product, then we eventually produced the CME in the amount as required for this particular experiment.

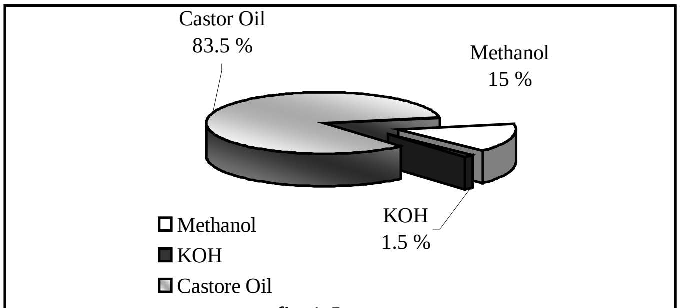

fig. 1. Input process

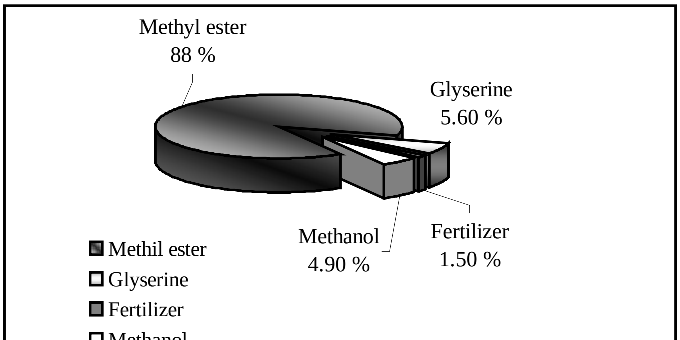

fig.2. Output Process

Castor oil tends to have the same characteristics as other vegetable oils, however its only produce a little glycerol. Castor oil has only around 5.1 – 6.1% of glycerol. Meanwhile the ester produced from the castor oil is more than the other vegetable oils, which is between 84 - 92%. Figure 1 is diagram an input process from bio-diesel production from the CME, and figure 2 shows diagram presented in the CME. Characteristic of the CME is slightly different from other kind of vegetable oils. The viscosity of the CME is much higher than the other bio-diesel. The average kinematics viscosity of this CME is 16.3 cSt, in the range of 12 – 22 cSt. This viscosity is measured in the temperature of 40^{o}C. Table 1 shows several characteristics of the diesel oil, the CME and the blending of those two fuels.

Test	Do	CME10	CME20	CME100
Strong Acid Num. mgKOH/g	Nil	0.268	0.536	2.68
Flash Point degC	75	87.5	100	200
Pour Point degC	2	0.8	-0.4	-10
Sediment %wt	Nil	0.021	0.042	0.21
Specific gravity 25/25 degC	0.837	0.848	0.859	0.945
Sulfur content %wt	0.4	0.36	0.32	
Viscosity Kin/40degC cSt	4.5	5.25	6	12
Water Content %Vol	Nil	Nil	Nil	Nil
Gross Caloric Value Kcal/L	9063	8992	8921	8353

Table 1. Properties of Diesel Oil, Castor Methyl ester and its blend

3. The Blending Technique of the Castor Methyl Ester (CME)

The blending process of this CME becomes an essential matter to be discussed since its blending process might be different with the other bio-diesels. Furthermore, every raw material has different characteristics thus, if we want to blend bio-diesel with diesel oil, in some cases they might not blend well. Therefore, the best way to study characteristics of bio-diesel is by doing experiment. Clements, in 1996 have developed one specification of bio-diesel which ensure its performance without considering from where the source of its tri-glycerol. So far, properties from a bio-diesel are always determined based on chemical experiment. However, it is also possible to get properties of the blending bio-diesel by using mathematical approach.

Most literatures mention that bio-diesel can dissolve in diesel oil. The CME can also dissolve in diesel oil, but separate again after a certain period. Puppung, in 1985 also reported that castor oil could not dissolve in diesel oil. The CME is not good enough when it is blended with diesel oil, and it is likely caused by the big difference of their viscosity. On the other hand, the CME can dissolve perfectly with MDO (Marine Diesel Oil).

Based on a report by *Clements,* in 1996 we carried out an experiment by dissolving palm methyl ester with castor methyl ester with 50/50% composition. The result was surprisingly because those two bio-diesel can dissolve well and there is no separation. The experiment is then proceed by blending the composition of 50/50% palm-castor methyl ester (CME) with diesel oil. At the first stage we made 50/50% palm-castor methyl ester. The result of this blending process is then blended with diesel oil. As the result, there is no separation, and this mainly caused by highly viscosity difference. By blending 50/50% palm-castor methyl ester (CME) we can get a mixture, which can dissolve well with the diesel oil. Of course the result of the blending forms a mixture with lower viscosity compare to that of the pure castor methyl ester (CME). This phenomenon proves that by using the blending technique as above described, we could eliminate the difficulties in blending the CME with the diesel oil.

It has been well understood that Blending vegetable oil with diesel oil will influence its viscosity. From this experiment, 20% castor methyl ester (CME) produces kinematics viscosity of 3.8 cSt at 40^{o} C, while MDO with 20% castor methyl ester (CME) results in 6.85 cSt. On the other hand, by blending 20% of 50-50% castor-palm methyl ester with diesel oil produces kinematics viscosity of 3.35 cSt. From this experiment, we can conclude that diesel engines can utilize all kind of bio-diesels. Theoretically, castor methyl ester (CME) is very excellent to substitute marine diesel oil (MDO).

4. Results and Discussions

There are two main subjects will be discussed in this section. The first one is the bio-diesel fuel oil itself (production and its characteristics) and the second one is the performance of the diesel engine. Both need to be discussed comprehensively since this research is aimed to provide recommendations on characteristics of fuel oil and its composition. The other focus on this section is that whether or not we need to modify the diesel engine system, in order to meet the regulation of exhaust gas emission.

4.1. Production and Characteristics of the CME

The raw material of the castor oil has characteristics as demanded by the exhaust gas emission regulation. Its viscosity is very high, and when it is used to produce ester, we need a large volume of methanol, since in the production of CME we need 15-20% weight unit of methanol. The density of castor oil is higher than the one from other vegetable oils. Despite production of bio-diesel from castor oil has succeeded; nevertheless we need to develop further in order to get better characteristics. From this particular experiment, we can reduce the production of the glycerol up to 5.1-6.1%, in other words, we can obtain 84-92% ester from the raw material. Despite the quantity of glycerol that can be taken from this process is lesser than the one we can get from other vegetable oils, but the viscosity reduction is considerably high, where the kinematics viscosity can reach 12-22 cSt.

The quality of the CME also varies and this depends on the quality of its raw material. Processing technique to produce the CME has also been developed, and at this first phase the result is shown in Table 1. The problem is, however, the glycerol that can be taken through this process only around 5.1-6.1%, hence its viscosity is still high enough. Regarding the resulted viscosity range, the CME castor methyl ester is similar to marine diesel oil. Despite the final viscosity is still relatively high, the CME has many advantageous such as low pouring point, unfrozen at low temperature, at which the temperature palm methyl ester oil will freeze. Another good point of the CME is the sensitivity to temperature. When heated, the CME easily expand and its density drops. This give benefit for the combustion process.

We have studied characteristics of bio-diesel by using the experiment and also the calculation technique. Table 1 shows the result of the calculation of fuel oil that is blended in composition of 10 and 20 %. Viscosity produced through the experiment, which uses the diesel oil sold in Surabaya, Indonesia, is slightly different from the one we get through the calculation. It is due to variation of commercial diesel oil viscosity, even though the diesel oil standard gives kinematics viscosity of 4.5 cSt. For clearer information, please look back the number of viscosity through experiment and compare to Table 1.

4.2. Performance of Diesel Engine

Using 100% bio-diesel does not give good performance since it increases the fuel oil consumption. At the certain revolution and the torque reach maximum, the fuel oil consumption increased in an average value of 20.38%. However, at a certain revolution and reach the maximum power, the increase of the fuel oil consumption is around 5.93% in average. The increase of consumption is mainly caused by the unburned fuel oil. Too high viscosity causes imperfect atomization process and evaporation. Both processes will extend physical change of fuel oil so its physical delay is long. Imperfect combustion also reduces the combustion temperature; hence much fuel is required to overcome the load, as shown in Table 2 for the exhaust gas emission temperature of CME100. In addition, the increase of the particulate matters, also indicates that unburned from fuel oil is large. The increase of particulate of CME100 is two times higher than the one using Diesel Oil. This tendency indicates that much fuel oil not burnt down. Theoretically, when bio-diesel burnt down, then its particulate matter will smaller. From the above description, it seems that operating diesel engine with 100% bio-diesel is less advantageous technically and economically.

CME 10 and CME 20 are more promising to be utilized. Though it is known that the CME characteristics are well applied as an alternative for marine diesel oil (MDO), through this experiment, we found that the CME blend also gives better engine performance. The engine performances obtained by using those two compositions are generally better compared to Diesel Oil. Only few characteristics in operation have worse performance than diesel oil. At the engine revolution of 1300 rpm at which torque reach maximum, fuel oil consumption decrease 0.44% for CME10 and 6.37% for CME20. At 1400 rpm at which power reach maximum, fuel oil consumption decrease 4.44% of CME10 and 1.59% of CME20. NO_X also decreases in the range of 9.04-30.49% for CME10 and decreases double for CME20. PM also decreases around 4.97-21.88% for CME10 and 8.64-14.74 % for CME20. Generally, CME10 and CME20 have better performance compare to that of Diesel Oil and CME100. However, efforts must be done to reduce the PM in order to comply with existing regulation. It is not too difficult to reduce the PM to meet the regulation, since we need to pay attention only at lower load. The problem faced by author also similar to the problem faced by *Grabosky and McCormick, 98*.

CME10 has the most advantageous performance when observed from all aspect of performance. The only worse performance is the fuel oil consumption at 1300 rpm by the difference only 0.44% which is considerably small. CME 20 is also good, because it provides low specific oil consumption at revolution of 1400 rpm, even though it's slightly high at the revolution of 1300 rpm. Furthermore, in emission point of view either NO_X or PM of CME 20 are better than CME10, though generally CME10 provide more advantageous performance.

4.3. NO_X and PM

NO_X and PM are part of the requirements that must be fulfilled by the diesel engine. All countries have issued standard like US Standard, West Europe, Japan, and even international organization such as IMO (International Maritime Organization) also issues standard. American standard requires NO_X product with maximum 5g/kWh and PM with maximum 0.1 g/kWh. During this experiment, NO_X was not a problem on diesel engine with conventional fuel oil. Despite it is still relatively higher compare to the CME, yet it still fulfills the requirement of exhaust gas emission, except at 1400 rpm on 10% load, which produce 5.3 g/kWh. PM of the conventional oil nearly cannot meet the regulation, only can be fulfilled by performance of 75% load at 1400 rpm. Average resulted PM is less than 0.2 g/kWh, so it just need slight modification of engine if we want the PM to meet the regulation.

CME 100 has no problem with NO_X, however its PM values are too high at all points. If we want to use them as fuel oil, it need special treatment. When compare to Diesel Oil, NO_X of conventional oil is far better. The problem is on PM, especially on small load it need special treatment.

CONCLUSION

From the results of the experiment that have been discussed previously, we can take some points particularly related to the characteristics of the CME as a bio-diesel and the performance of the diesel engine. The use of the CME as fuel oil for diesel engines is excellent, however its viscosity is still too high compared to other kind of bio-diesels. Even though the engine can run well, the use of 100% CME is not recommended. CME10 and CME20 are recommended to be used as a supplement for fuel oil of diesel engine. This experiment has also confirmed that the emission of the CME is generally better than that of the conventional fuel oil, but this need little modification especially on its fuel oil system in order to comply with the regulation on exhaust gas emission.

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Diesel oil

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	100	1.568924075	1094.534405	0.351674356	0.121707366
2	110	3.530079169	604.5999571	0.096081074	0.162276487
3	120	5.099003244	532.7244378	0.062432507	0.153198083
4	130	6.667927319	466.7867316	0.047924317	0.148391868
5	180	9.021313432	414.0195359	0.094174232	0.177028895

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	120	1.689610542	1078.326143	0.459216393	0.154900283
2	130	3.80162372	639.0080848	0.214833033	0.172111426
3	140	5.491234263	566.8124598	0.140707862	0.119154064
4	170	7.180844805	507.4475967	0.085801343	0.091117814
5	210	9.715260619	452.2902493	0.035750614	0.271316024

CME 100

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	97	1.568924075	1220.513884	0.503355781	0.752372805
2	110	3.530079169	721.5616674	0.279747286	0.516334278
3	130	5.099003244	661.894068	0.125655615	0.377888604
4	145	6.667927319	570.3146899	0.045158605	0.343644326
5	170	9.021313432	516.0193634	0.017972823	0.123150536

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	130	1.689610542	1129.329606	0.201063259	1.526874223
2	130	3.80162372	666.8759073	0.099494781	0.72286799
3	140	5.491234263	614.6159203	0.035818926	0.354057791
4	160	7.180844805	529.5779263	0.02749513	0.307197201
5	180	9.715260619	487.5671679	0.014087296	0.138544353

B10 CME

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	100	1.568924075	1077.790478	0.8968997	0.265543343
2	110	3.530079169	649.8306068	0.147551718	0.201616242
3	120	5.099003244	509.0778235	0.109130247	0.071492439
4	125	6.667927319	443.7960791	0.063235587	0.072894251
5	170	9.021313432	437.3642519	0.016577291	0.065423722

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	115	1.689610542	1094.630954	0.559808981	0.188093201
2	120	3.80162372	654.121205	0.227776165	0.127854202
3	120	5.491234263	498.9770731	0.100171976	0.119154064
4	125	7.180844805	447.9308252	0.080347527	0.067687519
5	170	9.715260619	441.4390741	0.016583081	0.055802587

B 20 CME

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	115	1.568924075	1037.653782	0.509127565	0.276607649
2	120	3.530079169	653.6401776	0.179651496	0.127854202
3	130	5.099003244	604.9479538	0.062653534	0.102132055
4	150	6.667927319	517.0316422	0.049795157	0.065084153
5	180	9.021313432	433.1076655	0.026768932	0.071196404

No	TG (deg. C)	Power (kW)	sfoc (g/kwh)	Nox (g/kWh)	PM (g/KWh)
1	120	1.689610542	1148.585549	0.22985393	0.210221813
2	130	3.80162372	637.0483667	0.115424963	0.132771672
3	140	5.491234263	523.1867808	0.026744279	0.098727653
4	160	7.180844805	491.6695048	0.012000116	0.098927912
5	190	9.715260619	437.1428301	0.005100608	0.059651041

Table 2. Perfoprmance of Diesel engine