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Biodiesel effects on fuel filter; assessment of clogging characteristics

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Biodiesel effects on fuel filter; assessment of clogging characteristics

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Abstract. Material compatibility is still one of the serious problems in the application of biodiesel on diesel engine. One of the main causes of the problem is related to the flow-ability and filterability of biodiesel. Due to its physical and flow properties, biodiesel potentially caused a blockage in the filter higher than petro-diesel. The profile and mechanism of filter clogging or blockage due to the use of to biodiesel and the blends are investigated in the present work. Typical fuel oil filter used is a cartridge with media made from porous synthetic materials. Biodiesel used in this work is palm oil-based which is applied purely and in the blends of petro-diesel with composition of 20:80 (B20). It was tested in on boiler fuel system. Fuel passed on the system through the filter with a contact time of 3500 hours. The filter media is also observed by immersing it in B20 and B100 in the same time period. The result showed that the filter contacted to biodiesel was clogged faster than diesel oil (B0). On endoscopy microscope image, the filter media surface was clearly degraded. It shown that the pores of filter media are mostly covered by oil sludge. The filter blocking tendency (FBT) value is used to predict filter clogging time limit. In this work, the use of B20 performing FBT in ranges from 1.51-1.84, whereas the use of B100 ranges of 1.58-2.42 in a contact period of 3500 hours.. The premature blockage was occurred in filter media contacted to B100, and a filter replacement is then required to conduct before 8 months. There is a significant relationship between the moisture content of biodiesel on the rate and characteristics of the filter clogging.

Keywords : Biodiesel, fuel filter, palm oil

1. Introduction

Biodiesel is considered as a renewable fuel which is derived from trans-esterification of vegetable oils. It is made from a diverse mix of feedstock including recycled cooking oil, soybean oil, and animal fats. Biodiesel is consisted of mono-alkyl esters of long chain fatty acid that conform to ASTM D6751 specifications for use in diesel engines. Biodiesel refers to the pure fuel before blending with diesel fuel. Biodiesel blends are denoted as "BXX" with "XX" representing the percentage of biodiesel contained in the blend (ie: B20 is 20% biodiesel, 80% petroleum diesel). Biodiesel can be used in existing diesel engines without modification as long as the fuel is technically suitable to engine performance specifications.

Currently in Indonesia, Biodiesel are widely used in automotive, industrial and commercial engines, it often in blends of up to 5 to 20 percent. As mandated by Indonesian government, it is targeted to use 30 percent of biodiesel in petro-diesel blends in 2020.

Fuel-grade biodiesel must be produced to strict industry specifications (ASTM D6751/EN 14214) in order to ensure proper performance in internal combustion engines. The stability and cleanliness of fuel is a key element in the context of its storage and the impact of the proper engine operation, in which it is burned, and it depends on the content and construction of compounds included in its composition.

Biodiesel may be believed to be a clean fuel due to its contours to emissions reduction and its biodegradability. On the other hand, biodiesel is a fuel that is prone to contamination. There is still considerable suspicion from users that biodiesel is safe and compatible with all diesel engine and its elements. There are also concerns that the use of biodiesel can shorten the durability of life span of the engine and its components, including filter.

Fuel filters serve a vital function in recent modern, tight-tolerance engine fuel systems. The fuel filter is a filter in the fuel line system that screens out any contamination from the fuel, normally made into cartridges containing a filter media. After use in a period of engine operation, the fuel filters need to be maintained. Technically, it is commonly proceed with disconnecting the filter from the fuel line and replacing it with a new one, although some specially designed filters can be cleaned and reused. Filter is commonly replaced regularly or anytime possibly when it is become clogged with contaminants and cause a restriction in the fuel flow. Filter clogging will cause serious engine operation problems. Clogging of filter phenomena is the primary failure mode leading to the replacement or cleansing of filter. Although the filter media can be replaced easily and the purchasing cost is low but replacement of the component cause an increase in the engine downtime frequency. It will cause in greater operating losses and reduced the engine durability.

Due to its characteristics and handling, the use of biodiesel in diesel engine may cause a very short fuel filter life. In this work, the fuel contamination contributed by biodiesel which affecting its filterability will be studied. It is important to know the clogging profile and mechanism on the a fuel filter due to the use of biodiesel in engine. Otherwise, it also crucial to find out the rate of clogging on filter media to estimate the appropriate time limit of filter use or maintenance requirement in the utilization of biodiesel as fuel.

1.1 Fuel filter system

The main role of oil filter is to cleanse oil from destructive contaminants within an engine. Most engine oil filters were of *cartridge* (or *replaceable element*) construction, in which a permanent housing contains a replaceable filter element or cartridge. Depending on engine model, the final fuel filter, mounted on the engine just before the injection pump, it commonly has a single-pass retention (pore size) rating of 2 to 10 microns. This is the size that most engine manufacturers figure will protect injector pumps and nozzle tips from damage [1]. The common media filter materials are cotton yarn, low twisted cotton yarn, accordion shape pleated paper, cellulose disks, bags woven with wool yarn and dense knit filter bags are used. The canister-type filters are the most common use in diesel engine [2]. Cellulose media are advantageous because it can absorb some water contamination.

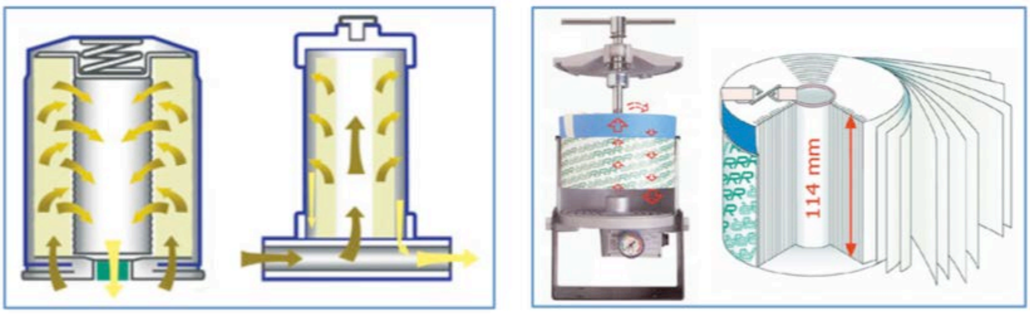

Figure 1. Filter types and media configuration

The filter media operate under several types of filtration mechanisms, including direct interception and depth entrapment, adsorption, inertial impaction, Brownian movement and gravitation effects [2]. Oil filters can be characterized by the method in which the contaminants are filtered or the method in which the oil flows through the housing. One technique used to control contamination in filters is through surface-type media. Fuel filter configuration in its system was responsible for the advanced performance of oil filtration technology according to engine operation requirement [3]. It supposed to consider the fuel characteristics as well.

1.2 Filter clogging mechanism and fuel contamination

Filter clogging/plugging/blocking is the failure mode seen most frequently in oil filters in varies of engine operation. Filter blocking problems must be seriously anticipated with appropriate techniques. Modern engine are incredibly sensitive to fuel contaminants. Engine filter can block and fuel injectors can suffer damage, resulting in total engine failure, it may also increase oil consumption during operation.

As known, fuel is expected leaving the refinery typically in clean and meet the specifications, but contaminations is always unavoidable. The principal source of contamination showed in particulates and water is in the transportation and storage. Contaminants are dissolved in fuel and most other captured by the filter.

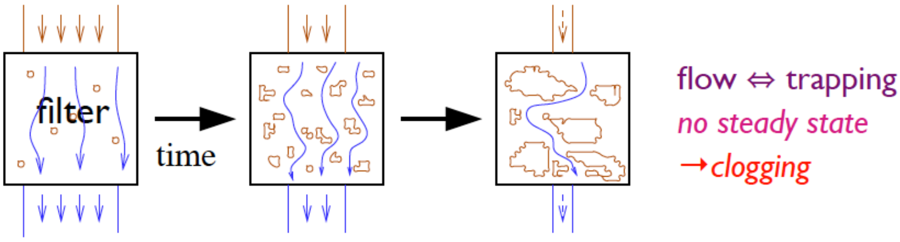

Figure 2. Typical filtration and clogging mechanism

The most critical factor in proper oil filtration characteristics is the structural integrity, contamination (dirt-holding) capacity, pressure loss and particle capture efficiency. The structural integrity relates to a filter's ability to prevent the passage of oil through an unfiltered flow path. Contamination capacity refers to the amount of contaminants that can be loaded onto the filter before the filters efficiency is limited. Pressure loss involves the overall differential pressure lost from the filter's placement on the system. The pressure loss will be influenced by the porosity of the filter and surface area.

There are several types of fuel contaminants found in a fuel filter, it may perform as water contamination, microbial growth, and solid particulate. Sometimes the contaminants are directly hard to detect without discharging the filter media from its house. Therefore the presence of filter contaminants can be observed through several engine performance parameters such as mechanical efficiency, engine power, fuel consumption, heavy smoke from exhaust, and clogging filters.

1.3 Biodiesel and the filter clogging

Contaminants in diesel engine systems can be found as in organic and inorganic. Organic contamination, otherwise known as sludge, is made up of all the by-products of combustion and comprises approximately 75% of the total contaminants found in diesel engine oil as reported by several filter manufacturer such as cummins filtration, Parker Racor, etc. Inorganic contaminant, referred to as dust, is made up of dirt, gasket material, core sand and wear metal. Those contaminants will plug a filter, limiting its ability to filter out other harmful contaminants.

As known, any kind of oil fuel may cause contamination that clog filters during operation, including petrodiesel fuel. The use of petrodiesel blends or neat biodiesel are suspected to exacerbate the occurrence of blockage in the filter a reported many researchers [5-8]. Introducing higher blends will make the occurrence of diesel bugs more prolific.

Biodiesel fuel properties are quite comparable to petro-diesel, but some of it is potentially trigger the formation of more contaminants. There are two major problems related to use of biodiesel as fuel, they are its oxidation stability and cold flow performance. Oxidation instability can led to the formation of oxidation products like aldehydes, alcohols, shorter chain carboxylic acids, in solubles, gum and sediment in the biodiesel [7;8]. Oxidation products originated with biodiesel affect storage life and contribute to deposit formation in tanks, fuel systems and filters. During a period of storage time, oxidation may occurred due to biodiesel having the chain of unsaturated fatty acids and the presence of double bonds in the molecule, which can cause the reacticity of the compound to increase oxygen, especially when placed in a container that allows contact with air or water [7]. Basic problem with biodiesel is that it oxidizes while in contact with environment with respect to time which further lead to increase in fuel viscosity and other physical properties as studied by [9, 10]. In most cases, the oxidation of biodiesel is known to cause deposits and corrosive materials [11]. Tang *et al.* [12] states that the formation of precipitates in biodiesel blends may have serious implications for diesel engine fuel delivery systems.

Several tests were conducted to show that filters are considered to be faster clogging due to contact with biodiesel rather than petrodiesel fuel as reported by [9; 13]. Based on severeal researches, engine requires quicker fuel filter change while running on biodiesel due to clogging by sediments and wear debris and pitting corrosion [9]. Filter analysis showed that blocking were caused by some insoluble components coming from FAME (Saturated monoglycerides) that precipitated at low temperatures [14].

Contaminants indicated to be problematic for fuel filters were detected. High concentrations of the monoglycerides of saturated C16 and C18 fatty acids, monopalmitin and monostearin were found on plugged diesel fuel dispenser filters [15] stated that biodiesel related contaminants such as saturated monoglycerides, sterol glucosides, and carboxylate salts due to its chemical properties [8;15].

Biodiesel has some solvent properties and will act as a solvent in the fuel. Blends greater than B20 may have enough of a solvent effect to break down the varnish deposits on the walls of the existing fuel storage tanks or fuel systems. The break-down of these varnish deposits will contaminate the fuel with particulate, which can cause fuel filters to plug rapidly [3]. Biodiesel may also degrade many non-metallic materials such as natural rubber, and other kind of polymers. Hydrocarbon fuels typically form a layer of deposits on the inside of tanks, hoses, etc. Biodiesel blends loosen these deposits, causing them to block fuel filters [16].

Diesel fuel should meet ASTM D 975 specification diesel fuel related to flowability in engine system. Petroleum diesel fuels are plagued by the growth and agglomeration of paraffin wax crystals when ambient temperatures fall below the fuel's cloud point (CP). These solid crystals may cause start-up problems such as filter clogging when ambient temperatures drop [17].

Cloud point and Cold flow issues with diesel containing FAME (biodiesel) and FAME material has been studied extensively. The fatty acid composition of biodiesel is the main factor that affects its cloud point, pour point and cold filter plugging point. The properties of biodiesel at low temperatures are poorer than those of diesel as conducted by [17; 18]. The poor cold flow properties result in crystallization of fuel particles. It may result in obstruction in fuel flow which causes a failure of engine operation by choking the fuel lines and filters. The cold flow problem arises due to higher number of saturated fatty acid present in the biodiesel as reported by some authors [18; 19]. The cloud point, is the temperature at which a liquid fatty material becomes cloudy due to the formation of crystals and solidification of saturates [18].

Biodiesel is hygroscopic, due to it has a polar chemical structure of carboxylate ester groups and presents the characteristics of absorbing more water than diesel. The water content of fuel was gradually increased with the increase of its blends [10]. The addition of biodiesel to diesel increases the retention capacity of the blend [20]. Humidity is one of important thing that affect in water content on fuel. Water that is chemically dissolved or absorbed into fuel and distributed molecule by molecule [21]. The *maximum* amount of allowed *water content in biodiesel* as specified in ASTM standard *D6751* is 500 *ppm.* The water present in B100 is considered to be free water.

As higher Biodiesel content in fuel blends, the risk of micro-organism growth increases due to less chemical stability and higher water solubility in biodiesel. The life activity of microorganisms in fuel is connected with the presence of water, dissolved oxygen concentration, the temperature range optimal for development, the neutral or alkalescent water environment reaction, the presence of appropriate compounds in fuel, the use of some types of enhancing additives, especially those that contain nitrogen [22].

Biodiesel is an organic fuel so it provides an ideal environment for microscopic fungi, yeast and bacteria to feed and grow. This environment provides dissolved water for germination, carbon for food, oxygen and sulphur for respiration, trace elements for growth and propagation.

In the presence of water in Biodiesel, it may promote the development of bacterial flora during storage as reported by [8;23]. Additional water accumulates in tanks as atmospheric moisture condenses. Moisture accumulates in diesel tanks as condensate droplets on exposed tank surfaces, as dissolved water in the fuel and as water bottoms beneath the fuel Microbes depend on this water for growth. Additionally, microbes depend on the organic and inorganic molecules in diesel fuel for nutrition. Dodos *et al.* [24] were investigated the effect of microbiological contamination on several parameters of biodiesel fuel and its blends during storage for 16 weeks. They found that FAME concentration was increased up to 20% v/v contributed to microbial stability reduction. The biodiesel blends produced considerably higher acid value. The minimization of sulfur content seems to allow enhanced microbial activity. The biodegradation of fuel, in support of microbial growth, is a direct impact of contamination. Color, heat of combustion, pour point, cloud point, detergent and anti-corrosive properties change as microbes selectively attack fuel components and potentially found in fuel filter.

2. Material and Methods

The fuel system used in this work is direct combustion engine for fire tube type boiler package. The set of apparatus is shown in Figure 3.

Figure 3. Experimental set up

The biodiesel used in this work is palm oil based which has met EN14214. The fuel is stored at average of 6-7 months since it was manufactured in a stainless steel tank. The fuel sample then analyzed to see the difference on several physical properties. The blending of biodiesel with diesel oil is done by splash blending technique. The fuel tested in this study was on a mixing of 20% biodiesel (B20), and B100. Filter media used is a type of canister with media paper (cellulose). A digital endoscope microscope camera is used to analyze the findings on the surface of the filter media with magnification up to 500x. The flow system was set in static (immersion) and dynamic at a fuel rate of 10 ml/min. Samples are evaluated every 30 days. After 3500 days of contact, surface morphology of filter media was observed.

The water content of each sample BXX and B0 was analyzed using the Karl Fischer Coulometric (KF) titration Metrohm KF coulometer method. Acid Value is measured using PP Colorimetric

Titration according to EN 14104. Pore size distribution then evaluated principly in close accordance with ASTM E 1294-89 and ASTM F316-03 standards.

A change in filtration performance after storage or pre-treatment, and operation in engine system must be evaluated to indicate potential filter blocking problems or small changes in fuel condition. It will be represented by the filter blocking tendency (FBT). Petro-diesel, biodiesel and its blends were evaluated using bench-top filtration testing equipment to determine its filter blocking tendency (FBT) values. Fuel Blocking Tendency (FBT) is a calculated dimensionless value that defines the tendency of particulates in a fuel to plug or block a filter. Standard Test Method for Determining Filter Blocking Tendency-Active Standard ASTM D2068 and IP 387. For this test, 300 ml of sample is pumped at a constant flow rate (20 mL/min) through a specified filter medium. Both pressure difference across the filter and the volume of fuel passing the filter are monitored until the pressure reaches 105 kPa or the volume of fuel passing the filter medium reaches 300 mL. When 300 ml of fluid is pumped, the end pressure is used to calculate the FBT number. However, when the pressure reaches 105kPa before the 300ml is passed, the volume of fluid pumped at this point is used to calculate the FBT number.

3. Results and discussion

The quality of fuel in this study is related to the level of cleanliness of the fuel according to its contamination occured. Before detecting the contaminants, the characteristics of biodiesel and the blends are evaluated, based on representative physical properties. In TABLE 1, it shown the change of fuel properties between initial condition and before being used in the engine system. The initial condition is represented from analysis of fuel after the production process. After several months of storage, Biodiesel properties has changed in density, viscosity, acid value, and water content. The significant changes were found in B100. A tolerable changes found in petrodiesel fuel (B0). Water content and acid numbers of biodiesel indicated a value that potentially exceeds the maximum limit of the specified standard.

Table 1. Properties of biodiesel, diesel fuel and the blends (B20)

Properties	Units	Initial Condition			Before Use Condition		
		petro-diesel (B0)	B20	B100	petro-diesel (B0)	B20	B100
Density at 15^{o}C	kg/m^3	822	843	873.1	831	852	895
Viscosity at 40^{o}C	mm^2/s	2.546	3.205	4.83	2.586	3.308	5.477
Acid Value	mg IOD/g	0	0.59	0.48	0	0.61	0.569
Water content	mg/kg	197	265	430	227	334	627

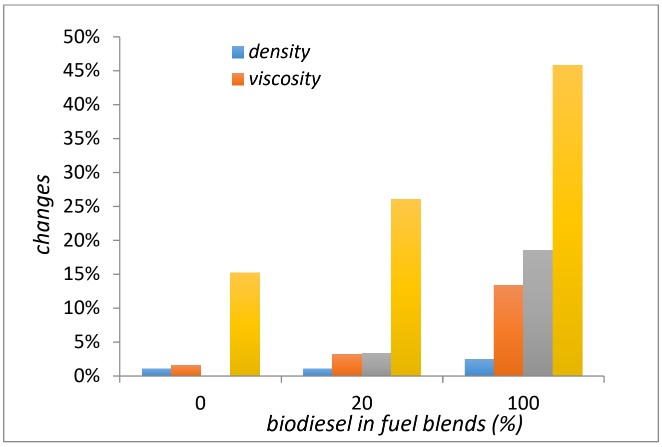

Figure 4. Properties changes on biodiesel and the blends

Environmental factors are very likely to aggravate the storage conditions of B100, particularly in the high increase in water content. As seen on Figure 4, the highest properties change was on water content. Biodiesel may absorbed more humidity since fatty acid methyl esters (FAMEs) are hygroscopic compounds. It is convincing stated that biodiesel getting more hydrophilic without a proper handling and storage. It is surely due to biodiesel has a polar chemical structure of carboxylate ester groups, it presents the characteristics of absorbing more water and more in triggered by environmental conditions. The humidity in the storage area were measured averagely in ranges from 80-90%. The larger changes in physical properties occurring in the biodiesel are expected to be equal to the increased risk of contaminant formation in the oil, thus allowing more blockages to be retained on the surface of the filter media.

Due to high amount of saturated fatty acid in the fuel, it potentially leads to nucleation and growth of solid crystals. Prolonged exposure of the fuel particularly in low temperature causes crystals to grow and form interlocking networks. Unfortunately it was not captured in the tank visually due to some technical difficulties. The solid crystals in oil fuel was not detected easily in the flow due to the sample was discharged from the tank with at ambient air temperature of 26-30^{o}C. However, in any appropriate condition solid materials will cease the fuel flow and lead to starvation of fuel in the engine.

The incidence fuel filter clogging was captured from the media. A diagnose filter blocking problems caused from biodiesel visually presented in Figure 6.

(a) fuel filter canister (initial) (b) after contact B20, 1500 hours (c) after contact B20 2500 hours

Figure 5. Visual impression of clogged filter for engine fuelled B20

Majority clogging in filter that contact with B20 appeared as typical slimy deposits. Within a longer contact period, sticky asphaltine and dirt are appeared in the filter media. Quartz, rust and silica were also found and considered as dirt (particulate), but not on the entire surface of the filter. This is very likely triggered by the higher biodiesel blending ratio with petrodiesel. A mixture of of biodiesel causes water uptake to increase but according to its proportions, the growth of slimy deposits formed in most part of media surface.

On the filter media contacted to B100, it shows more clogging and thicker deposits. The filter surface and the edge of the catridge are almost entirely covered by oil sludge that crystallized. Some particles are trapped inside and form a permanent gell as shown in FIG 6. Such particulates may arise from the biofilms formed in the tank that are thrown off and carried by the fuel line. Asphaltines are generally less than 2 micron in size, they can agglomerate into larger particles which can easily block engine filters or damage injectors. These particles collect at the bottom of a fuel tank and can form an oily sludge that is often confused with microbial contamination.

The oxidation stability of biodiesel is detected problematic in this work, due to it was measured >6 hours. It is inferior to that of petro-chemical diesel. As the fuel comes into contact with oxygen, chemical reactions break down the diesel into peroxide, organic acids and gummy sediment. These soft, sticky substances can stick to fuel filters and engine components and cause acid erosion as found in filter media.

Figure 6. Visual impression of clogged filter contacted to B100 for 3500 hours

The presence of slime deposits due to the use of B100 strongly indicates an increase in the contaminants that strongly possible shown in in the form of sterol glucosides. Sterol glucosides (SGs) occur naturally in vegetable oils and fats in the acylated form. During the biodiesel production process, they are converted to nonacylated SGs. The presence of SGs in biodiesel may contribute to flowability problem due to the high melting point of SGs 240 ^{o}C (=464 ^{o}F). Otherwise, SGs performed insoluble in biodiesel or diesel fuel. It can essentially be considered as dispersed fine solid particles in biodiesel. These dispersed SG particles may also promote the crystallization of other compounds [25]. The presence of SGs at double-digit parts per million (ppm) levels may cause the formation of a cloud-like haze in biodiesel, even at room temperatures. Under the microscope, the cloud-like substance appears as agglomerates of various sizes composed of discrete particles of 10 to 15 microns [15].

The presence of sterol glucosides in biodiesel has promoted filter blockage. Testing indicates that as the level of sterol glucosides increases, the frequency of Filter Blocking Test (FBT) values increase.

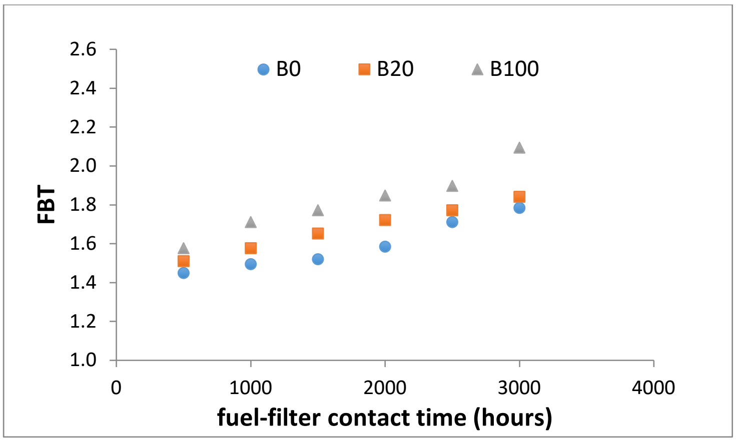

Figure 7. Fuel blocking tendency for various biodiesel blends

The regeneration filter is related to the limit of FBT. The FBT value limit specified as an indication of clogged filters for regeneration has not been widely regulated, due to the variety of filters type and media specification. However some manufacturers and users set some limits related to the sensitivity of the machine and the risks that are important to avoid. According to Tamson Instrument, high blocking tendency can be detected when FBT in range of 3.16 to 7.55. Otherwise, according to a British Standards Institution seen by Platts, all diesel engine user need to respect an FBT limit of 2.52. In this work, the use of B20 ranges in FBT ranges from 1.51 - 1.84, whereas the use of B100 shows FBT 1.58-2.42 in a contact period of 3500 hours.

Using linear regression of the graph, the regeneration time indicated by filter clogging limit may be predicted with the mathematical equations as stated in Table 2.

Table 2. Time limit projection based on filter blocking tendency

Fuel used	Linear Equation	Max Time limit [hours]
B0	y = 1E-04x + 1.3953	11,500
B20	y = 0.0001x + 1.4483	10,500
B100	y = 0.0002x + 1.4947	5000

From the prediction equation models, it requires replacement of fuel filter after 5000 hours contact time with neat biodiesel. It is represented a dramatical clogging on filter under 8 months after B100 being used in the system. In typical of cellulose filter media, the life span for B0 and B20 are respectively 16 months and 14 months. More operation time is still possible as long as petrodiesel fuel qualities kept with proper storage and transport handling before entering the engine system.

Depending on the type of micro-organisms, acids or bacteria sludge is also formed in the filter media. In order to descibe in details microbial growth occurring on the filter media, the type, characteristics and kinetics of growth of each kind of microbes require further testing in the laboratory. Including determining the number of microbial colonies grown per mL of oil sample and oil sludge (Colony Forming Unit) corresponded to the dirt (contamination) holding capacity on a fuel filter .

4. Conclusion

The magnitude of changes in the properties occurring in the biodiesel and its blends are aligned with the increased risk of contaminant formation in the oil. It may increase the possibility of a clogging or blockage on the surface of the filter media. The higher blending ratio of biodiesel used in the engine operation, more potential blockage of the filter occured. Filter regeneration rate becomes faster. Fuel Blocking Tendency (FBT) can be the representative value to predict the maximum time limit of filter use before it is blockage or clogged. The contribution of sterol glucosides to filter blocking is considered in addressing filter problems with biodiesel and biodiesel blends. From the macro image, it showed that the surface of the filter media contacted with biodiesel is more dominantly covered by oil sludge in the form of slime. It indicates that the content of fatty acids in biodiesel is high and forms a contaminant compound that is easy to become gell. This is due to low oxidation stability so it is easily crystallized and become solid.

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References

[1] Seagrant.uaf.edu. 1998 *Fuel Filters: Choose Well and Prosper From Pacific Fishing*
[2] Fitch B, 2013 Noria Corporation. Anatomy of Fuel Filter. Machinery Lubrication Magazine
[3] Filter Manufacturers Council 2011 *Technical Service Bulletin* **06-1** 1
[4] Redner S, Datta S. 2000 *Phys. Rev. Lett*. **84** 6018
[5] Dunn R, Knothe VG, and Krahl 2005 *The Biodiesel Handbook AOCS Pres*s
[6] NREL (National Renewable Energy Laboratory) U.S. Department of Energy 2009 *Biodiesel Handling and Use Guide*
[7] Kapilan N, Babu TP, Reddy RP 2009 *International Journal of ChemTech Research* **1(2)** 278
[8] Schmidt, Margret. DGMK 2009 German Interindustry Study: Filter Blocking, Biofiels, Microbs. Shell Global Solutions. Presentation File
[9] Jain S, Sharma MP 2010 *Renew Sustain Energy Rev* **14** 763
[10] Komariah LN, Marwani, Aprisah S, Rosa YSL 2017 *Matec Web of Conferences* 101. 02012
[11] Terry B. 2005. *Impact of Biodiesel on Fuel System Component Durability*. The Associated Octel Company Limited, Coordinating Research Council. The Associated Octel Company Limited.
[12] Tang H and Salley SO 2008 *Fuel* **87** 3006
[13] Jain SK, Kumar S, Chaube A 2011 *International Journal of Chemical Engineering and Applications* **2(2)**
[14] PM Tamson Instruments. User-Manual Filter Blocking Tendency. https://tamson-instruments.com
[15] Fersner A, Galante-Fox J 2014 *SAE Int. J. Fuels Lubr.* **7 (3)** 783
[16] Wardle DA 2003 *Renew Sust Energy Rev* **7** 1
[17] Dwivedi G, 2013 *et al., International Journal of Renewable Energy Research* **3(4)**
[18] Bhale BV and Nishikant V 2009 *Renewable Energy* **34**, 794
[19] Carraretto C, Macor A, Mirandol A, et al. 2004 *Energy* **29** 2195
[20] Fregolente PBL, Maciel W, and Oliveira LS 2015 *Braz, J. Chem. Eng.* **32**
[21] Williams A, McCormick RL, Hayes R, Ireland J 2006 *NREL*.
[22] Glab J 2016 *Journal of Konbin* **39**
[23] Christensen E, McCormick RL 2014 *Fuel Processing Technology* **128** 339
[24] Dodos GS, Konstantakos T, Linginos S, Zannikos F 2011 *Effecst of Microbiological Contamination in the quality of Biodiesel Fuels*, ICEST 12th Proceedings (2011).
[25] Biodiesel magazine 2017 The Role of Sterol Glucosides on Filter Plugging. Evonik Industries