The precipitation of biodiesel impurities at low temperature and its effect on fuel filter *

Minoru FUNAHASHI　Sareewan SUWANNAMIT　Jaratpong NGAMMOH

Mamoru TASAKI

Biofuels are expanding continuously in global market as one of renewable options to replace fossil fuels. Biodiesel is the most commonly used biofuel that can be blended into conventional diesels in any proportion. However, higher biodiesel blends may cause problems. One of its problems is that precipitation formation which arise from biodiesel may clog fuel filter at low temperature. This study focuses on fuel and environment factors on biodiesel precipitation and their influence degree on fuel filter clogging. The results indicate that monoglycerides and temperature have strong correlation with precipitate weight. Moreover, quantitative effect of precipitate weight on filter clogging was clarified.

Key words :

southeast asia, biodiesel, palm methyl ester, monoglycerides, precipitation, fuel filter, clogging, heater

1. INTRODUCTION

CHALLENGES ON BIODIESEL EXPANSION

According to the report of “World Energy Outlook 2017” announced by the International Energy Agency (IEA), renewable energy is said to be an important technology to reduce CO_2 emissions [1].

On the other hand, there are some concerns about the growth of domestic energy consumption and the unstable oil prices from national energy security viewpoint in the ASEAN countries that highly rely on oil as main energy source. Securing energy by utilizing raw materials which can be produced in their own countries is one of the key strategies. In response to these challenges, biodiesel which can be produced in individual countries and be effective to reduce CO_2 emissions has been widely implemented around the world especially the Southeast Asian countries where

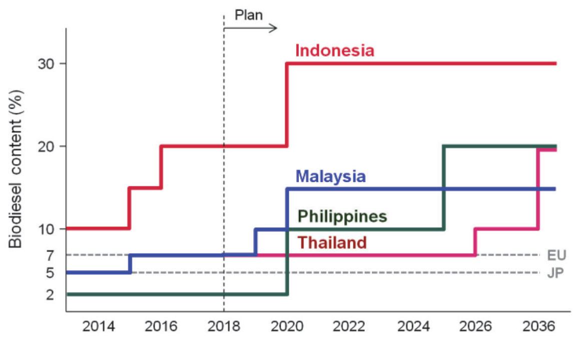

Fig. 1　Increase biodiesel concentration in ASEAN

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biodiesel concentration is continuously increasing [2)-5)], see Fig. 1.

Unlike conventional diesel fuel, biodiesel generally has lower oxidation stability, poor cold flow properties and contain significant proportion of impurities like glycerin, monoglycerides (MG), steryl glucosides (SG) which could be remained from the production process [6)]. These biodiesel characteristics can have a negative impact on fuel injection system. One of its impacts is Internal Diesel Injector Deposit (IDID) formation caused by its lower oxidation stability. Another impact is filter clogging caused by poor cold flow properties and biodiesel impurities as mentioned above.

Biodiesel is used all over the world and the above-mentioned issues vary depending on feedstock of biodiesel. In North America and South America, biodiesel made from soybean oil (Soybean Methyl Ester or SME) is popular. SME contains high percentage of unsaturated fatty acids which have a large number of double bonds cause it easy to oxidize. Oxidation products will polymerize and adhere on sliding components of injector which called IDID. However, IDID has been well studied and its countermeasure was developed [7)-10)].

While Southeast Asia widely use palm oil based biodiesel (Palm Methyl Ester or PME) and its concentration tend to increase continuously. As aforementioned, biodiesel has poor cold flow properties compare to conventional diesel fuel. It is known that when biodiesel is subjected to low temperature, it is easier to solidify than conventional diesel fuel and impurities remaining in the production process will be precipitated. These impurities precipitate at the temperature higher than biodiesel solidification temperature. In particular, it is also known that impurities contained in PME precipitate at the temperature higher than impurities in SME [11)-15)]. The mechanism of precipitates generation caused by biodiesel impurities at low temperature was discussed in many literatures [6) 16)-20)].

Above mentioned impurities cause filter clogging and it is one of the biggest problem of palm oil based biodiesel which used in Southeast Asia.

特集

INFLUENCE OF BIODIESEL PRECIPITATION ON FUEL INJECTION SYSTEM

Fig. 2 shows configuration of fuel injection system and function of fuel filter. Fuel is sucked by supply pump from fuel tank and pass through fuel filter before enter to fuel injection system. Fuel filter has the functions to remove contamination and water contained in fuel. So fuel filter is the necessary component to protect fuel injection system.

Their service life is determined by the amount of contamination contained in fuel and the size of fuel filter. The service life ends after filtering fuels for a long time. Therefore, fuel filter need to be replaced before the end of its service life. In general, the service life of fuel filter is related to the total amount of fuel passing through the filter. So the pressure loss of fuel filter (the pressure difference between the inlet and the outlet of the filter) caused by fuel filter clogging increases as the

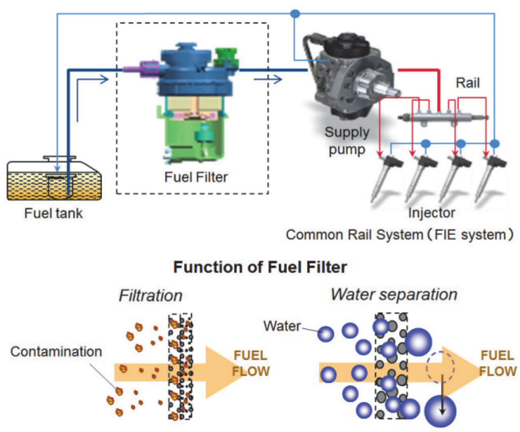

Fig. 2 Fuel injection system and function of fuel filter

mileage increases.

As mentioned in the above mechanism, biodiesel can cause precipitation formation at the temperature higher than conventional diesel fuel. When fuel filter which designed to be compatible with the conventional diesel fuel is used with biodiesel, its performance can be deteriorated by precipitation of biodiesel impurities and as a result, fuel filter clogging can occur even in the usual operating temperature range. If fuel filter was clogged, enough fuel cannot be supplied to injection system and result in vehicle system failure such as hard to start, lack of power etc.

OBJECTIVE OF THIS STUDY

Palm Methyl Ester (PME) which is often used in Southeast Asia has the main problem about precipitation at low temperature. The biggest concern of biodiesel precipitation at low temperature on vehicle is estimated as early clog of fuel filter. In order to confirm fuel and environment factors on biodiesel precipitation and clarify their influence degree on fuel filter clogging, we decided to proceed with the following procedure.

2. STUDY PROCEDUFE

STEP 1

Confirm the precipitation characteristics of aforementioned precipitation factors. Clarify the correlation between properties of fuel (both biodiesel and conventional diesel fuel), temperature and precipitate weight.

STEP 2

Clarify effect of precipitate weight on fuel filter performance.

STEP 3

Consider the countermeasure for fuel filter clogging based on the test result from STEP 1 and STEP 2.

3. METHODOLOGY

TEST FUELS

In this study, MG, glycerin, SG which are impurities of biodiesel that generally known as precipitation factor at low temperature [16)-20)] and aromatic content of conventional diesel fuel which was reported that it has an effect on solubility of precipitates [18)], were selected as parameters of test fuel, see Table 1. Test fuels were blended from PME which originally has high cloud point about 13-15°C and conventional diesel fuels produced in Southeast Asian countries. The properties of biodiesels (B100) and conventional diesel fuels (B0) are also shown in Table 2 and Table 3 respectively. The range of each fuel parameter was determined based on the fuel properties investigation in Southeast Asian countries.

Table 1 Properties of test fuels

FAME content	Fuel number: Biodiesels	Fuel number: Conventional Diesels	Aroma (%)	MG (%wt)	Glycerin (ppm)	SG (ppm)	CP (℃)
B7	B	b	21.5	0.039	10	11.8	8
B10	B	a	5.7	0.055	14	16.8	8
	B	b	20.8	0.055	14	16.8	8
	B	c	19.5	0.055	14	16.8	9
	F	b	20.8	0.030	<5	4.1	6
	G	b	20.8	0.040	<5	9.8	7
	H	b	20.8	0.046	9	13.6	6
	I	b	20.8	0.070	<5	5.0	6
B20	B	a	5.0	0.110	28	33.6	12
	B	b	18.5	0.110	28	33.6	10
	B	c	17.4	0.110	28	33.6	11
B30	A	b	16.2	0.046	75	8.7	10
	B	a	4.4	0.166	42	50.4	11
	B	b	16.2	0.166	42	50.4	15
	B	c	15.2	0.166	42	50.4	12
	C	b	16.2	0.228	75	14.4	14
	C	c	15.2	0.228	75	14.4	14
	D	c	15.2	0.150	12	4.8	14
	E	c	15.2	0.150	12	7.2	14

Table 2 Impurities of biodiesels

Fuel Number	MG (%wt)	Glycerin (ppm)	SG (ppm)	CP (℃)
A	0.15	250	29	14
B	0.55	140	168	14
C	0.76	250	48	14
D	0.50	40	16	14
E	0.50	40	24	14
F	0.30	<50	41	14
G	0.40	<50	98	13
H	0.46	90	136	14
I	0.70	<50	50	15

Table 3 Properties of conventional diesel fuels

Fuel Number	Aroma (%)	Sulfur (ppm)	CP (℃)
a	6.3	2	-4
b	23.1	37	6
c	21.7	19	11

TEST METHODS

As previously mentioned, this study will be divided to 3 steps. This section will explain test method which was used in STEP 1 and STEP 2.

STEP 1

Which aims to confirm effect of fuel properties and temperature on precipitate weight was done by precipitation test. This is a general method to measure quantity of contamination in liquids. Using this method, precipitate weight of each test fuel at any temperature can be measured. As the result, the fuel parameter which has high influence on precipitation weight was identified. Besides, the influence of temperature was also clarified.

STEP 2

Which target to clarify effect of precipitate weight on fuel filter performance was completed by filter paper test and filter assembly test.

Test condition was set based on actual vehicle condition and temperature in Southeast Asia including mountain area. Test fuel was firstly heated to 60°C [6] to dissolve the precipitates in the fuel that might occur during storage then it was cooled to desired test temperature before conduct the test.

Precipitation test method

As mentioned above, it was said that the precipitation of the biodiesel is generally caused by impurities like MG etc. and some conventional diesel component like aromatic content has an effect on precipitation formation. Then Precipitation test was conducted to confirm the influence of these fuel parameters. The constitution of the testing equipment is shown in Fig. 3. Test fuel was heated to 60°C for 4 hours then it was cooled to 10, 15, 20 and 25°C for 24 hours. After that cooled fuel was stirred for 2 hours to homogenize the precipitates and make it saturates.

The cooled fuel was sucked and passed through a filter to trap the precipitates. A filter (material: PTFE) having a diameter 47 mm and pore size of 0.45μm which is finer than the normal fuel filter was used. Precipitates trapped by the filter were weighed after drying in a desiccator.

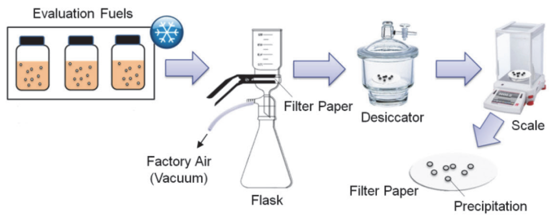

Fig. 3 Precipitation test equipment

Filter paper test method

Filter paper test was conducted to confirm the tendency of effect of precipitate weight on fuel filter performance by using filter paper with small filtering area before conduct filter assembly test. Actual filter paper (pulp, PET, rayon mixed filter paper) which have average pore size 4μm and thickness 0.5 mm was used. Fig. 4 shows the filter paper test equipment. For accurate evaluation of the influence of fuel filter performance, a stirrer was attached in the fuel tank to ensure uniform distribution of precipitates in the tank. A fuel pump was also installed on the outlet side of the fuel filter to prevent precipitates from being miniaturized through the pump.

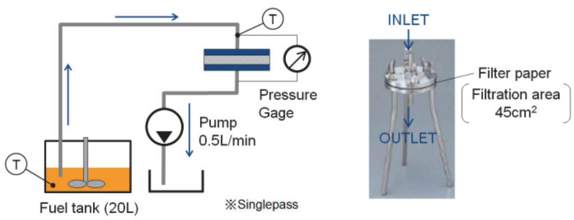

Fig. 4 Filter paper test equipment

20 L of test fuel was heated to 60°C for 4 hours then it was cooled to 10, 15, 20 and 25°C for 24 hours. After that cooled fuel was stirred for 2 hours to homogenize the precipitates and make it saturates. Then pass the test fuel through the filter paper at flow rate 0.5 L/min which is simulating actual vehicle condition. The pressure loss of filter paper was measured and recorded with time.

Filter assembly test method

This test was conducted to confirm the effect of precipitate weight on fuel filter performance by using actual fuel filter assembly. The high efficiency type filter paper that is used in emerging countries was selected for the test. Similar test method with the filter paper test was adopted. Representative test fuels were selected based on filter paper test result.

Four test fuels with different MG amounts were heated to 60°C for 4 hours then they were cooled to 15°C for 1 week. These tests were performed by using the actual fuel filter. Fig. 5 shows the filter assembly test equipment.

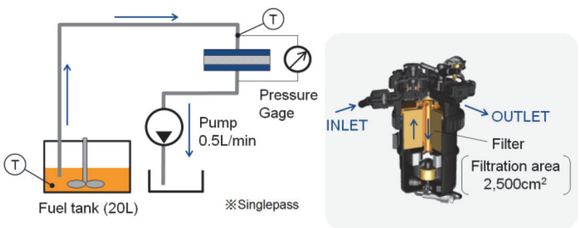

Fig. 5 Filter assembly test equipment

4. TEST RESULTS

INFLUENCE OF FUEL PARAMETERS AND TEMPERATURE ON THE PRECIPITATION OF BIODIESEL

Fig. 6 shows the precipitation test results. Precipitate weight was plotted with each fuel parameter to see the correlation. It indicates that there is a strong correlation between MG and precipitate weight while other fuel impurities have less or no influence on precipitate weight. Moreover, precipitate weight increases linearly with the amount of MG in test fuel at the constant temperature.

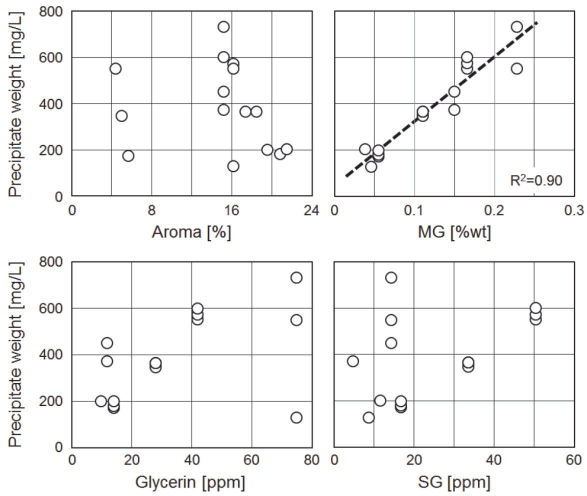

Fig. 6 Precipitation test results for each fuel impurities at 15° C

On the other hand, it was reported that aromatic content has influence on precipitation of biodiesel [18]. It was assumed that there was no clear correlation in the range of aromatic content of selected conventional diesels (range of fuel in Southeast Asia) in this study.

The trapped precipitate was also analyzed by Gas Chromatography (GC) and the analysis result is shown in Fig. 7. The result showed that the composition of the precipitate was dominated by MG. Therefore, it was clarified that MG is the main fuel parameter that affecting precipitation of biodiesel.

Next, the effect of temperature was confirmed while keeping the amount of MG constant. The cooling temperatures were 10, 15, 20 and 25°C which simulate ambient temperature in Southeast Asian countries. Fig. 8 shows the test results. The precipitate weight increased with decreasing temperature and increasing the amount of MG in test fuel. From these test results, the correlation between precipitate weight, MG and temperature was clarified.

INFLUENCE OF PRECIPITATE WEIGHT ON FILTER PERFORMANCE

<u>Correlation between precipitate weight and filter performance on filter paper</u>

Fig. 9 shows the example of results that obtained from the filter paper test. It indicates that pressure loss of filter paper increases faster when higher precipitate weight at any temperature.

In order to clarify correlation between precipitate weight and clogging time (time that pressure loss was reached to 30 kPa), clogging time was plotted with precipitate weight obtained from precipitation

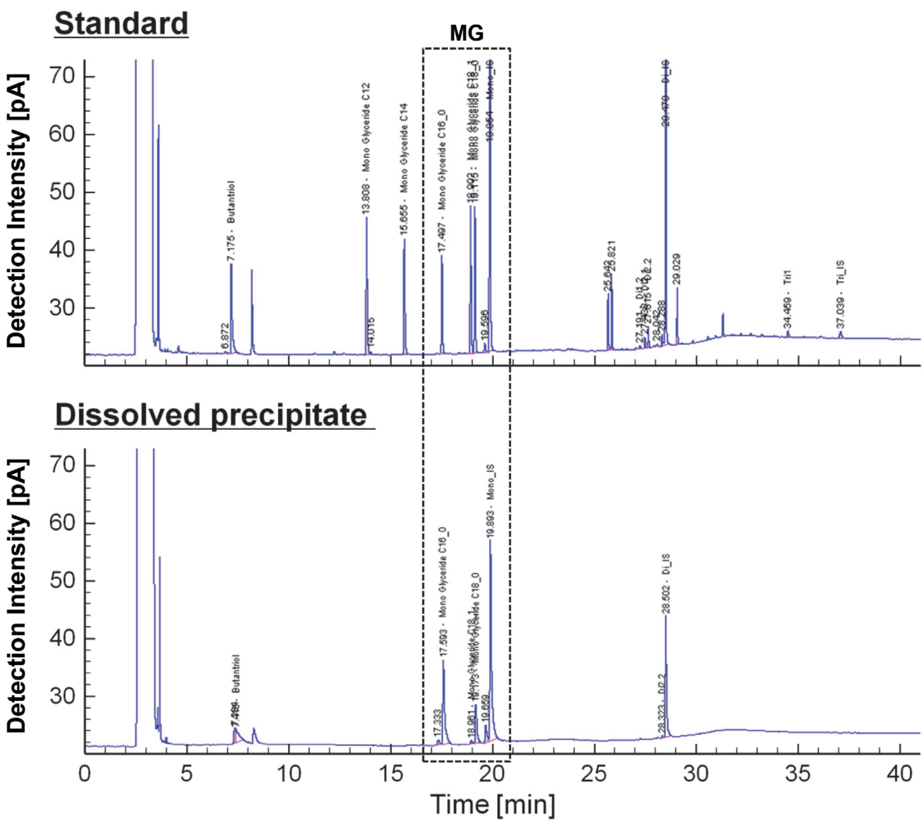

Fig. 7 GC analysis result

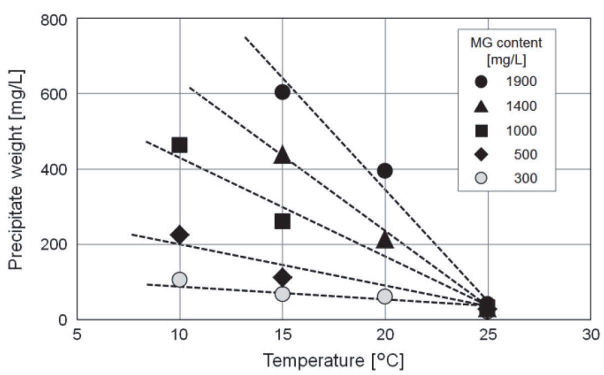

Fig. 8 Precipitation test result at each temperature

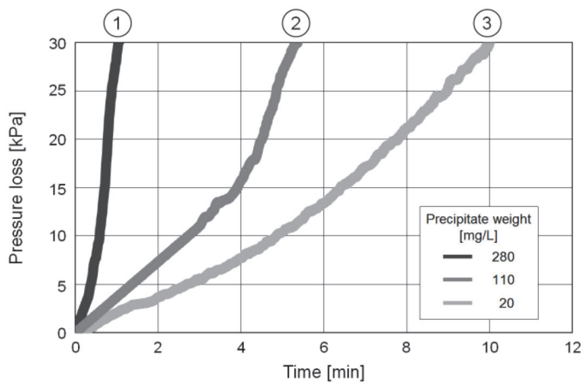

Fig. 9 Filter paper test result

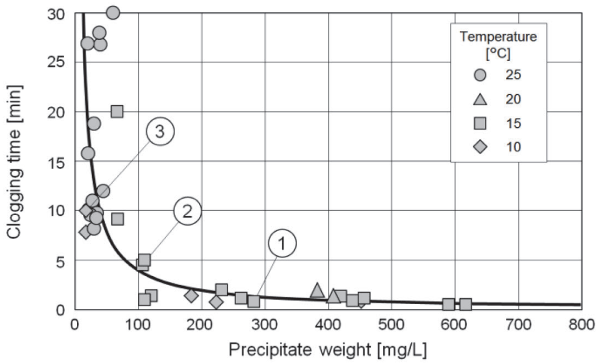

Fig. 10 Correlation between precipitate weight and clogging time on filter paper

test which was mentioned before. Fig. 10 shows correlation between precipitate weight and clogging time at any amount of MG and temperature. As a result, clogging time suddenly decreased with increasing of precipitate weight and tends to be saturated when exceed specific precipitate weight. Therefore, clogging time of fuel filter could be estimated by precipitate weight regardless of amount of MG and temperature.

Correlation between precipitate weight and filter performance on filter assembly

The results obtained from the actual filter assembly test were summarized by a similar procedure with the filter paper test.

Fig. 11 shows the result of 4 test fuels which greatly varies in precipitate weight. The result was similar to filter paper test that pressure loss of filter assembly also increases faster when higher precipitate weight.

Fig. 12 shows the correlation between clogging time and precipitate weight from the result mentioned previously. A characteristic of clogging time of filter assembly for each precipitate weight was clarified.

These data are very useful for considering countermeasure for filter clogging. For example, Indonesia introduced B20 with possible maximum

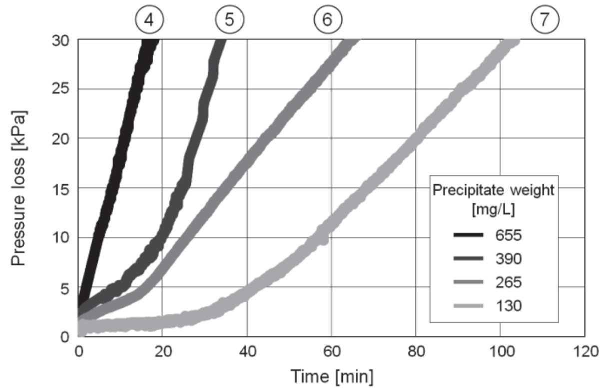

Fig. 11 Filter assembly test result at 15° C

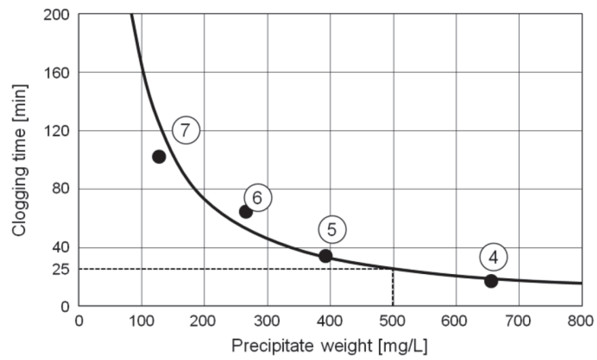

Fig. 12 Correlation between precipitate weight and clogging time on filter assembly at 15° C

amount of MG at 0.16%wt. (specification of MG at B100 is 0.8%wt[21)]). that might cause precipitate weight about 500 mg/L at 15°C according to precipitation test result in Fig. 6. Therefore, fuel filter can be clogged by this fuel in 25 minutes according to filter assembly test result in Fig. 12. Consequently, filter clogging could be prevented by making precipitate weight to lower than 500 mg/L before 25 minutes.

However, in real world this precipitate weight: 500 mg/L might be different depends on vehicle usage condition such as using mileage of fuel filter and temperature. Therefore, characteristic at each using mileage should be further investigated.

5. COUNTERMEASURE OF FUEL FILTER

By above-mentioned result, if the precipitate is dissolved by rising in fuel temperature within a clogging time, it is suggested that the biodiesel precipitation on the fuel filter does not impact the vehicle and this becomes as effective measures technique.

Generally, fuel filter has a cold region specification for heating fuel. This additional function is designed for preventing filter clogging from solidification of normal paraffin wax. It will be one of the effective strategies for precipitation of MG in biodiesel blends.

Fig. 13 shows the simulation test results with the fuel filter specified for the cold region. The warming device of the filter which was clogged under the same conditions as in Fig. 11 case ⑥ was turned on after 72 minutes. Then, the fuel heated up to 40°C in this simulation test flowed into the filter and dissolved precipitates on the filter paper. Thereby, it was confirmed that filter pressure loss was recovered.

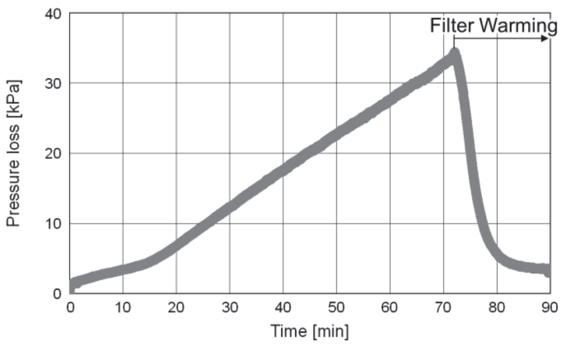

Fig. 13 Simulation test result with fuel filter warming

6. CONCLUSION

The Southeast Asian countries have been increasing biodiesel concentration in biodiesel blends continuously. The impact of fuel filter clogging at low temperature was investigated. The results indicate that:

1. There is a strong correlation between amount of MG and precipitate weight at low temperature;
2. The MG precipitate weight which affects the clogging time of fuel filter varies depending on temperature and amount of MG in the fuel;
3. There is a possibility to avoid filter clogging due to MG precipitation at low temperature with adopting a heating function on fuel filter.

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著者

舟橋 実
ふなはし みのる

DENSO International Asia Co., Ltd.
Technical Center Division
ディーゼル／ガソリンエンジンの燃料噴射装置開発に従事

Sareewan Suwannamit
サリーワン スワンナミット

DENSO International Asia Co., Ltd.
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Jaratpong Ngammoh
ジャラットポン ガンモー

DENSO International Asia Co., Ltd.
Technical Center Division
ディーゼル／ガソリンエンジンの燃料噴射装置開発に従事

田崎 守
たさき まもる

京三電機㈱ 技術部
燃料フィルター開発に従事