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PS2 BEYOND THE MINERAL OIL–IMMERSED TRANSFORMER AND REACTORS

Technological Development of Vegetable Oil (Rapeseed Oil) Immersed Transformer

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SUMMARY

The market for power transformers is expanding, in which ester-based insulating oil with excellent biodegradability, which contributes to reduction of environmental load such as reduction of CO_2 emissions, is applied as a liquid cooling insulating medium to replace conventional mineral oil. Among them, mineral oil has a burning point of 150 ° C, while natural ester oil (hereinafter referred to as vegetable oil) has a high burning point of 300 ° C or higher and is flame-retardant, and has been used mainly in North America. Since then, vegetable oils have been widely used because of their environmental properties and properties other than flame retardancy. Currently, it is estimated that more than 1 million power transformers are in operation around the world. The application has already been expanded to ultra-high voltage transformers with a rated voltage of 420 kV.
In Japan, the Japanese Industrial Standards (JIS C2390-1 to -3: 2019) for three types of biodegradable insulating oils, including chemically synthesized ester oils, were published in 2019, the application of vegetable oil based insulating oil to transformers is progressing. Natural ester-based insulating oils such as rapeseed oil and soybean oil are natural vegetable oils and have excellent biodegradability, disaster prevention properties, long-term stability, and low-temperature fluidity. In addition, they have a high flash point and are classified as a designated flammable material rather than a hazards material under the Fire Defence Law in Japan, making it easier to apply for oil storage conditions and equipment construction compared to mineral oil. In some cases, overseas insurance companies can reduce the insurance premium rate for facilities that have introduced soybean oil transformers. Further, a plant-derived ester (vegetable fatty acid ester) is an insulating oil in which the characteristics of a natural vegetable oil are improved by an esterification reaction or the like, and is excellent in biodegradability and oxidative stability, and has good low-temperature fluidity. Due to its high relative permittivity, transformers can be expected to improve the dielectric breakdown voltage. In this paper, we will explain the development contents of the rapeseed oil immersed transformer, which has a large number of operating units in Japan, from the basic examination to the actual production. The basic characteristics of rapeseed oil are described, such as basic features as an insulating cooling liquid of the transformer and a deterioration characteristics of the insulating paper in oil, etc.

KEYWORDS

rapeseed oil immersed transformer – ester based insulating oil - soybean oil - fatty acid ester - biodegradability - fire retardancy

1 BACKGROUND

Mineral oil has been widely used as an insulating oil used in oil immersed transformers. However, in recent years, due to the reduction of the environmental impact of oil spills and the growing awareness of reducing CO_2 gas emissions, transformers that replace insulating oil with vegetable oil have attracted attention and are being applied for use. Compared to mineral oil, vegetable oil generally has a high flash point and combustion point, is excellent in fire and disaster prevention, and is highly biodegradable. Furthermore, it contains almost no sulphur and has no problem of copper sulphide, and its volume resistance is lower than that of mineral oil, so it is less likely to generate static electrification [1].

Vegetable oil based insulating oils that have been put into practical use as insulating oils for transformers are classified into natural esters and plant-derived esters (vegetable fatty acid esters). Natural ester is a natural vegetable oil and is excellent in biodegradability, disaster prevention property, and effect of extending the life of insulating paper. Rapeseed oil and soybean oil, which contain a large amount of oleic acid in their components, have the characteristics of excellent long-term stability and low-temperature fluidity, and are used in transformers. Rapeseed oil and soybean oil have a higher flash point than mineral oil and are classified as designated flammable material under the Fire Defence Law in Japan (mineral oil is a hazards material), which makes it possible to simplify oil storage regulations and facility construction applications. In some cases, overseas insurance companies have lowered the insurance premium rate for facilities that have introduced transformers that use soybean oil, and in 2020, they delivered more than 2.5 million units worldwide. On the other hand, the plant-derived ester, vegetable fatty acid ester, is an insulating oil in which the characteristics of natural vegetable oil are improved by a method such as an esterification reaction, and is excellent in biodegradability and oxidative stability. Since the low-temperature fluidity is good, the cooling performance of the transformer can be improved, the relative permittivity is higher than that of mineral oil, and the breakdown voltage can be expected to be improved in the composite insulation system with solid insulation, the equipment can be reduced.

In Japan, the application of vegetable oil based insulating oil to transformers is progressing. The Japanese Industrial Standards (JIS C2390-1 to -3: 2019) for three types of biodegradable insulating oils, including chemically synthesized ester oils, have been issued and stipulate the performance that should be retained (Table 1). In addition, among these, the number of manufacturers supplying transformers using natural ester based insulating oils such as rapeseed oil, soybean oil, and fatty acid ester oil, and the maximum rated value of transformers with those oils are shown in Table 2. In addition, the designation of insulating oil in the power transformer purchase specifications of electric power companies has been changed to include vegetable oil or mineral oil and vegetable oil. Table 3 shows an example of their description.

An example of manufacturing a vegetable oil immersed transformer in Japan is shown. The total number of rapeseed oil immersed power transformers produced by 2020 is about 400, and the maximum capacity / voltage is 80 MVA / 187 kV. The total number of soybean oil immersed power transformers will be 30 by 2020, and the maximum capacity / voltage will be 30 MVA / 110 kV. In addition, the total number of palm fatty acid ester oil immersed power transformers produced by 2020 is 175. In the past, vegetable oil immersed transformers were supplied to specific customers who needed to reduce environmental impact and provide disaster prevention. However, as the application of vegetable oil transformers is expanded to the distribution class of electric power companies, it is expected to be applied to high-voltage and large-capacity transformers of transmission classes.

In this paper, we will explain the development process, its characteristics, and specific application effects of the rapeseed oil immersed transformer, which is a vegetable oil immersed transformer with a large number of operating units in Japan.

Table 1. Typical characteristics comparison of mineral oil and ester-based insulating oils

Item		Units	Mineral oil (Typical)	Synthetic ester	Natural esters (Vegetable oils)	Modified esters derived from vegetable oils
				JISC2390-1	JISC2390-2	JISC2390-3
Kinematic vicosity	40 ℃	mm^2/s	7.2	13 or more, 35 or less	50 or less	13 or less
	100 ℃		2.0	13 or less	15 or less	4 or less
Pour point		℃	-45	-45 or less	-10 or less	-27.5 or less
Water content		ppm	19	200 or less	200 or less	200 or less
Volume resistivity (80 ℃)		TΩm	42	0.01 or more	0.01 or more	0.01 or more
Dissapation factor (tanδ)(80 ℃)		%	0.001	2 or less	3 or less	3 or less
Breakdown strength		kV/2.5 mm	69	45 or more	45 or more	45 or more
Flash point		℃	130	250 or more	275 or more	150 or more
Oxidation stability 120 ℃×75 hr		mgKOH/g	0.21	0.6 or less	0.6 or less	0.6 or less

JISC2390-1 :2019 Readily biogradable electrical insulating oils – Part 1: Synthetic ester
JISC2390-2 :2019 Readily biogradable electrical insulating oils – Part 2: Natural esters (Vegetable oils)
JISC2390-3 :2019 Readily biogradable electrical insulating oils – Part 3: Modified esters derived from vegetable oils

Table. 2 Types of natural ester-based insulating oils and transformer ratings in Japan

Type of cooling insulation liquids		Rapeseed oil	Soy beans oil	PFAE
Number of transformer manufacturers		3	3	7
Ratings (manufactured)	Voltage kV	187	110	77
	Capacity MVA	80	30	40

PFAE :Palm fatty acid ester

Table 3. Specifications of power transformers to which vegetable oil can be applied

Company	Ratings		Insulating oil specification	Issued
Utility A	Capacity	10, 20 and 30 MVA	Use vegetable oil that has the performance as an electrically insulating oil.	2016
	Voltage (Primary / Secondary)	154, 64.5, 32.25 kV / 6.9kV		
	Others	With on load tap changer		
Utility B	Capacity	(unspecified)	Insulating oil for transformers shall be the manufacturer's standard. (Insulating oil was limited to mineral oil, but that limitation was excluded.)	2019
	Voltage (Primary / Secondary / Tertiary)	from 22/6.6 kV to 500/275/77 kV		
	Others	With on load tap changer		
Utility C	Capacity	30 MVA or 20 MVA	Whether to use mineral oil or vegetable oil as the insulating oil for the transformer depends on the manufacturer's standards.	2020
	Voltage (Primary / Secondary)	66 / 6.9 kV or 110 / 22 kV		
	Others	With on load tap changer		

2 EVALUATION OF BASIC CHARACTERISTICS OF RAPESEED OIL

2.1 Oil properties

Table 4 shows a comparison of the properties of rapeseed oil and mineral oil. Rapeseed oil has better oxidative stability than mineral oil, has a high kinematic viscosity, but has a high thermal conductivity. In addition, rapeseed oil is a natural ester, which has a high flash point and combustion point, is excellent in fire and disaster prevention, and is a highly safe insulating oil. Among vegetable oils, rapeseed oil has a low pour point as a base oil (-30 ° C) and contains a large amount of oleic acid with stability and fluidity, so it has excellent characteristics as an electrical insulating oil for transformers. Rapeseed oil has good hydrogen gas absorption, has the effect of suppressing the progress of discharge due to hydrogen gas generated by a small partial discharge inside the transformer, and contains almost no sulphur, so the copper sulphide problem that occurred in mineral oil does not occur. Furthermore, rapeseed oil is superior in biodegradability to mineral oil, and has cleared the Eco Mark certification standard (60 % or more) in biodegradability tests (OECD301C, etc.).

2.2 Insulation characteristics

Figure 1 shows a comparison of the breakdown voltage with respect to the water content of rapeseed oil and mineral oil. The saturated water content of rapeseed oil is more than 10 times higher than that of mineral oil, and it has the property of easily absorbing water in paper, but the effect of water in oil on the breakdown voltage is small, and even if the water content in oil is 500 ppm, the breakdown voltage is 60 kV / 2.5 mm. In order to prevent deterioration of the characteristics of insulating oil, if a pressure-free sealing type oil deterioration prevention device similar to a mineral oil immersed transformer is provided, the water content in the oil does not exceed 200 ppm even after 10 years of operation, and dielectric breakdown does not decrease.

Table 4. Comparison of proprerties of rapeseed oil and mineral oil

Item		Units	Rapeseed oil	Mineral oil
Kinematic vicosity	40 °C	mm^2/s	38.41	8.31
	100 °C		8.06	2.21
Flash point		°C	334	144
Fire point		°C	-30	-32.5
Oxidation stability 120 °C×75 hr		%	0	0.1
		mgKOH/g	0.15	0.2
Permittivity			2.9	2.1
Breakdown strength (water content)		kV/2.5 mm	78 (10 ppm)	70 (10 ppm)
			78 (30 ppm)	55 (30 ppm)
Gas absorbency			-24	-2
Saturated water content		%	Approx.1000	≦100
Sulfur content		ppm	<0.01	0.04
Thermal conductivity		W/(mK)	0.176	0.13
Biogradability (OECD 301C)		%	89	17

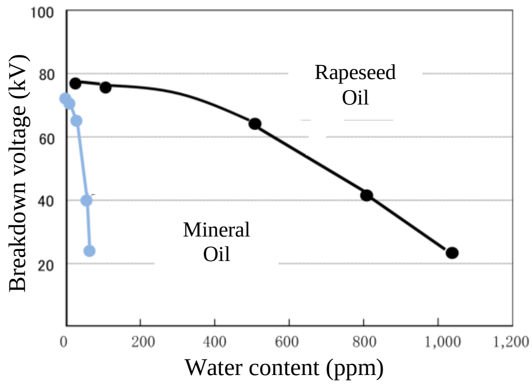


Fig.1 Comparison of dielectric breakdown voltage of rapeseed oil and mineral oil

2.3 Long-term stability

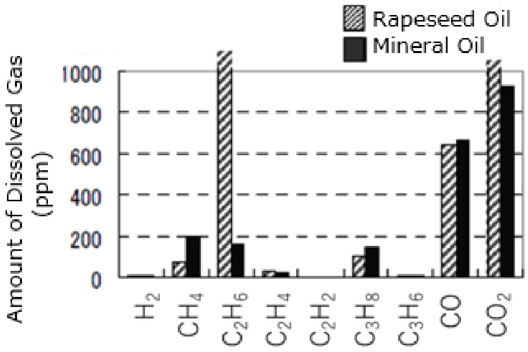
In order to confirm the long-term stability of rapeseed oil, an oxidative stability test (120 °C×75 hours) was conducted on mineral oil and rapeseed oil. As a result, the colour of the mineral oil changed and sludge was generated. However, no change in colour or generation of sludge was confirmed in rapeseed oil. This is considered to be due to the difference in molecular structures of two oil. Since rapeseed oil does not generate solid sludge due to deterioration, it has a feature that the dielectric breakdown voltage does not decrease over a long period of use. From the above, if the same management as the conventional mineral oil immersed transformer is performed for oxidation and moisture absorption, rapeseed oil can obtain longer-term stability than that of mineral oil.

2.4 Transformer status diagnosis

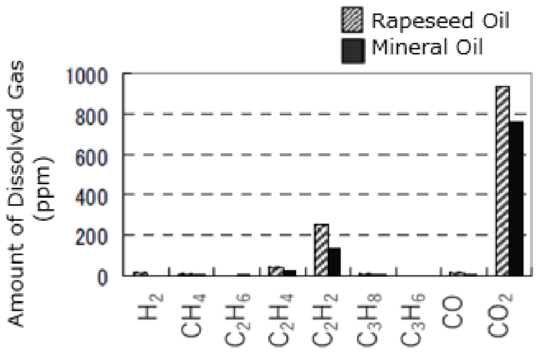
By analysing the flammable gas dissolved in the insulating oil, the internal condition of the mineral oil immersed transformer can be diagnosed. For rapeseed oil immersed transformers, the condition inside the transformer can be diagnosed by the same method, but the appearance of the generated gas is different because the oil type is different. To investigate this difference, rapeseed oil was heated and the generated gases were compared with gases generated in mineral oil. The results are shown in Figure 2 [2]. When an internal abnormality occurs due to overheating, ethane (C_2H_6) is clearly generated more than mineral oil. Therefore, compared to mineral oil, rapeseed oil enables early detection of internal abnormalities in the overheating aspect at relatively low temperatures due to ethane. In addition, in internal abnormalities such as arc discharge, the patterns of gas generated by rapeseed oil and mineral oil are the same [3].

2.5 Deterioration characteristics of insulating paper

Accelerated deterioration tests were conducted in mineral oil and rapeseed oil in order to understand the deterioration characteristics of winding insulation paper in rapeseed oil. In this test, insulating paper with an average degree of polymerization residual ratio of 80 % and 65 % was used assuming an aged mineral oil immersed transformer. Examples of test results are shown in Figure 3. This verification revealed that the deterioration life of insulating paper in rapeseed oil is more than twice that of mineral oil.



a) Over heart (450℃)



b) Arc discharge

Fig.2 Comparison of gas types and amounts generated in rapeseed oil and mineral oil

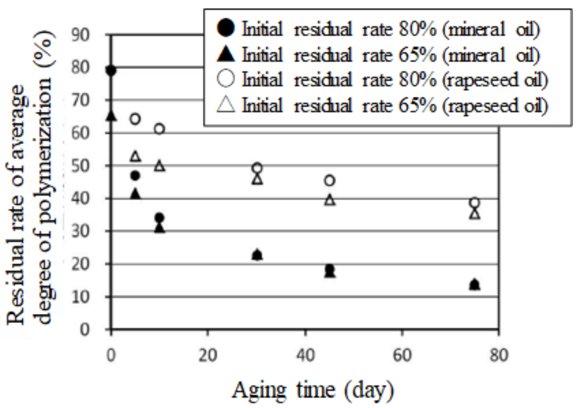


Fig.3 Accelerated deterioration test of insulating paper (130 ℃)

3 DEVELOPMENT OF RAPESEED OIL IMMERSED TRANSFORMER

The rapeseed oil immersed transformer is required not only the purchase price of the device itself, but also is to have a long life based on technical knowledge and an excellent life cycle cost in consideration of installation construction cost, maintenance cost, and inspection cycle. Based on the knowledge obtained in the basic characteristic evaluation, the transformer performance was evaluated by conducting long-term current and energization application tests with two types of verifiers equivalent to the actual transformer, the removed aged mineral oil immersed transformer and the model transformer.

3.1 Verification using the removed mineral oil immersed transformer (three-phase, 10 MVA-66 kV)

1) Energization and current load test

Two units of 10 MVA-66 kV mineral oil transformers with the same rating and 40 years of operation were removed and used as equipment for verifiers. In this equipment, a circulating current by the tap difference method was passed through the transformer winding. Furthermore, an energization test was conducted by simulating the actual operating state in which the core was excited. To confirm the temperature difference between rapeseed oil and mineral oil, one transformer was immersed with rapeseed oil and the other one was immersed with mineral oil. The radiator was partially stopped to raise the oil temperature and accelerated deterioration of the insulation. The verification test was conducted for about one year, and the equivalent acceleration years calculated from measured temperature such as air, oils and windings were 30 years or more. The outline of the verification test and the appearance of the transformer are shown in Figures 4 and 5.

Table 5 shows the results of measuring the average degree of polymerization of the insulating paper collected before and after the verification test and comparing the relative deterioration aspects. The degree of polymerization of insulating paper decreased by 46 % in mineral oil, but decreased by 15 % in rapeseed oil. Similar to the findings of basic characterization, the effect of extending the life of rapeseed oil on mineral oil is expected to be more than doubled.

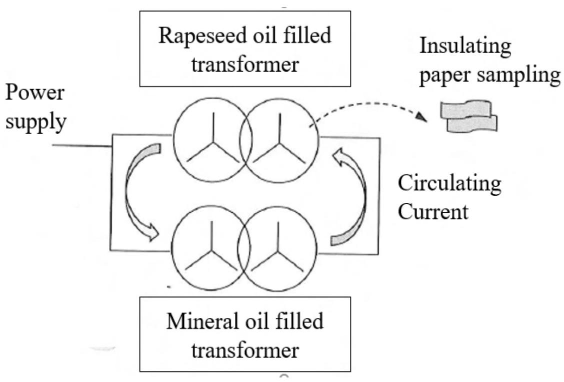


Fig. 4 Experimental equipment conceptual diagram

Fig. 5 Appearance during energization test of 2 Units of three-phase, 10 MVA-66 kV transformer

Table 5 Average degree of polymerization of winding insulation paper of verification transformer

Types of immersed insulating oil	Average degree of polymerization residual ratio	
	Before energization test	After energization test <aging test for equivalent to 30 years>
Mineral Oil	100% (initial value)	54 %（▲46 %）
Rapeseed Oil	100% (initial value)	85 %（▲15 %）

2) Insulation performance test

After the verification test was completed, a dielectric breakdown test of the verified transformer was conducted by AC and lightning impulse withstand voltage tests to confirm the insulation performance of the transformer deteriorated in rapeseed oil. As a result, it was clarified that the rapeseed oil immersed transformer has an appropriate insulation margin even when the average degree of polymerization of the insulating paper has decreased considerably after 30 years of operation with the mineral oil immersed transformer.

3) Cooling performance evaluation

A temperature measuring element was attached to each part of the winding to measure the winding temperature, and useful knowledge was obtained for the cooling design of the rapeseed oil immersed transformer, such as the internal cooling characteristics of the transformer and the winding temperature distribution. Fluid analysis that reflects these measured temperatures and the characteristics of rapeseed oil makes it possible to make the transformer active part more compact than the conventional design, and the space created there increases the cross-sectional area of the winding conductor, that is, the number of parallel conductors. As a result, the current loss could be reduced.

3.2 Verification using a model transformer (single-phase, 2 MVA-6.3 kV / 154 kV)

1) Long-term energization test

In order to verify the insulation performance of a 154 kV class rapeseed oil immersed transformer, a model transformer was manufactured and a long-term energization test was conducted. Three single-phase transformers with rating 2 MVA and a secondary voltage of 154 kV, were connected to each phase, and each transformer was immersed with rapeseed oil, soybean oil, and palm fatted oil for comparison by insulating oil type of transformer characteristics. An overvoltage with a rated voltage of 6.3 kV or more was applied to the primary voltage of the model transformer, and the accelerated deterioration multiple was calculated from the overvoltage ratio and the long-term V-t characteristics of mineral oil, and the equivalent cumulative years for the test period of 2.08 years was calculated [4]. The average overvoltage multiple is the average value of the overvoltage multiple of the primary voltage every 10 minutes. Due to the phase imbalance of the primary voltage, the overvoltage multiple of the V phase is larger than that of the other phases. Table 6 shows the overvoltage multiples, acceleration multiples, and cumulative years of the three model transformers. Figure 6 shows the appearance of the transformer in the long-term energization test. The verification test period of 2.08 years was equivalent to 60 to 94 years.

Table.6 Overvoltage multiple and cumulative period during long-term energization test of 2 MVA-154 kV rated model transformer

Instruments	Transformer 1 (Phase U)	Transformer 2 (Phase U)	Transformer 3 (Phase U)
Type of insulating oil	Rapeseed oil	Soybeans oil	Palm fatty acid ester
Verification test period (years)	2.08	2.08	2.08
Average overvoltage multiple *	1.054	1.062	1.055
Average acceleration multiple	28.0	43.4	29.1
Equivalent cumulative period (years)	60.5	94.2	63.1

*Calculation formula for overvoltage multiple [4]

$$\left(\frac{V_1}{V_2}\right) = \left(\frac{t_1}{t_2}\right)^{-\frac{1}{n}}$$

V1: Destruction voltage (kV) corresponding to time t1
V2: Destruction voltage (kV) corresponding to time t2
n: Index indicating the slope of V-t
In this study, n=60 for the general value of oil insulation (long-term region)

Fig. 6 Appearance during long-term energization test of 3 Units of single-phase, 2 MVA-154 kV model transformer

2) Evaluation of insulating oil characteristics and gas analysis in oil

In order to confirm the occurrence of abnormal signs in the model transformer, insulating oil characteristics by periodic oil sampling and gas analysis in oil were carried out. The results are shown below.

Figure 7 shows the measurement results of the water content in oil. It increases from 20 ppm to 40 ppm at the beginning of the verification test, and after that, it shows a gradual increase and decrease tendency depending on the seasonal temperature, which does not depend on the oil type. The increase in the amount of water in the oil at the initial stage of the verification test is considered to be due to the effect of moisture absorption of the insulation material due to the exposure to the air after the transformer active part have dried. In addition, for seasonal fluctuations, the water content in February at a temperature of 5 ° C is about 20 ppm, and the difference in oil type is small. However, in September when the temperature was 22 ° C, there was a slight difference of about 40 ppm for rapeseed oil and about 50 ppm for soybean oil and palm fatted oil. This difference is considered to be due to the saturated water content of each insulating oil in the pressure-free sealing type conservator.

Figure 8 shows the measurement results of the dielectric breakdown voltage. Throughout the verification period, the breakdown voltage is 60 kV or higher, which is sufficiently high, and the difference depending on the oil type and the influence of the water content in the oil are not clear. There is a difference in the measured values around 450 days after the start of the test, but this is because the measuring instrument has changed, it is not the effect of the change in the insulating oil characteristics. The transition of each gas of hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO), and carbon dioxide (CO_2) by gas analysis in oil is shown in Figures 9 to 15. Rapeseed oil and soybean oil, which are natural esters, tended to increase in C_2H_6 and CO, and palm oil, which is a fatty acid ester oil, increased only in CO. The increase in these gases is considered to be due to the deterioration of the insulating oil, and the water content in the oil may affect the deterioration of the insulating oil.

The water content in the oil of this verifier is slightly higher than 50 ppm, but the breakdown voltage is sufficiently high and does not affect the transformer performance. The characteristic gases generated when a partial discharge occurs, which is one of the electrical internal abnormalities of the transformer, are H_2 and C_2H_2. In the verification test, H_2 was generated very little and C_2H_2 was not detected. The amount of other gas generated was sufficiently lower than the control standard value of the rapeseed oil immersed transformer set with reference to the 95th percentile of soybean oil [5]. The reliability of the 154 kV class vegetable oil immersed transformer was confirmed without any insulation deterioration including partial discharge in the model transformer even during the operation period of more than 60 years of equivalent period.

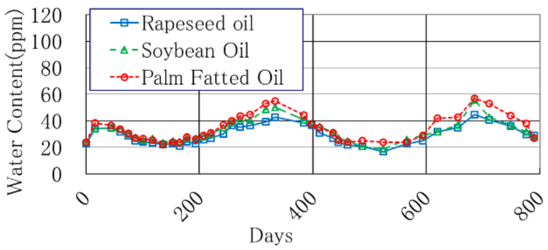


Fig. 7 Trend of water content in oil

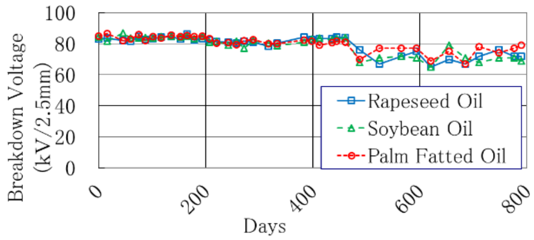


Fig. 8 Trend of breakdown strength of oil

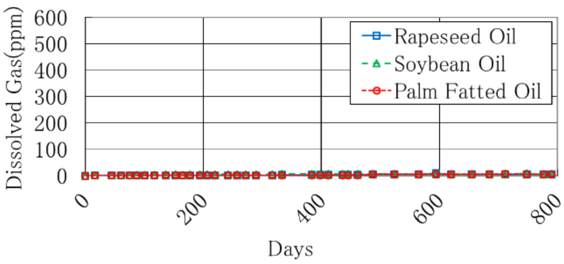


Fig. 9 Trend of hydrogen (H_2) by gas analysis in oil

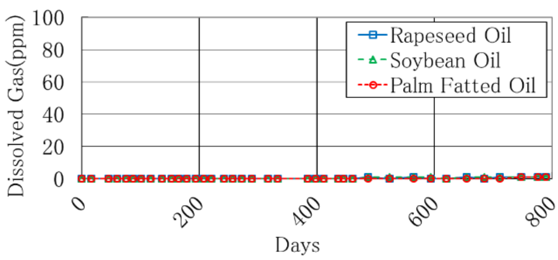


Fig. 10 Trend of methane (CH_4) by gas analysis in oil

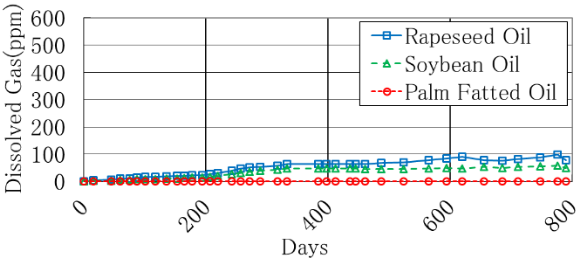


Fig. 11 Trend of ethane (C_2H_6) by gas analysis in oil

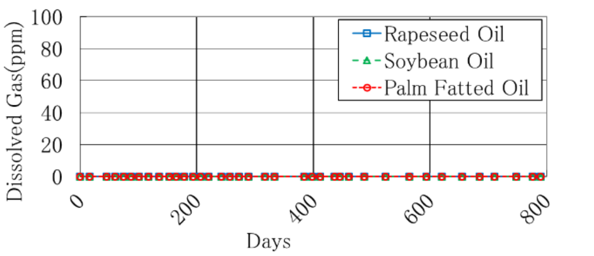


Fig. 12 Trend of ethylene (C_2H_4) by gas analysis in oil

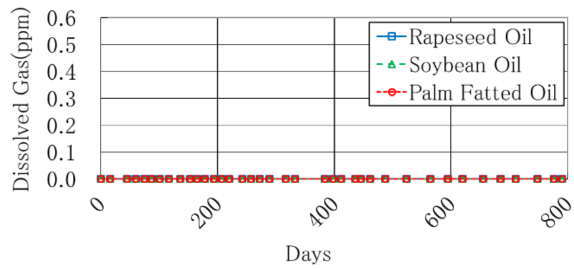


Fig. 13 Trend of acetylene (C_2H_2) by gas analysis in oil

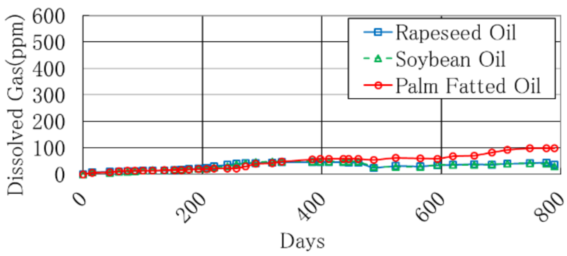


Fig. 14 Trend of carbon monoxide (CO) by gas analysis in oil

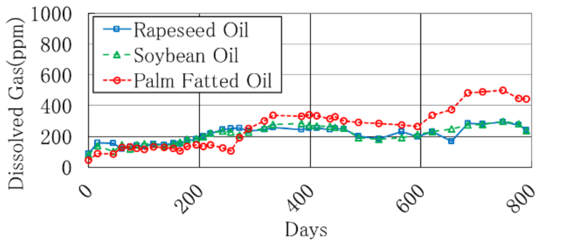


Fig. 15 Trend of carbon dioxide (CO_2) by gas analysis in oil

4 REFLECTION IN THE DESIGN OIL IMMERSED TRANSFORMERS

The specific development results reflected in the design of the product of the rapeseed oil immersed transformer are shown below.

4.1 Extending the expected life of the transformer to 60 years

The life of the transformer is determined by the degree of polymerization of the winding insulation paper and the press board, and is affected by the amount of water. Since the water absorption capacity of rapeseed oil is larger than that of mineral oil, the transformer design that optimize the expected life of the transformer under the rated continuous operation conditions were determined. As a result, it was calculated that the expected design life of the conventional mineral oil immersed transformer was 30 years, while that of the rapeseed oil immersed transformer was more than 60 years.

4.2 Low loss and transportation with all equipment

The cooling efficiency of the transformer was optimized by measuring the temperature of each part with a model transformer and fluid analysis reflecting the characteristics of rapeseed oil. As a result, the following results were obtained. By optimizing the cooling efficiency, the rapeseed oil immersed transformer can be made smaller than the mineral oil immersed transformer. Generally, to reduce winding loss, when the winding current density is reduced, that is, when the number of parallel conductors is increased, the transformer active part become large. However, the rapeseed oil immersed transformer can be manufactured with the same dimensions as the tank of the conventional mineral oil immersed transformer. As a result, the winding loss of the 20 MVA-66 kV class rapeseed oil immersed transformer is 15% lower than that of the same rated mineral oil immersed transformer.

Conventionally, 20 MVA class power transformers have been reassembled in the substation area by disassembling the radiator from the tank and transporting it independently due to the limitation of transportation restrictions. However, with rapeseed oil immersed transformers, the number of radiators has been reduced, and the height at which they can be attached to the tank can be reduced, making it possible to transport the transformer with radiators attached. This eliminates the need to reassemble the radiator in the tank on site, and the on-site assembly and installation period has been shortened from 9 days to about 3 days.

5 CONCLUSION

We have developed a power transformer that uses rapeseed oil, which is a vegetable oil that has advantages such as reducing environmental impact and improving disaster prevention, as an insulating cooling liquid instead of conventional mineral oil. We acquired the basic characteristics of rapeseed oil, which affects the insulation, cooling, and deterioration of transformers, and obtained findings that contribute to the deterioration characteristics of insulating paper and rationalization of cooling through long-term tests using a model transformer equivalent to the actual equipment. We have reflected them in the transformer design and commercialized, and have supplied more than 400 units by 2020 and are operating without any problems (Figure 16).

In North America, due to the disaster prevention evaluation of natural ester oil, legislation for mitigation measures for firefighting equipment has been established, and the application of natural ester oil immersed transformers to indoor substation equipment is expanding. If the same law is applied in Japan in the future, it is expected that the fire protection equipment will be simplified by installing a rapeseed oil immersed transformer.

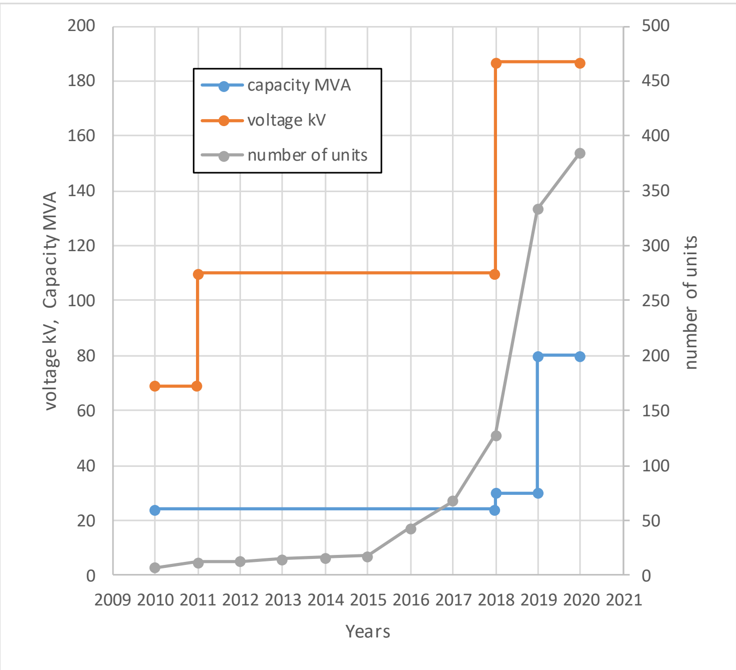


Fig. 16 Trends in voltage and capacity ratings and number of production units of rapeseed oil immersed transformer

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