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Water content analysis effect on dielectric breakdown voltage in 500 kv transformer oil using coefficient correlation method

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Abstract. Transformer is a vital component in distributing electrical power. The use of transformer oil which is continuously for a long time and not monitored can cause fatal damage to the transformer. This condition triggered by high water content in the transformer oil which causes breakdown voltage failure and electrical short circuit on the transformer. Therefore this study aims to analyze the influence of water content and breakdown voltage on 500 kV transformer oil type Kunlun Ki25x using the coefficient correlation method. The coefficient correlation method is statistical analysis technique used to look for relationships between variables that are quantitative. Two variables are said to be correlated if the changes in one variable will be followed by changes in the other variables regularly in the same direction (positive correlation) or opposite direction (negative correlation). For material testing and analysis data researcher using Megger OTS100AF instrument. This experiment conduct in paiton 9 power plant East Java for 36 month. Based on experimental data result researcher obtained a strong negative correlation value on the relationship of water content and breakdown voltage with the coefficient R = -0.88 on the function y = 0.7692x + 85.733 and it has characteristic that the increase in water content (x) is inversely proportional to increase the dielectric breakdown voltage (y). In addition, it is also known that the increase in transformer oil temperature is directly proportional to the increase in water content with a positive correlation of R = 0.92 at the function y = 0.4208x + 50.155. From the results above, it can be concluded that the parameters of water content and temperature have an impact on the value of the breakdown voltage and the performance of the transformer

1. Introduction

Transformer is important components in the process of distributing electric power from the generating system to the consumers. This component serves to increase or decrease voltage without changing the power, frequency and phase of the power distribution system. As a result of continuous use in a long time span has potential to cause damage or disturbance to the transformer. Generally this disturbance is caused by overloading. High temperature in overloading triggered hot spots arise in the internal area of the transformer. If this condition left continuously without maintenance it will causes decrease in the transformer oil insulation power capability. Zhao Tao research explains that the characteristics of transformer oil in high temperature conditions will produce water vapor that settles on the ceiling of the transformer [1]. While in low temperature conditions, the water vapor will drip and contaminate the transformer oil content. This condition causes the water content in transformer oil to be high and influences the performance of the transformer oil insulation and encourages the breakdown of dielectric voltage (breakdown voltage) of the transformer. Previous research on transformer oil was carried out by Jonathan Friz [2]. In his research, Jonathan stated that the increase in temperature affects the value of the transformer oil breakdown voltage. Other studies regarding the characteristics of transformer oil were carried out by Firdaus [3]. In his research, Firdaus found that the loading and temperature of the transformer affect the dielectric strength of the transformer oil breakdown voltage. Based on the two theoretical studies, the researcher wants to conduct research with a focus on the causes and effects of water content variables on the transformer oil breakdown voltage characteristics. Research was conducted through testing the water content and breakdown voltage on the kunlun ki25x type transformer oil with a 500 kv transformer test object. Coefficient correlation method is chosen to determine the characteristics influence of the water content on the breakdown voltage. Based on mathematical functions from this research will be obtained that indicates the presence or absence of thermal and electrical failures of the transformer. Furthermore, the results of this research will be analyzed whether the transformer oil insulation tested is still suitable for use, or needs to be purified or replaced with new ones.

2. Research method

The implementation and testing of transformer oil in this research were carried out based on the flowchart shown in Figure 1.

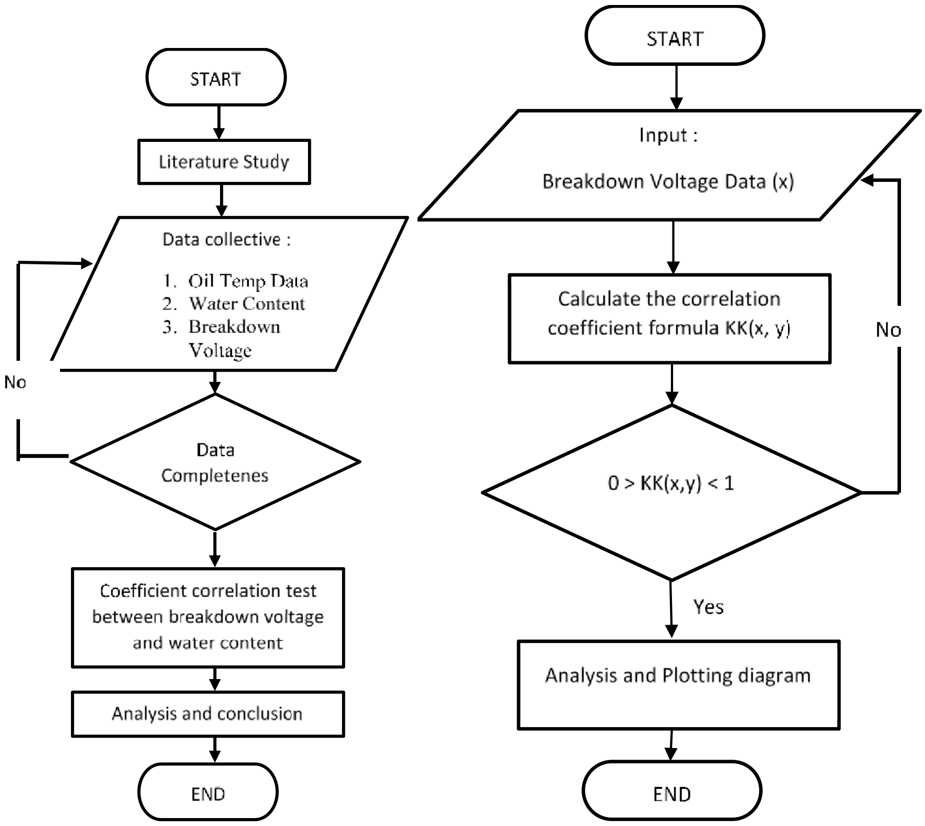
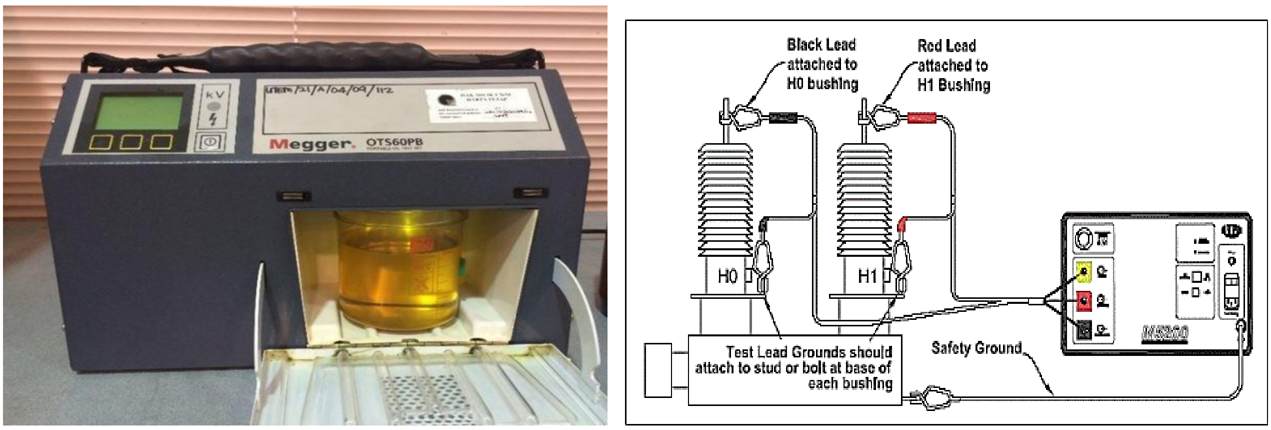


Figure 1. (a) Research flowchart, (b) Transformers oil test flowchart

Transformer oil testing was carried out in the Paiton 9 power plant laboratory using the Kunlun Ki25x oil test material with specifications as shown in Table 1. While the test equipment uses a set of Megger OTS100AF. This test is carried out to determine the relationship between the effect of temperature and water content in oil on the dielectric breakdown voltage of the transformer. Shape and schematic circuit test using instrument Megger OTS100AF are shown in Figure 2. After obtaining the test data the next step is to analyze and calculate using the coefficient correlation method

Table 1. Kunlun Ki25x transformer oil specifications

No.	Properties of Isolation Oil	Unit	Class I / Class II	Test Method	Test Place
1	Clarity	-	clear	IEC 296	Lab
2	Density (20^0) C	g/cm^3	< 0.895	IEC 296	Lab
3	Viscosity (20^0) C	cSt	< 40 < 25	IEC 296	Lab
	Kinematic – (15^0C)	cSt	< 800		
	Kinematic – (30^0C)	cSt	< 1800		
4	Neutrality Number	mgKOH/g	< 0.003	IEC 296 A	
5	Sulfur Corrosion	-	Not corrosive	IEC 296 A	Lab
6	Translucent Voltage	kV/2.5 mm	> 30	IEC 156	Lab
7	Dielectric Leakage Factor	-	< 0.05	IEC 474	Lab
8	Oxidation Resistance **1.** Neutrality number **2.** Impurity	mgKOH/g %	< 0.40 < 0.10	IEC 74	Lab



(a) (b)

Figure 2. (a) Megger OTS100AF, (b) Schematic circuit megger OTS100AF

Coefficient correlation method is a statistical analysis technique used to look for relationships between variables that are quantitative. Two variables are said to be correlated if the changes in one variable will be followed by changes in the other variables regularly in the same direction (positive correlation) or opposite direction (negative correlation) [4]. In general, the coefficient correlation method is written in equation 1 to 3 below

$$KK(x,y) = \frac{\sum (xi - x)(yi - y)}{\sqrt{\sum_{i=1}^{N} (xi - x)^2 \sum_{i=1}^{N} (yi - y)^2}} \quad (1)$$

$$a = \frac{n(\sum xy) - (\sum x)(\sum y)^2}{n(\sum x^2) - (\sum x)^2} \tag{2}$$

$$b = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)^2}{n(\sum x^2) - (\sum x)^2} \tag{3}$$

With :

$KK_{(x,y)}$ = coefficient correlationbetween variable x and y

xi = the value of first x variable ; yi = the value of first y variable

x = average value of x variable ; y = average value of y variable

To measure the level of correlation quantitatively, indicators interpretation of the coefficient correlation values are used, which are shown in Table 2 below. The range of coefficient correlation values range from 0 to 1 and is positive or negative

Table 2. Interpretation of coefficient correlation values

No	$KK_{(x,y)}$	Interpretation
1	0	Uncorrelated
2	0.01 – 0.20	Very Low Correlation
3	0.21 – 0.40	Low Correlation
4	0.41 – 0.60	A little low Correlation
5	0.61 – 0.8	Enough Correlation
6	0.81 – 0.99	High Correlation
7	1	Very High Correlation

3. Result and discussion

The 500kV transformer oil test results using two test parameters namely water content testing and breakdown voltage testing are shown in Table 3 below

Table 3. Oil sample trial results based on test parameters

No.	Working Voltage (KV)	Load (R)	Time (Month)		Temp (C)	Water content (ppm)	Breakdown voltage (KV)
			Duration	Date			
1	500	650	1	Apr-16	73	6	80.6
2	500	650	6	Sep-16	73	6	82
3	500	650	9	Des-16	77	7	78.1
4	500	650	12	Mar-17	80	10.09	76.8
5	500	650	15	Jun-17	84	15	76
6	500	650	18	Sep-17	87	18	74.6
7	500	650	21	Des-17	72	6	79.8
8	500	650	24	Mar-18	73	7	81.2
9	500	650	31	Okt-18	80	11	79
10	500	650	33	Des-18	84	15	75.5
11	500	650	35	Feb-19	88	20	65.7
∑ =	5500	7150	205		603	121.9	849.3

From the data above shows that initial indication of transformer condition is obtained from each oil sample tested where the results are presented in the form of Figure 3.

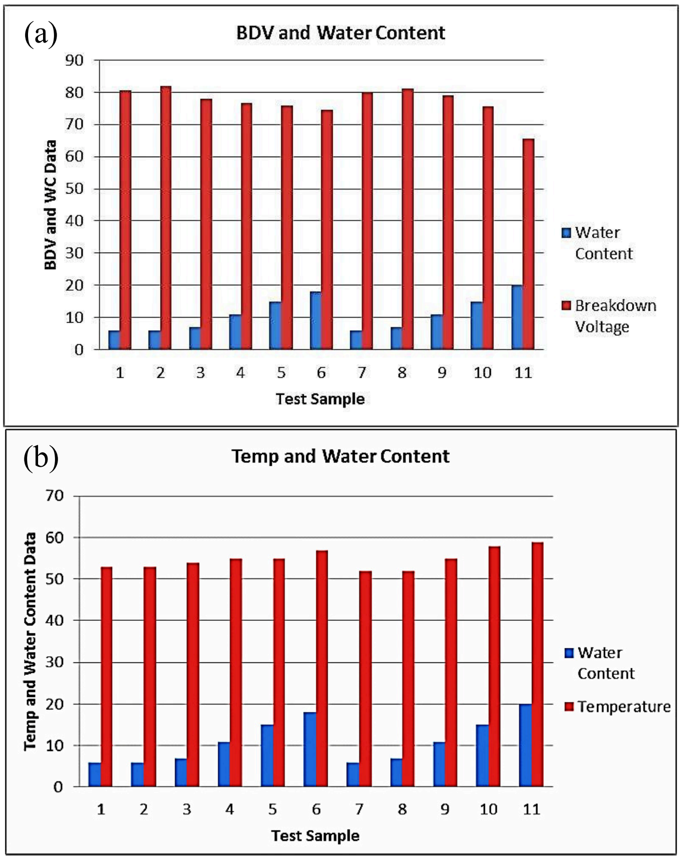


Figure 3. (a) Water content vs BDV graph, (b) water content vs temperature graph

From Figure 3. (a) Researcher found that the increase of water content in transformer oil causes the breakdown voltage value in the transformer oil to decrease. When the lowest water content value is 6 ppm the value of the voltage breakdown is 82 kV, while the highest water content value is 20 ppm the value of the voltage breakdown is 65.7 kV. Seen on Figure 3(a) the value of water content is inversely proportional to the value of the breakdown voltage. An experiment conducted by Zhang L shows when transformer oil is contaminated with water, its performance as insulation and cooling will decrease due to the nature of oil that cannot be fused with water [5]. If more water is contaminated with transformer oil, the dielectric properties of the transformer oil will also decrease as insulation. It will increase voltage insulation failure and short circuit to the transformers.

Characteristic comparison of parameters in water content and temperature can be seen in Figure 3(b). The increase of water content in the transformer oil causes the temperature value in the transformer oil to rise. When the lowest water content value is 6 ppm, the value of the transformer oil temperature is 53 C, while the highest water content value is 20 ppm the value of the transformer oil temperature is 59 C. this condition prove that relationship of water content and transformer oil temperature is linear. To analyze the correlation values of breakdown voltage and water content variables, it is necessary to calculate the components of the correlation method shown in Table 4.

Table 4. Coefficient correlation analysis breakdown voltage and water content

No	Water content (ppm)	Breakdown voltage (Kv)	ai - a	bi -b	ai - a)^2	(bi - b)^2	(ai - a)(bi - b)
1	6	80.6	-5.08	3.39	25.82	11.50	-17.23
2	6	82	-5.08	4.79	25.82	22.95	-24.35
3	7	78.1	-4.08	0.89	16.66	0.79	-3.64
4	10.9	76.8	-0.18	-0.41	0.03	0.17	0.07
5	15	76	3.92	-1.21	15.35	1.46	-4.74
6	18	74.6	6.92	-2.61	47.86	6.81	-18.05
7	6	79.8	-5.08	2.59	25.82	6.71	-13.17
8	7	81.2	-4.08	3.99	16.66	15.93	-16.29
9	11	79	-0.08	1.79	0.01	3.21	-0.15
10	15	75.5	3.92	-1.71	15.35	2.92	-6.70
11	20	65.7	8.92	-11.51	79.53	132.46	-102.64
∑	121.9	849.3			268.94	204.91	-206.87

Table description:
ai = the value of water content to i
a = *water content* average value
bi = the value of *breakdown voltage* to i
b = average value of breakdown *voltage*

By applying equations 1 to 3 we get the value of correlation R = -0.88; a = 0.7692 and b = 85.733 so that we get the linear equation Y = 0.7692x + 85.733. High negative value of R= - 0.88 nearly 1 prove that water content and breakdown voltage have strong inversely relationship. This condition influenced with many factor, one of them is the transfer of wet solid materials such as fiber and other contaminants such as water to the electrically pressure area between the two electrodes [6]. If this continues, a bridge will be formed between the two electrodes. If this continues, bubbles will be formed between the two electrodes [7]. Bubble will form along the bridge and cause conduction, ionization and breakdown voltage to occur. For testing and analysis of water content and temperature parameters using coefficient correlation method are shown in Table 5 below.

Table 5. Test results for water content and temperature parameters

No	Water content (ppm)	Temperature (C)	ai - a	ci - c	$(ai - a)^2$	$(ci - c)^2$	(ai - a)(ci - c)
1	6	73	-5.08	-1.82	25.82	3.31	9.24
2	6	73	-5.08	-1.82	25.82	3.31	9.24
3	7	77	-4.08	-0.82	16.66	0.67	3.34
4	10.9	80	-0.18	0.18	0.03	0.03	-0.03
5	15	84	3.92	0.18	15.35	0.03	0.71
6	18	87	6.92	2.18	47.86	4.76	15.09
7	6	52	-5.08	-2.82	25.82	7.94	14.32
8	7	73	-4.08	-2.82	16.66	7.94	11.50
9	11	80	-0.08	0.18	0.01	0.03	-0.01
10	15	84	3.92	3.18	15.35	10.12	12.47
11	20	88	8.92	4.18	79.53	17.49	37.29
∑	121.9	603			268.94	55.64	113.16

Table description:
a_i = the value of water content to i
a = average value of *water* content
c_i = the value of temperature to i
c = average value of temperature

By applying equations 1 to 3 we get the value of R = 0.92; a = 0.42 and b = 50.155 so we get the function of linear equation Y = 0.42 x + 50.155. The result give high positive value of R = 0.92 nearly 1 this indicate that water content and temperature have strong linear relationship. this condition indicate more water content in the transformer oil causes the condition of the transformer oil to heat up quickly. This is because the oil and water structure cannot be integrated [8]. The graph figure of the coefficient correlation relationship between each parameter test is shown in Figure 4 and Figure 5 .

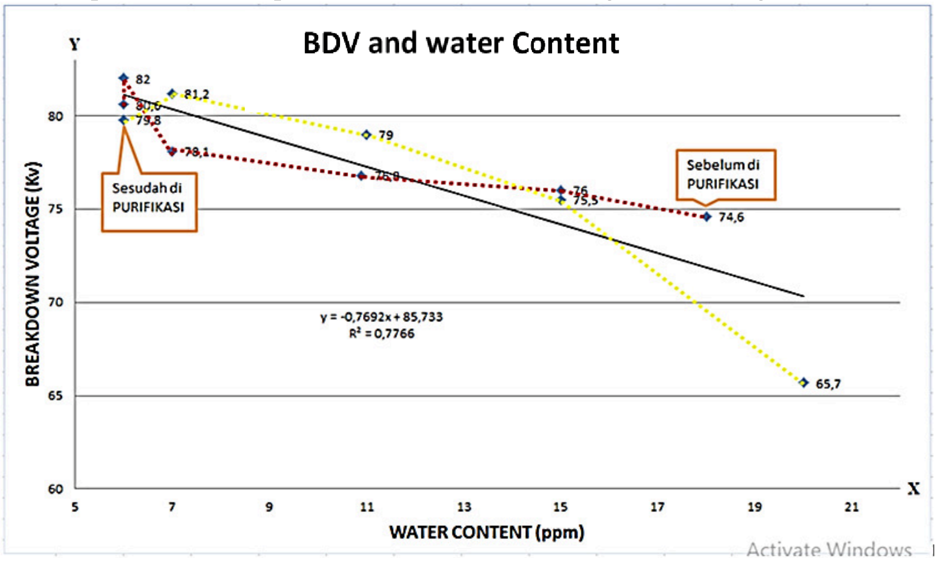


Figure 4 Water Content Vs BDV Value Curve

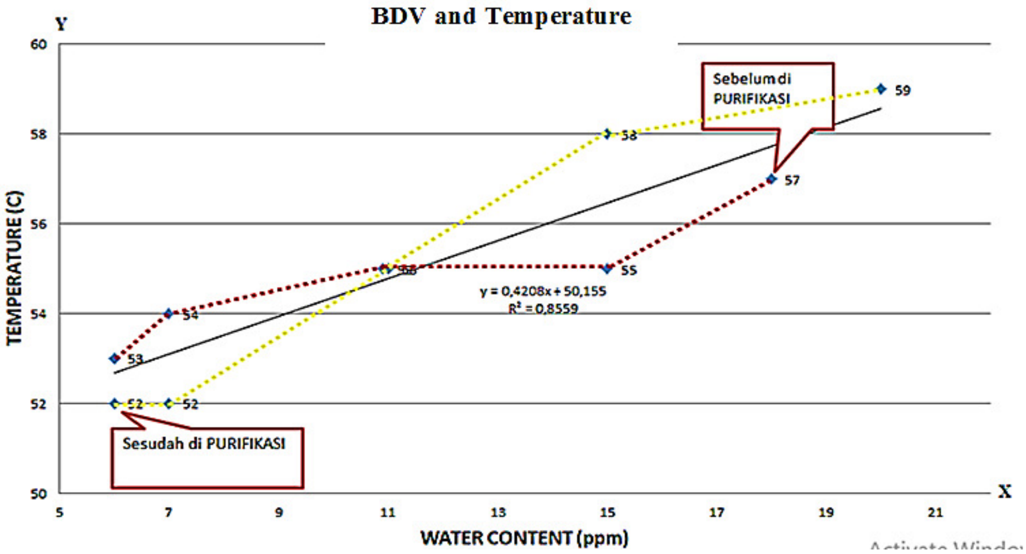


Figure 5. Value of water content vs temperature

The final discussion is the result of testing water content for the time at which these two parameters have an influence in determining the age of transformer oil use. Analysis of the coefficients correlation between two parameters is shown in Table 6 and Figure 6.

Table 6 Water content and time testing results

No	*Water content* (ppm)	Time (Month)	ai - a	di - d	$(ai - a)^2$	$(di - d)^2$	(ai - a)(di - d)
1	6	1	-5.08	-17.64	25.82	311.04	89.62
2	6	6	-5.08	-12.64	25.82	159.68	64.22
3	7	9	-4.08	-9.64	16.66	92.86	39.33
4	10.9	12	-0.18	-6.64	0.03	44.04	1.21
5	15	15	3.92	-3.64	15.35	13.22	-14.25
6	18	18	6.92	-0.64	47.86	0.40	-4.40
7	6	21	-5.08	2.36	25.82	5.59	-12.01
8	7	24	-4.08	5.36	16.66	28.77	-21.89
9	11	31	-0.08	12.36	0.01	152.86	-1.01
10	15	33	3.92	14.36	15.35	206.31	56.28
11	20	35	8.92	16.36	79.53	267.77	145.93
∑ =	121.9	205			268.94	1282.55	343.03

Table description:
a_i = The value of *water content* to i
a = average value of *water content*
d_i = The value of time to i
d = average value of time

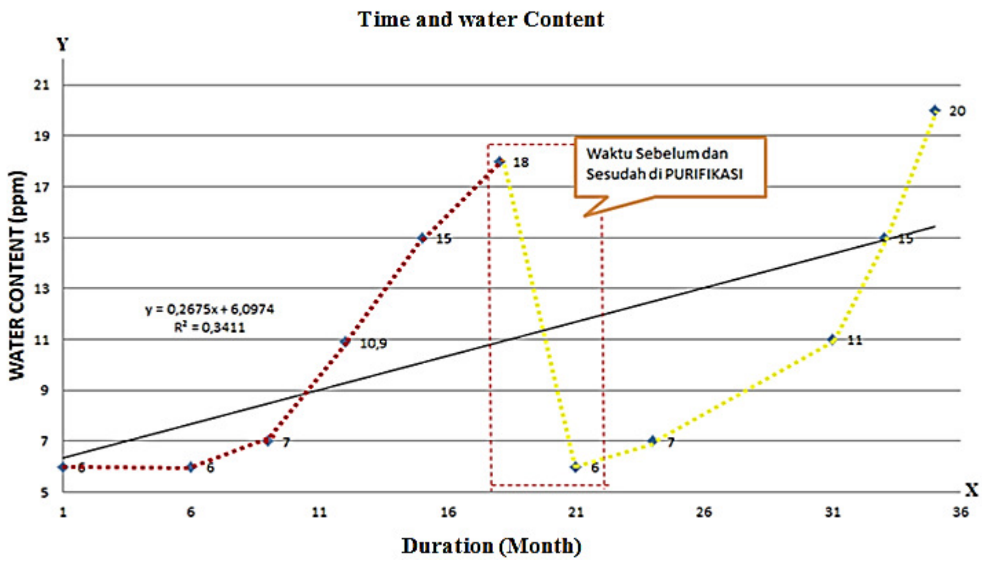


Figure 6. Water content vs time curve value

From the above table using equations 1 to 3 obtained the value of R = 0.58; a = 1.275 and b = 4.5 so we get the function of linear equation Y = 1.275x + 4.5.

From Figure 6, it can be seen data of water content before and after purification, after purification water content value will decrease and enter safe values category. This treatment also make transformer oil structure will not be as new again because there is still a little remaining water content that cannot be removed, this will effect in the performance of the transformer oil is reduced even if only slightly [9, 10].

4. Conclusion

Based on measurements, testing and analysis of water content and dielectric strength of transformer insulation oil in PT Paiton 9 power plant, the authors can conclude that the increase in water content is inversely proportional to the increase in the breakdown voltage of insulating oil with a strong negative correlation r = - 0.88, in other words the greater water content in the transformer, the smaller the breakdown voltage of the insulating oil. The increase in the temperature of the insulating oil is directly proportional to the water content of the insulating oil with a strong positive correlation r = 0.92, in other words the higher the temperature of the insulating oil, the higher the value of the water content in the transformer. From the correlation analysis of the relationship of the increase in water content with the dielectric strength (breakdown voltage) a linear graph is obtained. y = -0.7692x + 85.733 with r = -0.88 and R^2 = 0.7766

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