Space Charge and Electric Field Analysis on Contaminated XLPE Insulator

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Article Info

ABSTRACT

Nowadays, XLPE cable has been widely used because it has better resistance than other cables. XLPE insulation has unique features including a high dielectric strength and high insulation resistance. A lot of researches based on hardware and software have been conducted to prove the effectiveness of XLPE cable such as AC and DC applications and Space Charge Distribution measurement under HVDC at High Temperature. This research focused on analysis of space charge and electric field on XLPE cable with effect of non-uniform contamination layer by using Quickfield Software. Non-uniform contaminations have been applied along XLPE cable using Arsenic Tribromide (AsBr3), Boron Bromide (BBr3), Ethylene Dichloride (CH2C1), Formic Acid (CH1O2), Formamide (CH3NO) and Alcohol element. Presence of these contamination elements represent of underground contamination. The size and layer of the contamination were non-uniform type. From the results, it is shown that lower dielectric constant of contamination will affect more on charge of XLPE insulation. As a conclusion, it can be seen lower dielectric constant value of contamination element greatly affecting the performance of XLPE insulation. Furthermore, size of contamination also influences the content of charge in contamination where the bigger the contamination size, the more charge contained in the contamination.

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1. INTRODUCTION

XLPE has begun to develop since 1963. There are Underground Power Cable, Distribution Cable, Overhead Transmission Line and Industrial Cable [1]. Researches have been done on Electric field Calculations for AC and DC Applications of Water Controlled Cable Termination [2] and Simultaneous Measurement of Space Charge Distribution and External Circuit Current in XLPE under HVDC at High Temperature [3] and contamination [4-5]. Nowadays, XLPE cable has been widely used because it has better resistance than other cables [6-8]. The improvement of the XLPE cable has made from time to time under extensive research in order to prove XLPE cable is safe to use. This improvement will increase the demand of international market. In addition, XLPE cable has been classified into several use such as transmission and

distribution cable, aerial cable, underground cable, control cable,low voltage cable and,high voltage drop wire [8].

One of the interesting characteristic of XLPE cable is maximum conductor temperature which is 90˚C in normal continuous operation. Furthermore, XLPE cable has a good heat resistance, moisture resistance and good resistance to chemicals and atmosphere. XLPE cable is easy to control because it has a smaller overall diameter, lighter weight, easy to be installed and easy in joining and termination [6], [9].

An underground HV cable may exposed to various pollutants carried by water flow either on the surface or in the soil. Water content that we see are not only water, but it is contaminated as a result of human activities. Due to the contamination, this is likely lead to erosion of the cable including a reduction in life expectancy and also performance of the cable. Based on this factor, this research were done to determine effects might have on the XLPE insulation through a non-uniform layer contamination reaction from selected and differences dielectric constant held by elements of the contamination. The results were focused on space charge and electric field strength [10].

A lot of research based on hardware and software has been conducted to prove the effectiveness of XLPE cable. Effect of temperature and current density were one of the results by using XLPE cable. Therefore, this research was used Quickfield Software to identify the effect of an electric field and also to identify the space charge in XLPE cable insulator when expose to non-uniform contamination [11].

2.　RESEARCH METHOD

Underground cables were used in this study and this cable was tested against contamination of groundwater contamination, this can be identified by the permittivity value represented by groundwater contaminations and it is evident that there is groundwater contaminations as a result of the research conducted [12]. This research used Software Quickfield to examine the space charge, electric field and its effect on XLPE insulator [13]. Non-uniform contaminations have been used in this research. In addition, to confirm the presence of charge, the electric field was used as a measurement. Arsenic Tribromide (AsBr3), Boron Bromide (BBr3), Ethylene Dichloride (CH2C1), Formic Acid (CH1O2), Formamide (CH3NO) and Alcohol were used in this research [14].

The contamination that has been used for this research are shown in Table 1 and Table 2 below. The simulation was run based on these properties. The dielectric constant of the contamination was inserted in the material properties. Different value of dielectric constant has represent.

Table 1. The different properties used for contamination [4], [15-18]

	Chemical Formula	State	Dielectric Constant
Boron Bromide	BBr_3	Liquid	2.58
Arsenic Tribromide	$AsBr_3$	Liquid	9
Ethylene Dichloride	CH_2C_1	Liquid	15
Alcohol		Liquid	31
Formic Acid	CH_1O_2	Liquid	57
Formamide	CH_3NO	Liquid	84

Table 2. Properties Used in the designated model [9], [19-20]

Properties	Parameter	Dielectric Constant
XLPE Insulator		2.3
Size of conductor	Radius = 4.72035 mm	
Tickness of XLPE Insulator	3.4 mm	
High Voltage	11kV	
Ground	0V	
10 Size of Contamination (mm^2)	0.1819, 0.6787, 0.7637, 1.3105, 1.7879, 1.8142, 2.5496, 2.7026, 2.7171, 3.8484	

Figure 1 shows the beginning of model painting methods. In this research, the method of inserting the shape was used where the diameter of the conductor is 9.44 mm and insulator thickness is 3.4 mm. The contaminations also have been used based on two conditions which are hydrophilic and hydrophobic [20]. To find hotspot area, click "Mesh" and the green line will appear randomly. The maximum mesh is 255 nodes and in this research, the node has been set to maximum of 214 nodes.
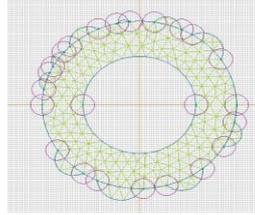
Figure 1. XLPE insulator model with Mesh

3. RESULTS AND ANALYSIS

This part will discuss about the space charge and the electric field effect on XLPE insulator with effect of non-uniform layer contamination as shown in Figure 2. It consists of 2D panel-parallel models made by Quickfield Student Version software. Based on the analysis, there have been changes between normal condition of XLPE insulation and ten (10) different size of contamination that randomly designed. For this research, only four (4) from ten (10) has been pickup to analyze the space charge and the electric field strength effect on XLPE insulator.

The results of the simulation of XLPE insulator through normal condition or without contamination shows the uniform reading of electric field strength on each thickness of 3.4 mm. Figure 2 shows the color map of normal condition XLPE insulator. From the colour contour map which was obtained, the reading of electric field strength for XLPE insulator under normal condition has been generated. Figure 3 shows a graph that has been formed through contour reading method. X-axis was labeled as the thickness of XLPE insulator, while the Y-axis is the reading of electric field strength. From the graph, it can be concluded that the further insulator from the conductor, the less electric field strength.
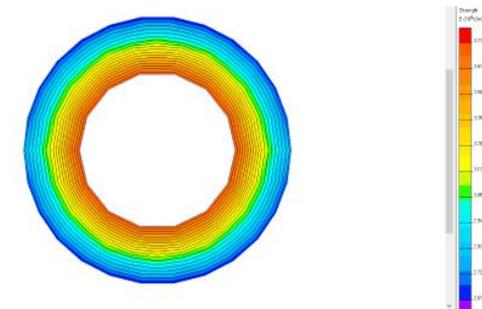

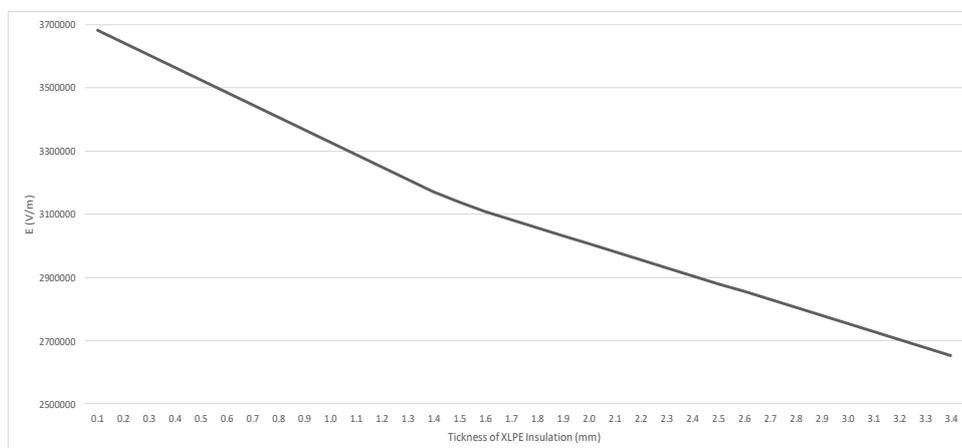Figure 2. Colour map contour Electric Field Strength for XLPE insulation cable

Figure 3. Graph thickness of XLPE insulator against Electric field strength

Figure 4 shows the charge contained in XLPE insulation under normal condition. Under normal condition, charge in XLPE insulator shows the positive number and the charge changed when contaminations were inserted. Based on Figure 4, the reading of the charge Qs = 5.5195e-8 C.
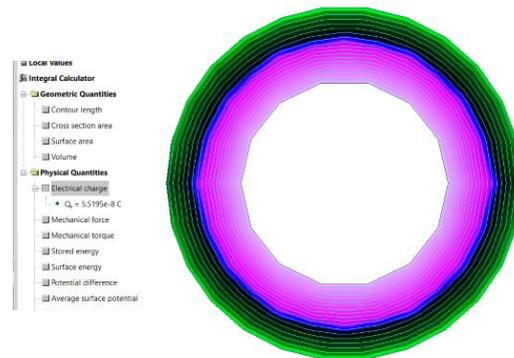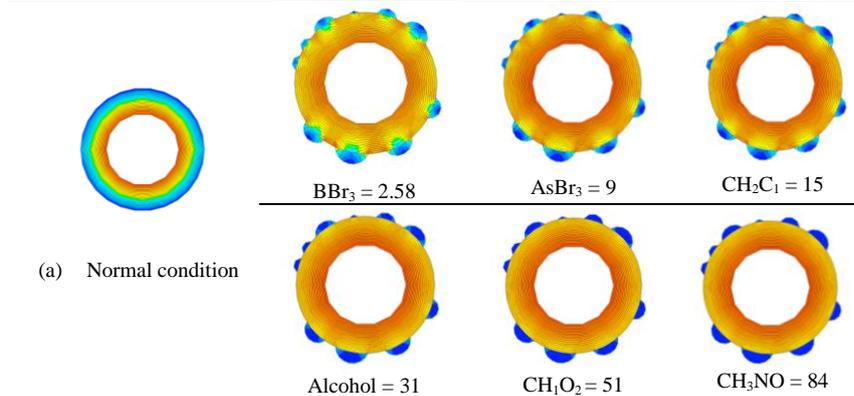

Figure 4. Colour map for charge at XLPE insulator without contamination

3.1. Contour Map on with Different Contamination

Table 3 shows different of overall colour contour map based on different contamination. There were six (6) contamination selected and each has different dielectric constant values. By referring to table 3 (a) where the XLPE insulator is in a state without the effects of contamination, have shown a good performance. After effect with contamination, the XLPE insulator performance changed according to the type of contamination which was determined. On table 3 (b), an effect that applies to XLPE is very significant because BBr3 have the dielectric constant lower value than dielectric constant values for the XLPE insulator which is 2.58. Unlike table 3 (g), where CH3CO have been approached and seemed unimpressed XLPE insulation or only slightly affected and are in a better situation in terms of performance.

Table 3. Difference colour contour map based on contamination with different dielectric constant

$BBr_3 = 2.58$	$AsBr_3 = 9$	$CH_2C_1 = 15$
Alcohol = 31	$CH_1O_2 = 51$	$CH_3NO = 84$

(a) Normal condition

Meanwhile Table 4 shows the different charge on XLPE insulator based on selected contamination. XLPE insulation has a full charge if in normal condition with the 5.5195e-9C. The charge value decreases if contamination that has a different dielectric constant value of BBr3 to CH3NO.

Table 5. Different charge on XLPE insulator based on selected contamination

Parameter	Charge (Coulomb)						
Layer contamination	Without contamination	BBr3	ASBr3	CH_2C_1	Alcohol	CH_1O_2	CH_3NO
XLPE	5.5195e-8C	-8.0024e-8C	-.1386e-8C	-.5798e-8C	-8.064e-8C	-8.33e-8C	-8.4444e-8C

3.2. Electric Field Strength with Different Contamination Size

Table 6(a) shows the selected contamination which is Boron Bromide (BBr3) that has the lowest dielectric constant of 2.58. From Table 6, it can be concluded that the smaller size of contamination has no effect on XLPE insulator compared to the bigger size of contamination. It can be shown at a contamination size of 0.1819mm2, where the effect on electric field strength and charge has no significant difference.

Meanwhile, at a contamination size of 3.8484mm2, the effect was obvious on electric field and the charge. Based on Figure 6(b) until Figure 6(f), Arsenic Tribromide (AsBr3), Ethylene Dichloride (CH2C1), Alcohol, Formic Acid (CH1O2) and Formamide (CH3NO) with dielectric constant of 9, 15, 31, 57 and 84 respectively has been used. It's clearly seen where the electric field strength of XLPE insulator is not affected by the selected contamination and the charge was increased in each contamination.

Table 6. Difference contour on XLPE insulation and contamination

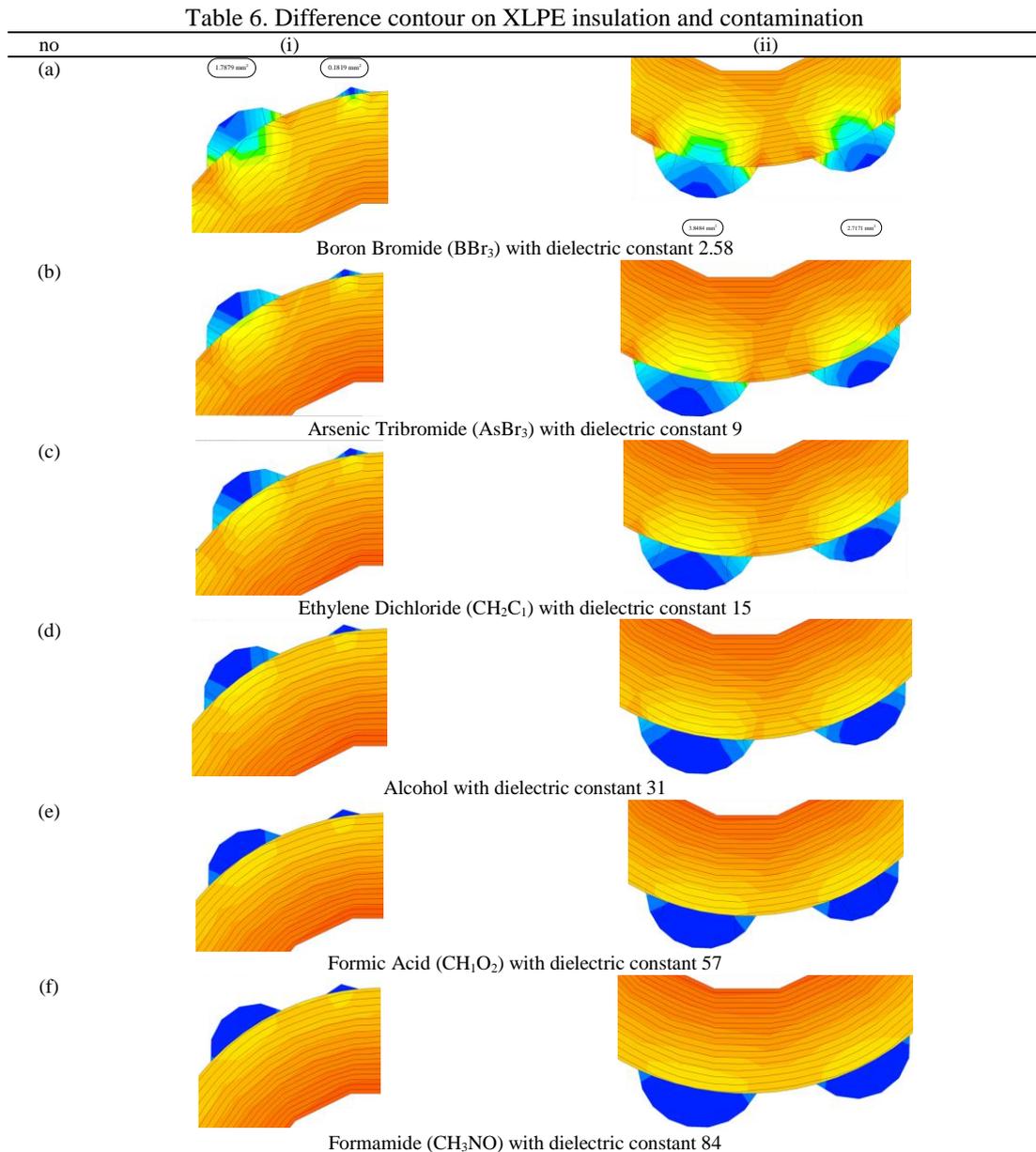| no	(i)	(ii)
(a)	Boron Bromide (BBr$_3$) with dielectric constant 2.58	
(b)	Arsenic Tribromide (AsBr$_3$) with dielectric constant 9	
(c)	Ethylene Dichloride (CH$_2$C$_1$) with dielectric constant 15	
(d)	Alcohol with dielectric constant 31	
(e)	Formic Acid (CH$_1$O$_2$) with dielectric constant 57	
(f)	Formamide (CH$_3$NO) with dielectric constant 84	

Figure 5 till Figure 8 show the changes in electric field on XLPE insulator when there was non-contamination layer on insulator surface. The changes happened due to the different dielectric constant that affect XLPE condition as an insulator. This situation was caused by smaller value of dielectric constant where the higher value of dielectric constant of contamination, the severe condition of the insulator. The electric field strength also was affected by this situation.

Based on Figure 5, the smaller size of contamination gave a small effect on XLPE insulator. The significant difference was observed on the surface of XLPE towards difference contamination with different dielectric constant. Contamination formed from 0.1819mm2 size did not has much impact on the XLPE insulation near the conductor. At the end of the XLPE insulator has visible effects carried by contamination on XLPE insulation. Boron Bromide (BBr3) is the most significant element that affects XLPE insulation starts at a distance of 3.0 mm - 3.4 mm.

Figure 5. Electric field strength on XLPE insulator with contamination size of 0.1819 mm2

Based on Figure 6, Boron Bromide (BBr3) with dielectric constant of 2.58 has greatly affects the electric field strength on XLPE insulator compared to other contaminations. Boron Bromide (BBr3) has shown that the effects of contamination is greater than others. This could cause XLPE insulation performance is on the wane. This sudden effect began to occur at a distance of about 1.6 mm-1.8 mm and thereafter, reading of electric field strength decreases. 1.7879 mm2 sized contamination is seen much influence permormance XLPE insulation itself.

Based on Figure 7, difference contaminations with different dielectric constant has shown significant changes on XLPE insulator. The significant difference of electric field strength has been shown starting from Boron Bromide (BBr3) to Formamide (CH3NO). Not too much difference in the size of the measuring contamination 2.7171 mm2 and 1.7879 mm2. Each contamination has significant differences value from the electric field strength readings start at a distance of 1.6 mm - 1.8 mm from the conductor and continued to fall sharply until the end of XLPE insulation.
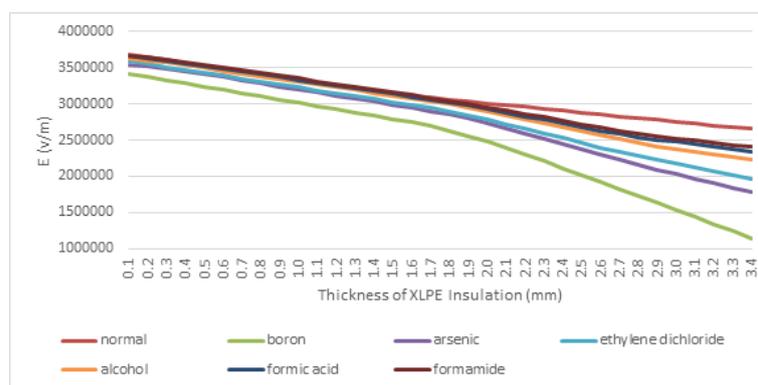

Figure 6. Electric field strength on XLPE insulator through contamination size of 1.7879 mm2

Based on Figure 8, it can be concluded that the bigger the size of contamination, the larger effect of electric field strength on XLPE insulator mainly of contamination with lower dielectric constant from XLPE insulator. The most significant impact came on Boron Bromide (BBr3), which at a distance of 3.2 mm from the conductor, electric field strength readings fall sharply compared with the reading of other contamination. This situation will result in deteriorating performance of the XLPE insulation.
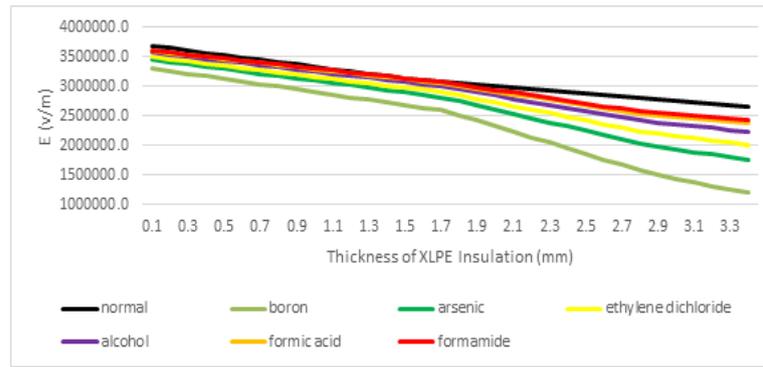
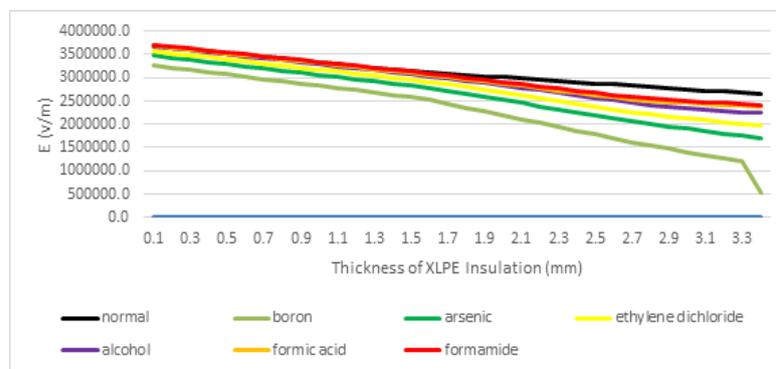Figure 7. Electric field strength of XLPE insulation with contamination size of 2.7171 mm2

Figure 8. Electric field strength on XLPE insulator with contamination size of 3.8484 mm2

3.3. Difference Charge on Different Size of Contamination of Non-uniform Layer

Figure 9 shows the difference charge on four different size of contamination which are 0.6787 mm2, 1.7879 mm2, 2.7171 mm2 and 3.8484 mm2. Contamination that has lower dielectric charge had higher charge compared to high dielectric. It has been proven through this analysis where Boron Bromide (BBr3) which has a dielectric constant of 2.58 has a higher charge compared to Formamide (CH3NO) which has a dielectric constant of 84. Furthermore, size of contamination also influences the content of charge in contamination where the bigger the contamination size, the more charge contained in the contamination. Through this research, it has been proven that contamination which has a size of 3.8484 mm2 has more charge compared to the mid and smaller size.
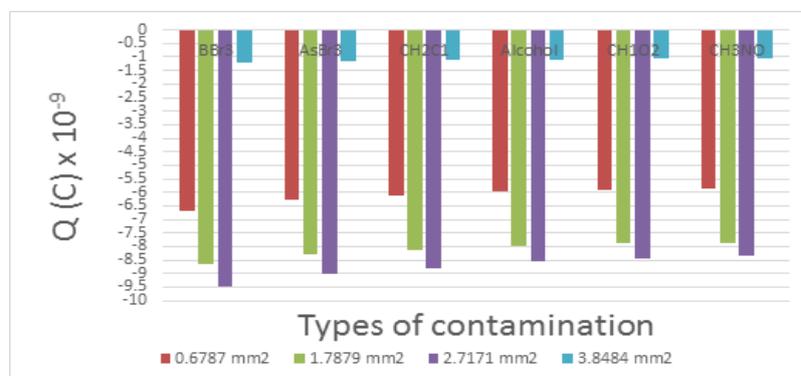

Figure 9. Difference charge on different size of contamination of non-uniform layer

4. CONCLUSION

The main goal of this project is to design XLPE insulated cable and evaluate the electric field and space charge from normal condition to effect of non-uniform layer contamination. Furthermore, XLPE insulation has unique features including high dielectric strength and high insulation resistance. Contaminations were selected based on the value of the dielectric constant for each of the elements of contamination as well as the size of the contamination itself was chosen randomly. From the results obtained, it can be seen and identified elements of contamination which is a lower dielectric constant value greatly affecting the performance of XLPE insulation. As well as the size of the non-uniform contamination layer, the larger the size of the contamination, the more emphasized XLPE insulation.

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