Study on Degassing Efficiency of Crosslinked Polyethylene High Voltage Cable

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ABSTRACT

Two different methods, multi head space extraction (MHE) gas chromatography (GC) on a piece of cable sealed in gas bag and head space GC (HSGC) for sliced cable sample sealed in HSGC vials, were utilized to measure methane concentration and its distribution across insulation layer of the high voltage (HV) cables made from both conventional and low degassing XLPE insulation after different degassing time. A semi-empirical degassing model was developed from slab diffusion model based on Fick's Laws and the semi-empirical diffusion coefficient, K, of methane in XLPE were estimated from both real and simulated degassing curves.

KEYWORDS

Power transmission, XLPE, high voltage cable, degassing, by-products

INTRODUCTION

Transmission class cables today are insulated with crosslinked polyethylene (XLPE) with the dominant crosslinking process using peroxide. These peroxide crosslinked cables are manufactured in a continuous extrusion and vulcanization process followed by an off-line process, called degassing, to remove the peroxide crosslinking reaction by-products. The by-products of the crosslinking reaction based upon the use of dicumyl peroxide include cumyl alcohol (CA), acetophenone (AP) and methane. The current degassing practice is mainly to reduce methane to a low level. Usually it will take 1 week to 1 month depending on cable configuration and degassing temperature. For submarine cable, the degassing becomes even longer due to the much longer cable length.

As demands of XLPE insulated HV land cable and submarine cable increase in recent years, the need to reduce degassing time has become more important, not only to improve cable manufacturing productivity but also to release the CV line capacity constrained by limited degassing chambers. Usually at least 10 degassing chambers are required for CV line to produce 220kV cable at the maximum capacity. Although degassing process has been practiced and studied [1-3] in cable industry for many years, the methane diffusion behavior in cable core during degassing was not fully understood mainly due to the less accurate methods to measure methane in cables. Depending on a sample preparation method, methane can be easily released from the sample, which can result in a significant error as the starting concentration in a cable is low.

In this study, multi-head space extraction (MHE) gas chromatography (GC) on a piece of cable sealed in gas bag [4-7] was used to measure the average methane in cable, and head space GC (HSGC) for sliced cable sample sealed in HSGC vials was used to measure methane distribution across an insulation layer. The methane diffusion behavior in degassing step was studied on different size of HV cables made of conventional XLPE, XLPE-1, or low degassing XLPE, XLPE-2, with these two methods. Furthermore, a semi-empirical degassing model was developed from slab diffusion model [4-6] based on Fick's Laws and the semi-empirical diffusion coefficient, K, of methane in XLPE were estimated from both real and simulated degassing curves.

EXPERIMENTAL

Several methane measurement methods have been recommended in CIGRE TB501 [8] including pressure, GC, weight loss, and Raman spectra. Among them, head space GC on a piece of pie shape specimen in a 620 ml vial is the most accurate one. However, the small sample pieces would not be representative of the whole cable core. Therefore MHE gas bag sampling method was developed to measure methane in a piece of cable core rather than a small amount of pie shape specimen. Methane measurement on a piece of cable core also reduces the methane released during sample preparation.

MHE gas bag sampling method

MHE is a technique that was introduced in 1980s as an accurate quantification method using headspace extraction independent of the matrices involved [9]. Gas bag sampling was combined with MHE in this study for accurate methane quantification in cable sample directly. After headspace extraction under certain conditions, a portion of methane can be released into a 10 L PVF gas bag from the cable. According to the MHE theory, exhaustive headspace extraction allows all methane to be released, resulting in complete recovery and eliminates the matrix effect of cable sample. As the amount of methane in the gas bag during the series of extraction steps decreases exponentially, the total amount of methane can be theoretically calculated with the value of first extraction after proper mathematical extrapolation. As indicated by equation [1], if A_1 and A_n are the peak area of methane at the first extraction and n times of extraction respectively, a linear fit will be observed between the extraction times (n) and the logarithm of An. By using the slope of the fit (K), the total peak area for infinite extractions can be estimated with equation [2], and with the response factor of the methane on GC, the total peak area can be converted to the total amount of methane.

$$\ln A_n = -K(n-1) + \ln A_1 \quad [1]$$

$$\sum_{n=1}^{\infty} A_n = A_1/(1-e^{-K}) \quad [2]$$