COMPARISON OF DIFFERENT ANALYTICAL TEST METHODS TO MONITOR CROSSLINKING BY-PRODUCTS IN XLPE INSULATED CABLES

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ABSTRACT

This study discuss in detail various analytical methods that can be used for the determination of different by-products present in crosslinked polyethylene after production and after degassing. The actual results, obtained by the different methods, are examined as well as the spread. The analytical techniques used are weight loss, TGA, GC, FT-IR line scan and extraction followed by HPLC analysis. To have a detailed understanding of the different by-products a combination of several analytical tools are needed. To use a simple analytical tool as, e.g. TGA, would be recommended as a monitoring tool when detailed knowledge already has been acquired.

KEYWORDS

Crosslinking, degassing, methane, cumylalcohol, acetophenone, by-products, TGA, HPLC, FT-IR, GC

INTRODUCTION

Today the preferred insulation material for cables rated from 1kV up to 500kV is crosslinked polyethylene (XLPE). The crosslinking of the polyethylene chains is accomplished by use of peroxides and dicumylperoxide (DCP) is the most frequently used type. For DCP, every decomposed peroxide molecule, whether it provides a crosslink or not, gives at least three decomposition products, also known as by-products. The main by-products are methane, cumylalcohol (CA) and acetophenone (AP) and these are contained within the crosslinked polyethylene. The ratio between CA and AP is determined by the actual temperature in the polymer matrix used during the crosslinking reaction. An increase of the crosslinking temperature normally results in a higher content of acetophenone and thereby in a higher content of methane as well [1]. Thus the composition of by-products will depend upon the cable type, production technology and the processing conditions used.

For all power cables, especially for high voltage (HV) and extra high voltage (EHV), there is a need to remove by-products or to reduce their concentrations [2]. The most important component to be removed, due to health and safety issues, is the methane. This is a flammable gas that can catch fire or create explosions during jointing and installation procedures. However, presence of methane can also lead to issues in service [3,4] as the gas pressure can create defects in the shielding and in the joints. For cables equipped with a metal barrier the gaseous products can exert a pressure, especially on the joints and terminations, and eventually cause a system failure. The polar by-products such as cumylalcohol and acetophenone mainly have to be reduced as they contribute to dielectric losses. During degassing, the by-products are redistributed and some are completely removed. Degassing is a diffusion controlled process and is dependent on many parameters including temperature, thermal processing history, morphology, orientation, crystallinity and degree of crystallinity, annealing, solubility and vapour pressure of the diffusion molecule(s) [5]. The peroxide by-products are most likely confined to the amorphous part of the low density polyethylene (LDPE) as small molecules are excluded from the crystalline areas.

In practice the temperatures used for the degassing operation range between 50 °C and 80 °C. However, care needs to be taken not to damage the core if high degassing temperatures are used, especially for heavy cables [2].

This paper will discuss in detail how the redistribution and removal of by-products from the cable core can be monitored by use different analytical techniques using different degassing temperatures, 50 °C to 70ºC, and after different degassing times. The focus of the discussion will be on the results obtained with the different analytical techniques used as well as on the spread in the data.

EXPERIMENTAL

Sample
The investigated cable is HV cable insulated with conventional material. The insulation thickness is 15 mm and the conductor area is 500 mm^2. The longer cable sample was taken at the cable core manufacturing line. Samples were cut in 1 meter lengths and each sample was immediately put into an aluminium bag that was sealed.

Sample preparation
The sample preparation started approximately 24 h after the cable core production. For the study cable core samples of around 9-10 cm in length were sealed at both ends with a tightened aluminium foil in order to only allow a removal of the by-products through the outer screen and not via the ends. The cable core pieces were degassed in an oven at the selected temperatures using maximum ventilation. It is understood that these procedures are significantly different from the actual degassing conditions used in practice where the whole cable core reel, with multiple layers of cable cores is put into the degassing chamber.

The repeatability of the analytical techniques used will also be discussed in this paper. The repeatability was investigated on samples before degassing ('zero samples') and on samples taken out after 11 days at 50 ºC, 9 days at 60 ºC and after 4 days at 70 ºC. For the repeatability test three different cable core pieces were analysed at each test condition.