VOLTAGE STABILIZERS FOR XLPE CABLE INSULATION

Thomas **Hjertberg**, Villgot **Englund**, Borealis AB, (Sweden),
 thomas.hjertberg@borealisgroup.com, Villgot.englund@borealisgroup.com

ABSTRACT

We have synthesized voltage stabilizers with increased efficiency as measured on XLPE small scale test objects. For the best addition of 0.4 wt-% gives 50% increase in electrical tree inception field strength. Moreover, by changing the substituents we could influence the electronic properties of our molecules. Molecular modeling shows that in each series the voltage stabilization efficiency can be related to the ionization potential only. It is also clear that the aromatic core has a significant influence. Benzophenones show higher efficiency than rigid aromatics at the same ionization potential. In addition, some properties essential for cable insulation applications are discussed.

KEYWORDS

XLPE, cross-linked polyethylene, voltage stabilisers, cable insulation

INTRODUCTION

The increase in energy consumption in the Western society and to an increasing extent in the growing economies, e.g. India and China, will drive further expansion in the power grid to meet the demands for electric power. In addition, there is a clear tendency to shift from overheads lines to underground installations. Together this creates increased demand for both quantities and quality of the insulation material.

Crosslinked polyethylene, XLPE, has become the dominating insulation material for high voltage power cables. The development of the material the last 4 – 5 decades has been tremendous and the electrical field strength across the insulation has increased.. Making the insulation material very clean and minimizing the impurities has been one important contribution to this development [1]. In addition the whole downstream process after producing the polymer to the finished cable has gone toward more or less clean-room conditions in order to minimize impurities [1].

The needs for increased power transmission put an increased stress to further increase the electric stresses on the insulation. It is however less realistic to achieve this by further increasing the cleanliness of the material. An alternative way to increase the resistance towards electrical breakdown is to add active species, i.e. voltage stabilizers. This has been tested earlier [2-4] with limited success and in the mid 70´s Ashcraft *et al* presented a theory on the mechanism for voltage stabilization (see below)[5]. Important drawbacks of the early attempts were limited solubility and efficiency. Martinotto *et al* have demonstrated that this can been improved by attaching alkoxy groups to an aromatic core [6].

In our work [7-9] we have focused on voltage stabilizers that will inhibit electrical treeing. A main focus has been to make highly efficient compounds in order to keep down the level of addition. We have used two main approaches:

- Molecular modelling to give input for synthesis and evaluation of the stabilization mechanism
- Synthesis of selected structures

In addition to this we have together with high voltage engineering at Chalmers University of Technology developed an alternative method for electrical treeing [10]. This was done to allow testing of small amounts of synthesized voltage stabilizers.

METHODS

Molecular modelling

The molecular properties of potential voltage stabilisers have been calculated using a quantum mechanical approach with the commercial software Gaussian [11] and DFT (Density Functional Theory). The DFT functional used was B3LYP [12] with the basis set 6-31G [13], chosen as they had a good accuracy to time ratio for the type of structures used in this study. While optimising the time consumption of the molecular modelling a number of molecules were calculated where the length of the alkyl side chains was varied to resolve their influence on the molecular properties calculated. This was done to investigate the possibility of reducing the side chain length needed to achieve an optimum between accuracy and time consumption. The investigation showed that the gained accuracy was minor to the time consumption when going further than ethyl substitution.

The ionisation potential is calculated by subtracting the total energy of the molecule in its neutral state from the total energy of the positive state [14]. The same approach is used for the electron affinity calculated but in this case the positively charged state was subtracted from the neutral state. In all these calculations the zero point energy was being taken into account and the total energy is calculated from the geometrically optimised species.

Materials

The reference material used was cross-linkable polyethylene with dicumyl-peroxide as cross-linking agent with $MFR_{2.16}$=2g/10min and a density of 0.920g/cm^3. As electrode support cross-linkable semi-conducting polyethylene was utilized. The electrode used was a tungsten wire with a diameter of 10μm supplied by Luma Metall AB, Sweden.

Preparation of test object

The polyethylene pellets were ground on a Retsch rotary mill using a sieve at 500 μm to obtain a fine powder. The polyethylene powder was then impregnated with the dissolved voltage stabiliser in an appropriate solvent during 60 minutes while agitated every 15 minutes to get the stabilisers homogenously dispersed in the polymer.