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Spatial dose distribution in polymer pipes exposed to electron beam

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HIGHLIGHTS

- High-speed program for estimation of dose non-uniformity in polymer pipes.
- The universal correlations offered to calculate local doses.
- Incomplete deceleration of electrons in shallow layers was taken into account.
- Both the unilateral and multilateral irradiation can be simulated.

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ABSTRACT

Non-uniform distribution of absorbed dose in cross-section of any polymeric pipe is caused by non-uniform thickness of polymer layer penetrated by unidirectional electron beam. The special computer program was created for a prompt estimation of dose non-uniformity in pipes subjected to an irradiation by 1–10 MeV electron beam. Irrespective of electron beam energy, the local doses absorbed in the bulk of a material can be calculated on the basis of the universal correlations offered in the work. Incomplete deceleration of electrons in shallow layers of a polymer was taken into account. Possibilities for wide variation of pipe sizes, polymer properties and irradiation modes were provided by the algorithm. Both the unilateral and multilateral irradiation can be simulated.

1. Introduction

The crosslinking of polymeric materials (mainly, polyethylene) by electron beam is a proved and well known technology in the pipes market (Auslender et al., 2002; Berejka et al., 2014). The electron beam delivers energy directly to macromolecules, initiating formation of network of joined polymer chains and thereby precisely modifying the bulk and surface properties of polymer material (Woods and Pikaev, 1994). Compared to chemical processing of polymers, electron-beam processing is exempted from volatile chemicals, the active residues and by-products. The radiation-induced crosslinking reactions can be complete immediately after processing and there is no need for strict temperature or moisture control. The accelerator parameters can be accurately controlled and consequently the electron-beam processing is highly controllable, reproducible and precise (Auslender et al., 2002; Cleland, 1983).

Taking into consideration these advantages, investors are interested in an electron-beam crosslinking of polymeric pipes to create new business or to upgrade old business. Both industrial designers and producers require the operative information concerning influences of accelerator parameters on quality and productivity of electron-beam crosslinking.

The matter is the rather non-uniform cross-sectional thickness of the pipe wall penetrated by an electron beam along a discrete direction (Fig. 1A). As consequence, the unilateral beaming results often in non-uniform dose (D) absorption and thereby to a non-uniform crosslinking in pipe walls (Miller and Pedersen, 1981). Usually the dose distribution is described by the uniformity ratio ($U=D_{max}/D_{min}$), which should be as close to unity as possible to provide superior quality of the cross-linking. In practice the sufficient uniformity ratio is 1.15. The knowledge of both spatial dose distribution and methods of dose adjustment is necessary to provide high quality of a crosslinking. Certainly, use of the computer program simulating dose distribution would be more preferable and precise in comparison with imaginary prediction of dose distribution (Cleland et al., 2002; Mihailescu and Borcia, 2006).

The present work describes a variant of the computer program

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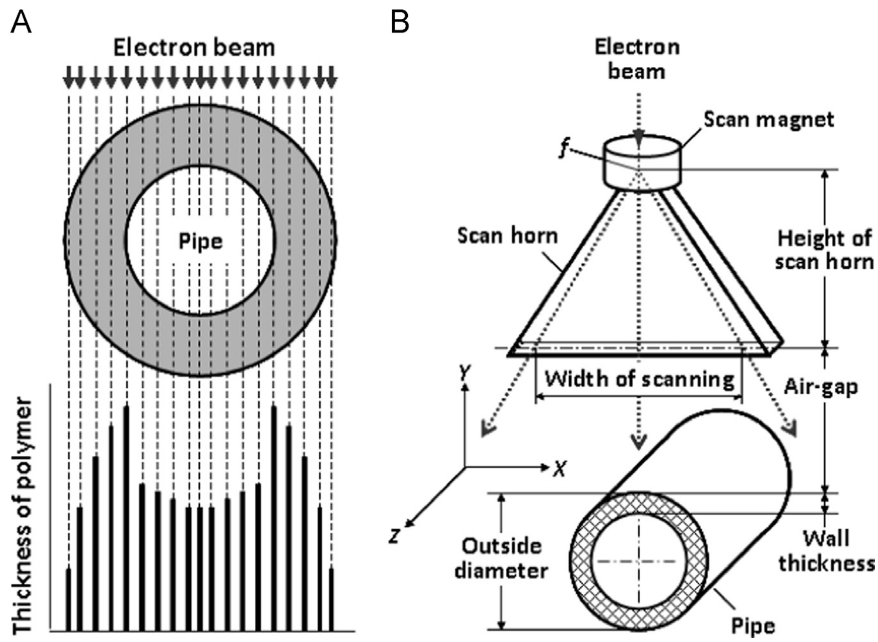

Fig. 1. Cross-sectional distribution of a polymer thickness in a pipe (A); and the schema of pipes processing (B).

to simulate a dose distribution in wide-assortment polymer pipes subjected to an irradiation with 1–10 MeV electrons.

2. Experimental

Both thematic references and own experimental data have been used to validate the program. The experiments have been performed using 8 MeV linear accelerator UELV-10-10T (pulse duration, 6 μs; pulse repetition frequency, 300 Hz; average beam current, 800 μA) and 2 MeV linear accelerator LIN-S-02-500 (pulse duration, 4 μs; pulse repetition frequency, 250 Hz; average beam current, 500 μA). Absorbed dose was measured by a polymeric film dosimeter with a phenazine dye-doped copolymer (GSO (Certified Reference Material) no. 7875-2000).

3. Results and discussion

The conventional schema of pipes beaming was taken into consideration (Fig. 1B). The pipe gets translation along direction X or Z on the preset distance from a beam window. Usually, pipes undergo to irradiation with a scanned beam. Therefore geometrical parameters of a beam (angle and width of scanning) should be necessarily taken into account. These parameters as well as air-gap distance between a pipe and a beam window influence actual dose rate and number of the pipes being located within irradiation area. The wider air-gap, the lower dose rate affects a pipe.

Correlation between energy of electrons and their penetration into polymer has been analyzed to find the most simple and all-inclusive mathematical description for the program. There are two key characteristics of electron penetration into material: the range and the depth–dose distribution. The range characterizes material's thickness sufficient to decelerate an electron completely. In turn, depth–dose curve characterizes local doses absorbed along a beam direction. Energy-range correlation is linear for 1–10 MeV electrons whereas depth–dose correlation has a maximum, originated via back-scattering of low-energy electrons (Cleland et al., 2002; Woods and Pikaev, 1994).

The typical depth–dose curve, shown in Fig. 2A for a case of a

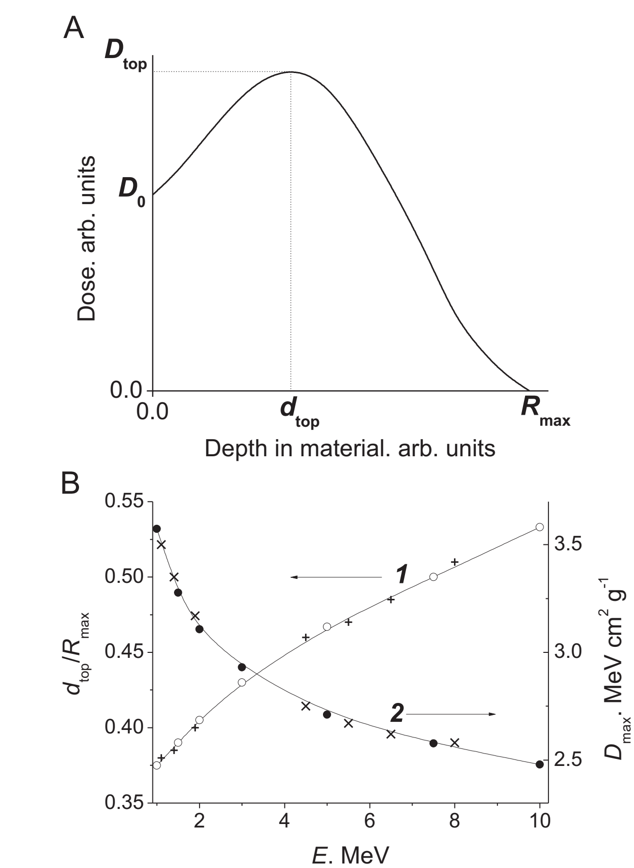

Fig. 2. The ascent-to-descent shape of the "depth–dose" curve (A); and influence of incident electrons energy on position of the maximum (B): +, × – this work; ○, ● – from Cleland et al. (2002).

unilateral irradiation, illustrates gradual buildup, and decline, of absorbed dose as the distance from the irradiated surface into the depth of a material is increased. Position of the maximum (D_{top} and d_{top}) depends on initial energy of incident electrons. Raising energy results in reducing dose D_{top} and increasing depth d_{top}