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Diffusion of mosquito repellents in textiles*

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I. Introduction

Health-workers, soldiers, and other people who are frequently exposed to vector-borne diseases during missions in hot and tropical conditions, are recommended to use a combination of DEET-based creme on exposed body parts and permethrin treated garments to protect themselves against mosquitoes infected with malaria and other life threatening diseases. Current solutions have some deficits because they are not used in a proper way, application is too complex or people don't want to use them because of a certain degree of toxicity mentioned in the press. Next to product failure, the limited lifetime of effectiveness is a matter of concern. Therefore the NO BUG project focuses on the improvement of garments treated with DEET and permethrin, and in the future garments shall be constructed with new repellents.

This study focuses on the diffusion of DEET and permethrin to the outer boundary of textiles that are treated with a polymer solution of both active ingredients (AI). Based on this observations an inverse problem is encountered and once solved it can answer the question how much of the AI has to be present on the textile fiber, so the concentration at the outer boundary of the textile stays high enough for as long as possible to repel and even kill mosquitoes.

II. The application

A. The setting

In this study treated bednets are considered. To model this application we make a distinction on three levels of the net. First we model the fiber with a coating consisting of AI DEET and permethrin. To this end the fiber will be seen as a cylindric object. Secondly we model the yarn, a porous structure built out of fibers, upscaling the outcome of the fiber model. The third model represents the net or fabric itself, with its environment, again using an upscaling method to calculate the overall properties of the fabric using the yarn properties.

B. The model

On fiber and yarn level we solve a diffusion model for the concentration of an AI in a polymer layer in cylindrical coordinates. The yarn level hereby has an extra source term that describes the amount of DEET coming from the fibers in the yarn which is computed using upscaling methods. On fabric level the governing equations are

$$\partial_t(C_{\mathrm{D}}\epsilon_{\mathrm{l+g}}) = -\partial_x(u_{\mathrm{g}}C_{\mathrm{D}}\epsilon_{\mathrm{g}}) + \partial_x\left(\frac{D_{\mathrm{D}}}{\tau_{\mathrm{D}}}\partial_x(C_{\mathrm{D}}\epsilon_{\mathrm{l+g}})\right) - \Gamma_{\mathrm{lg,D}} + \epsilon_{\mathrm{f}}\xi_2\Gamma_{\mathrm{f,D}},$$

$$\partial_t(C_{\mathrm{p}}\epsilon_{\mathrm{l}}) = \partial_x\left(\frac{D_{\mathrm{p}}\epsilon_{\mathrm{l}}}{\tau_{\mathrm{p}}}\partial_x(C_{\mathrm{p}}\epsilon_{\mathrm{l}})\right) + \xi_2\Gamma_{\mathrm{f,p}}$$

with $\Gamma_{\mathrm{lg,D}}$ the evaporation rate of DEET from the fabric; $\Gamma_{\mathrm{f,D}}$ and $\Gamma_{\mathrm{f,p}}$ are the sorption rates of resp. DEET and permethrin of the fibers covered by liquid water. These last two terms only exist if liquid is present, e.g. during washing.

III. Results

We present results of a numerical approximation of the above models which can be used to solve the inverse problem.

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