INFILTRATION INTO INCLINED FIBROUS SHEET

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Fibrous sheets are widely used in the health sector for fluid management, as wound dressings, babies nappies, sanitary towels, and incontinence products [1]. The fibrous sheets used are often complex, with a multi-layered structure and of varying geometry, with disposable products typically including super-absorbent polymers. The simplest class of these products are reusable bedpads, which consist of large homogeneous rectangular sheets of fibrous material, backed by an impermeable layer. Despite the general nature and wide spread use of such products, leakage is a common problem even though they have a large absorbent capacity relative to the volume of fluid received [2]. The distribution process for liquid within an incontinence product begins with liquid being introduced into the material under pressure over a short time, followed by a longer phase in which capillary and gravity-driven flow dominates to finally determine liquid distribution and storage within the structure. In order to understand how such products function, we need to first understand the more general problem of how fluid spreads in homogeneous fibrous sheets, and this forms the basis of the presentation.

The flow from line and point sources through an inclined fibrous sheet is studied experimentally and theoretically for the case of wicking from a saturated region and flow from a constant flux source. Richards' [3] and Washburn's [5] models are adapted to describe the infiltration process, with experimentally determined closure relations which relate permeability and capillary pressure to the moisture level. Wicking from a saturated line generates a wetted region whose length grows diffusively, linearly or tends to a constant, depending on whether the sheet is horizontal or inclined above or below the horizontal. A constant flux line source generates a wetted region which ultimately grows linearly with time, and is characterised by a capillary fringe whose thickness depends on the relative strength of the source, gravity and capillary forces. Good quantitative agreement is observed between experiments and similarity solutions.

On a horizontal sheet, capillary-driven and constant flux source flows issuing from a point generate a wetted region whose radius grows diffusively in time. The flow is characterised by the relative strength of the source and spreading induced by the action of capillary forces, γ. As γ increases the fraction of the wetted region which is saturated increases. Wicking from a saturated point corresponds to $\gamma = \gamma_c$, and spreads at a faster rate than from a line source. For $\gamma < \gamma_c$, the flow is partially saturated everywhere. Good agreement is observed between measured moisture profiles, rates of spreading, and similarity solutions.

Numerical solutions are developed for point sources on inclined sheets. The moisture profile is characterised by a steady region circumscribed by a narrow boundary layer across which the moisture rapidly changes. An approximate analytical solution describes the increase in the size of the wetted region with time and source strength; these conclusions are confirmed by detailed numerical calculations. Experimental measurements of the downslope length are observed to be slightly in excess of theoretical predictions, though the dependence on time, inclination and flow rate obtained theoretically is confirmed. Experimental measurements of cross-slope width are in agreement with numerical results and solutions for short and long times. The effect of a percolation threshold is to ultimately arrest cross-slope transport placing a limitation on the long time analysis.

Application of the models and closure relationships described in this paper to medical adsorbents is relatively straightforward, and initial calculations using representative incontinence pad geometry and discharge rates are in good agreement with laboratory experiments. The future challenge to applying the methodology in this paper to improve absorbent performance remains to relate the fabric micro-structure to their bulk fluid handling properties, and establishing new methods for combining closure relations to model the effective properties of layered composite materials. Preliminary progress has been made in resolving both these issues and are reported in [5,6].

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