

Some New Insights into the Fluid Flows in Debris Material and Porous Landscape

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1 Introduction

Proper understanding of fluid flows in debris material and porous landscape, and in general through porous media, is an important aspect in industrial applications, geotechnical engineering, subsurface hydrology and natural hazard related phenomena (Muskat, 1937; Barenblatt, 1952; Whitaker, 1986; Boon and Lutsko, 2007; Vazquez, 2007). Better and reliable understanding of the slope stability analysis, landslide initiation, debris flow and avalanche dynamics and their deposition morphologies, seepage of fluid through porous matrix, and consolidation require more accurate and advanced knowledge of fluid flows in porous materials. Understanding the dynamics of fluid flows in porous landscape may help to develop early warning strategies in potentially huge and catastrophic failure of landslides, reservoir dams and embankments in geo-disaster-prone areas (Pudasaini and Hutter, 2007; Pudasaini, 2013).

2 New models for fluid flows in debris material and porous landscape

Here, we present some new and exact solutions for Newtonian and non-Newtonian fluid flows through debris materials and porous landscapes. Solutions are based on the generalized two-phase mass flow model (Pudasaini, 2012, Pudasaini and Miller, 2012a,b). Exact solutions are presented for: (i) the steady-state downslope velocity for a fluid flow in a debris material, or a porous media in an inclined setting, (ii) steady-state lateral velocity of the downslope fluid flow in a channel including a lateral porous dam, (iii) sub-diffusive fluid flow in porous media and debris material, (iv) steady-state sub-diffusion and sub-advection of fluid with continuous discharge and decay, and (v) steady-state down-slope sub-advection and lateral sub-diffusion of fluid in inclined porous landscape (Pudasaini, 2013). We outline some possible and systematic ways to

construct exact solutions for our full sub-diffusion and sub-advection equation (Boon and Lutsko, 2007; Pudasaini, 2013). This includes the reduction of the model to the classical diffusion-advection equation for which we have constructed advanced exact solutions by using the Bring ultraradical (Bring, 1864) and higher-order hypergeometric function. Furthermore, separation of variables leads to special ordinary differential equations in the form of Lienard equation and Abel equation in canonical form, and provide other set of exact solutions (Linar, 1928). High-resolution, shock-capturing Total Variation Diminishing Non-Oscillatory Central (TVD-NOC) scheme is implemented to solve the model equations numerically (Pudasaini, 2011). Numerical solutions are presented for the full sub-diffusion and sub-advection model, which is then compared with the solution of the classical diffusion and advection model (Pudasaini, 2013). Moreover, the full sub-diffusion and sub-advection model solutions are presented both for the linear and quadratic drags, which show that the generalized drag plays dominant role in the form and propagation speed of the diffusion-advection waves. We demonstrate that the long time solution to sub-diffusive and sub-advective fluid flow through porous media is largely independent of the initial fluid profile.

3 Concluding remarks

Our novel models and results reveal that the solutions to the sub-diffusive fluid flow in porous media and porous landscape is fundamentally different than the classical diffusive fluid flow or diffusion of heat, tracer particles and pollutant in fluid. In the later case, the diffusion is linear, and the solution is represented by the classical Gaussian distribution. On the contrary, we found that, in the sub-diffusive processes of fluid flow

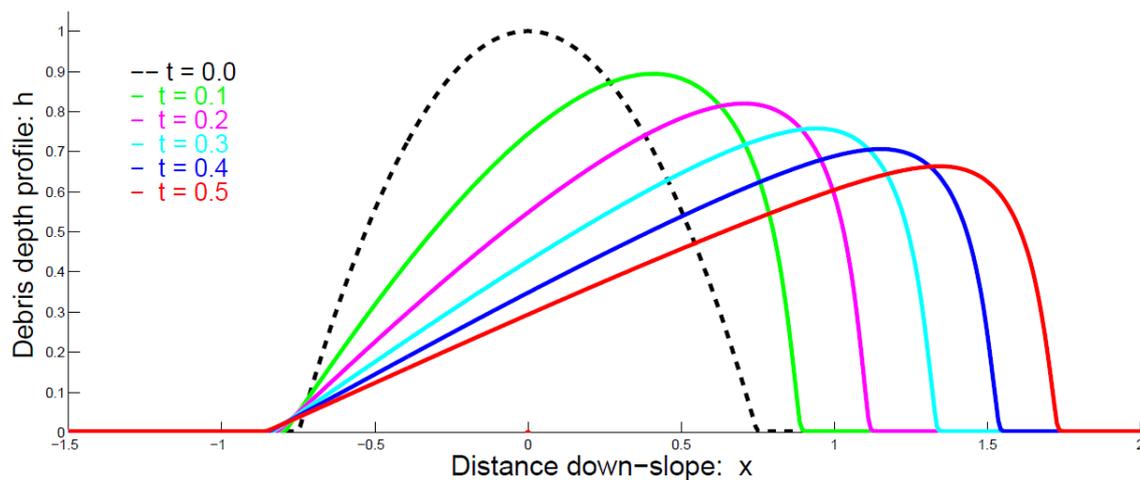


Fig. 1: Sub-diffusion and sub-advection of a fluid through a porous media (Pudasaini, 2013).

in porous media, porous landscape and debris material, the fluid diffuses slowly in time, and thus to maintain the mass balance, the fluid is less spread in the lateral direction.

These exact solutions and numerical simulations disclose many new and essential physics of fluid flow in porous

media, and thus, may find ample applications in modeling and simulation in environmental and industrial fluid flows through general porous media, natural slopes, embankments (e.g., of hydro-electric power reservoirs and dams), and debris materials.

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