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Interactive comment on "Comparing Thixotropic and Herschel-Bulkley Models for Avalanches and Subaqueous Debris Flows" *by* Chan-Hoo Jeon and Ben R. Hodges

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1. Authors should clarify the different terms used for the definition of the flow-like phenomena they are discussing. They should insert a synthesis figure showing the rheological characteristics of natural flow-like phenomenon discussed within this work. They should insist on the main difference between those fluids in terms of viscosity, mono/biphasic fluid, grain-size distribution, etc. They should also mentioned somewhere that lahars are considered as very specific viscous fluid in most of thosed classifications. Authors do not discuss some key elements concerning debris flows: (1) the triggering can be a fluidization of deposits within the channel or laying on connected side slopes, but also can be a enrichment of

a ‘classical’ flood with solid material during the runout, (2) the rheology of a single debris flow event can vary during its runout due to entrainment processes.

We have combined the answer to this comment with the answers for comment (2) below.

2. Authors should explain somewhere the influence of clays on the flow motion and how it varies according this clay content.

We have combined the answer to this comment with the answer for comment (1). These comments are similar to the comments (2) and (3) of Reviewer 1 in that they seek further details on the physics of real-world flows. In retrospect, we believe the original paper did not place our work carefully in context of prior work where non-Newtonian models are used as proxy for the macroscopic behavior of real-world flows. We have substantially rewritten the abstract and introduction to make it clearer that we are only aiming to understand the different behaviors that can be simulated by using a thixotropic model rather than a Herschel-Bulkley model for representing debris flows and avalanches. As we are building on a long history of using non-Newtonian physics as a proxy for these flows, we do not believe that it is appropriate to delve into the details of the rheology. However, these comments have helped us to see that we were deficient in our presentation of the background and motivation, which left the reader confused as to our purpose and scope. We have substantially expanded our introduction and included further references to review papers in the literature where more details on flow physics can be found.

In particular, the Reviewers questions are addressed in new text, pg 2, lines 1-27, and pg 2, lines 30-32 regarding general characteristics and definitions of different flows, along with citations of review papers for physics. The Reviewer will find their ideas directly addressed in this new text.

Also, see new text pg 5, lines 29-35 regarding clays in laboratory flows vs. real debris flows:

– “Thixotropic flows modeled at the laboratory scale typically use clays (e.g. Bentonite, Kaolin) to create the microstructure controlling non-Newtonian behavior (citation). Preparation of a homogenous clay suspension for such experiments is a demanding task, the details of which can be found in (citations). Unfortunately, we cannot expect the structure of a heterogenous large-scale debris flow to mimic the flow scales, yield stresses, and parameters for a homogeneous thixotropic laboratory flow. However, lacking data from a large-scale debris flow that could be adequately used for model comparisons, herein we take a first step by analyzing how thixotropic models compare to time-independent models for laboratory-scale flows."

3. A comparison between their results and observations of real study case is missing. They could insert a simple table with the main rheological and morphological characteristics of their experiments and some characteristics of other case studies.

   We believe our comparisons to laboratory experiments are as far as can be reasonably achieved in the present work. We have pointed out the challenge of validation to field experiments.

   New text, pg. 6, lines 1-7:

   – "Validating the use of a non-Newtonian model to represent a real-world debris flow presents challenges on two levels: first, does the model correctly represent a non-Newtonian flow? Second, does the non-Newtonian flow (when parameterized) represent a real-world debris flow? To date, successful non-Newtonian models of real-world flows have been parameterized using a time-independent approach, which limits the ability of the model to represent the transition phases, i.e. flow initiation and stalling (citations provided). Unfortunately, data on transition phases for real-world flows is lacking, and is severely limited even for laboratory-scale flows."

4. A sensitivity analysis could be discussed somewhere in the discussion part where authors could identify which input data has the most influence on the output data.

   We agree that a sensitivity analyses would be useful; however, with 5 parameters to test over essentially unknown ranges (due to the lack of sufficient experimental or field data) we believe this is beyond the reasonable scope for the present paper. We have added the following in the Discussion and Conclusions section to highlight this point.

New text, pg. 26, lines 25-27:

– "To improve our understanding of the thixotropic model, there is a need for a comprehensive sensitivity analysis of these five driving parameters for the expected scales of real-world systems (which are as yet unknown)."

5. Where's the final conclusion?

Our conclusions were integrated in the prior Discussion section. We have modified the name to "Discussion and Conclusions" as it contains both the summary of the results and observations as to the impact of the two sets of results taken together. We rewritten this section and provided a new final paragraph that provides greater insight into the future possibilities for this method.

New text, pg. 26, lines 22-32.

– "For time-dependent thixotropic models to be useful in modeling real-world avalanches and debris flows, there is a need for a consistent approach to defining the initial jamming (λ_0), the characteristic time of aging (T_0), and the asymptotic shear viscosity (η_0), along with the material parameters ω and α for real-world systems. As yet, these parameters are not well-defined for either simple laboratory models or complex real-world flows. To improve our understanding of the thixotropic model, there is a need for a comprehensive sensitivity analysis of these five driving parameters for the expected scales of real-world systems (which are as yet unknown). Furthermore, with or without the thixotropic model, there is clearly a need for (1) more detailed experimental measurements during flow initiation and restructuralization, and (2) a better understanding of the relationship between measurable microstructure parameters and the effective stress-strain relationship. The present work shows that a time-dependent (thixotropic) viscosity model may be an effective proxy for representing the inception and stalling of an avalanche or debris flow, but

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much work remains to be done before real-world natural hazards can be modeled in this manner."

6. Page 14, Figs. 5 & 6 ; Page 19, Figs. 11 & 12 : why the scale of X and Y-axis of both graphs are different? It could mislead the readers.

   The τ y-axes of figures 4, 5 and 6 use the same scale so that the comparisons can between figures can be readily made. However, the x axes have individual scales for clarity due to the large change in range. We agree this can be confusing, so we've added the following note to the captions of Figs. 4, 5 and 6:

   – "The τ axis is scaled for comparison with Figs. 5 and 6 while the $\dot{\gamma}$ axis has an individual scale for clarity."

   Figure 12 now has exactly the same x and y axes as Figure 11, which is now noted in the caption of Figure 12 as:

   – "Axes scalings are identical to Fig. 11 for comparison purposes."