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Memorandum
To: Dr. Jorge Isidoro, Editor, Hydrology and Earth System Sciences

Subject: Revision of hess-2021-588

Dear Editor:
We have carefully revised our manuscript following all suggestions and comments. Thanks to the reviewers and editors, the manuscript has been improved substantially by addressing the constructive comments. The followings are responses to the comments.

Response to Editor:
Minor comments

Dear Authors.
Thank you very much for submitting your replies to the excellent comments made by the two reviewers. The manuscript presents an interesting experimental study on non-Darcian flow characteristics in permeable stones. This theme, as well as the experimental techniques described in the manuscript, fits well in the content of this special issue.
I've carefully read the comments made by the reviewers, and the replies presented by the authors to the reviewers' suggestions and queries. In my opinion, the authors' replies are well-founded and respond clearly to the minor revisions suggested by the reviewers.
Apart from the suggestions made by the reviewers, I would also kindly suggest making the two following corrections/improvements to the manuscript:

- *[Line 169] - Fig 1 – please include the description of the seven components inside the figure's frame. Also, "Tank" should be capitalized.*

Reply: Implemented. We have modified the Fig. 1 as required.

- *[Lines 475 and 491] – Figs 14 and 15 – please make the caption to be more explicit by itself (ending the caption with "in different types" sounds awkward and it's ambiguous).*

Reply: Implemented. We have redefined the caption of Fig. 15 and Fig. 16. Please see lines 525 and 542.

Response to Reviewer #1:
Minor comments

I have completed the review of the manuscript entitled "Experimental study of non-Darcian flow characteristics in permeable stones" submitted to HESS for potential publication. In my experience, experimental research on non-Darcy flow is never out of data. In this manuscript, firstly, the seepage experiment of permeable stone provides experimental basis for non-Darcian seepage in relatively low permeability medium; then, pore distribution characteristics of various permeable stones are analyzed by mercury injection test with Gaussian distribution function; finally, the influences of particle size and porosity on Forchheimer equation coefficient are investigated and some interesting phenomena are found. This manuscript has potential to provide hints for non-Darcy studies, in terms of such as critical values of non-Darcy flow, influences of pore properties on non-Darcy flow in some specific views and enlightenment of some special phenomena. At this stage, I will recommend a minor revision since there are still some deficiencies that need to improve in this manuscript as follows:

1. Line 159: The basic information of permeable stone related to the manuscript topic, such as forming background and porous properties or generation, should be introduced firstly.

Reply: Implemented. We have added the relevant application background and research status of permeable stone. Permeable stone is widely used in urban road design, sponge city construction and ecological effect research. And the most commonly used permeable base materials are large pore cement stabilized macadam, large diameter permeable asphalt mixture and so on. For permeable stone, there must be a certain connected pore space to maintain a certain permeability for transmitting water. However, the increase of pore space will lead to the decrease of pavement performance and mechanical strength. Therefore, many scholars have carried out a lot of research on controlling the proper pore space of permeable stone. Please see lines 180-188. In addition, we have outlined the preparation process of permeable stone. Please see lines 176-180.

2. Line 226: As Fig. 4 indicates, the best-fitting yields Forchheimer numbers (F0=B/A=kβρv/μ) with orders of magnitudes to be about -4, but Zeng and Grigg (2006) suggested a critical F0 to be 0.11 to trigger high-velocity non-Darcian flow, which makes the flow in authors' seepage experiment looks like "super-weak non-Darcian type". If so, the authors should compare the best-fitting performances between Forchheimer equation and simple Darcy's law, to prove the necessity of existence of the inertial term of Bq2.
(Zeng, Z., & Grigg, R. (2006). A criterion for non-Darcian flow in porous media. Transport in Porous Media, 63(1), 57-69. https://doi.org/10.1007/s11242-005-2720-3)

Reply: Implemented. In order to better compare with the actual groundwater flow, we converted the specific discharge to meters per day (m/d). Therefore, the best-fitting exercise yields Forchheimer numbers ($F_0 = B/A$) is about 10^{-4} according to Fig. 4, which is fairly small. In addition, the critical Forchheimer numbers proposed by Zeng and Grigg (2006) and Javadi et al. (2014) are empirical, in fact, the transition between Darcy to non-Darcy is successional over a certain range of Forchheimer numbers. The non-Darcian flow criterion applicable to different pore media is established by conducting seepage resistance experiments in homogeneous and heterogeneous porous media in our previous study (Li et al., 2017; Li et al., 2019), which is consistent with the results of Zeng and Grigg (2006). Please see lines 228-237.

3. Fig. 4: The results of best-fitting by Forchheimer equation have unconspicuous connection with the subsequent discussion of "pseudo" hydraulic conductivity and critical specific discharge.

Reply: Implemented. Generally speaking, the *q-J* and *q-K* curves are the most common methods used to analyze flow regime when conducting seepage resistance experiments in porous media. However, the nonlinear characteristics of *q-J* curve are not obvious due to the relatively small velocity range used in the experiments. The traditional hydraulic conductivity is the ratio of the specific discharge versus the hydraulic gradient (*q/J*), and it is a constant if Darcy's law is applicable, which is denoted as K_D (Li et al., 2019). In fact, the ratio of *q/J* is no longer a constant for the problems discussed in this study. In a word, the *q-K* curve can be used to observe the transition of flow state more intuitively. Please see lines 237-244.

4. Lines 299-300: The pressure ratio is a macroscopic parameter but the inhomogeneity is a relatively microscopic one, so the authors should prove the reasonability of PC/PB representing the inhomogeneity.

Reply: Implemented. It is well known that for mercury injection experiments, as injection pressure increases, the injection saturation will gradually increase and eventually all the pores will be filled with mercury. As can be seen from Fig. 7, with the continuous injection of mercury, the pressure of permeable stones with different particle sizes varies with saturation, which is reflected in the different pressure P_B and P_C at different stages. However, the reason for the different pressure is the difference of pore size distribution in the permeable stones. Therefore, the pressure ratio of B and C (P_C/P_B) can be used as one of the criteria to characterize the heterogeneity of pore size in porous media. We have made relevant revision on this matter, please see lines 337-344.

5. Equations (3-3) to (3-7) can be assembled into a single table for the purpose of more concise expression.

Reply: Implemented. We have summarized a series of equation coefficients in Table 4 and revised the sentences. Please see lines 438-441 and Table 4.

6. References should be provided for Equation (3-8). Eq. (3-8) cannot be derived from Eq. (1-2) alone.

Reply: Implemented. We have added the relevant references. For specific derivation process, please refer to previous studies (Huang, 2012). Please see lines 467-469.

Response to Reviewer #2:

In this manuscript the authors perform experimental study of non-Darcian flow in four rock samples with different pore size distribution determined by mercury injection experiment. The authors determine the critical specific discharge and pre-Darcian flow regime using q-K curves for the rock samples. The Forchheimer coefficients are also determined form the experiments. It is an interesting work and, in my view, should be accepted after fixing the following minor issues:

1. The effective diameter (d10) of the pores is usually used to predict the permeability. As stated by Hazen (1892), the influences of the finer grain of the soil is more significant on pore space size and hydraulic conductivity comparing to that of coarser grain. In this work, however, mean grain size is used to draw a relation between hydraulic gradient and specific discharge. The authors should comment on this.

Reply: Implemented! From the point of view of pore composition, the porous medium has been screened for the preparation of permeable stone, which can be regarded as homogeneous. The pore distribution is relatively concentrated over a narrow pore size range, and the proportion of large pores and small pores is very small. The average particle size can reflect the overall permeability of the porous media.

2. Lines210-213: The particle size distribution of each sample should be given.

Reply: Implemented! We have carried out the seepage experiments of permeable stones with four different mesh sizes in this study. The porous media used to prepare the permeable stone are carefully sieved and can be regarded as homogeneous. To facilitate the description, we can convert above four different mesh sizes of permeable stones into corresponding particle sizes. In other words, the four groups of permeable stones in this study are homogeneous porous media. Finally, we obtained the pore distribution of different permeable stones by carrying out mercury injection experiment, as shown in Fig. 8 to Fig. 11.

3. Line 238: Izbash (1931) model is commonly used to simulate the pre-Darcy flow (Dejam et al., 2017). The authors should comment on this.

Reply: Implemented! In fact, Izbash (1931) presented the equation as $q = M\left(\frac{dH}{dx}\right)^m = Mi^m$, where M and m are the coefficients determined by fluid flow and properties of porous media. When m=1, the Izbash equation reduces to Darcy law, when m>1, the Izbash equation corresponds to the pre-Darcy flow and when m<1, the Izbash equation refers to the post-Darcy flow (Dejam et al., 2017; Soni et al., 1978). Besides, Dejam et al. (2017) carried out a more detailed study on the issues related to the pre-Darcy and post-Darcy flows. And the influence of pre-Darcy flow on the pressure diffusion for homogenous porous media is studied in terms of the nonlinear exponent and the threshold pressure gradient. We have added the relevant information, please see lines 265-272.

4. Lines 240-245: As another explanation: The pre-Darcy flow may also be due to an influence of the stream potential which generates the small countercurrent along pore walls in a direction opposite that of the main flow (Bear, 1972; Dejam et al., 2017).

Reply: Implemented! In addition, another justification for the pre-Darcy behavior may be due to an effect of a stream potential which generates small countercurrents along pore walls in a direction opposite that of the main flow (Bear, 1972; Scheidegger, 2020). And Swartzendruber (1962a) stated that the surface forces arose in a solid-fluid interface due to strong negative charges on clay particle surfaces and the dipolar nature of water molecules caused a pressure gradient response to be nonlinear and led to the pre-Darcy flow (Swartzendruber, 1962b). We have supplemented the hypotheses of other scholars, please see lines 275-281.

Reference cited in this reply:

Bear, J.: Dynamics of Fluids in Porous Media, American Elsevier Pub. Co., New York, N.Y., and Amsterdam,1972.

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Javadi, M., Sharifzadeh, M., Shahriar, K., and Mitani, Y.: Critical Reynolds number for nonlinear flow through rougˆ walled fractures: The role of shear processes, Water Resources Research, 50, 1789-1804, https://doi.org/10.1002/2013WR014610, 2014.

Li, Z., Wan, J., Huang, K., Chang, W., and He, Y.: Effects of particle diameter on flow characteristics in sand columns, International Journal of Heat & Mass Transfer, 104, 533-536, https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.085, 2017.

Li, Z., Wan, J., Zhan, H., Cheng, X., Chang, W., and Huang, K.: Particle size distribution on Forchheimer flow and transition of flow regimes in porous media, Journal of Hydrology, 574, 1-11, https://doi.org/10.1016/j.jhydrol.2019.04.026, 2019.

Scheidegger, A. E.: The physics of flow through porous media, University of Toronto Press, https://doi.org/10.3138/9781487583750, 2020.

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Swartzendruber, D.: Modification of Darcy's law for the flow of water in soils, Soil Science, 93, 22-29, https://doi.org/10.1097/00010694-196201000-00005, 1962b.
Zeng, Z. and Grigg, R.: A criterion for non-Darcy flow in porous media, Transport in porous media, 63, 57-69, https://doi.org/10.1007/s11242-005-2720-3, 2006.

Please contact me if you have further questions.

Sincerely Yours,

Hongbin Zhan, Ph.D., P.G.