Hall's Notes and Queries

NQ6

Capillary imbibition, trapped air and barometric pressure

In WT3e[1], note 2, p302 says: 'Close inspection of secondary imbibition curves such as those in Figure 8.8 shows that the volume of imbibed water deviates erratically from the trend line by small amounts that are nonetheless outside the measurement uncertainty. These deviations are caused by changes in atmospheric pressure. When the pressure rises, the trapped air is compressed and water is imbibed by capillarity to make up the decrease in volume; when the atmospheric pressure falls, trapped air expands and water is ejected. The size of these effects diminishes as the water content approaches saturation.'

This NQ presents some experimental evidence of the link between the volume of trapped air and atmospheric pressure.

Preamble The trapping of air during water absorption by brick, stone and concrete is a well established phenomenon, with a long history going back to Bloxam and Hirschwald as noted in NQ4. The volume-fraction of water-filled pores at the end of primary imbibi-

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[1] C Hall & W D Hoff, Water transport in brick, stone and concrete, third edition, CRC Press, 2021.

tion defines the fractional Hirschwald coefficient h. Therefore h fixes the Hirschwald moisture state of a material at the end of primary imbibition (for example in a test to measure the sorptivity). The fraction of the porosity occupied by trapped air is of course $\lambda = 1 - \mathsf{h}$. As measured, the quantity λ varies widely from material to material[2], and for the moment we have no good model to predict it.

Of scientific and practical interest is what happens to the trapped air over the long term. As Gummerson showed many years ago, the air gradually disappears, and so long as water is freely available the moisture state slowly evolves from the initial Hirschwald state to a final state of saturation. This process occurs because the trapped air is compressed by capillary forces and is at a pressure greater than the external barometric (atmospheric) pressure. By Henry's law, the concentration of dissolved air (oxygen and nitrogen) is greater at the surface of air pockets than at the external surface of the material. As a result there is a concentration gradient driving the diffusion of air in solution from the interior to external surfaces. The solubility of air in water is small so that this process is extremely slow. Gummerson used a whole clay brick and found that it took more than a year to reach saturation. Subsequent tests on 50 mm stone blocks show that many months and sometimes several years are needed.

Effect of barometric pressure The slow loss of trapped air is a process of some complexity. We have described a simple model of the process in WT3e (more or less unchanged from the first (2002) and second (2012) editions). Our new data deserve further analysis but have not yet received it. From unpublished tests, and as an example,

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[2] See WT3e Table 4.2, p164; also C Hall & A Hamilton (2018), Beyond the sorptivity: definition, measurement and properties of the secondary sorptivity, ASCE J Mater Civ Eng, v30, 04018049; C Hall & V Pugsley (2020), Spontaneous capillary imbibition of water and nonaqueous liquids into dry quarry limestones, Transp. Porous Media, v135, 619–631.

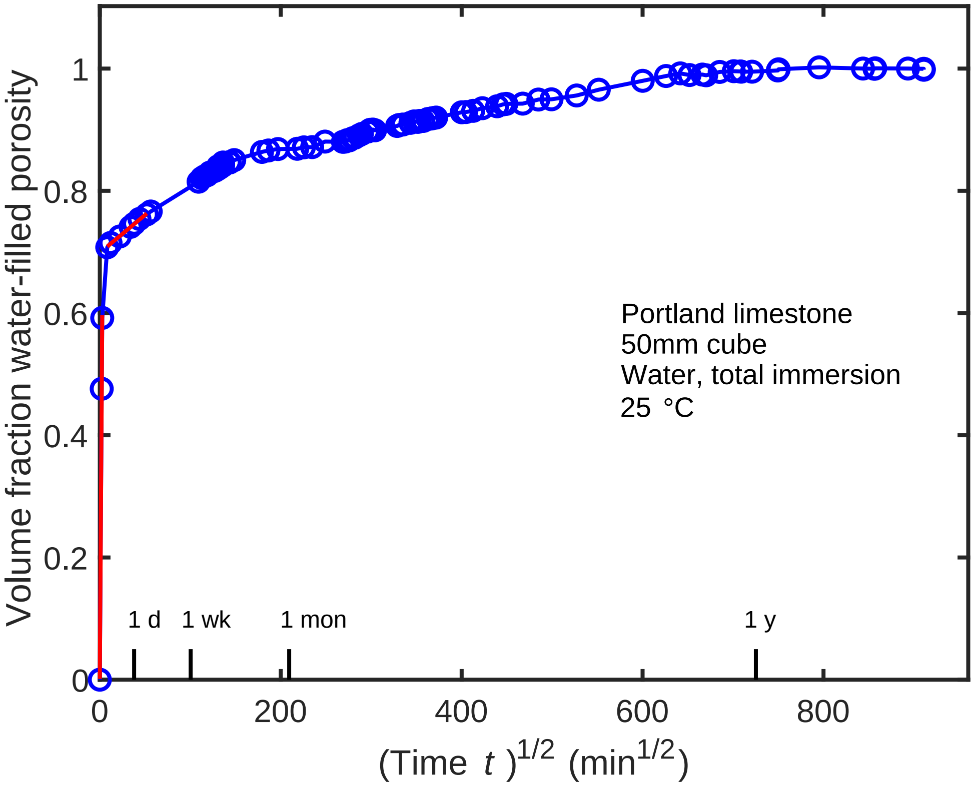

Figure 1: Long-term water imbibition into a Portland limestone block (Portland base bed from Fairhaven, Bottisham; volume-fraction porosity f 0.213). Test runs from 6 Nov 2017 to 5 Jun 2019

Fig 1 shows the long-term capillary absorption of water into a Portland limestone block. Saturation is reached after about 285 days. Small deviations from the trend line mentioned previously are apparent.

Fig 2 shows the clear correlation between the fluctuations in the volume of trapped air (or of imbibed water) and the variation in atmospheric pressure over a period of about 3 months. In Fig 2, data are plotted to show a positive correlation between an *increase* in trapped air volume and a *decrease* in barometric pressure.

Similar correlations are found in our data on long-term imbibition in other brick and stone materials (unpublished). Many decades

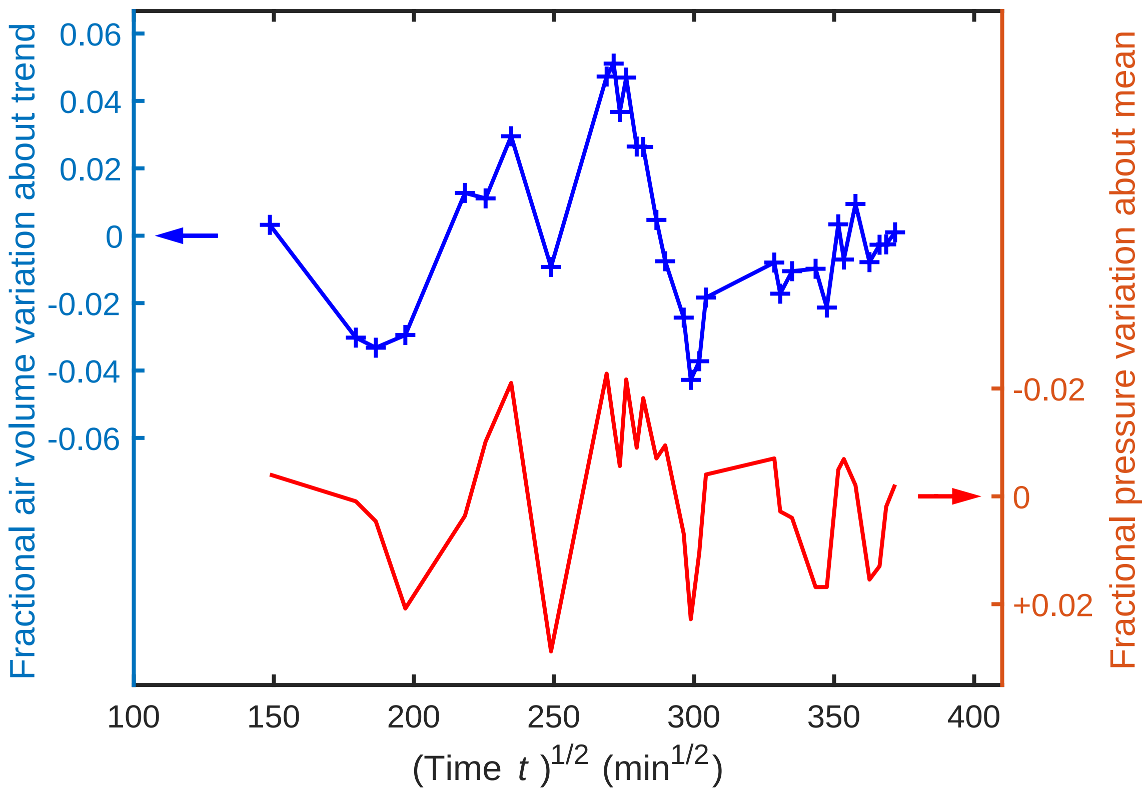

Figure 2: Correlation of fluctuations in imbibed volume with variation in barometric pressure. Variations in air volume about the trend line are data residuals after a smoothing spline fit to imbibition data. Note the variation in pressure about the mean on the right-hand axis decreases upwards. Data from 21 Nov 2017 to 10 Feb 2018. Imbibition data from Stapleford, Cambridge (CH); barometric pressure data from Cambridge University Computer Laboratory weather station archive

ago similar effects in soils were mentioned briefly by Adam et al[3], and analyzed rather more fully by Norum and Luthin[4]. So far as we know, this phenomenon has not been discussed elsewhere in connection with brick, stone and concrete.

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[3] K M Adam, G L Bloomsburg & A T Corey (1969), Diffusion of trapped gas from porous media, Water Resour. Res., v5, 840–849.

[4] D I Norum & J N Luthin (1968), The effects of entrapped air and barometric fluctuations on the drainage of porous mediums, Water Resour. Res., v4, 417–424.