

DISCUSSION

Swelling pressure of sodium montmorillonites

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The authors have compared the experimental test results of others on sodium montmorillonite with the theoretical $u - Kd$ (that is, non-dimensional electric potential function and distance function) relationship obtained from diffuse double layer theory. Such information is of particular interest to researchers who are dealing with highly compacted bentonite. This is a welcome paper just in time when researchers in many countries are involved in the investigations of backfill buffer material that is used as a barrier in storing high-level toxic wastes (such as radioactive waste).

The discussers would like to draw the attention of the authors regarding the use of the suggested equation 9(b) to determine the swelling pressure of highly compacted bentonite.

Sridharan & Jaydeva (1982) suggested an equation, the same as equation (6) in the paper, to compute the u values for any given Kd values. Equation (6) is valid for all pure clays (kaolinite, illite and montmorillonite). This equation has been established by considering a pressure range of 1–100 kN/m². In their paper the authors have considered a pressure range of 50–400 kN/m² (see Table 2), only for montmorillonite clay, to produce equation (7). It has been shown that the $u - Kd$ relationship (that is, equation (7)) and the $u - Kd$ relationship obtained from the best-fit line for the published data on Na-montmorillonite (that is, equation (8)) are different. The authors have suggested an equation (that is, 9(a) or 9(b)) based on others' experimental data for prediction of the swelling pressure of sodium montmorillonite.

In the authors' Fig. 4, the Kd values are in the range 0.008–10 for different ion concentrations (10^{-1} – 10^{-3} M), giving rise to a range of void ratio of 1.82–21 for a specific surface area of 800 m²/g and a cation valency of 1, whereas the working void ratio of highly compacted bentonites used in radioactive storage units (e.g. ENRESA, 2000) is in the range 0.32–1.04 (that is, a dry density of 2.0–1.3 Mg/m³). Thus the Kd values of highly compacted bentonites will be less than 0.26. It has been stated by the authors that, for higher pressures, particles are brought to closure, and hence the experimental swelling pressures will be greater than that predicted by diffuse double layer theory. The primary value of equation 9(b) suggested by the authors will be if it can also be used for lower Kd values. However, for Kd values less than 0.26, the $u - Kd$ relationship obtained for the experimental data of others (see Fig. 4) would result in lower u values than that determined theoretically using equation (7). Consequently, equation 9(b) will predict lower swelling pressures than those predicted from theory. Thus there is good reason to use equation (7) instead of equation (8) to compute u values. Langmuir's equation (that is, equation (3)) can then be used to determine the swelling pressures of compacted bentonites.

The discussers would also like to point out that double layer repulsion depends strongly upon dielectric constant, cation valency, and cation concentration (Sridharan & Jaydeva, 1982). For a given pore-fluid medium, the effect of the increase in valency is to suppress the diffuse double layer (Mitchell, 1993), and hence the swelling pressure will de-

crease. The compacted bentonites used as barrier materials are seldom of monovalent type. Hence equation (7) strictly cannot be used directly in the case of bentonites with a higher valency of cations. Further, in the case of Na-montmorillonite, Pusch (1982) noted that the swelling pressures from theory are too high at low densities and too low at high densities as compared with the experimental swelling pressures. It was stated that, at low densities, there is a deviation from the parallel plate concept, while the hydration power of neighbouring surfaces plays a vital role at higher densities that is not considered in the theory. Therefore the use of equation (7) given by authors to compute u values and equation (3) to compute swelling pressure will result only in an upper bound theoretical swelling pressure of compacted bentonites from diffuse double layer theory. Further modification will be required to use the theory in the case of highly compacted bentonite.

Authors' reply

The authors thank both Tripathy and Schanz for their discussion on the authors' paper. The authors note that their paper will be useful towards the investigations of backfill buffer material used as a barrier in storing high-level toxic wastes.

At the outset, the authors would like to clarify that their paper pertains primarily to sodium montmorillonites (exchangeable cation only monovalent) with water as pore fluid. In other words the recommendations in the paper do not refer to higher valency, other clay minerals or other pore fluid characteristics. Further, the authors have considered only a pressure range of 50–400 kPa. While carrying out their investigations, the authors have compared the available experimental results with that of theoretical prediction (Fig. 4) within the specified range mentioned above and in the paper. From their investigations, the authors have found that the theoretical and experimental findings do not vary much for the specified range of parameters considered, and hence recommended the equations based on experimental results: that is, equations (8) and (9). For ranges other than those specified with respect to the valency of exchangeable cation, other pore fluids and extended pressure ranges and other clay minerals, the equation proposed by Sridharan & Jaydeva (1982) (equation (6)) may be used. Thus it can be seen that the recommendation of the authors does not pertain strictly to the cases of highly compacted bentonites (higher swelling pressure ranges) with multivalent ions.

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