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Hydrodynamics of Fluid Injection

A more complete theory than has heretofore been available for transient flow in multilayered porous systems has recently been developed. The theory predicts the effects of injecting fluids into a permeable layer (aquifer) as well as adjacent confining beds of low permeability (aquitards). The system is "leaky" if the escape of fluid is detectable in the aquifer being used and "slightly leaky" if such escape can be detected only in an adjacent aquitard.

Pressure buildup in a multilayered system depends on the degree of communication that develops within the system between aquifer and aquitard. This communication can be characterized in terms of dimensionless parameters β and r/B. The β factor accounts for the contrast between aquifer and aquitard, of the combined effects of permeability and storage coefficients. The r/B factor accounts only for permeability contrast. Both factors take bed thickness into account.

Analytical equations have been derived for pressure buildup versus time in the various parts of three-layer and five-layer systems while fluid is injected in only one layer. The three-layer results have been evaluated using typical values of β and r/B to demonstrate how leakage affects pressure buildup. The solutions have been verified by independent numerical methods. As the governing equations are linear, the principle of superposition can be employed to determine the effects of multiple point injection.

At sufficiently small values of dimensionless time defined by $t_D < 1.6\beta^2/(r/B)^4$, injection into one aquifer can be treated as though the aquifer were confined above and below by semi-infinite aquitards. This has led to the "ratio" method of evaluating aquitard properties. The method requires measurement of s, the pressure buildup in the aquifer being used for injection, and s', the buildup in the aquitard whose permeability is desired; both values must be determined at the same elapsed time since injection began and for the same radial distance from the injection well. The above theory shows that the ratio s'/s has a direct relation to the hydraulic properties of the aquitard being tested.

Furthermore, an accurate determination of this ratio is not necessary because it has been found from both theory and field testing that a well with a standing column of water is sufficiently sensitive to pressure transients. The critical factor is the time lag, *i.e.*, the time for the pressure transient to reach a given point in the aquitard rather than the magnitude of the pressure effects. Examples of the application to both "leaky" and "slightly leaky" situations demonstrate how the ratio method works.

This new theory provides a sound basis for understanding the hydrodynamics of fluid injection in multilayered systems. It also leads to a simple method of determining the *in situ* properties of the low permeability layers that serve as confining beds for aquifers subject to fluid injection. One can therefore determine how effectively fluids injected into any given layer are retained within that layer. Such knowledge is of vital importance if environmental problems resulting from an unexpected migration of toxic or otherwise undesirable fluids are to be avoided.