The Multi-shell Model - A Conceptual Model Approach

C.I. McDermott, R. Liedl, M. Sauter, G. Teutsch

On a small (discrete) laboratory scale (typically of the order of 10 cm), individual processes and parameters defining the physical conditions of single fractures may be well defined and modelled. However, on a larger scale, where fracture networks dominate the flow and transport characteristics, the interaction of the various processes controlling flow and transport in the fracture system coupled in some cases with a porous medium cannot be easily defined. Here, a conceptual stream-tube model is presented where the stream-tube geometry is defined by the geometry of the flow in the system. This model was used to investigate the three-dimensional flow systems in bench scale laboratory samples (sample diameter 30 cm, length 40 cm) containing fracture networks in porous material. The model avoids the definition of the individual processes and concentrates on the integral flow and transport signal dependent on the geometry of the flow systems developed during gas tomographical flow and transport investigation. The use of the model to analyze the tomographical data allows the definition of three-dimensional anisotropic tensors characterizing the flow and transport characteristics of the fractured systems based on experimental results.

The model is based on the expected flow patterns within the dipole flow fields generated in the experimental cell. The geometry of the stream tubes comprising the model is controlled by the geometry of the flow field, which in turn led to the model being described as a multi-shell model. In principle, the flow field is represented by a series of one dimensional stream tubes which geometrically correspond to flow shells around the center line/plane joining the dipole source and sink, hence the term multi-shell. These stream tubes are combined to give the three-dimensional flow field signal measured in the experimental work.

Not only the multi-shell model provide an approximation of the flow and transport signal to be expected from the various geometries of the experimental investigation (see Chapt. 4) and thereby allow the deviation from this expected signal to be derived, but it also provides a clear conceptual un-
derstanding of the geometrical factors effecting flow and transport from a small laboratory scale through to the field scale. By an examination of the deviation of the expected signal, the effects caused by the fracture networks can be investigated.

The subsequent chapter starts with a discussion of the model principle, followed by the mathematical development of the model and a consideration of the effects of boundary conditions. Once the model has been described, it is use to understand the different effects of flow fields where the pressure is allowed to vary in one, two or three dimensions, i.e. a one-, two- or three-dimensional flow field. This is demonstrated on hand of experimental results gained from the Multiple Input Output Jacket discussed in Chapt. 4. The effects are then examined further by considering the transport signal and interpreting its form, again with reference to the development of the flow field. Finally, this conceptual approach is shown to provide a practical understanding of the distribution of tracer in the flow fields developed.

6.1 Model Principle

The principle behind this modeling approach is apparent from Fig. 6.1. The flow field is divided up into a series of shells around the center flow line / plane, i.e. the direct connection between input and output port. If the flow is three-dimensional, the shells have the form of a ball or onion (Fig. 6.1b) and if the flow is two dimensional, the shells have a cylindrically curved form (Fig. 6.1a). The flow in each individual shell is calculated, which allows the multi-dimensional flow to be determined as a combination of the flow occurring in the individual shells. For simplicity, two such shells are illustrated in Fig. 6.2. The shell in Fig. 6.2a illustrates the case where the distance \( h_n \) from the center of flow to the shell is less than the distance \( x_0 \), i.e. half the distance between the input and output positions. The shell in Fig. 6.2b illustrates the case where the distance \( h_n \) from the center of flow to the shell is greater than \( x_0 \).

An examination of Fig. 6.2 shows that the flow inside the experimental cell must be a subset of the unlimited flow conditions where no boundaries are present (Fig. 6.2b). Here, the unlimited flow conditions (i.e. flow without the boundaries of the cell walls) in a homogenous medium are considered firstly and then the limited boundary conditions of the experimental cell.

In the case of the two-dimensional flow system, an approach similar to a stratified two well system was applied by Güven et al. (1986): the flow field was approximated by a number of thin crescents which matched the pattern of the flow lines between the wells.