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Porous Medium

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Definition

A porous medium can be defined as a material which contains spaces which, when continuous in some way, enable the movement of fluids, air and materials of different chemical and physical properties. The ability of a porous medium to permit the movement of fluids, air or a mixture of different fluids is related to porosity and the variability of pore characteristics in that the presence of interconnected pore spaces, and thus permeability properties of the material, enables the movement of fluids and accompanying materials.

Characteristics of porous medium

The characteristics of a porous medium are a result of variability in porosity and permeability, and the spatial continuity of these properties (McKinley and Warke 2006 . Porosity as defined by Tucker (1994) is a measure of the amount of pore space in a porous medium and can be characterized as total or absolute porosity and effective porosity. Total or absolute porosity refers to the total void space within a porous medium including void space within grains. Effective porosity can be described as the interconnected pore volume in a porous medium (McKinley and Warke 2006). Effective porosity is more closely related to permeability, which can be defined as the ability of a porous medium to transmit fluids. Permeability is related to the shape and size of pores or voids and pore connections throats), and also on the properties of the fluids involved (i.e. capillary forces, viscosity and pressure gradient). Permeability as calculated from Darcy's law, in simple terms, is a measure of how easily a fluid of a certain viscosity flows through a porous medium under a pressure gradient (Allen et al. 1988).

Depositional and diagenetic characteristics of geological porous media

Geological materials exhibit inherited characteristics from their depositional, compaction and cementation or crystallization history (McKinley and Warke 2006). This results in individual pores or voids which vary in size, shape and arrangement, directing the movement of fluids, air and accompanying materials along preferred pathways and at differential rates. Natural porous medium such as rocks seldom retain their original porosity (McKinley and Warke 2006). The key factors that control porosity and permeability in geological porous medium are primary depositional characteristics (including fabric features) and diagenetic features such as cements and salts (Worden 1998). Primary depositional processes produce fabric characteristics which in turn may be further modified by processes such as compaction and cementation. This results inprimary and secondary porosity. Primary porosity is developed as a sediment is deposited and includes inter- and intraparticle/ granular porosity (Tucker 1994). Secondary porosity of a porous medium develops during diagenesis by dissolution or removal of soluble material and through tectonic movements producing fracturing. Fractures or vugs within geological materials may contribute substantially to the flow capacity (i.e. permeability properties) but contribute little to absolute porosity of a porous medium. Secondary diagenetic precipitation, in the form of cements and salts, has the potential to seal fractures or vugs and reduce the permeability properties of a porous medium. The predominant cements which affect sandstone porous media comprise carbonates, clay minerals and quartz cements. Aspects of carbonate, quartz and clay cementation in sandstones have been comprehensively covered in three special publications (Morad 1998; Worden and Morad 2000, 2001). The variability of porosity in limestone porous media tends to be more erratic in type and distribution than for sandstones (Tucker 1994). Based on the seminal classification scheme by Choquette and Pray 1970, porosity types in carbonate porous media can be defined as fabric selective, depending on whether pores are defined by the fabric (grains and matrix) of the limestone (e.g. intercrystalline), and non-fabric selective, porosity that cuts across the actual rock fabric (e.g. fracture porosity). Stylolites in carbonate porous media can form a type of porosity in terms of acting as conduits for fluid movement or conversely styolites can produce a reduction in porosity of the porous medium through the accumulation of clays and insoluble residue. Porosity in crystalline porous media, including igneous and metamorphic, occurs generally as a result of fracturing, granular decomposition or dissolution, and may be accentuated by mineral alignment or banding.

Heterogeneity of porous medium

No naturally occurring porous medium is homogeneous but some are relatively more homogeneous than others. The problem of nonuniformity or heterogeneity of a porous medium is inherent even at the pore scale, since individual pores vary in size, shape and arrangement. Small-scale features such as pore geometry or laminae also affect the heterogeneity of porous medium.

By definition a reservoir porous medium, such as sandstone, must contain pores or voids to enable the storage of oil, gas and water, which must be connected in some way to permit the movement of the same. Fluids of differing physical properties (oil, gas and water) move through heterogeneous porous media via preferred pathways and at differential rates. Primarily this is due to the variability in porosity, permeability, poro-perm relationship, viscosity, tortuosity, interfacial tension (wettability) and spatial continuity of the porous medium. Knowledge of how the petrophysical properties of porosity and permeability vary throughout materials and identifying the processes responsible for their reduction is important in accurate reservoir modelling of porous media.

The challenge to studies of porous media description, and intrinsically of heterogeneity, can be summarized as to:

- Describe the geology with as much detail and as realistically as possible and in a quantitative approach.
- Assess the spatial distribution of heterogeneities including cements, salts, contaminants etc. and their effect on fluid flow.
- Subdivide the porous medium into hydraulic or flow units (units that under a given driving force behave differently and in which the variation of properties is less than the hydraulic or flow units above and below).

In addition, studies must go beyond data capture to using this information in the development of mathematical simulation models that depict porous medium behaviour accurately and effectively. All of which combines to give a greater understanding of fluid flow processes in a porous medium to optimize recovery and aquifer capabilities. The issues which arise in porous medium description are well documented. The recurrent themes are:

- The detail required to adequately quantify the lateral variability of physical properties far surpasses the detail of sampling (interpolation, extrapolation and informed interpretation are necessary).
- Many heterogeneities have a spatial distribution much less than the average well or sample spacing.
- Heterogeneity at small scale is homogenised, simplified or smoothed over within mathematical modelling.
- Averaging of heterogeneity data for modelling purposes can lead to under estimation of their effect on porosity and permeability.

Conclusions

A porous medium contains spaces or voids that, when connected in some way, permit the movement of fluids, air and associated materials. Porous media tend to be heterogeneous within a larger ordered framework, as a function of scale. At the pore and microscale the sorting and packing of grains can be markedly variable. Random variations or heterogeneous elements at the pore scale may be sufficiently small to be considered homogeneous at a larger scale e.g. lamina, stratum or bedding scale. Porous media, therefore, may appear to be both heterogeneous and homogeneous: depending on the scale of measurement being considered. In view of this it is essential that the scale of measurement being considered be clearly stated. The importance of depositional history in naturally occurring porous media and diagenetic heterogeneities including the influence of cementation and the diagenetic growth of minerals on porous media need to be fully assessed and recognized in any modeling approach.

Cross-references

Porosity, permeability, tortuosity, Darcy's law, total porosity, effective porosity

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