

# Chapter 1

## Modern Theoretical Concepts of Water Treatment and Role of Porous Media in It

### ABSTRACT

*The level of modern knowledge about filtration, that directly ensures the removal of the dispersed contamination from natural and waste waters, was analyzed in Chapter 1. A detailed description of the packed porous media saturated with contaminated water as physical two-phase system is given in Section 1. It is under the conditions of progressive reduction of the pore space. Section 2 includes the description of general approaches to mathematical modeling of processes of different nature, which together promote the productive operation of water treatment units with a porous functional layer. The principles of developing mathematical models, setting appropriate problems, methods of solving them using exact and approximate methods are discussed consistently and specifically for the various filtration conditions. Section 3 provides a base for the technological analysis, including five criteria parameters and equations. Using simple models, the significance of two mass transfer mechanisms is analyzed.*

### 1.1. POROUS MEDIA IN MODERN WATER TREATMENT TECHNOLOGIES

Porous media belong to one of the main components of the natural environment (biosphere) and are an important link in the natural cycles of water, gases, organic substances and biogenic elements. They are of exceptional socio-economic importance, providing not only conditions for human creative activity, but also for human existence. In addition to participating in the formation and functioning of the human environment (atmosphere; vegetation cover; hydrosphere, including surface and underground sources), porous media are used by humans for practical solution of numerous everyday issues. Thus, they have many functions, including those of vital importance to humans.

From the ecological point of view, the porous component in the biosphere plays a key role, because unlike the water and air components, it prevents the widespread of anthropogenic pollutants by trapping and accumulating them. It is capable of holding a large amount of water and harmful substances. However, it can become a source of secondary pollution in case of excessive content of the indicated substances and unfavorable change of conditions in adjacent components of ecosystems. Therefore, the forecast of physicochemical state of porous media in dynamics, also development of microbiocenosis, phytocenosis

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in them and on this basis regulation of various conditions, primarily water-physical and closely related to it hydrochemical conditions and hydrobiological, are of great applied importance.

The monograph has a practical orientation, although it often touches upon issues of fundamental importance. The main attention is paid to various aspects of rational application of porous materials in modern (water) treatment technologies. It is here that they prove to be particularly effective due to the huge contact surface of the solid phase with the liquid (gas) phase. At the same time, such a surface and the accompanying extensive network of interconnected small voids (pores) negatively affect the intensity of the water flow process and the closely related performance of treatment plants and complexes. Thus, the area of application of porous media in practice is significantly limited and the search for ways to expand it is stimulated.

Both natural and artificial porous media most often represent a dispersed structured system, the elements (grains, granules) of which interact (cohesive media) or practically do not interact (non-cohesive, weakly cohesive) and are packed randomly. Nevertheless, simplified notions of porous media as a regular structure with simple geometry have been of great use in various applications. Their illustrative examples are, for example, the consideration of this structure as an ensemble of elements of the same size and regular (spherical, cylindrical, etc.) shape; pore space as a bundle of capillaries (Kozeny, 1931; MacDonald et al., 1991; Henderson et al., 2010; Tan et al., 2017), saturated dispersed medium as a set of spherical particles with a layer of liquid of appropriate thickness on their surface, etc. (Happel, 1958; Kuvabara, 1959; Payatakes et al., 1973; Reddy et al., 2005).

Mechanical, physical, chemical and, in the presence of organic substances, also biological properties of porous media are characterized by great diversity. It is natural that there are many classifications according to different features (by mechanical, chemical composition, flow and absorption capacity, origin, etc.). The mentioned properties and at the same time mechanical, hydrodynamic, physicochemical, biochemical, microbiological processes in the pore space and at interfacial boundaries have been studied for many decades both within separate sections of fundamental sciences (mechanics, hydraulics, chemistry, biology, geology) with the prefix “hydro” and at their junctions (geochemistry, biochemistry, etc.), as well as applied sciences (agrochemistry, hydrology, land reclamation, soil science, contaminant transport and phase transfer, microbiology, etc.).

Of primary importance for the characterization of non-cohesive and cohesive porous media, especially those of natural origin, is their mechanical composition according to (Polubarinova-Kochina, 1977; Sokovnin & Zagoskina, 2002; Vadyunina & Korchagina, 1961; Voznyuk et al., 1984). A complete representation of the number (volumetric content) of spherical particles of any size, from the smallest to the largest, is given by their diameter distribution function, which is described by the grain-size composition curve and cumulative curve (Rastvorova, 1983). The values of the particles diameter  $d_g$  may differ in soils by orders of magnitude.

In separation and, in particular, water treatment technologies, special filtering materials are used to enhance interfacial interaction, intensify the filtration flow process and, in general, the technological process of filtration (Kulikov et al., 2009; Fedorov et al., 1984). To make the work of filtration facilities effective, such material should be cheap, inert with respect to aggressive liquids, have high absorption and throughput capacities, large solids take-up capacity, strength, easy to regenerate. Obviously, a material that would satisfy all these requirements at once is unlikely to exist. In fact, it is rare for one material to combine cost-effectiveness and manufacturability. Synthetic fiber materials seem promising due to their very high porosity and solids take-up capacity, resistance to mechanical and chemical influences exposure (Bugai et al., 2007; Lebedev et al., 2006; Rahli et al., 1996; Stechkina & Kirsch, 2003; Tar-

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