

Chapter 7

Plane–Radial and Radial Detachment Filtration

ABSTRACT

The subject of the in-depth research by exact and approximate methods in Chapter 7 is an understudied variety of the deep bed filtration, namely filtration with an axisymmetric suspension flow, which is implemented in a filter media having the shape of a cylindrical layer. The stable supply of contaminated water to the filter bed through its external or internal surfaces is thoroughly studied for linear kinetics. According to the results of the technological analysis, it has been concluded that the operation of the filter can be noticeably prolonged due to replacing the plane shape of the filter medium and the suspension flow with an axisymmetric shape and thus, using filter materials with high absorption capacity. In turn, the design analysis allowed to substantiate the rational dimensions (radii) of the bed. Chapter ends with the research on the radial filtration with spherical symmetry of the suspension flow in the functional layer of a spherical or semi-spherical shape.

Fundamental importance for the theory and practice of the deep bed filtration has the long-established fact of the essential mutual influence of the filtration flow and mass exchange processes. Thus, there is a principal opportunity to increase the efficiency of water treatment filters by a purposeful change of filtration rate in time, which is confirmed by the results of the studies conducted in Chapter 5, and also within the filter media volume. Especially promising in technological terms seems to be the arrangement of the filtration flow in the filter bed, the rate of which decreases or increases with distance from the inlet cross-section. Then, taking into account the expressions for the mass exchange coefficients (3.54) and physical and chemical properties of suspension, filtering material, it is realistic to achieve a significant intensification or weakening of the absorption process, which plays a key role in the dispersed impurity removal. When materials with a high absorption capability are used, as a rule, the clarification resource of a packed bed is not fully utilized. The reason of the unsatisfactory operation of the filter, which is expressed in premature termination of filtration and overconsumption of wash water, is the excessive expenditure of mechanical energy due to the accelerated clogging of the section adjacent to the inlet surface. It is possible to significantly prolong the filter operation in such situations by creating unfavorable conditions for the sticking of suspension particles to the bed elements (grains) at the specified section and, on the contrary, favorable conditions at the peripheral section. Thus, if the thickness of the filter media is sufficient, on the one hand, the required amount of the suspended solids will be retained within it and, on the other hand, its hydraulic resistance will increase much more slowly. As a result,

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the amount of the clarified suspension with the normative outlet suspended solids content will increase commensurately by extending the continuous operation of the filter. Stable filtration flow with its moderate spatial irregularity can be provided using filters, structurally equipped with the rate regulators and a uniform bed of small thickness and special shape, for example, in the form of a cylindrical or spherical layer (Dzyubo, 2006; Poliakov, 2014, 2015b).

In general, axisymmetric (plane-radial) filtration flow of liquids in natural porous media has been given extremely great attention for several decades due to the wide use of vertical drainage in engineering practice (Oleinik, 1978; Bear, 1979). Modeling of flows of such geometry is significantly complicated in the case of heterogeneous fluids in the presence of intensive interfacial mass transfer due to the change in filtration rate in the radial direction. Therefore, the relevant studies conducted by experimental (Voi-tov, 1974; Bolton et al., 2004) and theoretical (Dzyubo & Alferova, 2007; Liu, et al., 2016; Tiller, et al., 2004; Vigneswaran, et al., 1985) methods were scattered. Nevertheless, they have clearly demonstrated the advantages of the plane-radial filtration over the plane filtration. Such advantages are especially clear in the case of a high absorption capacity of the filtering material. The theory of the (plane-) radial filtration was thoroughly developed in a series of works by the author (Poliakov, 2013a; 2013b; 2015b; 2015c), which were used to write this Chapter. The results obtained using analytical methods provide a significant contribution to the above theory and can serve as a basis for the applied optimization of the corresponding technological and design parameters.

In five Sections of Chapter 7, two types of the uneven detachment filtration (plain-radial and radial) at linear kinetics of the interfacial mass exchange became the subject of research. The main attention was paid to the plain-radial filtration, which is dedicated to the first four Sections. An important design advantage of this method of the suspension clarification is the compactness of a filter facility. Indeed, it is possible to increase the performance of the cylindrical bed at a constant hydraulic load proportionally to increasing its height without complicating the filter design. The ultimate goal of this development was a reliable prediction of changes in the characteristics of the plane-radial filtration, as well as an engineering methodology for the substantiation of the technological and design parameters, which is based on approximate solutions of two similar axisymmetric non-stationary problems of the joint mass transfer, mass exchange, and filtration flow. This methodology is presented in fragments in Sections 7.2, 7.3 and 7.4. It should be noted that the efficiency of the (plane-)radial filtration depends significantly on the place of suspension feeding into the bed. In the first three Sections, plane-radial filtration is analyzed when the suspension enters through the outer cylindrical surface, and in Section 7.4 – through the inner surface. In order to assess the validity of both approximate solutions, and thus, of the engineering methodology based on them, particular exact solutions were obtained to serve as a reference for the comparative analysis. They are presented in the first and fourth Sections. The radial filtration of suspension through a bed in the form of either a full spherical layer or a spherical half-layer is studied in the last Section. Certainly, the use of such beds due to the complexity of their design, operation and especially washing can make sense especially at a very high cost of absorbing material. Nevertheless, the study of this type of the uneven detachment filtration is useful in that it provides a deeper understanding and evaluating the capabilities of water treatment filters with a spatial unevenness of the filtration flow.

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