Chapter 2
Linear Theory of Detachment Filtration With Constant Rate

ABSTRACT

Chapter 2 highlights the basic provisions of modeling the detachment filtration of aqueous suspensions at a constant rate with linear mass exchange kinetics under the operating conditions similar to reality. Thus, the initial contamination of the packed bed of the rapid filter, significant changes in the initial content of the suspended solids over time are taken into account. Thanks to the use of exact and approximate analytical methods, formulas suitable for predicting an increase in the impurity concentrations and mechanical energy expenditure are derived, firstly, in a simple integral form, and secondly, in an even simpler form of combinations of elementary functions. In addition, similar solutions to the problem of clarification of the suspension in the packed bed of a special layered structure, as well as the calculation expressions, are obtained. There are comments on the key mass exchange coefficient.

The materials contained in this chapter deserve special attention because they are the basis for further theoretical studies of aqueous suspension filtration on rapid filters, as well as for the development of practical recommendations for their rational operation. First of all, it is necessary to note an extensive area of practical application of the new developments, which in the remaining chapters of the monograph is significantly expanded due to the correction of the basic model and the system of assumptions. The subsequent regular technological and design analysis is partly based on the results obtained in this chapter. The found and tested exact and approximate analytical solutions are of the methodological value. Indeed, the procedures of the derivation of the calculation dependences are practiced on their example, which are then used for more complicated from the formal point of view filtration conditions.

The subject of an in-depth study by analytical methods was the detachment direct flow deep bed filtration of aqueous suspension with a constant rate. The linear filtration and kinetics of exchange of dispersed impurity particles between liquid and solid phases of a special porous (granular) medium, which has high absorption and flow capacity, were assumed. A mathematical problem of clarification of a low-concentration suspension with stable composition and impurity content in an initially partially clogged uniform packed bed of a rapid filter is formulated and solved rigorously (Section 2.1) and approximated (Section 2.4). In addition, an exact solution of a similar problem is obtained, but without taking into account the initial contamination of the filtering material and with a significant change with time in the suspended solids concentration at the inlet to the filter media (Section 2.2). As a generalization of the first two problems, we can consider the problem of suspension separation in a layered bed (two-

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layer, three-layer) with a special structure and properties that ensure active participation of all layers in the removal of suspended solids (Section 2.3). In the case of relatively high initial suspended solids concentration and low absorption resource of a uniform packed bed, the second stage of filtration was distinguished when the zone of complete saturation with deposit occurs (Section 2.5). Here modeling of the clarification of an aqueous suspension was performed using approximate analytical methods on the basis of the corrected formulation of the first problem. The main calculation expressions from the many ones presented in the first five sections of the chapter are illustrated by a large number of examples with initial data corresponding to normal and extreme filtration conditions. Finally, considering the key role of the sorption (in the wide sense) component of interfacial mass transfer in suspension separation, attention is emphasized on the mechanisms of delivery of its particles to the collectors-particles (grains) and the relationship between the most important mass exchange coefficient, which directly controls the clarification process, and the sizes of the specified particles (both equivalent diameters), as well as the filtration rate.

2.1. SUSPENSION FILTRATION THROUGH INITIALLY CLOGGED UNIFORM PACKED BED (EXACT SOLUTION)

The filtration of a low-concentration suspension (natural water or partially treated wastewater) through the granular medium of a rapid filter, which initially contains insignificant amounts of a solid contaminant, is investigated using analytical methods (Poliakov, 2006a). It is preliminarily assumed that

- the packed bed is made of highly permeable, well-absorbing filtering (granular) material;
- the operating volume (active medium) is a uniform, isotropic porous medium;
- constant filtration rate;
- composition and content of a dispersed impurity at the filter inlet do not change during the calculation period;
- convective mechanism of the dispersed impurity transport prevails (relevant estimates are made in Section 1.4);
- mass exchange between the liquid and solid phases of the bed is caused by the absorption of the suspended solids and the hydrodynamic detachment of the deposited suspension particles;
- linear mass exchange kinetics;
- suspension motion in the bed obeys the linear filtration flow law;
- vertical filtration;
- the bed contains a deposit except the start of operation;
- the filter transportation system causes additional head losses determined by suspension and filtrate flow rates.

Within the framework of this monograph, the above system of assumptions can be considered as a conceptual one, since it is used except for two or three positions, which are removed, replaced or supplemented when formulating most of the mathematical problems. The specified system is necessary for adequate reflection of filtration conditions and correct formulation, in essence, of the basic problem of a rapid filtration. In the future, the system will be expanded when specifying phenomenological relations contained in the initial mathematical models. And only analytical solutions of the classes of problems