

Chapter 6

Nonlinear Detachment Filtration

ABSTRACT

Since the absorption rate of the suspended solids and the corresponding kinetic coefficient often decrease or increase as the deposit accumulates in the bed, Chapter 6 raises the issues of the detachment filtration with nonlinear kinetics. At the same time, the exact solutions of the suitable nonlinear problems were obtained in the presence of an initial deposit and a two-layer structure of the filter media, taking into consideration the autocatalysis phenomenon, progressive decrease in the absorptive capacity. Based on them the significance of the nonlinear effect was estimated, numerous technological calculations were performed. In view of the cumbersome calculation formalisms and the unambiguous choice of kinetics, an approximate solution of a similar problem with a kinetic equation of general form is obtained, which allows to calculate the characteristics of nonlinear filtration with minimal errors. The accuracy of the above solution is evaluated in case of linear filtration for the head losses due to severe clogging of the packed bed.

The deposit formed in filter facilities has often an active effect on the deposition of the suspended solids in the pore space of a packed bed. On the one hand, it can noticeably increase the number of vacancies for the suspended solids and thus, intensify the suspension clarification especially at the initial stage. A short-term enhancement of the absorption capability of the filtering material, the so-called “ripening”, was regularly observed in experiments (Bugai et al. 2004; Calvin, 1992; Elimelech & O’Melia, 1990). On the other hand, the deposit formation means gradual filling of such places that existed in the filter bed initially and negatively affects the suspension separation. Thus, these effects have directly opposite consequences for the technological process of the aqueous suspension separation. In mathematical terms, however, both of them cause the nonlinearity of the mass exchange kinetics between liquid and solid phases in the bed. Naturally, linear kinetics is primarily suitable for the mathematical modeling of filtration if these effects compensate each other and then the deposit actually becomes inert with respect to the suspended matter. At the same time, if the granular and even more so the fibrous filtering material has a high absorption capability and the “ripening is negligible or stops quickly, the use of the linear mass exchange kinetics is also justified. Similar conditions are typical for the operation of many filtration facilities, which explains the wide use of linear kinetics equations in theoretical developments. If the above-mentioned effects are significant and mutually not compensated, then, first of all, they are reflected on the absorption process. And then the selection of the correct formal representation for the key mass exchange coefficient is very important. Being constant in linear kinetics, the coefficient α in nonlinear kinetics will already be a function of the concentration of the deposit S_s or deposited particles

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S . Thus, in accordance with representation (1.14) and taking into account (1.15), (1.29), it is possible to consider that the absorption function of a dispersed contaminant will be as follows

$$f_{\alpha}(d_g, d_p, V, T, S) = \alpha_0(d_g, d_p, V, T) \chi_s(S) \quad (6.1)$$

where the adhesion function $\chi_s(S)$ characterizes the effect of the deposited particles on the absorption rate of the suspended solids. If it is necessary to simultaneously take into account both of the above-mentioned effects, this function can be nonmonotonic for rapid filters in contrast to slow filters (Ojha & Graham, 1994), and then it is often justified to use polynomials of the second degree and higher, the coefficients of which are selected on the basis of experimental data. Below, however, its linear form, namely, the following two linear functions according to (1.17) and (4.14) (Alekseev & Kommunar, 1974; Jegatheesan & Vigneswaran, 2000; Kuhn & Briesen, 2016; Ornatsky et al., 1955; Poliakov & Martynov, 2021; Tan, 1994) will be involved in the theoretical studies of the nonlinear detachment filtration by exact analytical methods

$$\chi_s(S) = \chi_{sm}(S) = S_m - S \quad (6.2)$$

$$\chi_s(S) = \chi_{sa}(S) = 1 + \theta S \quad (6.3)$$

where S_m is actually the concentration of the limiting saturation by the deposited particles of a filtering material, which depends on the properties of a dispersed impurity, the method of the reagent treatment, and the filtration mode (Dzyubo & Alferova, 2007; Mintz, 1964; Senyavin et al., 1977). Just such a formalization of the absorption process is used in the theoretical analysis of mass exchange in the case of the contaminated water filtration in natural and artificial porous media for several decades, and its validity has received convincing experimental confirmation. For the nonlinear representations of $\chi_s(S)$, we have to use exclusively the approximate solution methods. According to (6.2), the formed deposit only complicates the subsequent removal of the suspended matter and, due to the progressive reduction of vacancies for the suspension particles, its accumulation rate will steadily and smoothly decrease. In accordance with (6.3), the suspended solids deposition is enhanced by the formation of the deposit and thus, the creation of new vacancies. Just such a formalization of the absorption process is used in the theoretical analysis of mass exchange in the case of the contaminated water filtration in natural and artificial porous media for several decades, and its validity has received convincing experimental confirmation. More general representations for the function $\chi_s(S)$ have been used both in this Chapter and in Chapter 4 in the study of the non-detachment filtration. For the nonlinear representations of $\chi_s(S)$ in case of the detachment filtration, we have to use exclusively the approximate solution methods.

The main content of this Chapter includes rigorous and approximate analytical solutions of a number of typical problems of the nonlinear direct-flow (plane) detachment filtration. Their practical expediency is demonstrated on numerous test examples, in which the factors essentially influencing the current physical and chemical state of the operating medium and considered in the formulation of the mentioned problems (instability of the contamination in natural water or pretreatment effluents, initial clogging of a filter bed, its non-uniform structure, limited absorbing resource of a filtering material, active participation of a deposit in the mass exchange) vary within wide limits. At the same time, the significance of the mentioned factors was assessed, which allows to outline the ways of their targeted change for the

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