Studies and Researches for Water Resources and Environmental Protection Program

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This paper presented experimental studies and research carried out on a laboratory plant to optimize the exploitation of rapid filters factory equipped with homogeneous granular media. Filter material used was composed of quartz sand, with increasing grain size as the current flow direction (d = 0.3 to 3.0 mm) and layer thicknesses of 50-60 cm. The experimental research carried out for different concentrations and different filtration rates determined optimal values of operating parameters to ensure a good quality filter and constant flow during the filtration cycle.

Keywords: downward filtration, filtering medium, optimal filtering cycle, operating parameters, speed filter, homogeneous quartz sand

Within the complex protection program of water resources and the environment, rapid filtration is the process that ensures completion of the rinsing process of water supply for drinking and industrial purposes.

Large variety of filtration plants, in terms of the composition and functioning requires detailed knowledge of each process so that a judicious choice and rational exploitation to ensure good quality of water at the lowest possible cost price [9- 12].

Rapid filtration must be considered as an essential component of all the processes needed for the clearing of underground and surface water with the purpose that in the optimal deployment, favoured by the chemical pretreatment and settling processes, to succeed perfection of the rinsing process.

In value terms, the filters are on average more than 30% of total investments allocated to treatment plants. This finding led the specialists, who work in this area to pay special attention to filtration, which has generated numerous studies and researches that led to continuous improvement of constructions and filtering plants.

The researches refers in particular to knowledge and the profund study of water filtering mechanisms, the development of mathematical models of filtration, filter material choice and optimization of filtration rates, so that filtered water to be the best quality, in sufficient quantity and at the lowest cost price.

Homogeneous materials can be increasing or decreasing grain layers depending on the direction of water filtration (downward or upward). These materials should be resistant enough so that in case of repeated washing the structure size to be maintained on periods of time as long as possible [1-3].

Theoretical considerations

To establish the optimal parameters involved in the process of separating the suspensions from water, it is required intimate knowledge of all phenomena that arise from the passage of water through an aqueous medium.

If we know the mechanisms which contribute to the rinsing process we can determine the optimum filtration rates, thickness and granulometry of filter media and dosage of reagents, so that the lifetime of the filter between the two washings to be as high as possible [7, 9].

For a complete description of the phenomena involved in the process of rapid filtration it is necessary to consider simultaneously both physical and chemical factors.

Mechanisms involved in the removal of particles in suspension from water are dependent on: the filtering medium density, filtering medium granulometry, filtering medium depth, the speed of filtering; the water column above the filtering medium, the concentration of particles in suspension from raw water; temperature, density and viscosity of the fluid [7, 9].

The experimental research found that the quartz sand grains are loaded with negative electric loads, but the effect of the electrostatic potential is reduced by aluminum or iron floaters adhesion. If the particles have not enough kinetic energy, then they will be strongly attracted to the grain surface.

Finally, it was agreed that the removal of particles from the water passing through the filter is due to transport, attachment and detachment mechanisms [3, 4].

The researches made until now on laboratory facilities or factory filters, established that in the first part of the filtration, effluent turbidity is reduced gradually to a value which remains constant throughout the treatment period after which it begins to grow, to the maximum quality allowable by current technical norms [11, 12].

Qualitative and quantitative changes in the rapid filtration proccess

Taking into account a filtering layer, consisting of sand, of thickness x, through which is filtered a flow Q, with a concentration C_0, initial concentration changes in relation to the filtering thickness, develops experimentally an exponential law, evidenced for the first time by [3]:

$$C = C_0 \cdot e^{-\lambda \cdot x} \qquad (1)$$

$$\ln\frac{C}{C_0} = -\lambda \cdot x \qquad (2)$$

where:

C_0 - the initial concentration of the effluent in suspensions, in mg/dm^3;

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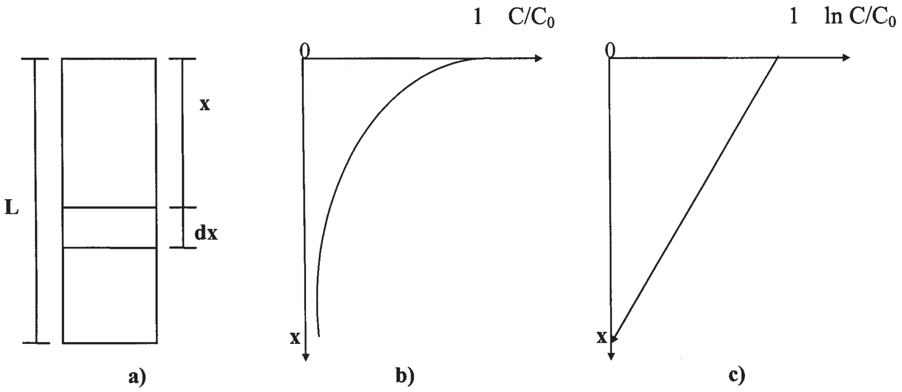

Fig. 1. Variation of suspension concentration on the filtering thickness

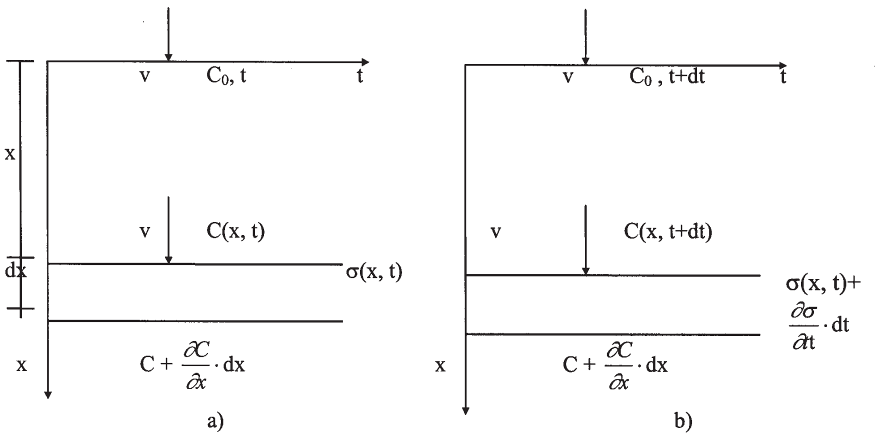

Fig. 2. Variation with depth of concentration in suspensions of filtered water, in time t and t + dt

C – suspension concentration of the effluent at depth x of filtering layer, mg/dm^3;

λ - filtering parameter or retention parameter, in m^{-1};

dx – elementary filter layer thickness, in m^{-1};

L – filtering layer thickness, in m^{-1}.

By differentiating function 2 it is obtained an expression for the retention suspensions gradient in filtering mass, as being proportional to the suspension concentration in the effluent:

$$\frac{\partial C}{\partial x} = -\lambda \cdot C \qquad (3)$$

By filtering, suspensions of purified water, are retained in filtering material pores as well as on grains of sand surface. Deposits retained on an elementary thickness dx, at time t, can be calculated using mass balance equation:

$$\rho_s \cdot v \cdot c \cdot dt - \rho_s \cdot \left(c + \frac{\partial c}{\partial x} \cdot dx\right) \cdot v \cdot dt =$$
$$= -\rho_s \cdot \sigma \cdot dx + \rho_s \cdot \left(\sigma + \frac{\partial \sigma}{\partial t} \cdot dt\right) \cdot dx + \rho_s \cdot p \cdot \frac{\partial c}{\partial t} \cdot dt \cdot dx \qquad (4)$$

After reduction and simplification the equation 4 becomes:

$$-\frac{\partial C}{\partial x} = \frac{1}{v} \cdot \frac{\partial \sigma}{\partial t} + \frac{p}{v} \cdot \frac{\partial C}{\partial t} \qquad (5)$$

where:

σ is specific deposit, defined as the suspension retained per unit volume of filtering material;

v = Q / F - apparent speed of filtration;

ρ_s - specific mass of suspension;

p – filtering medium porosity;

F - filtering surface.

The term $\partial C / \partial t$ beeing very small, can be neglected, resulting the second differential equation of rapid filtration:

$$-\frac{\partial C}{\partial x} = \frac{1}{v} \cdot \frac{\partial \sigma}{\partial t} \qquad (6)$$

Parameter λ is a size determinant of the process of rinsing proccess defining filtration efficiency, being a complex function, depends on: filtering medium characteristics; characteristics of the liquid which is filtered; conditions in which takes place the filtration process.

Most researchers have agreed to describe mathematically the process of rapid filtration, the system of differential equations with partial derivatives, proposed by [3]

$$\frac{\partial C}{\partial x} = -\lambda \cdot C \qquad (7)$$

$$-\frac{\partial C}{\partial x} = \frac{1}{v} \cdot \frac{\partial \sigma}{\partial t} \qquad (8)$$

In the filtration process, simultaneously with the transport and suspension mountings mechanisms, it was noted their deployment mechanism, hence of the separation of already fixed deposits and of returning in current streams of the liquid, moving towards the layers of the filtering layer. In this case, the term ($\beta \cdot \sigma / v$) was introduced into the general system of differential equations, which take into account this phenomenon [4].

Equation proposed complete equation 8 proposed by [4], expressd as:

$$-\frac{\partial C}{\partial x} = \lambda \cdot C - \beta \cdot \frac{\sigma}{v} \qquad (9)$$

where:

λ is the retention parameter, in m^{-1};

β - detachment parameter, in s^{-1}.

Systems of differential equations with partial derivatives proposed for mathematical description of rapid filtration proccesses, give analytical solutions for particular values of parameters λ and β [9].

Deposits accumulated in the filtering mass may increase the load losses and interstitial speeds in parallel with a significant reduction of flow and filtering medium pores.

Load /pressure losses in the filtering medium where σ <<p can be determined by the relationship [9]:

$$\frac{\left[\frac{\partial H}{\partial X}\right]}{\left[\frac{\partial H}{\partial X}\right]_0} = 1 + (2\varepsilon + 1)\frac{\sigma}{p} + (\varepsilon + 1)^2\left(\frac{\sigma}{p}\right)^2 + (\varepsilon + 1)^3\left(\frac{\sigma}{p}\right)^3 \quad (10)$$

where:

H and H_0 are the load losses in the filtering medium at time t and respectively t_0;

X- filtering layer thickness;

p – filtering medium porosity; ε=p/(1-p)

Optimization of the rapid filtration proccess

Optimization of the rapid filtration proccess is performed when at the filtration plant exploatation is ensured at T1 = T2 the simulation achieving of qualitative (C_{lim}) and quantitative (H_{lim}) limits without the filtered flow to be reduced (Q = const), [9].

This aspect is illustrated by graphical representation depicted, in figure 3 [9].

Rapid filtration process is considered optimized when:

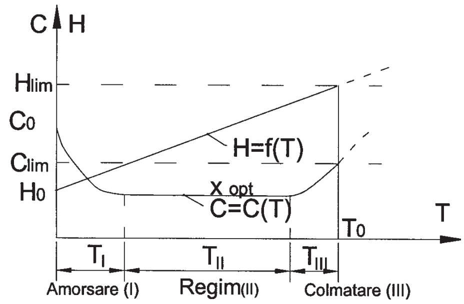

Fig. 3 Characteristic functions C = C (T) and H = H (T) for optimization of rapif filtration exploitation

$$T_1 = T_2 \quad (11)$$

T_1 represents filtration cycle in which the concentration in suspension of affluent $C \le C_{lim}$ and T2 is filtration cycle up to the load pressure/loss in filtering layer $H \le H_{lim}$.

It is considered C_{lim} = 5 mg/L S_iO_2 = 5NTU; H_{lim} =2–2.5 m

where:

1mg/L S_iO_2= 1NTU (Normal Turbidity Unit), [9].

This requirement can be realized only when the constructive and exploitation elements of the filter are provided (thickness and granulometric structure of the filtering medium) or in conjunction with exploitation parameters (speed of filtration, concentration of influent and effluent (C_{lim}), size of load loss (H_{lim}) and filtration cycle (T1 and T2) [5, 9].

Optimization of filtration processes within the factory units can be established only through studies and research carried out on an experimental stand, arranged in a laboratory or in the industrial filters hall.

Experimental Studies and Research

Laboratory Plant

Experimental researches were conducted on a laboratory scale rapid filter, equipped with quartz sand of different thicknesses and different granulometric sizes.

In relation to the purpose it was intended to increase retention capacity of the filtering media by using homogeneous materials (quartz sand) with increasing grain according to the flowing direction [6, 7].

Researches has been conducted on a experimental laboratory plant, equipped with homogeneous materials with constant density - quartz sand, according to table 1.

Table 1

Nr. crt.	Input concentration C_o (NTU)	The height of sand layer L (m)	Filtration speed v (m/h)
0	1	2	3
1	15	0,50	5
			10
			15
	52÷58		5
			10
			15
2	14÷21	0,60	5
			10
			15
	55÷59		5
			10
			15

For experimental research was used water of Bega, captured in the aspiration tank of pumping station to supply the hydraulic circuits of the hydrotehnical laboratory [2, 8].

Filter equipment was made with quartz sand obtained from Faget career, having granulometry from 0.3 to 3.0 mm equivalent diameter $d_{ec.}$ = 0.85 mm of thick layer Δx = 0.50 m and $d_{ec.}$ = 0.78 mm of thick layer Δx = 0.60 m.

Experiences were made for four different thicknesses of filtering layer from 5 to 20 cm and respectively from 5 to 30 cm, consisting of four varieties sorts of quartz sand having granulometry: 3 to 2 mm, 2 to 1.5 mm; 1.5 to 0.7 mm and 0.7 to 0.3 mm, through which was filtered water with following average concentrations: 15 NTU; 52 ÷ 58 NTU;14÷21 NTU; 55÷59 NTU.

Filtration speeds, used in the experimental program were on average 5, 10, 15 m/h. In parallel with the measurement of qualitative changes in the characteristic thickness of the filtering layer were determined too the load losses with a piezometric panel [2].

Homogeneous material characteristics

Filtering materials were composed of quartz sand with granulometry between 0.3 and 3 mm, resulting in screening samples, equivalent diameter (d_{ec}.) and porosity (p_0), for the filtering structures of 50 cm and respectively 60 cm, measurements given in tables 2 şi 3, [1, 2].

Uniformity coefficient ($u = d_{60}/ d_{10}$) was determined according to the filtering material characteristics and water quality requirement (drinking or industrial water).

The filtering layer of sand for the factory filters had the following characteristics: thick layer of sand L = 0.7 ÷ 1.2 m; uniformity coefficient u = 1.5 ÷ 2.5; efficient diameter d_e=d_{10} = 0.4 ÷ 0.8 mm.

Results and discussions

In the downward filtration through homogeneous layers were revealed by experimental researches, qualitative

Table 2

Nr. crt.	Grain size d (mm)	Thickness Δx (cm)	Percentage Share %	Equivalent diameter $d_{ec.}$ (mm)	Uniformity coefficient $u= d_{60}/d_{10}$	Initial porosity p_0
0	1	2	3	4	5	6
1	3 ÷2	5	10	0,85	1,935	0,391
2	2 ÷ 1,5	7,5	15			
3	1,5 ÷ 0,7	17,5	35			
4	0,7 ÷ 0,3	20	40			
Total		50	100	-	-	-

Table 3

Nr. crt.	Grain size d (mm)	Thickness Δx (cm)	Percentage Share %	Equivalent diameter $d_{ec.}$ (mm)	Uniformity coefficient $u= d_{60}/d_{10}$	Initial porosity p_0
0	1	2	3	4	5	6
1	3 ÷2	5	9	0,78	2,0	0,385
2	2 ÷ 1,5	7,5	12			
3	1,5 ÷ 0,7	17,5	29			
4	0,7 ÷ 0,3	30	50			
Total		60	100	-	-	-

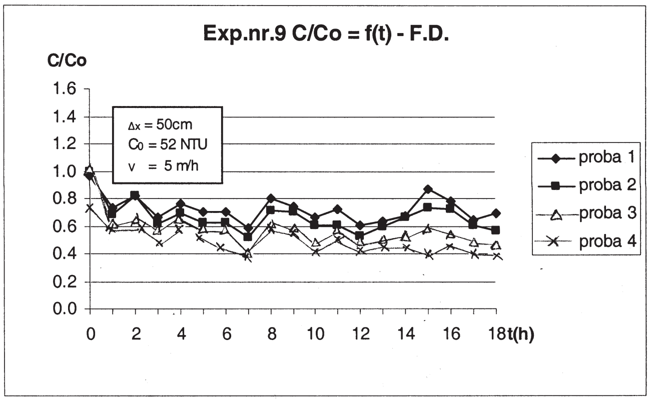

Fig.4. Qualitative changes to downward filtration with v = 5 m/h in relation to the filtration cycle

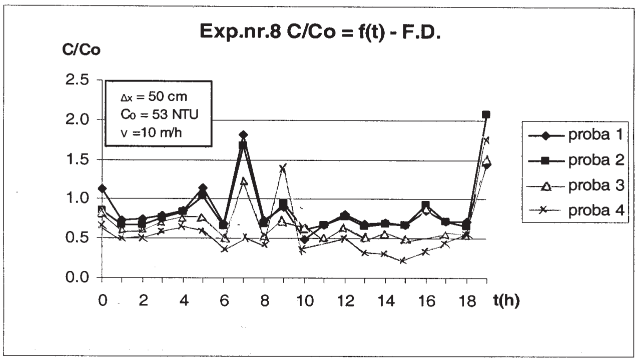

Fig. 5. Qualitative changes to downward filtration with v = 10 m/h in relation to the filtration cycle

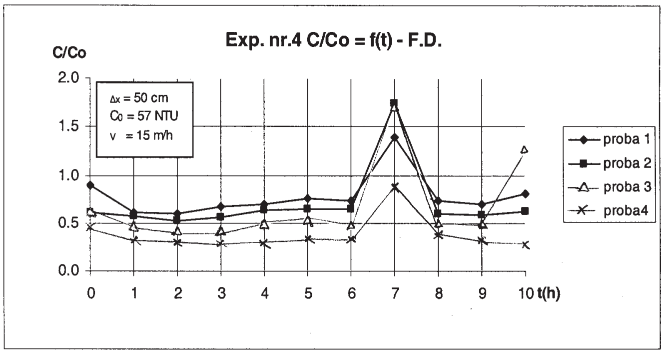

Fig. 6. Qualitative changes to downward filtration with v = 15 m/h in relation to the filtration cycle figure

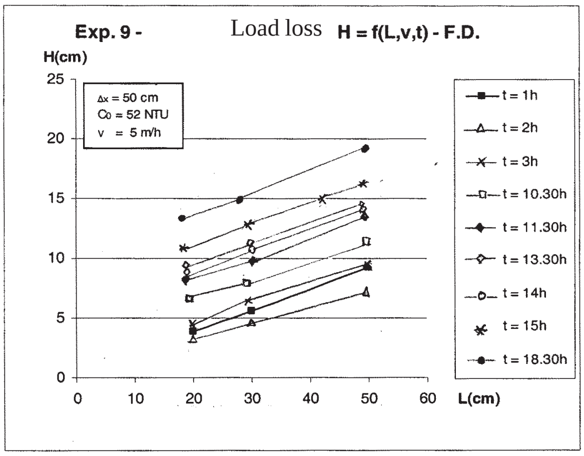

Fig. 7. Load losses at downward filtration with v = 5 m/h in relation to the filtering thickness

changes of the filtered in relation to the size of the filtration speeds [11, 12].

Qualitative changes to a filtering structure consisting of quartz sand of 50 cm thick, in the case of some turbidity of 52 ÷ 57 NTU at speeds of 5, 10 and 15 m / h are shown in figures 4, 5 and 6.

Analyzing the results obtained, especially at speeds of 10 and 15 m/h were noted lift off (washes) after (6 ÷ 7) h after the entry into operation of the filter.

Changes of load losses during filtration cycles revealed slow growth for speed of 5m/h and significant (exponential) for speeds of 10 and 15 m/h. Load losses (H) reached values of 20 ÷ 60 cm after 18÷ 19 h operation of the filter (T).

In figures 10, 11 and 12 are shown, based on experimental measurements, qualitative changes between the upper and lower layers, confirming that the filtering medium is used poorly on the entire filter thickness, filter layers of the lower strata being exploited to a lesser extent.

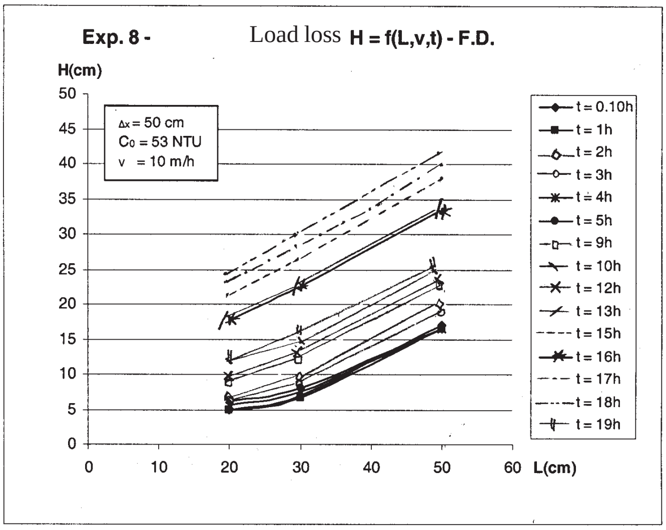

Fig.8.Load losses at downward filtration with v=10 m/h in relation to the filtering thickness

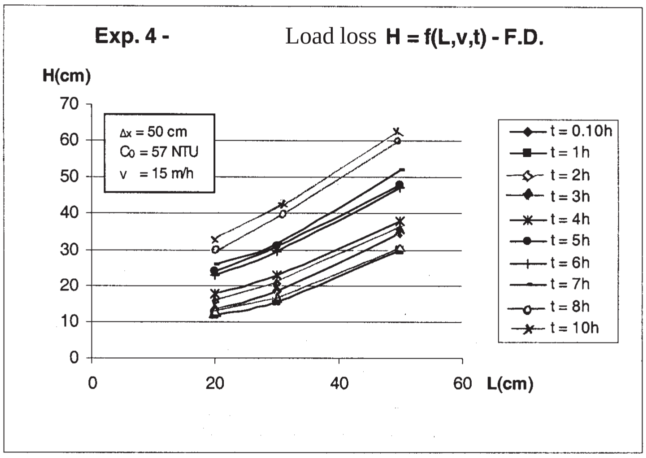

Fig. 9. Load losses at downward filtration with v = 15 m/h in relation to the filtering thickness

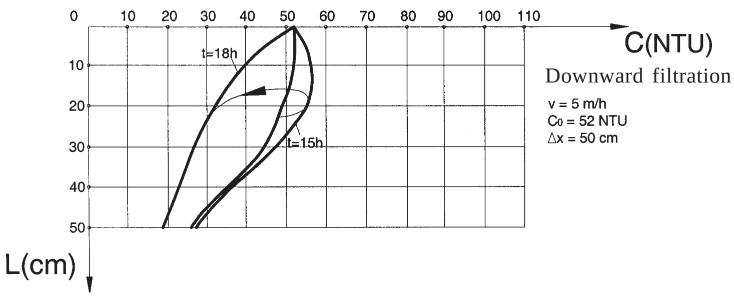

Fig. 10. Qualitative changes of the effluent in the filtering thickness for v = 5 m/h

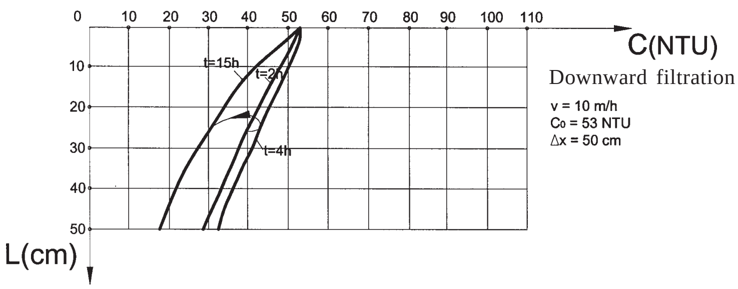

Fig. 11. Qualitative changes of the effluent in the filtering thickness for v = 10 m/h

In parallel with the separation of suspensions in the different horizons level are highlighted pressure increases as a result of these qualitative changes.

Quantitative changes emphasize the load loss increases during filtration cycles, even more than the maximum limit reached by the filter to vacuum operation, load loss values obtained for the three filtering speeds are 19 cm for v = 5 m/h; 42 cm for v = 10 m/h and 62.5 cm for v = 15 m/h.

Limits obtained at speeds of 10 and 15 m/h correspond to the vacuum filters operation. This phenomenon can be avoided by increasing the water column above the filtering layer, leading to increased water column pressure to the

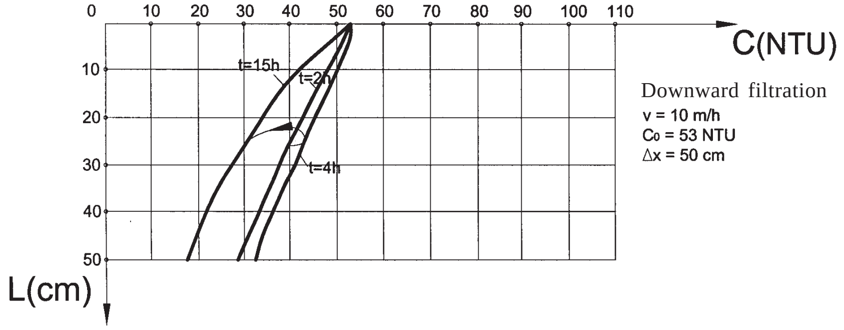

Fig. 12. Qualitative changes of the effluent in the filtering thickness for downward filtration with v = 15 m/h

maximum limit permitted up to 2 to 2.5 m, height required by the investment costs related to those of exploitation.

Jumps shown in experimental researches for downward filtration (figs. 5 and 6), are determined by the lift off deposits on layers of the superior horizons, due to increasing interstitial speeds and amplification of transport phenomena.

Load loss increases in filtering weights are determined by additional resistance taken by deposits retained in filtering weights.

Conclusions

The paper presents experimental researches and studies used to optimize the exploitation of factory rapid filters equipped with homogeneous medium grain. Filtering material used in laboratory plants consisted of quartz sand from Faget career.

After studies and experimental researches result characteristics of filtering material (thickness, grain size, coefficient of uniformity) and exploitation parameters to ensure a high degree of rinsing within the maximum load losses limit of 2 to 2.5 m.

To equip rapidly downward filters quartz sand with granulation between 0.3 and 3.0 mm with d_{ec} = 0.85 mm for Δx = 0.50 m and respectively d_{ec} = 0.78 mm for Δx = 0.60 m was used.

Optimizing filter factory operation can be achieved through studies and researches on pilot installations.

Granulometric structure must be checked every six months by lifting the granulometric curves of filtering material. If significant changes are held of filtering material structure shall be removed the fine surface layer, then replaced and supplemented with a coarse range for granulometric curve correction bringing it to its original form.

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