УДК 628.1

IMPROVEMENT OF THE CLARIFIER WITH SUSPENDED SEDIMENT LAYER CONSTRUCTION IN WATER SOFTENING TECHNOLOGICAL SCHEMES

Odud L.M., post-graduate student,
National University of Water and Environmental Engineering, Rivne
liudmylaodud90@gmail.com

Abstract. The calcium and magnesium (hardness) ions in water causes scaling in boilers, heat loss in heat exchangers and more problems in industrial equipment and edifices. Water softening is a familiar process for solving hard water problems. Separation and removal of hardness ions is called softening. Water softening is almost a common unit operation in many industries and makes the water suitable for use in cooling towers or prepares it for additional purification.

Disadvantages of existing water softening methods are: high temperatures of process passing, what causes significant energy costs; high cost of some reagents; some substances can cause appearance of additional compounds, which supposed to be removed or neutralized.

Lime-soda is widely spread method and one of the most important facility in current technological scheme is clarifier with suspended sediment layer. In our research we tried to find ways for its improving, simplifying and decreasing exploitation costs.

Due to received results we may claim that the reconstruction of clarifier with suspended sediment layer by replacing switchgear, air separator, horizontal perforated partition, sludge receiving windows to expanded polystyrene filling and holding grate will be a great solution nowadays.

Applying lime-soda method on reconstructed clarifiers is a new way of water softening and it allows to hold water softening process in one facility, decrease washing and energy expenses.

Keywords: water hardness, water softening, lime-soda method, clarifier, suspended sediment layer, expanded polystyrene filling.

ВДОСКОНАЛЕННЯ КОНСТРУКЦІЇ ОСВІТЛЮВАЧІВ З ШАРОМ ЗАВИСЛОГО ОСАДУ В ТЕХНОЛОГІЧНИХ СХЕМАХ ПОМ’ЯКШЕННЯ ВОДИ

Одуд Л.М., аспірант,
Національний університет водного господарства та природокористування
liudmylaodud90@gmail.com

Анотація. Наявність іонів кальцію та магнію у воді є причиною відкладень в бойлерах, втрат тепла в теплообмінниках та інших проблем з промисловим обладнанні. Для покращення якості води часто застосовують пом’якшення вапняно-содовим методом. Основною спорудою технологічної схеми даного методу є освітлювач з шаром завислого осаду, конструкція та експлуатація якого є складними. В даній статті запропоновано удосконалення вапняно-содового методу реконструкцією освітлювача з шаром завислого осаду шляхом заміни розподільчого пристрою, повітровідділювача, горизонтальної перфорованої перегородки, шламоприйомних вікон на шар пінополістирольного завантаження та утримуючу решітку. Це дозволить проводити процес пом’якшення води в одній споруді, зменшити витрати на промивку та енергозатрати.

Ключові слова: жорсткість води, пом’якшення води, вапняно-содовий метод, освітлювач, завислий шар осаду, пінополістирольне завантаження.

СОВЕРШЕНСТВОВАНИЕ КОНСТРУКЦИИ ОСВЕТЛИТЕЛЕЙ С СЛОЕМ ВЗВЕШЕННОГО ОСАДКА В ТЕХНОЛОГИЧЕСКИХ СХЕМАХ УМЯГЧЕНИЯ ВОДИ

Одуд Л.Н., аспирант,
Национальный университет водного хозяйства и природопользования
liudmylaodud90@gmail.com

Аннотация. Наличие ионов кальция и магния в воде есть причиной отложений в бойлерах, потерь теплоты в теплообменниках и других проблем с промышленным оборудованием. Для улучшения качества воды часто используют умягчение известково-содовым методом. Основным сооружением технологической схемы данного метода есть осветлитель с слоем взвешенного осадка, конструкция и эксплуатация которого сложные. В данной статье предложено совершенствование известково-содового метода реконструкцией осветлителя с слоем взвешенного осадка путем замены распределительного устройства, воздухоотделителя, горизонтальной перфорированной перегородки, шламоприемных окон на шар пенополистирольной загрузки и удержующую решетку. Это позволить проводить процесс умягчения в одном сооружении, уменьшить расходы на промывку и энергозатраты.

Ключевые слова: жесткость воды, умягчение воды, известково-содовый метод, осветлитель, взвешенный слой осадка, пенополистирольная загрузка.

Introduction. Water with a high content of calcium and magnesium is called "hard". Hardness can be alkaline (calcium and magnesium bicarbonates) or non-alkaline (calcium and magnesium sulphates and chlorides), which are scale-forming when heated [1]. Quality improvement can be achieved by softening - removal the proper cations from water. For this the following methods can be used: thermal, reagent, ion exchange; dialysis; combined [2].

Reagent methods of hardness removal are based on conversion of soluble calcium and magnesium compounds in hard soluble ones. For this purpose the following reagents are used: lime, soda, sodium hydroxide, sodium phosphate. Suspended particles, which are formed during chemical reactions, are removed by sedimentation and filtration [3].

Lime-soda method is one of the often used among reagent water softening methods. In this process, at pH around 11.00 and after hydroxyl ions addition, magnesium ions are precipitated as solid magnesium hydroxide. The hydroxyl ions added are lime or calcium hydroxide. Calcium reduction is achieved by adding sodium carbonate or soda to the precipitate slurry until concentration reaches a prefixed value [4].

Lime-soda softening process consists of three stages: reaction (which converts hardness to a low solubility salts), precipitation (which happens after oversaturation of water with low soluble salts), and the sedimentation of generated particles [5]. This method is still remained as cost-effective and favorite process in some conditions. Nevertheless it requires high capital costs and is recommended especially where both the flow rate and the bicarbonate (temporary) hardness of raw water are high due to its lower operating cost [6]. Scheme of lime-soda water softening is shown on Fig. 1.

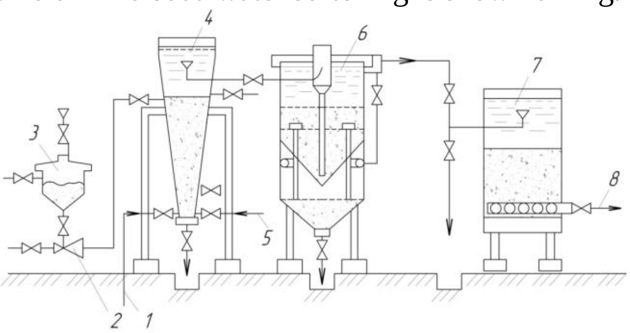

Fig 1. Scheme of lime-soda water softening:
1, 8 – supply of initial and removal of softened water;
2 – ejector; 3 – hopper with contact substance; 4 – vortex reactor; 5 – supply of reagents;
6 – clarifier with suspended sediment layer; 7 – rapid clearing filter

One of the most important facilities of this scheme is clarifier, which is a device where chemical reactions, associated with the supply of reagents, and also physical processes of sediment (sludge) formation, which was formed in the water bulk of clarifier, and filtering water through this layer, occur simultaneously. Contact medium in clarifiers, which is called sludge filter, consists of sludge particles, which are formed earlier and are forming now, and are in suspended condition as a result of water upward flow action. Water that has passed through the sludge filter, is exempt of the coarse particles, which are contained in the initial water and those, which are formed by chemical reactions in clarifier [7].

Due to [8], they were comparing applying lime-soda and caustic soda reagents for water softening. The tests were conducted under real conditions in clarifier. After using lime-soda treatment they achieved total hardness reduction to 150 ppm (1,49 mmol/dm³) in average. The temperature during the process was 90 ºC, what is relatively high. The effect depends of pH level, what can be regulated by reagent dosage.

Goals and task. Construction and exploitation of clarifier are quite difficult, and moreover nowadays existing edifices work with much more lower productivity than designed. So it’s quite important task to find ways for its improving, simplifying and decreasing exploitation costs.

The aim of our research is to obtain and compare the results of the water softening process through suspended sediment layer and expanded polystyrene filling with using lime-soda method at different rates with different duration of filtering cycle.

Objects and methods of research. The object of research is the process of water purification from hardness ions (calcium and magnesium).

Purposed method consists in mixing of water with lime and soda solutions, then passing this mixture trough suspended sediment layer, which in necessary to be gradually increasing, and after it water passes through floating expanded polystyrene filling.

The research of softening process in laboratory conditions was conducted on experimental water filtration plant in the laboratory of Water supply, sewerage and drilling department of the National University of Water and Environmental Engineering in Rivne, Ukraine. Schematic diagram is shown on Fig. 2.

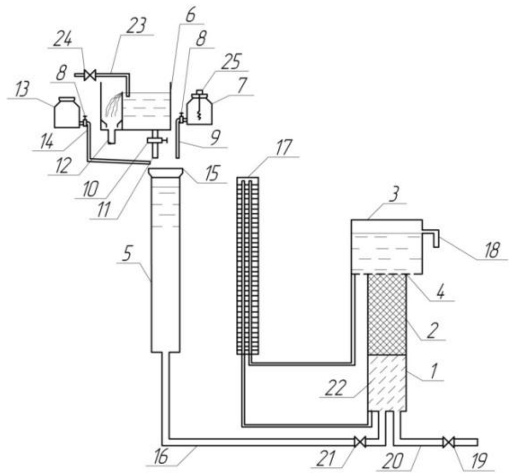

Fig. 2. The scheme of laboratory plant for water softening:
1 – filtration column; 2 – filtration filling; 3 – tank for washing; 4 – holding grate; 5 – contact camera; 6 – flowing tank; 7 – vessel for preparation of lime solution; 8 – screw clamps; 9 – lime solution supply tube; 10 – stratified faucet; 11 – pipeline for water supply to contact camera; 12 – discharge to sewage system; 13 – vessel for preparation of soda solution;14 – soda solution supply tube; 15 – funnel, where mixing with the lime takes place; 16 – pipeline for aerated water supply to filter; 17 – piezometers shield; 18 – pipeline for filtrate removal; 19 – valve for scourage removal; 20 – pipeline for scourage removal; 21 – valve on the pipeline for water supply to filter; 22 – suspended sediment layer; 23 – pipeline for running water supply; 24 – valve on the pipeline for running water supply; 25 – device for permanent interfusion of lime solution

For treatment we took running water from Rivne water supply system. As reagents there were used packed soda ash TU 6-18-171-78 (Crimean Soda Plant) and slaked lime OP-1 ISO B V.2.7-90-99 ("Ferezit" m. Lviv). As filtration material we used expanded polystyrene type PSV-S. Filtration filling had such parameters: the minimum diameter of granules was 0,8 mm, maximal one – 1,5 mm, equivalent diameter was equal to 1,17 mm, coefficient of heterogeneity was 1,29.

The plant operation procedure is the following. Running water through pipeline runs to the flowing tank, which provides constant pressure and thus constant water flow to the plant. Mixing of water with lime and soda solutions is held in contact camera funnel. Water with reagents comes from contact camera to the bottom of the filtration column, where firstly passes the suspended sediment layer and filtration filling, and then purified water is collected in the tank for washing, from where is removed to the consumer through pipeline. Filtering process has to be conducted with a constant filtration rate. The main chemical reactions of this method are (Eq. 1, 2, 3, 4) [8]:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O, \quad (1)$$

$$Ca(HCO_3)_2 \rightarrow 2CaCO_3 + H_2O, \quad (2)$$

$$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow Mg(OH)_2 + 2CaCO_3 + 2H_2O, \quad (3)$$

$$MgSO_4 + Ca(OH)_2 + Na_2CO_3 \rightarrow Mg(OH)_2 + CaCO_3 + Na_2SO_4, \quad (4)$$

Suspended sediment is a polydisperse system in which the rate of particles precipitation depends on the volumetric sediment concentration [9]. Forming of suspended sediment layer and getting the needed effect takes time. According to [10], to create the necessary conditions for sediment working firstly we should start with lower flow rate and increase the reagent doses. Sediment formation process consists of crystallization of calcium carbonate, magnesium hydroxide sorption on calcium carbonate crystals, adhesion of crystals coated with magnesium hydroxide, structure formation [11]. Sediment, which is removed from the filling grains, has more dense structure, than sediment, which is formed in free space, and even in compressed condition it provides greater compressed sediment rate. However, this sediment can stay in suspended condition only with a certain filtering rate. Preliminary research shows rate up to 4 m/hour [12].

The washing of filtration column is conducted when the filtering cycle is completed. To do it, we supposed to cease the supply of initial water and to open valve on the pipe for removal of scourage. Then the cleared water from flowing tank passes through holding grate and filter filling. Thus, it washes the pollutants from filling and formed surplus of sediment, and all these things are removed to sewage system. For following effective work it is necessary to leave in under filtering space suspended sediment layer with height of 0,2 ... 0,3 m after washing process.

During research we hourly controlled filtration rate, pressure loss in the column and analytical parameters in initial water and filtrate: pH; total and calcium hardness; alkalinity.

For total hardness determination we put 100 ml of investigated water sample in volumetric flask. Then we add there 5 ml of ammonia buffer and a bit of indicator “Eriohrom black T”. Mix well till dissolving of crystals and appearance of violet colour. Then we titrate the resulting solution by adding trilon B (0.1 n) till appearance of blue colour. The quantity of trilon B (0.1 n) in ml will be the total hardness value.

For calcium hardness determination we also put 100 ml of investigated water sample in volumetric flask. Then we add there 2 ml of NaOH solution (2 n) and a bit of indicator “Murexide”. Mix well till dissolving of crystals and appearance of pink colour. Then we titrate the resulting solution by adding trilon B (0.1 n) till appearance of violet colour. The quantity of trilon B (0.1 n) in ml will be the total hardness value. Magnesium hardness determines as odds between total and calcium hardness.

For alkalinity determination we take 100 ml of investigated water sample and mix it with indicator “Methyl orange” till appearance of yellow colour. Then titrate the mixture by adding hydrochlorid acid till colour changing to bright orange.

Research results. The average indeces of initial (running) water for the whole research period were: total hardness – 6,35 mmol/dm^3, alkalinity – 6,43 mmol/dm^3, pH – 7,50. Laboratory research were conducted in the rate range 3,0-4,0 m/hour. Filtering cycle durations were determined from 8 to 24 hours. The maximum decrease of total hardness was observed up to 0,5 mmol/dm^3, with pH – 10,6. The best results were achieved during filtering cycle with filtration rate 3,5 m/hour and they are represented in Table. Table 2 and Fig. 3 are representing results of expanded polystyrene filling washing process.

Table 1 – Qualitative indeces of filtered water during the period of filtering cycle (19 hours) with filtration rate 3,5 m/hour

Time from the beginning of filtering cycle	Total hardness	Calcium hardness	Magnesium hardness	Alkalinity	pH of initial water	pH of filtrated water
(hours)	(mmol/dm^3)	(mmol/dm^3)	(mmol/dm^3)	(mmol/dm^3)		
0,50	3,00	1,50	1,50	3,90	9,95	8,65
1,00	1,80	0,70	1,10	5,00	9,70	9,80
2,00	1,80	0,60	1,20	4,40	10,05	10,05
3,00	1,70	0,50	1,20	5,20	9,65	9,25
4,00	1,60	0,40	1,20	7,10	9,95	9,80
5,00	1,60	0,40	1,20	5,90	10,85	10,30
6,00	1,30	0,20	1,10	5,10	11,25	10,50
7,00	1,30	0,20	1,10	4,00	10,15	10,45
8,00	1,20	0,20	1,00	4,10	9,90	10,55
8,50	1,50	0,20	1,30	5,00	9,80	10,25
9,00	1,20	0,20	1,00	4,00	9,25	10,50
10,00	1,20	0,30	0,90	4,80	9,85	10,15
11,00	1,15	0,20	0,95	4,70	10,40	9,95
12,00	1,10	0,20	0,90	4,00	10,20	10,30
13,00	1,10	0,20	0,90	3,80	11,15	10,50
14,00	1,40	0,20	1,20	3,80	11,25	10,40
15,00	1,50	0,20	1,30	4,00	10,60	10,40
16,00	2,00	0,20	1,80	4,60	10,00	9,95
16,50	1,20	0,15	1,05	6,90	10,40	10,20
17,00	1,50	0,10	1,40	6,30	9,80	10,30
18,00	1,90	0,10	1,80	6,10	9,85	10,30
19,00	1,80	0,30	1,50	4,00	11,75	9,50

Table 2 – Results of expanded polystyrene filling washing

Time, s	Washing mode			Filling height, sm			e,%	TSS, mg/dm^3
	W, dm^3	Q, l/s	I, l/s·m^2	L_1,sm	L_2,sm	L, sm		
0	0,283	0,094	5,3	79,8	79,9	0,1	0,1	59016,39
5	0,495	0,10	5,6	79,8	82,2	2,4	3,0	85213,11
10	0,777	0,16	8,8	79,8	85,8	6,0	7,5	10868,85
15	1,201	0,24	13,6	79,8	91,3	11,5	14,4	3068,85
20	1,766	0,22	12,5	79,8	95,8	16,0	20,1	2557,38
40	2,190	0,22	12,4	79,8	101,6	21,8	27,3	1844,26
60	4,239	0,21	12,0	79,8	102,7	22,9	28,7	2675,41

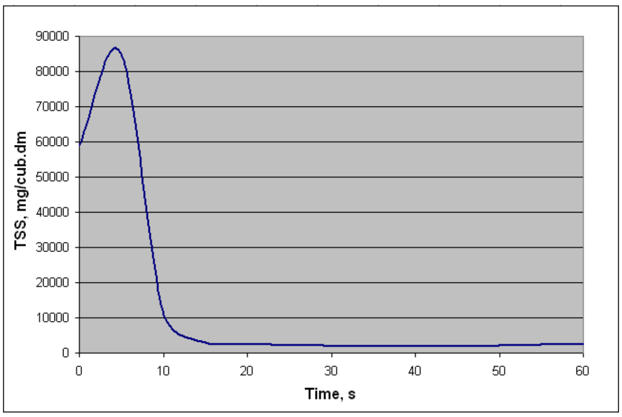

Fig. 3. Change of TSS in washing water at different sample time

As the existing scheme of clarifier of suspended sediment layer is rather complicated, thus we offer to simplify it by removing switchgear, air separator, horizontal perforated partition, sludge thickener, sludge receiving windows. Instead of that to arrange in the frame a layer of expanded polystyrene with holding grate. Schematic diagram of clarifier with suspended sediment layer after reconstruction is shown on Fig. 4.

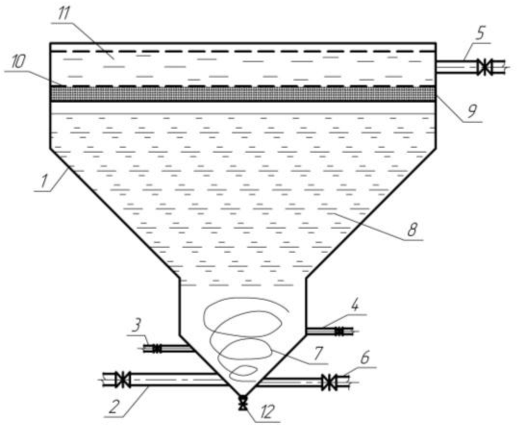

Fig. 4. Schematic diagram of clarifier after reconstruction:
1 – clarifier frame; 2 – pipeline for initial water supply; 3 – pipeline for lime solution supply; 4 – pipeline for soda ash solution supply; 5 – pipeline for softened water removal; 6 – pipeline for scourage removal; 7 – zone of initial water and reagents mixing, initial stage of flakes formation; 8 – suspended sediment layer; 9 – expanded polystyrene layer; 10 – holding grate; 11 – softened water zone; 12 – pipeline for removal coarse particles

Initial water enters the bottom of the clarifier outer cone - water and reagents mixer. Here also above water supply input on one side the lime solution is supplied, on the other – soda ash solution. To get the needed purifying effect it is necessary to maintain pH in the clarifier mixing zone within 9,0 – 10,5. To create suspended sediment layer the process should be started with lower flow rates and gradually increase the quantity of reagents.

Filter material of clarifier is polystyrene (expanded granules). Holding grate is placed over a filtering expanded polystyrene layer. It serves for maintain expanded granules and prevents their breakthrough in purified water.

Initial water, which passes through suspended sediment layer and expanded polystyrene layer, is relieved from hardness, and also from suspended solids. Softened and filtered water after clarifier is collected in over filter space, from where by removal pipeline enters reservoir.

Washing of filtering expanded polystyrene layer starts when it is polluted and treated water quality is worsened by suspended solids. It is held with using softened water. Washing occurs from top to down. Then we should open the valve on pipeline for washing at the bottom of clarifier and discharge scourage into the canal, which is located under this pipeline. We must keep an eye on to avoid sludge removal.

Based on laboratory research results we have conducted a calculation of the size of clarifier with suspended sediment layer which is applied in water treatment system at one of Ukrainian chemical enterprise, PJSC "RIVNEAZOT".

Fractional composition and height of the filtering layer are taken with the following parameters: minimum diameter of the granules is 0,8 mm, maximal one – 1,5 mm, equivalent diameter is equal to 1,17 mm, total filling height H_t = 0,7 m.

Conclusions. This research was conducted due to the direction "Fundamentals of rational use of closed water supply systems at industrial enterprises and complexes, circulating cycles of their water supply, devices and equipment used in circulating systems", that belongs to industry of water supply, sewerage. The purposed method of using lime-soda treatment on the clarifiers with suspended sediment layer reconstructed with expanded polystyrene is new and was applied for the first time. We have obtained a significant result in decrease of total hardness.

Use of expanded polystyrene for reconstruction of clarifier (Fig. 4) will intensify the water softening process through simplifying the technological scheme by reducing it instead of three buildings – vortex reactor, clarifier with suspended sediment layer and clarifying quick filter, to one, in which will be mixing, softening and filtering held; increase the efficiency of removing hardness cations from water; reduce the resource costs.

The suggested construction of clarifiers with suspended sediment layer can be used in preparation of water at enterprises, technological schemes of which use steam-power property equipment, that require water of the proper quality.

References

1. Water chemistry control to minimize degradation of heating equipment at abattoirs / Lycopodium Process Industries Pty Ltd. – Sydney: Australian meat processor corporation, 2015. – 43 p.
2. Nikoladze G. I. Natural-water purification technology / G. I. Nikoladze. – Moscow: Vysshaya Shkola, 1987. – 479 p.
3. Tchaikovsky G. P. Water softening on industrial enterprises / G. P. Tchaikovsky. – Habarovsk : Publishing house FESTU, 2005. – 127 p.
4. Agostinho L. C. L. Water hardness removal for industrial use: application of the electrolysis process / L. C. L. Agostinho, L. Nascimento, B. F. Cavalcanti // Open Access Scientific Reports, 2012. – 1 (9). – 5p. – URL: dx.doi.org/10.4172/scientifivreports.460.
5. Lime softening / Engrowth training inc., 2013. – 10 p. – URL: engedu.ca.
6. Amiri M. C. A cost effective technique for chemical wastes reduction in lime water softening process / M. C. Amiri, M. Ostovar, T. Amiri // 4th International Conference on Chemical, Biological and Environmental Engineering IPCBEE, 2012. – 43 (5). – P. 21-25.
7. Kopylov A. S. Water treatment in power engineering / A. S. Kopylov, V. M. Lavygin, V. F. Ochkov // Textbook for colleges. – 2-nd edition, stereotype. – Moscow: Publishing house MEI, 2006. – 309 p.
8. Zadghaffari R. Water softening using caustic soda: privileges and restrictions / R. Zadghaffari, S. S. Asr // Polish Journal of Chemical Technology, 2013. – 15(2), P. 116-121.
9. Mints D. M. The theory of water treatment technology / D. M. Mints. – Moskow: Stroyizdat, 1964. – 155 p.
10. Kurgaev E. F. Bases of the theory and calculation of clarifiers / E. F. Kurgaev. – Moscow: Stroiizdat, 1962. – 163 p.
11. Kurgaev, E. F. Water clarifiers / E. F. Kurgaev. – Moskow: Gosstroiizdat, 1977. – 163 p.
12. Orlov V. O. Expanded polystyrene filters in water preparation technological schemes / V. O. Orlov, A. M. Zoschuk, S. Y. Martynov. – Rivne: RSTU, 1999. – 143 p.

Стаття надійшла 18.09.2017