P a r t 2

WATER PROTECTION FROM DISCHARGES

2.2. Contemporary water treatment technologies at power plants and their environmental impact assessment

2.2.1. Water clarification and coagulation

Shishchenko V.V., VNIPIenergoprom; Fedoseev B.S., JSC "VTI"

A specific feature of the domestic water treatment plants is that as a rule as water from surface reservoirs is used initial. The natural water polluted by industrial admixtures, contains a large number of the mineral impurities, suspended and organic substances. For decrease in their concentration water is clarified and coagulated, frequently with lime treatment. Efficiency of such preliminary treatment depends on a clarifier design, reagent, applied for water clarification, and degree of advanced treatment of water in mechanical filters. Quality of clarified water is of considerable influence on the following treatment efficiency.

Clarifiers of VTI or CNII MPS type installed at thermal power plants have been designed about 50 years ago and fail to prepare water with quality sufficient for new technologies. For implementation of up-to-date ways of softening and demineralization, based on membrane technologies or counter-current ion-exchange, water with minimum content of suspended and organic substances is required. Installation of fine layer filters, often called lamella, at the top and bottom parts of clarifiers is offered by experts from VTI, municipal water industry NIIKVOV with VODGEO and ORGRES [1] as the basic technical decision for the above mentioned clarifier reconstruction.

For manufacturing of lamellas various materials are used: film polyethylene, sheet form molding plastic, etc. According to VTI experts' opinion, application of the film polyethylene, recommended by designers for manufacturing of lamella, is not an absolutely successful decision though simple and cheap. The problem consists in low durability and extreme mobility of a polyethylene film. VTI experts suggest to produce lamellas from plate molding plastic yielding elimination of the above disadvantages. For the first clarifies plastic lamellas were delivered to a water treatment plant in the form of the blocks formed at a manufacturer that led to height transportation cost and damages of blocks at transportation, especially in winter. Now the decision is found consisting in fastening of plastic plates during installation in place.

Use of plastic for gathering and water drainage system at the top of the clarifier eliminating corrosion problems of these element and peculiar design of the air-remover are rather successful decisions of specialists of the scientific research institute-KVOV.

It should be noted that such small reconstruction prevents from obtaining of specified clarifier production in certain cases. Experience of VTI in commissioning of a clarifier with lamellas designed for coagulation of water with comparatively low mineralization, low suspended particles content, average content of organics showed that the clarifier is capable of producing 70% of the expected load. In the given conditions lamellas do not prevent from sludge carrying out [1].

At present clarifiers with different types of lamellas are in operation at Kashirskaya and Konakovskaya state regional power plants, Nizhnekamskaya thermal power plant, Lipetskaya thermal power plant-2, Naberezhnochelninskaya thermal power plant, etc. In most cases suspended particles concentration in the clarified water has decreased from about 4 mg/l and more to 1 mg/l and less.

VTI design of clarifier-circulator is of interest [2, 3]. In a clarifier of such design a sludge concentrator is not provided, and a build in diffuser promotes intensive mixing of water with reagents. Absence of a sludge concentrator considerably increases useful section of a clarifier yielding higher efficiency under the same speeds. A clarifier of this kind has many advantages compared to traditional. Its first prototypes are in successful operation at TPP No 22 of the "Mosenergo" SC, where one clarifier of VTI-250 type and one neutralizing tank of 250 м^3 capacity have been reconstructed using this technology. Metal lamellas were installed in the clarifier and plastic lamellas un the tank. Suspended particles content in clarified water reduced from 4…7 to 1…2 mg/l.

At the same time, according to designers [1], such clarifiers have two drawbacks: badly organized sludge withdrawal and high speeds of mixing resulting in the fact that water alkalinity is higher than alkalinity provided by traditional clarifies. As a result reconstruction of a clarifier at Stavropolskaya state regional power plant provided parameters lower than expected. The possible reasons for that was initial water peculiarities (high rigidity and low alkalinity) resulted in formation of rather low quantity of heavy sludge.

Absence of automatics and a variable temperature mode influenced negatively. All the above mentioned has been taken into account when designing clarifiers for other water treatment units, nevertheless the optimum design of a clarifier isn't to time designed yet.

Operating experience of modernized clarifiers has shown that at their optimum design and operation modes concentration of suspended substances in a clarified water makes 1 mg/l and less, oxidability decreases on the average at 70 %, colloidal silica almost absent, and decrease in the general silica makes from 30 to 70 % of the initial, iron — from 40 to 80 %. Therewith clarifier design should consider characteristics of treated water.

Interest has recently increased to use of flotation in coagulation process for clearing of natural water. In 2008 commissioning of a new design clarifier of flotation type with production of 600 m^3/h is planned at the Kirishskaya state regional power plant of JSC «JUIT Rakenius». It is expected that such clarifiers will have higher technical and economic characteristics compared to commonly used ones.

Membrane technology can serve as an alternative to clarifiers. Ultra- or microfiltration are applied abroad for preliminary water treatment, including waste water. In such technologies water from surface reservoirs passes a stage of mechanical clearing (basically on self-cleared filters) and arrives on membranes where is 100 % cleared from colloidal impurities, suspended substances and 60 … 80 % cleared from organic substances. Mineral salts content remains. Water after such clearing is very well suited for the reverse osmosis units and for ion-exchangers of any type. For example, employees of NPP "Biotehprogress" have tested a pilot ultrafiltration unit for treatment of water from the Neva river and water after washing of the mechanical filters, operating at direct-current coagulation mode. The results obtained are presented in tab. 2.2. Despite of absence of data on silica acid, the efficiency results of filter wash water treatment do not require comments.

Units can operate only in a completely automatic mode. Selection of membrane type and water treatment technology is made based on total chemical analysis of initial water. Washing of membranes is automatically carried out based on duration of operation. Chemical reagents are applied with an expense of 2…3 kg/day when pressure difference occurred on a membrane. Chemical washing is also performed automatically.

Table 2.2. **Results of ultrafiltration of the Neva river water and mechanic filter washing waste water**

Parameter	River water		Wash water	
	initial	cleared	initial	cleared
Turbidness, mg/dm^3	2,8...6,8	< 0,3	69...146	< 0,3
Content of, mg/dm^3:				
aluminium	0,06	< 0,04	6,1...16,0	< 0,07
ferrum	0,05...0,3	< 0,05	0,55...2,0	0,05...0,1
Oxidability, mg O/dm^3	7,5...9,1	2,0…3,7	to 30	2,8...3,8
Water colour index, grad	30	4…10	Not determined	7...11
pH	7,6	7,1…7,3	6,7…6,9	6,5...6,9

At correctly picked up type of membranes and qualified commissioning and adjustment membrane service life makes more than 5 years. Installations are extremely compact. In 2005 "Biotehprogress" experts at the Zainskaya state district power plant commissioned an installation with productivity of 270 m^3/h.

NPK "Median-filter" experts are preparing for commission an ultrafiltrational installation with productivity of 250 m^3/h for water treatment prior to revise osmosis at Novocherkasskaya state district power plant.

The gained experience proves the efficiency of a given technology for water pre-treatment. Weight and size of such installations are considerably smaller in comparison to common clarifiers; coagulant consumption is 2 … 3 times less, and therefore quantity of sludge. At the same time the volume of waste water after washings reaches 7 … 10 % of the clarified water volume and additional measures for its processing are necessary.

There are still difficulties with the choice of coagulants and flocculants in our country. Imported reagents are expensive; therefore power plants are not willing to buy them. During the last years aluminum oxichloride having obvious advantages compared to traditional sulfate of aluminum has appeared on a domestic market. Specialists of the department “Technologies of water and fuel” of Moscow power engineering institute” are hard working and with positive results on implementation of the given coagulant [4]. Long experience of application of this coagulant at thermal power plant-23 of JSC "Mosenergo", the Konakovskaya state regional power plant, etc. has confirmed its efficiency. However, application area of this coagulant is limited, as liquid forms of a coagulant are offered that excludes its delivery to long distances, and it is supplied having uncertain and more often low aid-to-base ratio, and is therefore used only on several water treatment units.

Thermal power plant staff rather reluctantly applies flocculants as for their preparation, storage and dosing additional equipment is required. Only single cases of skilled flocculent selection are known by now. The experiences carried out by VTI experts at some enterprises, show that correct coagulant and flocculent selection can essentially increase quality of the clarified water (by several times).

At some water treatment units clarification process is completely automated. Its productivity is accepted as a basis, as a rule. Reagents are entered continuously proportionally to productivity. More often lime milk is dosed with a special valve directly from the circulating pipeline in which pressure is maintained by the centrifugal pump. Coagulants and flocculants are dosed by dosing pumps with frequency-regulated electric motors. State of the art computer technologies allow correcting automatically a reagent dose based on concentration of the prepared solutions. Attempts failed to conduct process in a clarifier based on pH-measuring instruments impulse and to control blow off based on suspended materials concentration.

For loading of clarifiers anthracite is widely used. Now the market offers anthracite of any fractional structure that was an unrealizable dream for chemists about 10 years ago. But for some pretreatment units silica sand or mixture of silica sand and anthracite is more expedient.

The works performed by VTI at one of the water treatment units, showed that application of two layer loading yields 1,5 time increase of production of traditional filter “chains” and considerable (in 2 … 3 times) reduction of water auxiliary needs [1]. Silica sand was applied crushed, disseminated, but the effect was short-term as sharp sides of sand destroyed chemical protection of filters, drainage systems and anthracite. Recently domestic industry doesn't offer silica sand of high quality, and it is not efficient to import it in mass quantities. In perspective it is efficient to use these materials together with a considerable quantity of different fractions.

Sludge appearing at preliminary water treatment with coagulation, flocculation and lime treatment in different combinations causes substantial environmental problems. Application of liming with coagulation in clarifiers allows not only deep removal of silicate and organic compounds, but also considerable decrease in rigidity and alkalinity of water. At the same time lime use is connected with environment pollution during producing, transportation, preparation of lime milk directly at thermal power plant. As a result sludge volume, formed at liming of initial water, considerably exceeds volume of impurities, removed from it. Content of solid substances in blowing-off water of clarifiers usually doesn't exceed 1 … 5 % that creates additional problems at its dehydration and evacuation.

Foreign experience testifies possibility of obtaining high quality lime from lime sludge.

Nine installations for regeneration of a lime from lime sludge are in operation in the USA [5]. Experience of operation shows that this technology is economically efficient only under certain conditions: the share of calcium carbonate in sludge, directed to the rotary calcioner, should be not less than 90 %, and its humidity — no more than 30 %. Therewith rotary calcioner production on CaO should be not less than 50 t/days. In order to reduce magnesium share in a sludge, blow-off water of clarifier is process by carbonic gas, appearing in the process of burning. As a result of such processing magnesium hydroxide sediment turns into well soluble bicarbonate of magnesium and is disposed together with a liquid phase. The compressed sediment is dehydrated in the vacuum-filters, on the basket centrifugal driers or in the tape pressure filters. Before rotary calcioner the sediment is dried with exhaust gases. After that exhaust gases are exposed to the two-level cleaning. Surplus of a lime is saled.

Rotary calciners, reactors with pseudo-liquid loading and burning furnaces are used for sludge burning. Natural gas, the black oil, the crushed anthracite can be applied as fuel. Power consumption on lime regeneration depends on humidity of an arriving sediment and on efficiency of heat recuperation. One of the options of installations for regeneration of lime sludge is shown in fig. 2.1 [5].

In our country the first installation for lime regeneration from clarifier sludge has been built at Nizhnekamskaya TPP No 1 (fig. 2.2).The clarifier sludge is directed to two sedimentation tanks where its humidity decreases on the average to 86% due to natural pressing. Pressed sludge arrives in vacuum-filters for the following humidity decrease (on the average to 50 %). Dewatered sludge goes in sludge basins where is mixed and acquires fluidity, sufficient for pumping by special membrane pumps to the spray furnace. At the top of the furnace sludge is dried, and at the bottom — its burned. Produced lime activity reaches 55 … 60 %.

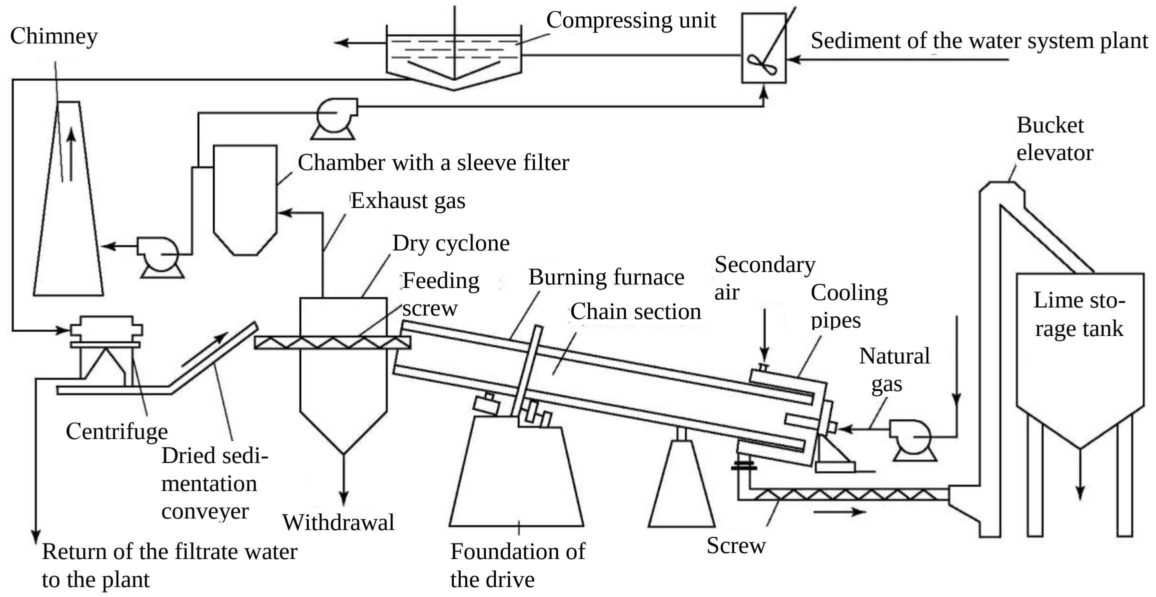

Fig. 2.1. Scheme of lime regeneration in the rotary calciner

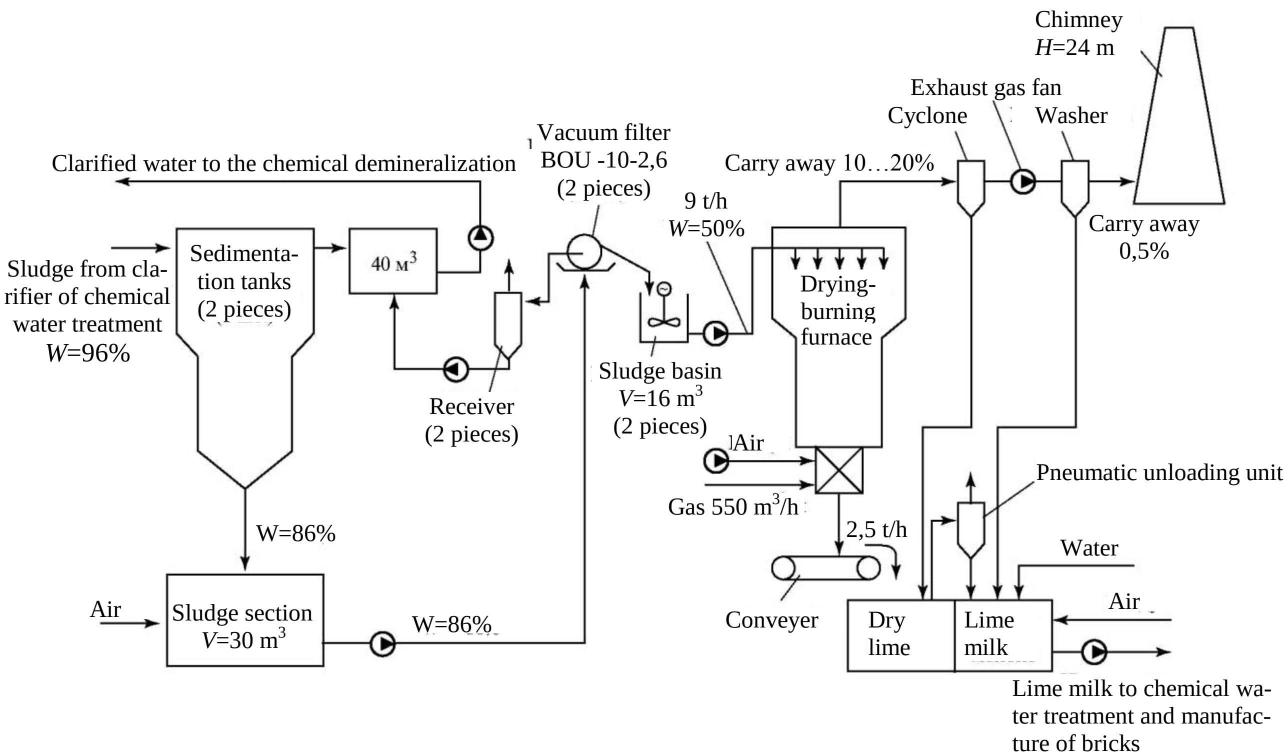

Fig. 2.2. Scheme of lime regeneration at Nizhnekamskaya TPP-1

Magnesium is not removed from sludge therefore, at repeated use of the regenerated lime it is accumulated that worsens an operation of initial water clarifiers.

For elimination of this negative phenomenon a mixture of regenerated and fresh lime is recommended to be used for water treatment [6]. Thus the share of fresh lime depends on proportion of calcium and magnesium hardness of initial water. When magnesium content in initial water makes 20 % of the general hardness it is necessary to add 20% of a fresh lime to the recycled lime. With growth of magnesium content up to 40 % the share of a fresh lime reaches 50%. Burning of a sludge aimed at re-use for water treatment isn't recommended when magnesium content is more than 40%.

At Nizhnekamskaya thermal power plant-1 a wide experience on use of lime, processed from sludge for production of silicate bricks by using an autoclave method, is gained. However negative influence of the elevated magnesium hydroxide content in sludge here again showed. The reason for that is that periclase (hard burned MgO) appears in a sludge burning process, that is at lime extinction remains as unmelted grains[7]. Periclase getting to bricks worsens their quality. For elimination of this drawback at Nizhnekamskaya thermal power plant-1 lime milk processing in autoclaves under the pressure of above 0,5 PMf when periclase clearing is organized.

Thus, though sludge burning is the most efficient way for repeated use of lime, a series of conditions should be satisfied for its successful implementation.

Clarifier lime sludge can be widely used in power and building industry. At the enterprises with coal fired boilers natural limestone is usually applied for decreasing of sulfur dioxide in flue gases and is directed to a boiler fire chamber or an absorber. The interaction results in sulfate of calcium which is disposed independently or together with ashes and slag. As VTI researches have shown lime sludge being a type of limestone, can be used for decrease in concentration of sulfur dioxide. Clarifier sludge can be directed to the unit of preparation of lime suspension or to a limestone warehouse. Application of clarifier sludge in agriculture as ground limestone for neutralization of acidic soils is possible [7]. For such use clarifier sludge its deep dehydration with application of thermal drying, and also granulation for increase in the size of particles is required.

At Beltsskaya thermal power plant (Republic Moldova) since 1987 installation is in operation for processing of sludge water of clarifiers functioning in a mode of liming and coagulation of initial water. Productivity of a unit on a primary blow-off makes 10 t/h, and on pressed sludge — 2 t/h. In the technological scheme the sludge waters sedimentation is provided for decrease of sludge humidity for 97 to 89 %. Then sludge moves on drum-type vacuum-filters BOU-10-1.8. The remaining humidity of the sludge after such processing makes 40 … 50%. Dehydrated sludge is taken away from the territory of a power plant by motor transport and it is used in building industry for preparation of liquid cement.

Sludge pressing plants are in successful operation at a TPP No12 of “Mosenergo” SC, Minskaya TPP No 3, Gomelskaya TPP, boiler-house in Minsk.

The Rostov construction institute has offered and investigated possibility of use of such sludge as a filler in construction solutions, a mineral powder for bituminous concrete, a filler for preparation stopping filler, etc.

Lime or clay is usually applied for preparation of complicated building solutions. The specified researches have shown that to 60 % of the lime in such solutions can be substituted by sludge wastes without durability decrease. Introduction of sludge wastes in masonry and stop filler solutions based of cement allows lowering the cement consumption to provide un-raveling and pumping ability of a solution, to improve its other characteristics.

In manufacture of stop fillers sludge wasted can substitute commonly used commercial chalk stone.

In the manufacture technology of bituminous concrete microfillers are widely used. Sludge wastes on the physic-mechanical and chemical properties satisfy to requirements to this category of materials. Results of researches of the Voronezh construction institute and Rostov Thermal Power Design have confirmed possibility of application of clarifier sludge as a filler for bituminous concrete instead of a mineral powder [8].

Clarifier sludge may be applied as a filling in manufacture of cellular and polymeric concrete, a brick, easy porous fillers (expanded clay, agloporite, hydite, etc.), paints.

At Lipetsk TPP-2 and the Volga TPP-1 clarifier sludge is applied as a component at manufacture of some construction items.

Studies of water pretreatment lime sludge produced at several power plants of “Mosenergo” SC carried out by "Mosgorstrojmaterialy" development design office, have also confirmed possibility of their use in manufacture of construction items as the following:

- Raw material for manufacture of quicklime of the third quality
- additives to the mineral powder for bituminous concrete mixtures in quantities up to 10%;
- fillers and solid colourant for self-leveling floors in quantities up to 10%
- fillers and solid colourant for wall materials (bricks) of semidry pressing
- solid colouring for building tiles manufactured with vibro pressing
- additives in the amount of 2…8% to keramzite gravel
- an ameliorant for processing of sour soils in agriculture, etc.

In the overwhelming majority of lime sludge utilization options its use is possible only after its dehydration or drying.

Special researches and the designs carried out for a considerable number of power plants, have shown that clarifier sludge dehydration with vacuum-filters, press filters, centrifuges and other equipment must be performed directly at a thermal power plants. Thus the sludge volume is reduced in 15 … 20 times, and the filtrate (lime treated and coagulated water) returns back in clarifies.

Problem of partly dehydrated sludge drying as well as its burning at lime regeneration, is connected with determination of its economic and environmental expediency in operation conditions of a specific thermal power plant.

For thermal power plants where sludge volume is insignificant, establishment of a centralized enterprise for drying or burning of dehydrated sludge supplied from several enterprises can be expedient. For thermal power plants, located in city boundaries, such decision can be caused also be environmental reasons as sludge burning and drying, transportation of a ready product will be constantly accompanied by danger of negative influence on environment. Besides, liming is in most cases inexpedient for treatment of water fed further to the reverse osmosis units because lime treated clarified water appears to be supersaturated on a carbonate of calcium and magnesium hidroxide that creates additional problems during concentrating in demineralization process.

Clarifiers of flotation type and ultrafiltration units can't operate in a lime treatment mode at all.

The basic components of sludge, formed at water coagulation, are aluminum hydroxide, silicate and organic compounds. Calcium and magnesium compounds, salt of heavy metals, oil products, biogene and other substances are contained in small amounts. Sediments of this kind are formed at plants for preparation of potable water from surface sources water; therefore thermal power plants may make use of experience of public utilities on recycling of sludge [9]. Use of water supply system sediments for improvement of structure and fertility of soils is possible.

Water supply system sediments can be applied in a manufacture of construction items. The researches executed in Japan [10] have shown that at addition of plaster and lime sediment hardens and has rather high durability. The territories filled with the hardened sediment, can be used as a site for construction. Application of the hardened sediment for filling of the developed coal mines is possible.

According to scientific research institute of municipal water supply and water treating of Academy of municipal services of the Russian Federation, sediments of the considered type can be also used as one of the components of rather hard-to-find high-alumina cements, manufacture process of concrete mixes, as additives by brick manufacture etc.

Regeneration of a coagulant from sediment for re-use is of great interest. Technologies of acid and alkaline regeneration are developed.

The common scheme of acid regeneration includes sediment pressing, its processing by sulfuric or hydrochloric acid, division of a reactionary mixture into a solution of the regenerated coagulant and a secondary acidic sediment, neutralization of a secondary sediment by a lime and its dehydration [9—13]. With the help of such technology about 75 % of aluminum hydroxide (depending on sediment composition, time of treatment, type and quantity of acid) is transferred into solution when sulfuric acid is used. The regenerated coagulant possesses the coagulating ability close to a commercial reagent.

The basic drawback of coagulant acid regeneration consists in dissolution in acidic environment of various substances of the organic and mineral origin contained in a sediment and, as consequence, their accumulation at repeated regeneration.

Technology of acidic regeneration of coagulant with use of a liquid not mixed with water, selective to aluminum is developed aimed at elimination of the above drawback [14]. At the beginning aluminum is extracted to this liquid, then a solution is separated from water, processed with sulfuric acid, liquid and a coagulant are separated and reused.

Alkaline regeneration method for regeneration of coagulant is based on amphoteric properties of aluminum hydroxide which has maximum solubility within pH = 11 …12 [15]. The technology includes processing of sediment by lime to the specified pH values and separation of regenerated coagulant solution by natural sedimentation of solids. The secondary sediment produced, as a rule, has layered structure and possesses good water giving ability. In some cases additional introduction of lime to pH> 12 is recommended [16—18].

Dehydration of the received secondary sediment on the chamber type press filer allows lowering its humidity to 60 %. The regenerated coagulant is represented as alkaline solution containing in basically $Al(OH)_3$, Ca^{2+} and OH^-. Depending on specific conditions from 25 to 45 % of coagulant contained in sediment is regenerated by the means of such technology. The restored coagulant solution is slightly polluted by other impurities and is applied in a combination with a commercial reagent.

Discharge of sediments of waterworks into city sewage system is widely used abroad (in the USA, Great Britain, Germany, Norway, Sweden, etc.) [19].

Extensive researches [18—23] showed that discharge of small amounts of waterworks sediments to the city water sewage system do not influence operation of primary sedimentation tanks of sewage treatment, and increase of waterworks sediment volume may result in improvement of clarification effect, decrease in a sedimentation time. Negative influence of waterworks sediments was also not revealed in the following stages of sediment processing including anaerobic or aerobic stabilization, their dehydration and pressing. Properties of sediments also don't worsen when used as fertilizers in agriculture.

For thermal power plants located in large residential areas the amount of sediment, appearing at water coagulation is insignificant compared to quantity of sewage in a sewage system. So, calculations, made for a number of thermal power plants of JS "Mosenergo" located in Moscow and using coagulation for water clarification, have shown that discharge of sludge into the city sewage system will lead to increase in the concentration of the suspended substances in waste water less than on 1 g/m^3 and won't affect operation of treatment facilities. Such decision yields reduction of waste water treatment plants at a thermal power plant itself, exclude necessity of warehousing or transporting of dehydrated sediments, to improve an environmental situation and to utilize sludge waters of water treatment together with wastes of sewage system waste water.

Thus, environmental aspects, and also implementation of new to the national power engineering practice water treatment technologies (an ultrafiltration, a reverse osmosis, etc.) stimulate coagulation application even in those cases when liming was traditionally used.

Unfortunately insufficient attention is paid in our country to recycling of sludge from water treatment and its accumulation in sludge collectors, designed for 10—15 years of power plant operation proceeds.