 https://doi.org/10.1051/bioconf/202411603005

The use of precipitation from water treatment plants

Elena Shutskaya[1*], *Oksana* Shishova[1], and *Natalia* Yudina[1]

[1]Don State Technical University, 1 Gagarin Square, Rostov-on-Don, 344000, Russia

Abstract. Urban water purification by sedimentation treatment is one of the important steps widely used in a large cities' infrastructure. The waste of technology mentioned is a high-humidity sludge with a different mineral and biological composition and various particle size. Due to the presence of significant amounts of active fractions, these sediments can be secondary used as an additional water treatment agent. To explore this statement in a more detail, the study presented deals with the natural-derived waste obtained through Rostov-on-Don urban water sedimentation treatment with aluminum sulfate $Al_2(SO_4)_3$ and polycationite VPK-402. The following parameters were analyzed: humidity, density, mass and volume fractions of solid phases coupled with its chemical and physical characteristics. It is shown that the secondary utilization of the sediment produced will lead to treatment agents' economy up to 30%.

1 Introduction

A common problem that occurs during urban wastewater treatment is a precipitation formation. This side product is produced in significant amounts and requires a noticeable consumption of economic resources for storage and processing [1-10]. In addition, such a tap sludge accumulation leads to mechanical and chemical pollution that follows by decline of urban environment quality. The reason mentioned emphasize the needs of closed-loop technologies development that allows recycling of precipitations in the borders of urban wastewater treatment processes.

However, tap sludge is a complex mixture that contains different products of primal treatment reagents hydrolysis in pair with wastewater extracted mineral and organic substances. Additionally, noticeable amounts of unreacted primal chemicals are also falling into the sediment suspension that means the recycling potential of such compounds [4-7, 11-14].

There are different mechanisms that occur during the wastewater treatment. However, the general process can be described as a reaction series between individual particles of water pollutants and primal chemical agents that leads to a merger of derived products into a flake-like solid insoluble structures that settles in the bottom of a reservoir [8-10]. The obtained sediment usually performs a gel-like spatial structure that contains a significant amount of moisture. The latter is encaged between insoluble flakes and need to be extracted by drying before the secondary use [8, 11, 12].

* Corresponding author: elenashuk71@mail.ru

The paper presented is devoted to sediment recycling opportunity studying that could lead to economic and ecologic profits. The natural-derived waste obtained through Rostov-on-Don urban water sedimentation treatment with aluminum sulfate Al2(SO4)3 and polycationite VPK-402 is used as the sample. The humidity, density, mass and volume fractions of solid phases measurements coupled with chemical and physical analysis is performed to investigate the suspension recycling potential.

2 Materials and techniques

The objects of the study are the water sludge obtained during water purification at the Rostov-on-Don sewage treatment plants. Water is supplied to the city's sewage treatment plants from the Don River. The composition of the sediment varies greatly and depends on the methods of water treatment, the use of reagents, and seasonal conditions. It is assumed that the further use of sediment in production and agriculture will depend on its basic physical and chemical parameters [7,8].

Precipitation of various origins was used in the study:

1. a layer of suspended sediment from settling tanks and clarifiers ;
2. sediment on filters for washing water and contact clarifiers;
3. sediment from tanks for solutions with reagents. The experiment was carried out by obtaining sediment from horizontal settling tanks, which give a stable effect of water purification and are characterized by operational simplicity, low construction cost, and high productivity.

3 Results

The unifying characteristic of sediments obtained by water intake from the rivers of the arid region is the presence of clay minerals with a predominance of montmorillonite, kaolinite and hydrosludes with particles greater than 1.0 microns [1,2].In sediments with a high content of mineral suspension, the solid phase is characterized by a floccular medium. As time passes in the sealing zone, they lose their characteristics. The peculiarity of the sediment at the bottom of the sump during compaction, the flakes become part of the sediment binder.

After observing the sediment compaction using a glass bathometer, samples were taken from the upper layers with minimal structural disturbance. In the experiment, a precipitate with Al2(SO4)3 and a precipitate of VPK-402 were used. The observations were carried out during the day with the fixation of lowering the sediment level into cylinders with a layer height of 200 mm, 400 mm. The most typical observation results (average values from ten measurements) are shown in Table 1.

Table 1. Compaction of precipitation.

Sediment age, hours	The concentration of the suspension in the selected sample, g /dm^3	Sediment compaction time, hours	The concentration of the suspension in the compacted sediment, g /dm^3	Sealing effect, %
1	**2**	**3**	**4**	**5**
$Al_2(SO_4)_3$				
1	187	5	199	6.4
2	187	6	202	8.0
3	124	8	141	13.7
4	151	5	172	13.9
5	257	8	268	4.3
6	275	10	280	1.8
12	151	5	167	10.6
24	175	4	196	12.0
36	161	3	189	17.4
48	160	3	190	18.8

72	178	3	199	11.8
VPK-402				
1	135	5	139	3.0
2	204	5	211	3.4
3	138	6	142	2.9
4	177	5	183	3.4
5	244	5	247	1.2
1	**2**	**3**	**4**	**5**
6	192	8	196	2.1
12	241	8	245	1.7
24	148	10	151	2.0
36	132	5	139	5.3
48	177	4	182	2.8
72	238	4	244	2.5

In the sediment of turbid waters of the Kuban River, the insoluble sediment is 40-50%, while in the sediment of colored waters only 2-15%. With an increase in mineral impurities in the source water, the sediment becomes more dense and the rate of the compaction process increases (Table 1).

The sediment density depends on the volume concentration of flakes, the diameter and hydraulic size of the particles, as well as on the strength of the sediment. Sediment compaction at zero pressure is reduced to the kinetics of lowering the upper boundary of the suspension layer during its settling. The nature of sediment compaction of sedimentation tanks varies over time. At the beginning of compaction, the upper boundary of the layer decreases at a constant rate. Then the speed is constantly decreasing. Reaching zero during the day.

All these stages of compaction range from an average of 30 minutes to 72 hours. An increase in the density or concentration of sediment as the turbidity of water increases occurs as a result of an increase in the proportion of mechanical impurities in it (the introduction of new portions of sediment) and, consequently, the nature of the suspension structure formation. The recycled sludge helps to achieve the critical concentration (the concentration of sediment that gives the greatest reduction in turbidity) necessary for flocculation, which reduces the relative dose of the coagulant.

A change in the nature of the structure formation of the floccular suspension occurs as a result of the adsorption of aluminum hydroxide on the particles of the sediment introduced into the water, which causes an increase in the density of the newly formed sediment and an increase in the compaction coefficient. These two factors indicate an increase in the strength of the flakes.

An increase in the color of water and a reduction in mineral impurities in it leads to the formation of a light (loose) sediment, high humidity, the degree of compaction of which decreases and the duration of compaction increases. Since several hours are enough for gravitational compaction of sediment of waters with increased turbidity, it takes much longer to seal low-turbidity, high-color waters.

The main properties of tap precipitation, in addition to the listed density and water-releasing capacity, are: humidity, sliding angle, viscosity, etc. The sediment of the Don River has a high humidity and, accordingly, a low concentration of sediment formed during the purification of waters of medium turbidity (Table 2).

It is noted that in the sediment obtained from turbid waters 40-50% refers to insoluble, and in the sediment of colored waters this indicator is 2-15%. Table 1 shows the relationship between the amount of mineral suspensions in the sediment and the rate of its compaction process. It is established that the sediment density depends on the volume concentration of flakes, diameter and hydraulic particle size. At zero pressure, sediment compaction is reduced to the kinetics of lowering the upper boundary of the suspension layer during settling. The nature of compaction in time has been revealed. At the beginning of the process, the upper boundary of the layer decreases at a constant rate, then the speed constantly decreases and reaches zero per day. Thus, all sealing stages take from 30 minutes to 72 hours. An increase in sediment concentration occurs with an increase in water turbidity, as the proportion of mechanical impurities and their structure formation increases.

The introduction of a dose of coagulant accelerates and enhances the flocculation process as a result of the adsorption of aluminum hydroxide on sediment particles. This process leads to the compaction of the flakes.

In non-ferrous waters with a low content of mineral suspensions, a loose sediment with high humidity, low density and a longer time for precipitation is formed.

The main properties of tap precipitation, in addition to density and water-releasing ability, include humidity, sliding angle and viscosity.

Sediment from the water of the Don River (water of medium turbidity) belongs to high-moisture and has a low concentration during water purification (Table 2).

Table 2. Humidity and concentration of the solid phase of the sediment formed during water treatment with various combinations of reagents.

Source of water supply	Suspended solids M, mg/dm^3	Color, degree	Reagent	The dose of sulfuric acid aluminum, mg/dm^3	The dose VPK - 402, mg/dm^3	Sediment dose	M/Dc ratio	Precipitation humidity, W,%	Concentration C, mg/dm^3
Precipitate with $Al_2(SO4)_3$									
R. Don	< 10	7.0-7.5	$Al_2(SO_4)_3$	15	-	10	0.7	98.2	17.95
	10-20	7.5-8.0	$Al_2(SO_4)_3$	17	-	12	0.7	97.1	28.86
	20-40	8.0-9.0	$Al_2(SO_4)_3$	15	-	10	0.7	97.2	28.00
	> 40	7.0-8.5	$Al_2(SO_4)_3$	30	-	20	0.7	96.0	40.00
Precipitation of VPK-402									
R. Don	< 10	7.0-7.5	VPK-402	-	0.2	0.4	44	94.7	53.00
	10-20	7.0-7.5	VPK-402	-	0.4	0.4	50	93.8	62.30
	20-40	7.0	VPK-402	-	0.5	0.4	69.4	97.7	23.00
	> 40	7.5	VPK-402	-	0.3	0.4	153	93.8	63.00

The analysis of Table 2 shows that the average concentration of the solid phase of the sediment depends on the ratio of turbidity of the source water to the dose of the injected reagents in the form of Al2(SO4)3, VPK-402.Humidity of the sediment obtained using Al2(SO4)3 varies in the range of 95.0-98.7%, and when using VPK-402 as a flocculant, the humidity fluctuated between 93.8% and 97.7%.

To accelerate the determination of the sediment dose when introducing it into the treated water (sediment recirculation), an experiment was conducted that makes it possible to make a rapid transition from volume concentration when determining the sediment dose during coagulation water. The studies were conducted according to the standard methodology. The sediment was settled for an hour with fixation of the beginning of the boundary of the Hh sediment (initial level) and a layer of compacted (settled) Nk suspension.

The volume concentration of the Co precipitate was determined from the expression:

$$Co = (Nc/Nn) * 100\% \tag{1}$$

where: Co - volumetric sediment concentration;

Nn is the initial or initial level of sediment in the cylinder, mm;

Nc is the final level of sediment in the cylinder after one hour of settling, mm.

Based on experiments to determine the volume concentration of sediment, the dependence of the weight concentration on the volume concentration for various precipitation is constructed, i.e. the sediment formed by VPK-402 and the $Al_2(SO_4)_3$ sediment 3. The volume concentration of the sediment is shown in Fig. 1.

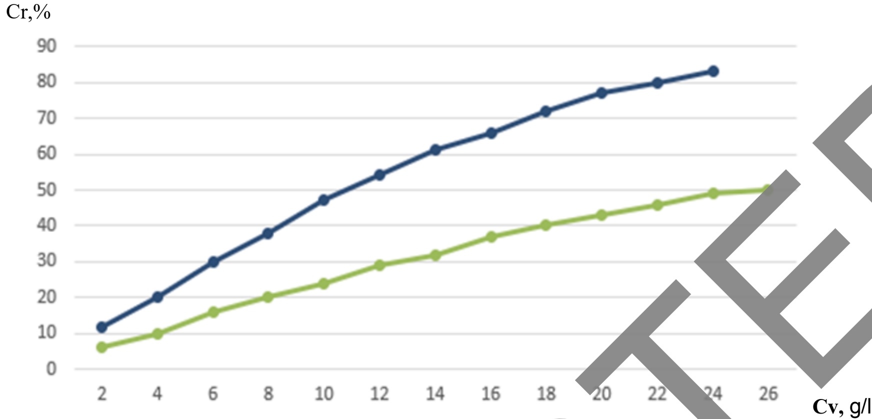

Fig. 1. Dependence of the weight concentration of sediment on the volume concentration. precipitate $Al_2(SO4)_3$; precipitate VPK – 402.

The graph shows a directly proportional dependence. For precipitation containing VPK-402, the volume concentration is significantly lower than for precipitation with Al2(SO4)3, which is due to the varying degree of particle adhesion.

A common property of tap sediments as colloidal systems is their viscoplasticity. Thus, at a low shear stress, it exhibits the creep property and flows with a constant maximum viscosity.

The structural and rheological properties were determined on a rotary vascosimeter (Table 3).

Table 3. Boundary values of sediment shear resistance.

Precipitation humidity W, %	Temperature t,^{0}C	The ultimate shear resistance of the sediment Q, din/cm^2
1	**2**	**3**
Precipitate with $Al_2(SO4)_3$		
99.9	-	-
99.0	4	7.01
98.0	5	7.27
97.0	3	7.67
96.0	8	7.76
95.0	9	7.80
94.0	7	7.97
93.0	8	8.02
92.0	10	8.04
91.0	13	8.20
90.0	20	8.49
Precipitation of VPK-402		
99.9	-	-
99.0	2	10.90
98.0	2	11.10
97.0	12	14.89
96.0	20	15.89
1	**2**	**3**
95.0	12	16.01
94.0	10	17.16
93.0	23	18.27
92.0	24	19.32
91.0	17	21.22
90.0	21	22.28

The data in Table 3 show that the ultimate shear resistance of sediment increases with a decrease in its humidity. Under equivalent initial conditions, the ultimate shear resistance of the sediment with Al2(SO4)3 is significantly less than with the VPK – 402 precipitate, since the flocculant has a high viscosity and is less mobile. This feature of the sludge with flocculant can be technically realized through pumping it with earltfts or peristatic pumps for sludge recirculation.

In our study, water precipitation is considered as a dispersed system in which water on the surface of particles is retained due to coordination electrostatic and plumbing bonds. [11, 12]. The viscosity of dispersed systems is not constant and varies depending on the velocity gradient. By their behavior, the precipitation of water treatment plants is close to pseudoplastic liquids.

To determine the dispersed composition of the sediment, the method of continuous weighing using torsion scales was used. The method was tested at different times of the year with different quality of natural waters. Samples were taken from the surface. Since the dispersed composition of hydroxide sediments has been studied in sufficient detail, the emphasis was placed on precipitation with VPK-402 sludge. In accordance with the general method of sludge recycling, the dispersed composition of the suspension in the treated water was determined at the first stage, as shown in Table 4.

Table 4 .The dispersed composition of the suspension.

River, city	Particle diameter, mm and their content in % by weight					
	>1.0	1.0-0.5	0.5-0.1	0.1-0.05	0.05-0.01	<0.01
R. Don , Rostov-on-Don	-	-	4.2	1.2	29	65.6
Kuban river, Armavir	-	-	1-6	3-16	21-40	44-76

The sedimentation analysis was carried out according to the scheme:
1) the initial purified water;
2) circulating sediment;
3) water, after treatment with the application of sediment repeatedly.

It was revealed that the dispersion composition of the precipitate with VPK-402 for use as a turbidifier, and the precipitate with Al2(SO4)3 As a precipitation intensifier, it is more suitable for recycling.

Table 5 shows the data on the physico-chemical composition of the sediment from the VPK-402 Central water pipeline and the Al2(SO4) sediment3 of the Alexandrovsky water pipeline in Rostov-on-Don and for comparison of southern rivers.

Table 5. Physico-chemical composition of the sediment.

Name of the treatment facilities	Concentration (mass),g/cm^3	Humidity, %	Losses during calcination of research institutes, %	SiO_2, %	Fe_2O_3, %	Al_2O_3, %	CaO, %	MgO, %	Remains MIC-402, %
Rostov-on-Don, Central water supply of the Military industrial complex-402	5-50	99.5-96.5	20-60	50-69	1.10-2.00	1.00-3.00	0.10-0.20	traces	5-10
Rostov-on-Don, Alexandrov water supply $Al_2(SO4)_3$	5-35	99.5-96.5	12.6-48.0	64-82	1.20-2.30	2.20-7.60	0.10-0.03	traces	-
rivers of the South of Russia	-	69.0-86.0	7.4	572	0.53	18.70	11.10	1.85	-

Considering that the cationic flocculant VPK-402 has an organic origin, in further work it is necessary to study the possibility of using sediment in the form of fertilizer, having previously assessed the environmental risks.

4 Discussion

The staff of the Department of Water Supply and Sanitation of DSTU conducted research on the possible practical use of precipitation in life and production. When solving the issues of recycling, possible reuse and disposal of sludge from any water supply station, its physico-chemical, rheological properties, as well as bacteriological and parasitological properties are of great importance.

Large volumes of tap precipitation formed at water treatment plants during water clarification can be reused taking into account the main identified properties. The presence of clay minerals of the kaolinite and hydroslude groups in the sediment having an isometric shape with dimensions within 0.03-7.0 microns opens up prospects for their use as components of building materials.

Local sediment can be used at water treatment plants to accelerate the process of water coagulation and save industrial coagulants.

The studied properties of tap sediments obtained with the help of flocculant VPK-402, such as humidity, solid phase concentration, structural-rheological and physico-chemical properties open up new prospects for its secondary use.

5 Conclusions

The study of the sediment of water treatment plants using various reagents made it possible to give a comparative assessment of the precipitation of horizontal sedimentation tanks. The humidity and concentration of the solid phase of the sediment formed during water treatment with various combinations of reagents, rheological properties and compaction of the sediment, volume concentration of the sediment, structural and rheological properties of the sediment, dispersed composition of the sediment, physico-chemical properties of the sediment were determined. The graphical dependence of the sediment weight concentration on the volume concentration is established. The implementation of the developed recycling methods is possible when mechanical sludge dewatering workshops are introduced at water treatment plants. Disposal of water sludge will complement the drainless operation scheme of sewage treatment plants. This will prevent their discharge into ravines and reservoirs, contributing to the preservation of the environment. After appropriate treatment, water sludge can be used in various sectors of the national economy.

References

1. O. P. Shishova, E. E. Schutskaya, A. S. Smolyanichenko, IOP Conference Series: Mater. Sci. and Eng. **913**, 042046 (2020)
2. E. Schutskaya and O. Shishova, IOP Conf. Ser.: Earth and Envir. Sci. **937**, 042057 (2021)
3. T. Ahmad, K. Ahmad, M. Alam, J. of Cleaner Production **124**, 1-13 (2016)
4. K.-W. Jung, M.-J. Hwang, D.-S. Park, K.-H. Ahn, J. of Env. Manag. **181**, 425-434 (2016)
5. B. Zaman, T. Haryanvi, M. A. Budiharjo, et al., IOP Conf. Ser.: Mater. Sci. Eng. **852**, 012014 (2020)

6. G. S. Kachalova, IOP Conf. Ser.: Mater. Sci. Eng. **451(1)** (2018) DOI:10.1088/1757-899X/451/1/012226
7. T. Ahmad, K. Ahmad, A. Ahad, M. Alam, J. Manag. **182**, 606-611 (2016)
8. S. I. Patsios, T. B. Goudoulas, E. G. Kastrinakis, et al., J. of Membrane Science **482**, 13-24 (2015)
9. D. Butko, E. Shutskaya, O. Shishova, IOP Conf. Ser.: Mater. Sci. Eng. **363**, 04017 (2022)
10. M. D. Nguyen, M. Thomas, A. Surapaneni, E. M. Moon, J. of Env. Techn. Inn. **28**, 10265 (2022)
11. H. Luo, X.-an. Ning, X. Liang, et al., Biores. Tech. **139**, 330-336 (2013)
12. T. Ahmad, K. Ahmad, M. Alam, Environ Monit Assess **124(189)**, 453 (2017) DOI: 10.1007/s10661-017-6166-1
13. A. G. Mora-Leon, C. C. Castro-Jim´enez, J. C. Saldarriaga-Molina, et al., J. of Cleaner Production 346, 131229 (2022)
14. A. Maldhure, G. Khadse, P. Labhasetwar, Water Supply **3**, 2793 (2022)