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MAIN METHODS AND TECHNIQUES OF MINE WATER TREATMENT IN THE USSR

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ABSTRACT

The paper discusses the different methods of mine water treatment used in the main coalfields of The Soviet Union. The technology used in treating the water in order to reduce suspended solids, salts, petrochemicals and bacterial contamination are fully described and the relative costs of each method are also given. The development of new methods of treatment and sludge disposal necessary to meet the requirements of recent legislation are also dealt with.

INTRODUCTION AND CLASSIFICATION OF MINES BY WATER INFLOW VOLUMES

Underground coal mining is not practically possible without pumping water to the surface. Mine water contains various pollutants and therefore cannot be used at coal mines or be discharged into reservoirs without treatment.

Depending on hydrogeological and mining factors absolute water inflows range from 10 to 4000 m^3/h (Table 1) and relative inflows - from 0.5 to 20 m^3/t.

Table 1 - Classification of mines by water inflow volumes in the main coal basins in the USSR

Mine water inflows, m^3/h	Donetsk		Kuznetsk		Karaganda		Pechora	
	Number of mines %	Total inflow %	Number of mines %	Total inflow %	Number of mines %	Total inflow %	Number of mines %	Total inflow %
Up to 150	47.1	22.0	25.0	9.5	80.7	62.2	48.0	25.0
150-300	35.7	39.6	36.8	24.3	19.3	37.8	40.0	39.0
300-500	12.7	24.2	22.4	24.4	-	-	4.0	9.8
500-1000	4.0	10.9	11.8	25.8	-	-	8.0	26.2
More than 1000	0.5	3.3	4.0	16.0	-	-	-	-

CHEMICAL CHARACTERISTICS OF MINE WATER

Acid Mine Water :-

The chemical composition of mine water is rather variable and caused by the differences in composition of underground aquifers which play a decisive role in water inflow. The mine water can be alkaline (pH 8.5), neutral (pH 6.5-8.5) or acid (pH 6.5) (Table 2).

Table 2 - Distribution of mine water inflows by pH in mines of the main coal basins of the USSR

Basin	Acid		Neutral		Alkaline	
	Mine water inflow %	Number of mines %	Mine water inflow %	Number of mines %	Mine water inflow %	Number of mines %
Donetsk	8.2	4.0	89.0	93.8	2.2	2.2
Kuznetsk	-	-	98.2	97.4	1.8	2.6
Karaganda	7.8	9.7	92.2	90.3	-	-
Pechora	4.8	4.0	71.7	76.0	23.5	20.0

The largest volumes of mine water are neutral. In some coal basins and deposits acid mine water rarely occurs and its amount does not exceed 10% of the whole volume. According to the degree of mineralisation about 50% of the whole volume of mine water is referred to as fresh water (mineralisation up to 1 g/l) and approximately 50% - to brackish water (mineralisation 1-25 g/l) (Table 3).

Table 3 - Distribution of mine water by degree of mineralisation in mines of the main coal basins in the USSR

Basin	Fresh		Brackish	
	Mine water inflow, %	Number of mines, %	Mine water inflow, %	Number of mines, %
Donetsk	3.2	1.8	96.8	98.2
Kuznetsk	66.1	68.6	33.9	31.4
Karaganda	-	-	100.0	100.0
Pechora	37.0	41.7	63.0	58.3

Mineralisation

Mine water in the category of saline water (25-50 g/l) and brines (more than 50 g/l) makes up less than 1%. The main ions are calcium, magnesium, sodium, potassium, chlorides and sulphates.

Suspended solids, petrochemicals and bacterial pollutants are the main contaminants present as a result of mining operations.

Suspended Solids

Contamination with suspended solids depends on the physio-chemical properties of the coal and the enclosing rocks; mining technology and its intensity; water inflow values and other factors. The coarsest fractions of suspended solids settle in underground water collectors. The size and number of settled particles are determined by the dimensions and capacity of the underground water collectors; the degree to which they fill with sludge and the type of water drainage system. Depending on these factors the susnended solids concentration in mine water pumped to the surface ranges from 30 to 2000 mg/l (Table 4). Mines where highly metamorphosed coals have been developed are characterised by relatively less contamination level.

Suspended solids mainly include the particles of coal and enclosing rocks. Usually coal particles predominate over rock particles, however, the ratio is not constant and can vary with changes in mining conditions. The size composition of suspended solids represent a polydispersed system.

Table 4 - Distribution of mine water inflows by suspended solids concentration in mines of main coal basins in the USSR

Suspended solids concentration mg/l	Donetsk		Kuznetsk		Karaganda		Pechora	
	Mine water inflow %	Number of mines, %	Mine water inflow %	Number of mines, %	Mine water inflow %	Number of mines, %	Mine water inflow %	Number of mines, %
Up to 50	16.4	18.5	0.6	2.0	-	-	2.2	4.4
50-100	25.5	23.1	8.9	8.2	1.0	3.7	13.1	13.0
100-150	15.9	15.6	16.9	14.3	5.3	11.1	15.6	17.3
150-300	23.5	24.6	18.3	34.7	31.6	25.9	42.7	47.8
300-500	10.2	10.7	36.5	32.6	20.7	22.3	19.8	8.7
500-1000	7.4	5.5	18.8	8.2	28.8	25.9	1.8	4.4
More than 1000	1.1	2.0	-	-	12.6	11.1	4.8	4.4

Under normal operation of underground water collectors and water drainage systems the maximum size of particles in mine water pumped out to the surface as a rule does not exceed 100 μm and the main mass of suspended solids contains particles less than 50 μm. The amount of particles less than 10-16 μm which are difficult to remove by sedimentation methods without addition of chemical reagents can reach 50-70%.

Petrochemicals

The concentration of petrochemicals in mine water varies widely and mainly depends on the amount of mechanisation in mining operations and the application and efficiency of measures taken to prevent loss of petrochemicals in the mines. The most typical concentration of petrochemicals does not exceed 1 mg/l.

Bacterial Contamination

Bacterial contamination level in mine water is highly variable. The most typical concentrations are in the 400-10000 range. It is noticed that bacterial concentration level is lowered with pH reduction and mine water mineralisation increase.

The main parameters affecting suspended solids technology include the sedimentation rate in static conditions and flocculation resulting from specific chemical dosing of the water with reagents.

TREATMENT OF MINE WATER

Environmentally, mine water represents a specific type of industrial wastewater subjected to treatment before its discharge into natural reservoirs.

To a considerable extent treatment technique largely depends on desired amount controlled by current legislation. Mine water discharge like other wastewater is regulated by a number of legislations and standards such as "USSR and Union republics water legislation guidelines", "Union republics water code" and "Surface water protection from waste water pollution rules".

In compliance with legislation now in force all reservoirs are divided into two types according to their use :

Type I - domestic-potable and recreation water use;

Type 2 - water use for fish industry.

Each type is divided into two categories by their significance. The number of reservoirs totals about 500 and depending on the type and category of water use common requirements for composition properties of water and maximum concentration limit (MCL) for harmful substances, have been established. Mine water discharge can result in a change of composition and properties of water in a reservoir but the chemical composition should not be outside established limits.

Optimisation of mine water quality for treatment

The desired degree of mine water treatment (as well as other wastewater) during discharge into reservoirs is determined by the reservoir condition and probable degree of dilution depending on pollutant MCL. In mine water discharges into reservoirs the following condition should be maintained;

$$\frac{C_1}{MCL} + \frac{C_2}{MCL} + \dots + \frac{C_n}{MCL} \leq 1$$

where the concentration of different harmful substances (C_1, C_2 ... C_n) with similar limiting indices and also harmful substances occurring in upstream outfalls are taken into account.

The maximum concentration of harmful substances allowed and considering the diluting ability of reservoirs can be defined by solution of the known equation;

$$q\,K_{cr} + a\,Q\,K_p = (q-aQ)\,.\,K\ np.non$$

where Q and q = water discharge in a river and mine water discharge, m^3/h;

a = mixing coefficient;

K_{cr}, K_p = concentration of similar pollutants in mine and reservoir water, g/m^3;

K np.non = maximum concentration limit of pollutants in a reservoir.

Calculations show that allowable concentration of suspended solids in mine water range from 5 to 30 mg/l depending on the reservoir category. Petrochemical products concentration is in the 0.05-0.3 mg/l range. Suspended solids concentration in treated water depends on the industrial use to which they are put and varies between 1.5 mg/l and 5.0 mg/l.

Methods of mine water treatment

Nowadays it is expedient to carry out mine water treatment at detached treatment plants because, in contrast to other industrial waste water, it does not contain large amounts of harmful and immovable impurities. Sedimentation, floc blanket clarification and filtration are the main methods of mine water treatment for suspended solids. Sedimentation is used either without treatment or with water treatment by reagents and filtration - mainly with reagent usage and floc blanket clarification with reagent application. To realise these methods the following facilities are used : settling ponds, horizontal (earth and ferro-concrete), vertical (plate) settling tanks, sludge blanket clarifiers, rapid one-layer or two-layer downward flow and upward-flow filters. Research work and practical experience have shown that operational effectiveness of these facilities is characterised by the data given in Table 5.

Table 5 - Operational effectiveness of facilities for mine water treatment from suspended solids

Methods and Facilities	Suspended solids maximum concentration limit, mg/l	
	In raw water	In treated water
1. Sedimentation without reagent usage in horizontal settling tanks (sedimentation duration - 2-24 h)	Unlimited	50-150
2. Sedimentation without reagent usage in settling ponds (from 1 to 10 days)	Unlimited	30-50
3. Sedimentation with reagent usage in horizontal, vertical and thin-layer settling tanks	Unlimited	50-100
4. Floc blanket clarification	Unlimited	10-15
5. Filtration in rapid one-layer and two-layer filters	30-50	1.5-5
6. Filtration in upward-flow filters	150-	1.5-5

Suspended materials :-

It is more economical and effective when treating suspended solids to feed the mine water into settling tanks and filters. In this connection great significance is given in mines with regard to technical measures aimed at decreasing contamination level of mine water pumped to the surface. Due to these measures the average suspended solids concentration in raw water at 50% of mines in Donbass does not exceed 100 mg/l.

Petrochemical

On account of the low concentration of petrochemicals in the mine water treatment is carried out simultaneously at 50-70% of the same facilities used for treatment of suspended solids. High concentrations of petrochemicals adversely affect the treatment facilities performance, and can even cause failure of the filters. Thus particular importance is attached to the elimination of penetration of petrochemicals into mine water.

Bacterial contamination

The treatment of mine water from bacterial contaminants is achieved in the final stage and is carried out with the addition of liquid chlorine, chlorinated lime, sodium hypochlorite and bactericidal irradiation. Water treatment with liquid chlorine is the most reliable disinfection method and is widely used at mines. Chlorine dose for disinfection varies from 2 to 10 mg/l.

Disposal of sludge

Sludge formed during mine water treatment is stored in settling ponds, sludge ponds or is dewatered at sludge beds, and then disposed of in mined-out underground workings. The preferred methods of sludge treatment are with centrifuge and filter-press dewatering resulting in a dewatered sludge with 40-60% moisture content which is suitable for transportation, storage and utilisation.

THE TREATMENT PROCESSES

Because of the restrictions on mine water quality it is recommended that effective one-stage and two-stage processes are used in the construction of new treatment facilities. One-stage processes are used where the average suspended solids concentration in raw water is no more than 150 mg/l. Also included is floc blanket clarification (or filtration), disinfection, backwash water thickening and sludge disinfection. Upward-flow filters, one-layer coarse-grained and two-layer rapid upward-flow filters with high mud capacities are recommended for filtration. Wash water is condensed in thin-layer settling tanks and sludge is disinfected with centrifuges.

Two-stage processes are used where mine water contamination levels with suspended solids of more than 150 mg/l and petrochemicals of more than 1 mg/l occur. At the first stage of treatment settling ponds are used without water treatment by reagents. In the second stage, thin-layer sedimentation tanks, sludge blanket clarifiers, reagents, and two-layer rapid filters are used.

Treatment facilities based on these designs provide treatment for suspended solids up to 1.5-5 mg/l and also for petrochemicals and bacterial contaminants. Facilities ranging in volume from 300 to 1000 m^3/h incur capital costs of between 0.11 and 0.59 roubles per m^3 and treatment costs of between 2.7 and 9.4 kopecs per m^3. Acid mine waters are a relatively small amount of the total volume, but if they are discharged into reservoirs without pretreatment they can have a disastrous effect. The developed and adopted technology of acid mine water treatment includes equalisation and metal ion conversion into solid phase by means of neutralisation with lime or limestone and lime. Also included are water clarification and sludge thickening by a sedimentation method with intensification of this process due to utilisation of two-mode neutralisation; recirculated sludge and synthetic flocculant (polyacrylamid); sludge dewatering in vacuum filters and centrifuges with reagent addition and storage of dewatered sludge in retention basins or mined-out areas. Treatment facilities ranging in volume from 1700-2000 m^3/h incur annual capital costs between 0.3 and 0.4 roubles per m^3 and treatment costs between 5.5 and 8.6 kopecs per m^3. Treatment facilities using this technology are under construction at some mines of Donetsk and Kizel coal basins. Due to the large volumes involved sludge storage in retention basins is considered to be temporary until its utilisation problem is solved. Various methods of mine water sludge utilisation have been investigated.

DESALINISATION OF MINE WATER

Nowadays desalination of mine water with salt content up to 3 g/l does not take place due to high cost of desalination plants and the high energy costs involved. Decreasing the detrimental effect of saline mine water with mineralisation more than 3 g/l on the reservoirs has been achieved by retention in special basins with subsequent discharge into reservoirs during floods and discharge into astatic salt lakes and evaporation ponds. They can also be used for other mining operations such as coal preparation, hydro-filling, dust suppression and others.

Electrodialysis, thermal and reverse osmosis are effective methods of mine water desalination. Complex processing of mine water with mineralisation up to 15 g/l has been developed and introduced on an industrial scale at a pilot plant. This technology is based on electrodialysis and provides fresh water and salt products (calcium carbonate, magnesium oxide and sodium sulphate) suitable for industrial utilisation. Mine water containing sulphate, chloride and sodium can be used in this technology.

Thermal desalination of mine water with production of desalinised water and crystal salts has also been developed where mine water with mineralisation more than 15 g/l occur. In the near future construction of major industrial plants using these technologies is planned at two mines.

Reverse osmosis is preferred for desalination of mine water with mineralisation up to 15 g/l. Expenditure on energy for desalination by this method is 3-4 kW/m^3, which is 20-30 times less than using distillation methods. Capital costs are also reduced by a factor of three.

In order to decrease expenditure on desalination the application of a combined method using reverse osmosis-distillation or electrolysis-distillation is allowable.