Optimization of the Choice of the Sewage Treatment Method and Device at Industrial Enterprises

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Abstract: Industrial, agricultural production wastewater and household drains are the main cause of intense pollution of surface water resources, which lead to the violation of the natural biological cycle and aquatic organisms’ environment destruction. In this regard, water resources protection is one of the most pressing environmental problems at the present stage of human development.

Key words: Sewage • Treatment • Industrial • Water

INTRODUCTION

The amount of sewage discharged into water bodies depends largely on the volume of the treated effluents used in the enterprise water supply systems. For example, some chemical, metallurgical plants and refineries use 70-75% of sewage in water recycling after appropriate treatment and only 25-30% is discharged into water bodies. In some cases it is appropriate to transfer the sewage of one company to use it at the nearest neighboring plants if water quality meets the requirements of these enterprises [1-3].

Volumes of sewage generated in industrial plants and pollutants concentration are determined by many factors: industrial production branch and initial raw materials type, technological processes mode, waste recycling possibility, specific water consumption per unit of production. Most businesses sewage contains mineral and organic pollution in various combinations. It must be kept in mind that industrial wastewater polluted predominantly with mineral or organic substances as well as their mixture may be formed at the same enterprise but in different workshops.

Sewage treatment aims to eliminate harmful and dangerous properties, which may result in adverse effects in the environment. Application of different treatment technologies aims to neutralize sewage hazards. Thus, the type of the applied treatment technology and equipment depend primarily on the sewage properties, deviations of these properties on the natural water parameters. In other words, the choice of sewage treatment method depends on the wastewater hazards necessary to neutralize.

Hazards are not only harmful and toxic substances - oil products, surfactants, heavy metals ions, but also such generalized indicators as environment aggressiveness, general rigidity (above admissible), the content of ammonium nitrogen, oxidation, etc.

The presence of hazards in sewage is determined by the analysis of water characteristics. Each hazard matches a group of indicators, i.e. the presence of hazards in water can be determined by several characteristics and in the absence of some water characteristics, there are no hazards. In addition, the same sewage indicator may testify the presence of several hazards.

Sewage hazards are conveniently separated into classes and each class matches one or a group of indicators uniquely determining the class. We’ll name this group of indicators as hazard class identifier.

Each sewage class corresponds to a method or a group of methods suitable for neutralization. At the same time, many treatment methods provide the ability to remove more than one class of hazards from sewage. Therefore there is no direct correspondence between the class of hazards and processing method.

Analyzing numerous literary sources [4, 5], there were revealed several classes of hazards and a variety of methods able to neutralize these classes.

A list of some revealed classes, their identifiers and processing methods groups are given in

Industrial enterprises sewage treatment process usually consists of several stages, each of which can apply different methods of purification with corresponding equipment. This is primarily due to the fact that many methods (especially of deep purification) may
Table 1: Hazard classes and neutralization methods examples

<table>
<thead>
<tr>
<th>Classes</th>
<th>Groups of indicators (identifier)</th>
<th>Neutralization methods example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse suspended particles</td>
<td>The content of suspended solids, particle size of more than 0.5 mm</td>
<td>Sieving, Primary sedimentation without reagents, Hydro-cyclones, Filtering</td>
</tr>
<tr>
<td>Coarse emulsified particles</td>
<td>Droplet contamination, organic substances, mixed with water</td>
<td>Gravity separation, Hydro-cyclones, Filtering, Flotation</td>
</tr>
<tr>
<td>Microparticles</td>
<td>The content of suspended solids, particle size of more than 0.01 mm</td>
<td>Filtering, Hydro-cyclones, Coagulation, Flocculation, Pressurized flotation</td>
</tr>
<tr>
<td>Stable emulsions</td>
<td>Petroleum products &gt; 5 mg/l, substances extractable with sulfuric ether</td>
<td>Space-thin layer sedimentation, Vacuum hydro-cyclones, Reagent pressurized flotation, Coalescence</td>
</tr>
<tr>
<td>Colloidal particles</td>
<td>Concentration particle size from 0.1 to 10 mcm</td>
<td>Microfiltration, Flotation</td>
</tr>
<tr>
<td>Aggression of the environment</td>
<td>pH, general alkalinity, general acidity</td>
<td>Neutralization</td>
</tr>
<tr>
<td>Oils</td>
<td>Oils concentration more than 10 mg/l</td>
<td>Gravity separation, Vacuum hydro-cyclones, Flotation</td>
</tr>
<tr>
<td>Dispersed particles of organic nature</td>
<td>TDP concentration with biochemical oxidability</td>
<td>Coagulation, Electroflotation, Galvanocoagulation</td>
</tr>
<tr>
<td>High content of organic impurities</td>
<td>(OBC/OCC) ≥ 0,5</td>
<td>Biochemical, Radiochemical, Sorption</td>
</tr>
<tr>
<td>Heavy and non-ferrous metals ions</td>
<td>Concentration Cu, Zn, Ni, Fe and others &gt; MPC</td>
<td>Reagent, Electrocoagulation, Galvanocoagulation, Ion exchange, Electrodialysis</td>
</tr>
<tr>
<td>Hexavalent chromium (Cr⁶⁺)</td>
<td>Concentration Cr³⁺ &gt; MPC</td>
<td>Galvanocoagulation, Electrochemical reduction, Reagent</td>
</tr>
<tr>
<td>Cyanide</td>
<td>Concentration CN⁻ &gt; MPC</td>
<td>Oxidation of “active chlorine”, Ozoneation, Electrolytic oxidation</td>
</tr>
<tr>
<td>Chlorides</td>
<td>Concentration &gt; 300 mg/l</td>
<td>Electrodialysis, Reverse osmosis</td>
</tr>
</tbody>
</table>

not be used, if there are suspended and emulsified particles, certain groups of components in sewage. In addition, almost all the methods have an upper limit of pollutants concentration, which is to be treated by the method. Therefore, there is a problem of sewage pretreatment before applying the basic purification methods. Application of the multistep treatment is also explained by the fact that a combination of several types of processes achieves the necessary degree of purification at the lowest cost.

Various industrial enterprises use different number of stages. This depends on the treatment organization, applied methods and sewage composition. But for the information system development, sewage treatment processes are to be appropriately considered on the basis of a more generalized approach and not in terms of narrow specialization.

The most appropriate seems to divide the sewage treatment process into four stages, in accordance with the contaminants division on the basis of the phase state of academician A.I. Kulsky [6].
Of course, such a classification (by the dispersed phase characteristic) is not completely decisive, but expresses the general direction. At the first stage of processing it is necessary to get rid of large suspended particles and coarse emulsions, neutralize poisons (by specific technologies), remove oils and fats. If there are no such contaminants, it is necessary to immediately proceed to the second stage, which removes almost all mechanical impurities and, if necessary, water is prepared for further purification, for example, reducing environment aggressiveness, reducing individual pollutants unacceptable concentrations. The third step is the treatment of all contaminants to a certain level. If this level is not sufficient, there is a need in the fourth stage, which applies particularly “pure” methods.

The use of specific methods or their combinations at each stage of treatment is defined by the water chemical composition and physical properties, i.e. determined by the presence of various hazard classes. Depending on the presence or absence of specific hazard classes in water, one can skip some of the treatment stages. But it is easy to find that the second and the third stages - an integral part of any sewage treatment scheme. These mandatory stages - primary and secondary treatment is the foundation of any treatment process. The first stage, by implication, is preliminary treatment and the last - deep purification (Fig. 1)

Primary treatment. Many different types of primary treatment with different efficiency coexist now. According to [7, 8], this treatment stage is to be expressed as:

- Simple primary (mechanical) treatment (PT);
- Chemically amplified PT with a low dosage of chemicals (CAPT);
- Suspension primary treatment (SPT);
- Biological primary treatment (BPT).

**MATERIALS AND METHODS**

Primary treatment - is mainly mechanical processing, although there is also a significant pollution reduction. This stage is ambiguous, applied methods can vary greatly according to the treatment principle.

Secondary treatment. This is the main stage of sewage treatment, which removes most pollutants. Secondary treatment often applies waste biological decomposition processes as well as physical-chemical treatment methods.

Deep tertiary treatment. Generally, the secondary treatment methods are usually sufficient for the acceptable sewage treatment. However, the treatment meeting the MPC requirements is possible only after a deep treatment stage. This stage applies the most
effective physical-chemical treatment and desalination methods, such as ion exchange, electrodialysis and reverse osmosis.

Sine qua non of water resources conservation in the low-water region is the division of industrial sewage into conditionally pure and contaminated. To reduce the cost of direct-flow water, conditionally pure water comes back to production. Before being discharged contaminated water is exposed to treatment, the choice of which is determined by the enterprise profile and the type of water polluting substances.

RESULTS AND DISCUSSIONS

We have developed an algorithm for choosing an industrial enterprises sewage treatment method and device. Usually it consists of several stages, each of which applies different treatment methods and the corresponding equipment. Due to the large amount of pollutants in the sewage properties classification it is impractical to allocate any specific pollutants. The substances peculiar classes should group pollutants. Each method has different variations of equipment registration.

To compile the algorithm let’s introduce some definitions. Let C be the set of all classes of hazards and M- the set of these class’s treatment methods. A single method and class will be denoted by the corresponding Roman alphabet lowercase letters with an index: m, and c, for the i-th method and the j-th class.

A set of effluent indicators is denoted as D. Of the entire D region one can distinguish subsets corresponding to the hazard individual classes.

Let icj - a group of effluent indicators unambiguously identifying the j- th hazards class (cj class identifier). All hazard classes of the specific effluent form a set of F.

The condition of belonging to the set of F:

\[ \forall f_i : ic(f_i) \in D; \ f_i \in C; \ i = 1,2...k, \]  

where: k – a number of elements of the set of F.

Between the sets of C and M there is a controversial match, that is, each cj element is assigned to a subset of (m), which may interfere with any other similar subset.

The set of F is a subset of the set of C and thus each fi element also corresponds to its subset of methods Si(f_i) \subset M.

Let’s make now the effluent analysis step-by-step scheme (Fig. 2)

**Step 1:** (Identification)
Define the set of F:

\[ F \subset C; \ \forall f_i : ic(f_i) \subset D, \]  

**Step 2:** (Correspondence)
Define the set of the G sets (each element of which is a set):

\[ |G| = |F|; \ \forall g_i : g_i = H(f_i); g_i \subset M, \]  

**Step 3:** (Validation)
To consider this choose the set of P:

1) \( P = \cap \);  
2) If \( P = \emptyset \): \( P = g_a \cap g_b \), where a and b are
\[ \max \in F |g_a \cap g_b| \]  
3) If \( P = \emptyset \): \( P = g_c \) - an arbitrary set of G.

Define the set of V:

\[ V \subset P; \ \forall v_i : D \subset v_m(v_i), \]  
If \( V = \emptyset \), then \( g_i = g/P \); \ i = 1, |G|; go to the top step.

**Step 4:** (Comparison)
Define the new set of Q:

\[ Q \subset V; \ \forall g_i : R \subset v_m(q_i), \]  
if \( R = \emptyset : Q = V \);
If \( Q = \emptyset \), then \( g_i = g/P ; \ i = 1, |G|; \) go to the step 3.

**Step 5:** (Choice)
Create a set of devices of M:

\[ K = \cap \ L(q_i); \ \ K \subset E; \ \ i = 1, |G|; \]  

**Step 6:** (Check)
Define the set of Z:

\[ Z \subset K; \ \ \ \ \ \forall z_i : D \subset v_e(z_i) \]  
Having chosen a definite device of z, one need to find the new options of an effluent:

\[ D = ef_j(D); \ (o.e.Z_n = e_i) \] (go back to the step 1.)
The criteria of the search ending are hazard classes, i.e. \( F = \varnothing \). The search can be stopped if there are no suitable processing methods, when the set of \( G \) will have the form:

\[
\forall g_i : g_i = \varnothing,
\]

(11)

Figure 3 shows the way of choice of sewage treatment method and device. We introduce a function of \( L \) over all the methods, that assigns a specific subset of devices \( (e_i) \) for each element of the set of \( M \), as well as the function \( H \) over hazard classes, that returns the corresponding subset of methods \( (m_i) \) for each element of the set of \( C \):

\[
H(f) = M_i \land M_i \subseteq M \land L(m_i) = E_j \land E_j \subseteq E,
\]

(12)
Either method has its applicability limitations depending on the values of the effluent individual indicators. Some methods do not work if there is a large amount of suspended particles, others with strong environment aggressiveness. Thus, each method has its own applicability area, admission area. Moreover, methods have advantages and disadvantages, which can be expressed as a logical expression and used to compare methods. A set of such expressions constitutes the method limitations area.

Let $v_m$ - i-th method admission area, i.e. a collection of all the indicators and their values at which the method is feasible and $r_m$ - the same method restrictions area. We also define $v_e$ as a j-th device admission area.

Each device has certain efficiency and after passing a specific device, the effluent parameters must be different. A number of hazard classes may also vary.

We introduce a set of functions $e_f$, defined on a set of the effluent indicators, each element of which is put into correspondence to each device of the set of $E$. Function of $e_f$ (D) gives back the new values of the effluent indicators after the i-th device.

In the above mentioned algorithm there is the possibility of the decision deadlock, when it is impossible to pick up any device for the effluent treatment. This is due to the fact that there is no priority of classes and any hazard class may be treated with equal probability. A situation may arise when considering any class that requires particularly pure methods, none of these solutions will not pass the validation step, because there will be classes in the effluent, the presence of which is not acceptable (suspensions, emulsions, etc.).

Hence there is the need for the treatment stages and hazards classes’ priority (Fig. 4).
We introduce a new group of sets of $S$, appropriate to the effluent treatment stages. The set of $S \subset C$, defines a group of hazard classes that should be processed at the $i$-th stage.

In connection with this change it is necessary to modify the algorithm. Considering the set of hazard classes, one must not take all the effluent classes, but only the part to be treated at this stage – the set of $T$,

$$T = F \cap S_i; \text{ for the } i\text{-th stage},$$

Thus the set of $G$ is defined as:

$$P = \left( \bigcap_j g_i \right) \bigcup H(x_i), \text{ where } X = F/T,$$

where $X = F/T$.

Some changes can be added to the validation area. A variety of methods that are used to neutralize not only all the stage classes, but also the rest processed at other stages must have the highest priority in review:

$$P = \left( \bigcap_j g_i \right) \bigcap H(x_i), \text{ where } X = F/T,$$

It is necessary to provide additional terms of the devices search ending, since the primary stages may not provide a complete treatment of certain hazard classes, their tertiary treatment may occur at later stages. One can provide such an opportunity, if one adds an additional condition to the validation step after selecting the first or several devices (solved individually):

$$\text{If } g \subset \bigcup_j H(x_j), \text{mo}\Gamma = G | g_i, \text{ i}=1.2...|G|;$$

where $X = F/T$.

Thus the set of $G$ is defined as:

$$P = \left( \bigcap_j g_i \right) \bigcap H(x_i), \text{ where } X = F/T,$$

where $X = F/T$.

It should be noted that the set of $F$ varies considerably after each stage, its capacity reduces. This is due to reducing the number of hazard classes as a result of treatment. Effluent identification process is carried out before each stage.

Thus, based on the classification of sewage hazards and the division of the treatment process at the stage there is developed a sufficiently general algorithm of sewage treatment, allowing to purify any kind of industrial wastewater to the required conditions.

### REFERENCES