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Review of effective tools for monitoring the performance of membrane bioreactors

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Abstract. The production of high quality wastewater after treatment plants using a membrane bioreactor (MBR) probably requires less control than traditional processes of activated sludge. However, the use of MBR leads to additional problems associated with the activated sludge filtration, the formation of a sediment layer on the surface of the membrane and membrane fouling. Operation engineers require simple tools for controlling and monitoring the operation of treatment plants that can provide timely information about the biological state of the activated sludge and the filterability of the waste fluid, as well as the risks of membrane contamination. To this end, effective means of monitoring MBR and methods for determining biological activity are considered. For a broader characterization of the wastewater composition, the use of total nitrogen and total carbon analyzers is considered, which have significant advantages over the analysis of chemical and biological oxygen consumption (COD, BOD). These tools can be used regularly to ensure timely intervention and more stable monitoring of the operation of MBR systems.

Key words: membrane bioreactor, sewage, biochemical wastewater treatment, treatment plants, analysis of operation MBR.

1. Introduction

As is known, the main water users are industrial enterprises, agriculture, household needs of the urban population. Considering the fact that 75% of industrial enterprises and 72% of Russia's population are located in the European part of the country, where only 16% of surface waters are located, and the problem of ensuring the proper quality of sewage discharged into water bodies becomes more acute.

The huge volume of sewage produced by industrial enterprises and agricultural organizations represents, on the one hand, a potential danger, on the other hand is a vital resource for mankind and the environment. In Russia, as in most developed countries, the bulk of this wastewater is treated in centralized treatment facilities, where the content of pathogenic microorganisms and nutrients decreases to the required value before the sewage is discharged into water bodies. Or disinfection of wastewater for subsequent reuse in industrial plants is carried out.

The process of cleaning with the use of activated sludge, which has already become traditional, has been used for more than a hundred years for treating both domestic and industrial wastewater [11, 15]. Probably, this biological process has the longest history of application in industry. The active sludge process is used to treat wastewater of various origins in different environmental conditions.



Purification processes using activated sludge can be disrupted from various biological phenomena, such as swelling and reduced sedimentation in sedimentation tanks, which lead to the formation of a poor runoff that contains biomass particles [6]. The increase in the number of membrane bioreactors (MBRs) over the past 15 years is due to the desire to reduce pollutant emissions, increasing demands on the quality of discharged wastewater, the need for reuse of water, and new developments in the field of membrane technology [8].

MBR are a recognized technology that is currently used in construction treatment facilities [10]. Although the MBR includes the use of an activated sludge process, problems with the removal of particles from the secondary settler are mitigated by membrane separation. However, MBR are unable to process the required volume of wastewater, with critical contamination of membranes or low biomass filtration [8]. In addition, because of the need for constant membrane mixing and chemical purification to remove contaminants, the capital and operational costs of owning MBR are higher than for active sludge processes [12].

A significant part of the literature on MBR examines the influence of various properties of waste water on the process of membrane separation and the tendency to contaminate membranes [9, 12, 16]. The results of the studies convincingly indicate that higher concentrations of extracellular polymers and / or soluble microbial polymers are the keys to explaining the low biomass filterability and, as a result, increase the tendency to contamination [14]. The literature is complex and marred by a change in extraction methods and analytical methods. Given the uncertainty regarding operational issues affecting biomass filtration and the costs of owning MBR, the question of how best to monitor the operation of MBR and their biomass becomes more urgent. This review analyzes a range of analytical methods (tools) available to engineers and operators for monitoring biomass status and cleaning efficiency in MBR.

In this review, methods of chemical analysis for determination of ion concentration, ion sums of pollutants and methods for volumetric evaluation of solids are considered.

Analytical instruments were evaluated from the practical point of view, by the cost of equipment and reagent, ease of use, repeatability and time spent on the analysis, which allows you to quickly respond to changes (on the same day). Although this review is largely focused on the operation of MBR, many methods are transferred to the operation of activated sludge plants.

2. Evaluation Tools

2.1. *The cost of reagents and capital equipment costs*

Initially, it is worth to estimate the costs of the analysis, which include two categories. First, the cost of consumable reagents, and, secondly, the amount of capital investment. The lower these costs, the more likely that the tests should be included in the daily analysis. These costs can vary significantly depending on the manufacturer, the amount of purchase and the place of purchase.

2.2. *Location*

From the point of view of obtaining data that can be used on the day of sampling. Methods that can be used on-site are, of course, the most profitable.

2.3. *Time*

The time it takes to perform each analysis or prepare it for automated processing is another determining factor of suitability for daily use.

2.4. *Training*

An analysis that requires considerable scientific knowledge to perform is less desirable than one that is easy to use. To this end, technological processes are required, which are simple and require less preparation. These processes deserve more appreciation.

2.5. *Accuracy*

This category is intended to distinguish between tests with a low accuracy of the operational value and with uncertainty of the value reading.

3. Evaluation results

An established set of analytical chemical tests is usually used to monitor both the initial runoff and the filtrate in order to monitor the progress of the necessary chemical reactions and the removal of suspended particles. The data obtained from this analysis can help the operator understand that there are no serious process failures and that the wastewater meets the regulatory requirements for discharge without studying the internal processes. Typically, the initial purified runoff analysis involves the determination of various ions (for example, NH_4^+ , PO_4^{2-}) and total measurement (COD and TOC).

4. Ionic analyzes

The determination of the concentrations of nitrogen and phosphate ions is often carried out by colorimetric analysis using commercially available test kits. Although these kits are a quick and easy option, large treatment plants or complex processes may require testing of several parameters on many samples. In this case, the economic cost of using the test suite can quickly increase, taking into account the costs and time associated with ordering, delivery, storage, actual use and final disposal.

A recommended alternative for high throughput is ionic analysis using ion chromatography. Ion chromatography offers lower detection limits and the possibility of analyzing without interference for high-color or sulphide-containing waters, for which colorimetric determination is often unsuitable. A full range of base cations (Li_2 , Na_2 , NH_4 , K_2 , Ca_2O и Mg_2) and anions (F_2 , Cl_2 , Br_2 , NO_2 , NO_3 , PO_4^{2-} ; SO_4^{2-}) can also be quantified. It can also be used to detect transition metals such as iron and manganese.

Although the capital costs of ion chromatography are significant, one should not overlook the advantages of integrated ion analysis conducted on site, which is valuable for membrane processes that have a risk of formation (inorganic) sediment. The ability to quickly check the Langelier saturation index or calcium carbonate precipitation potential, and adjust or initiate acid dosage, can save many tens of thousands of dollars for cleaning chemicals, extend the life of the membrane and shorten the time for the regeneration process.

5. Total amount of analyzes

A summary general analysis is tests that are aimed at giving an overall assessment of the sample. They usually include BOD5, COD and total organic carbon (TOC). They are often used to assess the effectiveness of organic loading or removal processes. [3] BOD5 limitations are often characterized by regulatory requirements [5].

5.1. BOD5

Biological oxygen demand (BOD5) is the amount of oxygen expended on aerobic biochemical oxidation under the action of microorganisms and the decomposition of unstable organic compounds contained in the water under study. Thus, the indicator is a relatively raw indicator of degradable material in the sample and depends on the viability of the microbial population. BOD5 has a long history of application [7] and is valuable for quantifying the potential biodegradability of a sample. For the daily operation of the station, the use of BOD5 is impractical due to a five-day incubation [4]. An obstacle to an accurate analysis in BOD can be iron ions, sulphides or reduced nitrogen compounds [3]. In the latter case, "carbon BOD" can be established by suppressing nitrogenous bacteria with nitrification inhibitors.

Despite the shortcomings of the BOD indicator, it is important to periodically compare the COD: BOD 5 ratio. This may indicate a change in the purification ability or the toxicity of the incoming substance. The cost of the reagents for this analysis is minimal, the equipment requirements include incubators and dissolved oxygen or pressure measuring devices. To date, the search for a technology that will allow the measurement of BOD5 in a short time, or can be used as an online sensor, continues.

5.2. COD

Chemical oxygen demand (COD) is the amount of oxygen consumed during the chemical oxidation of organic and inorganic substances contained in water under the action of various oxidants. This test gives results in less than 3 hours. Reagents are usually cheap, but disposal costs can be in the same order. COD as an organic load measurement can be artificially high in the presence of reactive inorganic elements, such as Fe^{2+} [3]. Despite this, COD is the most commonly used method for estimating the consumption of oxygen spent on oxidation [2]. Although interference caused by oxidation of inorganic compounds can not be a significant problem for domestic sewage, industrial wastewater can contain high concentrations of inorganic compounds in the reduced state (e.g. H_2S). In the aerobic MBR process, H_2S will be oxidized to form SO_4^{2-} ions. Therefore, the organic balance of the mass, based on COD, will require measurement of the influence and flux of various types of sulfur. Despite these drawbacks, COD is the most commonly used method for estimating oxygen demand [2]. The necessary equipment is a heating unit and a spectrophotometer, and it can be performed even in basic laboratory rooms.

5.3. TOC

Given the shortcomings in the measurement of BOD5 and COD, there is a growing trend towards direct analysis of total organic carbon (TOC) compounds in wastewater [1]. The method used for the broadest range of TOC analysis is high-temperature / infrared, but is applicable only to pure water (i.e., MBR filtrate), the UV / persulfate method has lower detection limits.

TOC analyzers are available that include simultaneous measurement of the total "bound" nitrogen, which makes it a very attractive primary tool for large laboratories. It should be noted that not all TOC analyzers are accurate enough for processing samples with solid particles [17], therefore the samples to be analyzed need to be filtered using a 0.45 mm filter prior to TOC analysis. A more appropriate name for the analysis results will be the total amount of dissolved organic carbon (KRU), and not the total amount of organic carbon of TOC. More reliable analyzers have the ability to determine both TOC and CRU and allow a more complete picture of the movement of carbon compounds.

The accuracy and usefulness of analyzers of this type is high, which could not but affect the magnitude of the capital costs that are associated with the high cost of the device. However, the cost of consumables is the minimum amount of high purity oxygen. Laboratory requirements are the desktop space, access to the oxygen of the bottle and clean water of the required quality. The analysis can be carried out in fully automatic mode, without the need for operator intervention.

6. Analysis of suspended solid waste water particles

In the MDB system, the analysis of the undiluted water (solids in which it is suspended) can provide important information either about the removal of nutrients or about the propensity for contamination. For example, the level of ammonia, nitrate and orthophosphate in supernatant water taken from different zones can help determine the causes of nitrification / denitrification problems or the removal of phosphates. Normally, the supernatant water is separated from the biomass by centrifugation and then filtered (0.45 mm) before analysis by analysis [13]. Supernatant water can significantly differ from the filtrate of the MBR process in terms of the content of organic substances and colloidal materials. This is due to the preservation of all materials that are not soluble enough to pass through the MBR membrane. Sampling and analysis of the water in the water require more caution than simply measuring the filtrate. The foam present on the top of the MBR reactors can contaminate the samples. Secondly, centrifugation and filtration should occur as soon as possible after sampling [6], or the results will depend on the continuation of microbial removal of substrates. For example, phosphate accumulating organisms (PAO) can release phosphate in conditions of low dissolved oxygen.

7. Conclusions

Timely and reliable analyzes are of vital importance for the stable and economical operation of MBR. Various technical solutions were considered and evaluated to create a standard set of timely and

reliable analytical tools for monitoring and regulating the operation of MBR. The choice of technologies for monitoring the operation of MBR and their biomass should be carefully analyzed. For less equipped laboratories, colorimetric analysis (including COD) will remain the basis of the laboratory operation. It is recommended to invest large treatment plants of industrial enterprises in their own local laboratory systems that are capable of measuring nutrient elements, and also helped in monitoring sedimentation on the surface of membranes. The combination of such indicators as total organic carbon, total nitrogen yield results that are faster and more accurate than BOD, and have a lower environmental load than COD. The introduction of the latter into local laboratories will prevent violations in the operation of treatment plants, as well as avoid a complete violation of the cleaning process, which will ensure the exclusion of emergency discharges of waste water into water bodies.

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