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Optimum performance of activated sludge systems can be achieved only when sludge age is maintained at an optimum value. Below this value, a system can experience low dissolved-oxygen (DO) filamentous bulking, poor ammonia removal and nitrite breakthrough, dispersed growth of biomass, and an overloaded thickening facility. Above the optimum sludge age, a system may face low food-to-microorganism (F:M) filamentous bulking and foaming, increased oxygen demand, and increased clarifier loading.

The traditional formula for calculating optimum sludge age is

SRT = V × MLSS ÷ (WAS suspended solids × waste flow)

where
SRT = solids retention time,
V = volume of the aeration basins,
MLSS = mixed liquor suspended solids, and
WAS = waste activated sludge.

However, there are two problems with using this formula for day-to-day operations. The first is the formula's susceptibility to the inaccuracy of total suspended solids (TSS) measurement, which on average is around 10%. Realizing this shortcoming in the formula, many operators use "one-time change of waste flow should not exceed 10%" as a rule of thumb.

The other problem with the formula is that SRT is equal to sludge age only under static conditions. Under dynamic conditions, SRT does not reflect sludge age. For example, if the SRT is 10 days and the waste flow is reduced by a factor of two, the formula dictates that the sludge age immediately equals 20 days. However, it is clear that even if wastage is stopped completely, the sludge age cannot be increased by 10 days earlier than in 10 days. If new wastage is calculated using the above-mentioned formula, the new sludge age target will be reached only after about 20 days, and not instantly as the formula suggests.

Another rule of thumb states that a period of up to three sludge ages is required to see the results of a change in sludge age. This guideline likely considers that it takes a very long time to reach a new target sludge age if waste flow is calculated using the above formula. As can be seen, both rules of thumb are related more to the deficiency of the formula than to the nature of the activated sludge process.

Improved Calculation Methods

Two decades ago, professor Davis Vaccari from Stevens Institute of Technology (Hoboken, N.J.) proposed an elaborate method for calculating sludge age. Sludge age calculated based on his formula is called dynamic SRT. Dynamic SRT calculations take into account historical data and, as a result, better reflect sludge age.

One of the best methods for calculating sludge age under dynamic conditions is to calculate the mean solids retention time (MSRT), which is the average of SRT values. However, the challenge with using this method is determining the averaging time period. An improperly selected averaging time can eliminate the advantages of calculating the MSRT. While there are several ways to determine the averaging time period for each operating condition, a method using mathematical modeling of activated sludge systems is one of the best.

There are two obvious advantages to using a properly calculated MSRT or dynamic SRT instead of the traditional formula: First, the desired sludge age will be reached much earlier, and second, these calculations are considerably less susceptible to measurement inaccuracies, especially if sampling frequency will be increased.

Selecting the Sludge Age Target

After the method for calculating sludge age has been chosen, the next challenge is to correlate sludge age to activated sludge performance (such as effluent quality, sludge settleability, and operating costs). Unfortunately, some practitioners pay little attention to the correlation between sludge age and operating costs, considering only effluent quality and operational convenience when selecting the desired sludge age.

Yet sludge age has a critical effect on plant operating costs. Calculations show that a decrease in sludge age below the optimum value by just 1 day (a 1-day SRT instead of a 2-day SRT) at a conventional 10-mgd (38,000 m^3/d) complete-mix activated sludge plant may increase operating costs by $45,000 a year, due to the extra energy required for aeration to avoid low-DO bulking, excessive pumping in the thickening facility, and excessive use of chemicals (see the figure, below). In addition, operating at a low sludge age sometimes leads to a low mixed-liquor concentration, causing poor settleability. Under certain conditions, settleability may start to deteriorate even at a concentration as high as 1200 mg/L. On the other hand, increasing sludge age above the optimum value may increase oxygen demand and associated energy costs.

As the figure shows, operating costs may increase by $210,000 a year when the plant operates at a sludge age that is 1 day longer than optimum (a 3-day SRT versus a 2-day SRT). This drastic cost increase is caused by oxygen demand required to satisfy nitrification, which can start to occur in warm temperatures at an MSRT of 3 days. If not required, nitrification is detrimental not only to the treatment plant budget, but also to effluent TSS

Effect of Sludge Age on Operating Cost — Conventional Process

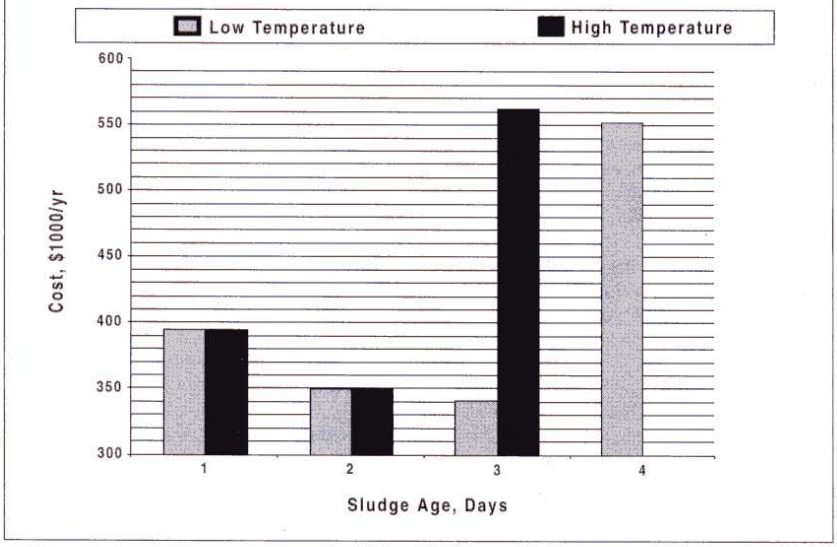

Table 1. Effect of BNR Operating Parameters on Effluent Quality and Power Use

Flow	Waste flow, gal/min	Sludge age, days	DO, mg/L	Internal recycle, mgd	NH_3 mg/L	NO_3 mg/L	MLSS mg/L	Power, kWh
10 mgd	50	14	1	15	0.5	3	4000	580
10 mgd	63	11	1.5	27	0.5	3	3500	600
10 mgd	75	9.3	2	40	0.5	3	3000-3100	635
10 mgd	88	8	3	50	0.5	3.5	2900	725

BNR = biological nutrient removal
DO = dissolved oxygen
MLSS = mixed liquor suspended solids
NH_3 = ammonia
NO_3 = nitrate

and biochemical oxygen demand values due to the potential of sludge floating in the clarifiers.

The effect of sludge age on the operating cost of biological nutrient removal (BNR) plants is also substantial. Modeling shows that the same effluent ammonia and nitrate concentrations can be achieved by different combinations of such operating parameters as sludge age, DO, and internal recycle flows (see the table, above). It seems that an increase in sludge age leads to lower BNR energy costs due to the reduced energy demand for aeration and internal recycling. However, an increased sludge age often increases foaming and low F:M bulking. When selecting the optimum parameters, it is important to count not only energy costs but also the cost of chemicals used to control these problems and the cost of foaming handling. As a result, the longest sludge age may not be the optimum one.

Maintaining Optimum Sludge Age

After the optimum sludge age is found, it should be maintained precisely. As discussed, a change in age of just 1 day may cause a significant increase in operating costs and a deterioration in effluent quality. The most cost-effective method for precise control of optimum sludge age is automation of the entire wasting process. On-line suspended solids monitors provide a cost-effective way to improve sludge age control because of their continuous data collection abilities. However, such monitors cannot provide 100% reliable readings, and so to avoid controlling the process based on erroneous data, a special meter fault-detection algorithm is required. Otherwise, using these sensors may actually damage process control rather than help it.

A combination of an automatic controller and automatic valves or variable-speed pumps allows a substantial increase in the frequency of the waste flow change, and as a result improves control of both sludge age and the WAS thickening processes. At the same time, variation of the waste should not be excessive; otherwise, it will cause excessive variability of the mass loading on the thickening facility, resulting in drastic deterioration of the sludge thickening process. To strike a perfect balance between maintaining precise sludge age and avoiding deterioration of the thickening process, most practitioners recommend using the proportional-integral-derivative algorithm for waste flow calculations. Finding tuning coefficients for this algorithm requires modeling of each activated sludge system.

Case Studies

Experience shows that every activated sludge plant can benefit from sludge age optimization and automatic control. For example, operators at a 32-mgd (121,000-m^3/d) trickling filter–activated sludge plant in Oxnard, Calif., observed considerable improvements in sludge settleability and a 25% reduction in effluent TSS after implementing a sludge age optimization and automatic control program. In addition, oxygen demand was decreased by 4% and polymer use by 25%. Operators at the Oxnard plant have realized that optimizing sludge age is a continuous improvement process and, as a result, work continuously to adjust the sludge age target based on quarterly performance, water temperature, and other factors.

In San Jose, Calif., a 167-mgd (632,000-m^3/d) BNR plant was able to get rid of *Nocardia* foaming after implementing sludge age optimization and automation. Implementing the same program at a 160-mgd (606,000-m^3/d) conventional activated sludge plant in Toronto, Canada, allowed polymer use for excess sludge processing to be cut in half.

These case studies have shown that proper optimization and automation of sludge age is a cost-effective way to improve plant performance and enhance the bottom line.

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