Strategies to improve energy efficiency in sewage treatment plants

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Abstract. This paper discusses on strategies to improve energy efficiency in Sewage Treatment Plant (STP). Four types of STP; conventional activated sludge, extended aeration, oxidation ditch, and sequence batch reactor are presented and strategized to reduce energy consumption based on their influent flow. Strategies to reduce energy consumption include the use of energy saving devices, energy efficient motors, automation/control and modification of processes. It is envisaged that 20-30% of energy could be saved from these initiatives.

1. Introduction

Rapid urbanization and increase in population will require wastewater service. It has the potential of increase pollutant loading in municipal wastewater treatment facilities and driving the construction of more treatment facilities and installation of advanced treatment technologies. It will increase energy consumption in treatment facilities unless efforts are in placed to optimize energy consumption in current treatment plants and future treatment plants.

The main objective of sewage treatment is to render sewage become harmless to human and environment before disposal. If untreated sewage is allowed to accumulate, the decomposition of the organic materials can lead to the production of malodor gases. It contains numerous pathogenic or disease causing microorganism and also nutrients that encourage algae growth. Hence it’s important to treat sewage to a level that is fulfilling Effluent Standard criteria.

Wastewater utilities in US consume about 2% of the total amount of electricity produced in US [1]. During the next 20 to 30 years, wastewater treatment plant energy consumption in US is expected by 30 to 40%. In activated sludge treatment, approximately 1100 to 2400 MJ of electricity are required to process each 1000 m³ of wastewater [2].

According to a report by Electric Power Research Institute EPRI, the main energy consumption is activated sludge aeration (EPRI, 1994). It shows that activated sludge aeration consumed about 55.6% of total energy usage at a plant.

Wastewater system energy use is dominated by the treatment process itself. Aeration is the most energy intensive part of wastewater treatment, with approximately 70% of energy used in municipal secondary stage wastewater treatment facilities. Sludge conditioning and dewatering processes are also significant energy users in conventional wastewater treatment processes, where about 10% of wastewater sector energy is used.

Preliminary and primary treatment stages are less energy intensive than conventional secondary treatment, while tertiary treatment can be energy intensive as secondary treatment depending on the type and quantity of pollutants being removed and the desired and/or regulated effluent quality.

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Most energy usage in waste water treatment is aeration and pumping. Aeration introduces dissolved oxygen into wastewater to support aerobic oxidation and also for nitrogen removal. Pumping is used to move and re-circulate water and solids through the sequence of treatment processes. Sewage aeration at an activated sludge sewage treatment plant accounts for about 30-80% of total plant electricity demand; 67% aeration, 21% pumping, 9% other loads and 3% lighting [3]. Aeration electric demand and energy consumption could be reduced by using fine-pore diffused air system and aeration process control, or lowering the sludge age (mean cell residence time or MCRT) [4].

With certain operating constraints many plants could achieve substantial energy cost savings by treating normal flows in off-peak hours when the cost of electricity is lowest. At plants with excess process capacities, sewerage treatment and sludge management would be minimized during on-peak hours [4]. Normal diurnal sewage flow pattern into a sewage treatment plant closely parallels an electric utility’s system demand and energy cost curves. Shifting electrical load from on-peak to off-peak hours or levelizing electricity use throughout the day usually requires temporary storage of the influent waste water either at treatment plant site or within wastewater system, possible sludge storage for batch processing. Costs and benefits of wastewater storage and time of day electricity pricing need further development [4].

Due to oversized equipment, inefficient operations or lack of controls, the amount of air is delivered to the aeration basins is usually much more than required for mixing and biological activity. This excess air represents wasted energy and highly aerated wastewater may lead to sludge setting problems and solids carryover into the plant effluent.

Conversion from coarse bubble or mechanical aeration to a fine-pore system should lower the energy costs for wastewater aeration by at least 25%. Adding a feedback control system that monitors a treatment variable and automatically adjusts the operation of the fine-pore aeration system according to the reading of the measured variable could boost the energy savings to 35% or more. Reducing the sludge age in the aeration tanks at STP has an energy benefit for the activated sludge process. In [3] and [4] it is reported that energy consumption could be reduced 10% to 30% through the application of proven energy efficiency technologies.

2. Types of sewage treatment plants

2.1. Conventional activated sludge treatment

Conventional activated sludge CAS treatment process consists of screenings, aerated grit chambers, primary settling tank, aeration tank and secondary settling tank and sludge treatment and disposal. It involves the production of activated mass of microbes that digest organic matter aerobically. The aerobic environment in the reactor is achieved by the use of either diffused or mechanical surface aerators. In typical conventional activated sludge process, the aeration time ranges from six to eight hours. After a specific period of time, the mixture of new cells and old cells is passed through settling tank. Some of the settled sludge is returned to the reactor as to maintain the optimum food over microbe’s ratio. At mixed liquor temperature of between 18 to 25°C, a sludge retention time or sludge age of minimum 3 days is desired.

Currently, activated sludge process may incorporate nitrification, biological nitrate and phosphate removal. These design use reactors placed in series that employ under aerobic, anoxic, ad anaerobic condition. To maintain high levels of treatment performance, one must focus on the process control such as,

- maintaining dissolved oxygen level in aeration tanks,
- regulating returned activated sludge RAS and
- Controlling waste activated sludge WAS.

The dissolved oxygen concentration in aeration tank should be maintained at 1.5 to 2 mg/l. Higher DO of 2mg/l may improve nitrification, however values above 4 mg/l do not improve treatment performance instead increases aeration cost (Metcalf & Eddy, 2003).

2.2. Extended aeration

Conventional extended aeration system is another form of suspended growth activated sludge process. The aeration is implemented over the longer period than conventional activated sludge process. It operates either as a plug-flow or completely mixed system with high sludge retention time (20 to 30 days). It is possible to have high quality effluent. The typical F/M ratio is 0.04 g substrate/g biomass per day. Generally no primary settling tank is used. It is suitable for small communities. One of the examples of extended aeration design is oxidation ditch.
2.3.  **Oxidation ditch**
OD consists of a ring or oval-shaped channel equipped with mechanical aeration and mixing devices. It allows one directional flow and a relatively long hydraulic retention time. The most common use aeration system is horizontal shaft aerator i.e brush aerator. The mixing and the flow velocity generated allow suspended solids to remain in suspension. As the wastewater leave aeration zone, denitrification process can occur. OD is highly reliable process and simple to operate. It requires less energy as aeration to meet oxygen requirement rather than mixing requirement, It requires more energy than conventional activated sludge process. Normally, the sludge retention time SRT is more than 20 days. Malaysian sewerage design guideline stipulates that the minimum velocity within the channel shall not less than 0.3 m/s.

2.4.  **Sequence batch reactor**
Another type of suspended growth process is sequential batch reactor. Sequential Batch Reactor system is a mixed culture suspended growth activated process which operate in a sequential process of Fill, React (aerate), settle, Draw (Decant) and Idle. For municipal wastewater system at least two basins are used so that one basin is in the fill mode and the other basin goes through the react, settle and decant. The period for each cycle is varies depend on the organic loading. The benefit of SBR is lower space requirement and the treatment efficiency is comparable to conventional activated sludge process. The supporters of SBR system contend that the system is less expensive, more efficient and more controllable than other biological treatment approach particularly for low PE plant. The energy consumption will consist of aeration system, sludge flow and sludge treatment. SBR is a compact facility and with flexible operation with adjustable time for each process mode. With the development of simple inexpensive program logic controllers PLC and availability of level sensors and automatically operated valves, more SBR plants are built for small communities but also in large cities.

3. **Strategies to improve energy efficiency in sewage treatment plants**
Energy represents a significant cost to sewage treatment as it is used at all stages of treatment process, from the collection of raw sewage to the discharge of treated effluent. The aim of strategies to improve energy efficiency (EE) in Sewage Treatment Plant (STP) is to reduce the amount of energy consumed while maintaining a reasonable amount of reliability to meet effluent quality. For existing plants, EE in STP could be achieved through operational changes, and/or the use of technologies, whereas for new plants, EE strategies could be incorporated at the design stage.

To improve energy efficiency of the sewage treatment plant first we need to analyze in-flow rate and energy consumption of the plant, normally, for high inflow, the electricity consumption is higher. Then identify power profile and energy consumption of major loads using power recorders. The major loads of conventional activated sludge (CAS) plants are blowers, sewage lift pumps and aerators. The major loads of extended aeration (EA) plants are surface aerators and raw sewage pumps. The major loads of oxidation ditch (OD) plants are brush aerators and raw sewage pumps. The major loads of sequence batch reactor (SBR) plants are air blowers and raw sewage pumps.

3.1. **Strategies that could be applied to major loads**
   i. Motors should be operated as close to nameplate voltage as practical because any deviation from nameplate rating affect motor efficiency. In general it is recommended that the motor line drop should not exceed 5% of line voltage.
   ii. Right sizing of motors is required based on the connected load to improve the energy efficiency of the motor.
   iii. Replacing the standard motors with Energy-efficient motors, which are typically between 2 to 6% more energy efficient than standard motors.
   iv. Variable-speed drives are used to vary the speed of a pump to match the flow conditions. The result is a close match of the electrical power input to the pump with the hydraulic power needed to pump the water. The 20% reduction in speed can achieve 50% reduction in energy consumption.
   v. Capacitor banks can be installed to improve the power factor of the big motors. Improving power factor is beneficial as it improves voltage, decreases system losses, and decreases power costs where fees for poor power factor are billed.
   vi. Installing energy saving device with load detection system in series with big motor. This device continually monitors electrical load at 380 cycles per second, and ensures that optimal
power is being supplied at all times. This automatic feedback corrective system reduces waste and save electrical power.

vii. Pump testing can help where the pump operates on its performance curve. If the over designed condition is encountered then the pump impeller to be trimmed to achieve more efficient operating point. Energy savings result from lowering of pumping capacity to better match system demands and replacing inefficient pumps with high efficiency pumps.

3.2. Other general strategies

i. A common approach is to use tapered aeration to reduce the rate of oxygen supply along the length of a basin. It can be accomplished by placing more diffusers at the inlet to the basin where the organic loading is highest and decreasing the number of the diffusers along the basin’s length. Tapered aeration better matches the oxygen demand across the basin by providing more air to the head of the basin where it is needed and less air near the end of the basin where the food-to-microorganisms (F/M) ratio is lower, thereby saving energy.

ii. Intermittent aeration saves energy by reducing the number of hours that an aeration system operates or the aeration system capacity. The methodology involves momentarily stopping air flow to an aeration zone or cycling air flow from zone to zone. The cycle length can be controlled with DO concentration or can be strictly time based. When controlling with the DO concentration, air flow is turned off at a set high level and turned back on based on a lower limit. The cycle length on time-based systems is strictly controlled by a set maximum time.

iii. The oxygen required to maintain biological processes within the aeration basin is proportional to organic and ammonia loading in the influent wastewater. Oxygen demand for aeration, therefore, follows the same diurnal pattern, dipping in the middle of the night and peaking in the morning and evening. Intermittent discharge of ammonia-rich supernatant from sludge dewatering operations can also dramatically increase the oxygen demand in the basin. Conversely, dilution from storm water flow can reduce oxygen needs. In addition to fluctuating oxygen demand of the wastewater itself, the oxygen transfer efficiency in the basin also varies in response to changing air and water temperature and other wastewater characteristics such as concentrations of solids and surfactants. Automated dissolved oxygen control can achieve significant energy saving.

iv. Biogas is a natural complement to operations at many STP’s that use anaerobic digestion to stabilize waste water solids. An effective way to use biogas is in a combined heat and power application. All of the biogas is directed to and burned in an engine or turbine that in turn powers an electrical generator. The electricity can be used on STP site. The waste heat is recovered and used to heat the anaerobic digestor to provide heat to the other uses in the plant site.

vii. Processes/systems should be scrutinized for the opportunity to eliminate reduce energy during expensive on-peak rates by shifting them to off-peak rates.

4. Conclusions

Influent flow could be used as a parameter to relate energy efficiency of STP. Energy efficiency studies indicated that there is great potential and numerous energy conservation opportunities in STP that could be implemented which results in 20-30% energy savings. Additionally, there is great potential to harvest renewable energy such as solar, biomass, biogas and minihydro from STP.

References

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