Scientific Bulletin of the University "Politehnica" of Timisoara

HIDROTEHNICA Series

TRANSACTIONS on HYDROTECHNICS

Tom 57(71), Fascicola 1, 2012

Strategies for improving the energy efficiency of the wastewater treatment plants in the populated centers

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Abstract: This paper highlights the considerations regarding the improvement of energy efficiency of the wastewater treatment plants collected from the populated centers.

Keywords: wastewater treatment plants, exploitation costs, energy efficiency.

1. GENERAL CONSIDERATIONS

Wastewater, by its content in various substances under the form of floating materials, suspensions, in colloidal or dissolved stage as well as various pathogenic bacteria, is an important source of contamination and a serious danger to the public health.

Wastewater treatment represents a succession of technological methods through which the polluting materials are retained, neutralized and eliminated from the waters resulting from the various human activities [1], an operation absolutely necessary to ensure the protection of the groundwater and surface water quality.

The main performance criteria followed in the exploitation of wastewater treatment plants are both of ecological nature - pollutant concentrations as low as possible in the treated water - as well as economical nature - minimum exploitation costs in order to achieve maximum purification efficiency.

One of the most important components of the operating costs are the costs with the energy - costs which represent approximately 32.5% of the average costs of maintenance and exploitation of the upgraded wastewater treatment plants [2]. Under these conditions, the improvement of the energy efficiency of the wastewater treatment plants represents a priority of our days. The goal is to achieve a reliable and economic energy management which exploit the same time the potential for the recovery and energy production and heat treatment plants.

The specific energy consumption for individual purification units generally ranges between 25-40 kWh / (PT•a); low values corresponding to large treatment plants (LE 100,000) and high values to the smaller plants (about 10,000). The more the station is smaller the specific energy consumption is higher. Depending on the treatment plant capacity and on the required efficiency, namely the used technology, the specific energy consumption is distributed on the technological objects as follows:

- Grates and screens 0.3 - 0.5 kWh/(PT•a)
- Fat desanding 1.7 - 2.2 kWh/(PT•a)
- Primary sedimentation, including the pumps for sludge and wastewater 0.4 - 0.6 kWh/(PT•a)
- Activation tanks for nitrification-denitrification 17.2 - 25.8 kWh/(PT•a)
- Secondary settlers including the sludge recirculation pumps 1.2 - 2.3 kWh/(PT•a)
- Sludge thickener 0.7 - 1.1 kWh/(PT•a)
- Anaerobic sludge fermentation tank, including the power generators 2.4 - 2.9 kWh/(PT•a)
- Fermentation and sludge dewatering 0.8 -1.2 kWh/(PT•a)
- Other consumptions (dosing station, phosphorus removal, laboratory, administration, etc.) 2.3 - 3.0 kWh/(PT•a)
- Total, 27 - 39.6 kWh/(PT•a) [2].

Studies conducted for 23 wastewater treatment plants in Germany and Switzerland revealed that the specific can be reduced by 20-80%, on average approx. 67% if the equipment is used with low energy consumption [3]. This consumption can be reduced in the form of biogas by exploiting anaerobic fermentation of the organic mass retained in the sludge.

Improving the energy efficiency of municipal wastewater treatment plants can be ensured by:

- proper dimensioning of the technological objects, especially to avoid their oversizing and the treatment plant as well;
- reduction of the meteoric influent in the treatment plant by using the separation systems for the wastewater collection;
- reducing the infiltration waters, in order to ensure the optimal biological processes to remove nitrogen compounds and phosphorus;
- choosing high efficiency treatment technologies;
- the selection of reliable equipment in terms of energy consumption;

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- using of the monitoring and control systems, respectively the automation of the technological process (SCADA);
- recovering energy from the organic sludge by sludge fermentation biogas production, which is heated by thermal power stations and conversion stations, to produce heat namely electricity;
- valuing the thermal energy resulted from certain processes of the sewage treatment cycle or heat energy contained in the wastewater;
- drying and incineration of sludge by valuing the energy obtained in parallel;
- the use of renewable energy in the technological processes, such as solar, wind, heat and the hydraulic energy from the evacuation hydraulic channels in the emissary;

2. ENERGY EFFICIENCY OF THE WASTEWATER TREATMENT PLANTS

The energy efficiency of a treatment plant is determined by how to ensure the functioning of separate components or whole objects. Although it differs in size and the technology used, most of the stations of the urban wastewater treatment plants have a close constructive scheme (Fig. 1).

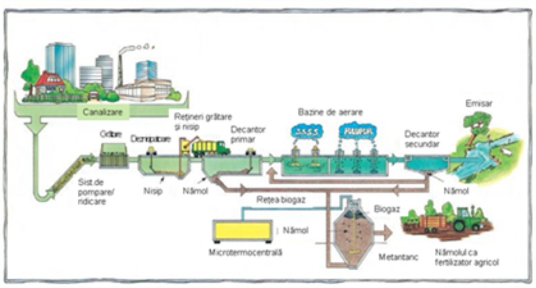

Fig. 1 The principle scheme of a wastewater treatment plant (source: www.vias.org)

Figure 1shows the design scheme of a wastewater treatment plant that collects domestic wastewater from a population center. It has to be mentioned that in recent years a lot of new equipment/ facilities have been developed, more efficient in exploitation by using advanced technology, reliable and with high energy efficiency.

Depending on the influent characteristics and the discharge requirements in the emissaries, the treatment technologies require two or more purification steps.

2.1. **The primary stage (mechanical treatment)** provides the wastewater treatment by physical and/or chemical processes, using the technological equipment which consists of: grates, screens, installations for compacting and drying the retainments from the screens, coupled desanding and grese traps, primary settling tanks and clarifiers. The method of treatment consists in retaining the suspensions which are heavier than water (sand, different solids) respectively the flotation of the lighter particules than water (fats, oils). The electricity consumption during this stage is relatively small. Grates, screens, conveyor belts and wash-presses can reach consumptions between 0.5 to 1.5 Wh/m3 of wastewater. The efficiency of this treatment phase can be improved by using rotating screens e.g. ROTAMAT screens from - HUBER (Fig. 2) where the energy consumption is much lower than in case of using screens with traveling rakes [7]

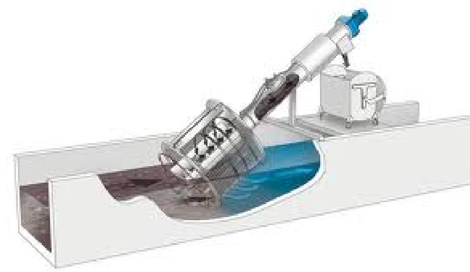

Fig. 2 - ROTAMAT® - Fa. HUBER system (source: http://www.huber.de)

The energy consumption can also be reduced by compaction and the dehydration of the retainments resulting in enclosed spaces.

The desandings ensures the retention of the fine sand and gravel and of the other particles that have passed the thik screens, ensuring the removal of up to 95% of the grains of sand with diameter greater than 0.2 mm. We can distinguish between longitudinal horizontal desandings, circular desandings with or without mechanical shaker; desandings with or without air injection (aerated or not aerated) desandings with or without air insufflation coupled with a lateral grease trap. The nonaerated circular desandings (Fig. 3) with mechanical shaker are more compact and with less power consumption than the aerated longitudinal ones.

Fig. 3 –VorMax- Fa. HUBER desander (source: http://www.huber.de)

The aeration of the longitudinal horizontal desanders requires an energy consumption of 0.3 to 1.0 kWh / (PT•a). The aeration can be reduced or even eliminated if the retained sand washing is done in an efficient way with special washing equipment which removes solid organic material (20-50%), thereby achieving a clean sand (max. 10% water), which can be sold as construction material or filler. The efficient sand washing can result in a volume reduction of 50% or more, which means reducing disposal costs [7].

The chemical processing of wastewater through the coagulation - flocculation leads to the reduction of the content of organic substances of approx. 20 to 30% allowing to avoid excessive loading of activated sludge. Chemical treatment with ferric chloride is made in order to reduce or eliminate the phosphorus compounds and the polyelectrolits are used to treat the sludge retained through the technological way.

The primary clarifiers of the mechanical stage can be horizontal longitudinal, radial longitudinal, vertical and with multiple layers (Fig. 4). The layered desanders, respectively the settling tanks, can be equipped with hydraulic dischargers without additional energy consumption, the evacuation being made through the hydraulic load effect (1,0 - 1,5 m).

Fig. 4 Longitudinal and radial horizontal clarifiers.(source: http://www.aquatim.ro)

In the primary treatment stage, the speed of the circulating water is determined by the type of object (grates, screens, desandings, clarifiers) and the detention time, depending on the nature of the suspension, and is 0.5 - 2 hours. Foams and the other floating substances (fats, oily substances, etc.) are retained and separately removed and the sludge deposited on the bottom are collected and removed (gravitationally or pumped) to the fermentation tanks (metantanks) or the dewatering platforms.

The power consumption of the primary stage is relatively low. The scrapers and the primary sludge disposal pumps have a power consumption of approx. 0.1 kWh/(PT•a). The correct dimensioning of the technological objects of the mechanical treatment is of great influence on the energy consumption throughout the treatment plant.

- In the absence of an adequate primary treatment, the whole organic load reaches the biological treatment stage and will be transformed, with excessive power consumption, into water and carbon dioxide.
- If the primary treatment is inadequate, the organic mass that reaches the biological treatment stage will be converted into water and carbon dioxide with excessive consumption of electricity, and a considerable waste of energetic potential of the organic matter in form of biogas.
- In dry weather, when the detention time is between 0.5 to 1.0 h, during the primary treatment stage only about 20% of the BOD is removed.
- Primary treatment with a detention time of 2.0 h, removes approx. 30% BOD, aspect highlighted by the oxidation of small quantities of organic matter, resulting in lower energy consumption in the biological stage and a higher biogas production in the metantanks (digesters).
- A primary stage with long detention time in combination with anaerobic sludge digestion, reduces the electricity consumption by 50%, This has to be considered when designing treatment plants provided with fermentation facilities for the retained sludge.
- The primary treatment must be designed so that it can allow variation of the detention time in order to optimize the processes, based on the composition of wastewater, and to ensure maximum energy efficiency.

2.2 **The secondary stage (biological treatment)** includes complex operations and technological phases through which the existing organic matter in wastewater resulting from the various human activities are transformed using cultures of microorganisms in non-harmful degradation products (CO_2, H_2O, CH_4, etc.) and a harmless cell biomass. The procedure is based on the use of organic dissolved and undissolved substances by microorganisms for breeding and conservation (maintaining biological processes), leading ultimately to reduce/eliminate these substances [4]. The composition and the concentration of active biomass as well as the efficiency, the destruction of organic substances by mineralization are dependent on the environmental conditions. Several treatment system parameters, such as dissolved oxygen concentration, nutrient loading, temperature [5], pH, sludge age, presence of toxic substances, adjusts the number of organisms and species diversity. This implies a large variation in both daily and seasonal quality of the activated sludge [6]. We distinguish two major categories of artificial biological processes:

• Systems with "free culture" (on mobile bed), in which the bacterial culture is maintained in suspension in the wastewater to be treated;
• Installations with "fixed cultures" (on fixed bed), where the bacterial culture (also called "biofilm", "biological film" or "biomass") lies on a support (stone, plastic, finely granular medium).

The energy consumption of the biological treatment step represents 50-80% of the entire consumption of the weastewater treatment plant - so the energy efficiency of the station depends largely on its construction and design.

• Simultaneous or separate installations for aerobic stabilization have a power consumption of 25 to 30 kWh/(PT•a).
• the biological stage for the N removal with activated sludge, requires (together with the mechanical stage) a consumption of approx. 15 to 20 kWh/(PT•a) and permits the operation of micro power plants based on biogas.
• Nitrifying installations with percolation filters consumes 7-10kWh/(PT•a) and the rotating biological contactors with biodisks have a consumption of only 2-4kWh/(PT•a).
• When the effluent is used for irrigation in agriculture, the removal of nitrogen and phosphorus is no longer necessary. The installations designed only for the disposal of biodegradable organic substances based on carbon removal have a consumption of about 10 kWh / (PT•a).

In the case of activated sludge basins it is recommended to take following aspects into account:

- the largest amount of electricity is used for aeration and mixing;

- The increase of the interphase specific contact surface by dispersion of fine bubbles (d <0.5 mm) in the mass of water from the tank - that is the use of fine bubble diffusers - means low energy consumption compared to the usage of large bubble diffusers or mechanical aerators;
- optimum injection depth in the case of fine bubble diffusers is 4 - 6 m;
- Intensification of turbulence shall result in the increase of mass transfer coefficient KL and so it reduces the energy consumption;
- uniform distribution of vents on the basin's bottom improve the efficiency of oxygen and thus reduce energy consumption;
- The use of turboblowers that have an approx. 10% lower energy consumption than the rotating piston blowers;
- automatic correction for the concentration of oxygen, Redox potential, or concentration of ammonium and nitrate for energy saving;
- agitators arranged in the anaerobic and the anoxic activation basins have an energy consumption of 1.5 - 3.0% W/m3 respectively from 1.5 to 3.0 kWh / (PT•a);
- it is recommended to use automatic adjustment of the sludge flow of the recirculation pumps by using centrifugal pumps with adjustable speed that have an energy consumption of about. 0.5 kWh / (PT•a);
- The raclors of the secondary settling tanks and the excess sludge pumps require an energy consumption of 0.15 kWh /(PT•a).

Basically we can say that the lower the energy consumption required for water aeration, in terms of ensuring a given level of treatment, the more advantageous the aeration process is. The efficiency of reducing or eliminating of organic substances using the activated sludge processes, ranges between 60 and 98%, depending on the treatment technology adopted, the aeration procedures applied as well as the wastewater characteristics.

A modern method of secondary treatment of wastewater resulting from the populated centers is represented by the biological aerated filters and membrane bioreactors, which combines activated sludge technology with activated carbon filtration, or semi porous membrane (Figure 5).

Fig. 5 Membrane Biological Reactor (source: http://www.barangroup.com)

This method allows the elimination of the colloidal and dissolved substances, processes which are partly undergoing a process of oxidation in order to form carbon dioxide, partly undergoing a process of metabolism in order to build up biomass and some absorb matter on their surface. Modern technologies which ensure simultaneous removal of nitrogen and phosphorus are characterized by the following attributes:

• The membrane filters retain both solids and bacteria from the wastewater;
• The activated sludge concentration is 3-5 times higher, leading to a reduction of 20-25% of the tank capacity;
• Power consumption is 40-80 kWh /(PT•a), of which approx. 50% is consumed for the functioning of membranes;
• The membrane aeration equipment has a power consumption of cca.10% higher than conventional equipment and installation of sand filters for disinfection;
• Such facilities are recommended to be used if a high quality effluent is needed or where space is limited.

2.3 **The tertiary stage** (the advanced biological) is meant to remove its refractory compounds in excess (eg nitrogen and phosphorus) through denitrification and to ensure the water disinfection. The used procedures are depending on the specificity of the effluent coming from the secondary level and they are:

• Biological methods based on: biological membranes; fields irrigation stabilization ponds, pools denitrification, biological filtration.

• Physical methods based on: microfiltration, filtration through granular masses.

• Physic-chemical methods based on: chemical coagulation, absorption, neutralization, ion exchange, reduction, oxidation.

• Special methods based on: electrolysis, dialysis, reverse osmosis.

In order to remove residues of suspended solids as, BOD5, COD, N and P are used the following processes: multilayered filtering, fixed sand filters or with mobile bed and micro screens of 0,01 - 0,1 mm. Such equipment has approx energy consumptions. from 1.0 to 2.0 kWh / year. It should be noted that the efficiency of the micro filters are lower than that of fixed sand filters.

The membrane equipment in addition to biological treatment provides a very good filter. Bioenergy technologies replace the primary settling tanks with a series of digesters in series or in parallel in order to exploit the energy potential of organic wastewater masses. The wastewater resulted after the fermentation tanks follow the secondary treatment pathway respectively the tertiary.

2.4 **Sludge treatment**

The Sewage Sludge is the main waste material of treatment plants. The better wastewater was treated, the higher the amount of resulting sludge. Besides this, the amount of resulted sludge also depends on the number of inhabitants connected to the wastewater disposal system. The level of connection varies from country to country, but also between urban and rural areas. In general we can consider a quantity of 20 - 45 kg MS / person / year.

The sludge from the primary and secondary settling tanks is introduced into the fermentation tower, called metantanks. Usually the reinforced concrete tanks are large, where ensures relatively high temperature, constant, and anaerobic conditions in which bacteria ferments the sludge and decompose the organic materials until the inorganic materials, resulting in a sludge rich in nutrients and gases containing much methane and it can be used as fuel.

The treatment of sewage sludge requires only 10-20% of electricity consumption, but 80 -90% of the heat consumed stations equipped with metantanks. By valuing the biogas resulted in the power plants it obtains a much greater quantity of electricity and heat than that required in the sludge treatment processes. The volume in excess of heat can be used to heat buildings or in the sludge drying processes. Furthermore, by the incineration of sludge can be produced both current and heat, which can then be used to dry the sewage sludge.

The energy balance of the sludge treatment plant will be optimized according to specific consumption following the processes: filtration, thickening, conditioning, dewatering, drying and incineration.

Filtering is done to eliminate harmful substances. It is recommended where the mechanical grates and screens level are not sufficiently fine, when there is the danger of clogging of the treatment equipment (eg. if we have heat exchangers) or when foreign substances interfere with the treatment processes or sludge valorization.

Thickening is a method of concentrating the sludge, resulting in volume reduction and improvement of specific resistance to filtration. The amount of energy saved by thickening is much larger than the energy consumed by this process. The primary and secondary sludge will thicken separately to reduce power consumption and gelling agents.

- Static thikeners requires only a small amount of electricity for the processing of the primary sludge and stabilized sludge;
- the sludge thickening process allows secondary flotation without the use of coagulants, but solid content will be only 3-5% TR in energy consumption from 0.8 to 1.6 kWh / m³.
- The process of spinning requires high energy consumption (0.5 to 1.3 kWh / m³) and a pretreatment with coagulants.
- The filtrant thikeners (eg. The centrifugal, with screw or with discs) requires coagulants, but the energy consumption of only 0.2 - 0.4 kWh / m³.

In order to stabilize the sludge are practiced the following technologies, with and without disinfection:

- Aerobic-thermophilic stabilization (ATS) is a compact way, but requires a high consumption of electricity. Sludge is disinfected.
- Chemical stabilization also means disinfection. Energy consumption is reduced. This method results in increase of the volume of sludge and therefore increasing transportation costs.

Mesophilic fermentation requires 1 kWh / current It and 14 kWh / her to produce heat. From the aluing of the biogas produced results around. 48 kWh / (PT•a).

3. CONCLUSIONS

The wastewater treatment relates to several aspects:

• Mineralization of the biodegradable organic matter by action of microorganisms and elimination of their pollutant potential;

• The inactivation or elimination of pathogens that contaminate the wastewater;

• The elimination of minerals that occur during the treatment process;

• Reducing the volume of sludge obtained and its biological stabilization [5].

No wastewater treatment process can ensure with certainty a completely clean effluent, free of pathogens, although it can achieve a high degree of purification [8].

Analyzed in this work are specific energy consumptions for wastewater treatment. These inputs are determined by the site of the treatment plant (horizontal land, sloping or opposed), the manner in which waste water are drained (gravitational, cascading, pumping or combined), the construction type and the reliability of the equipment (reduced energy consumption), by the way in which the sludge are valued, by energy aspect, (biogas, agricultural fertilizer), or how technological processes are insured and managed at object level or on the entire treatment plant.

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