

THE MODERN AND INNOVATIVE WASTE WATER TREATMENT PLANT

Ján Cigánek

Abstract:

The modern and innovative waste-water treatment plant (WWTP) was developed in cooperation of two partners - Slovak University of Technology in Bratislava and private industrial company Tercial, a member of BOST Group. WWTP achieves exceptionally high and stable treatment values over a long period. The treatment plants are suitable wherever it is too expensive to build a multi-kilometre long connection to existing sewage networks, in areas with increased environmental protection and where the construction time and the size of the built-up area play an important role. WWTP is mobile container with individual construction parts - modular system which can be modified according to the customer's requirements and location properties. The main innovation is in usage of membrane bioreactors (MBR) and nanotechnologies with unprecedented 99% efficiency which is achieved by modern control, scanning and communication technologies. The innovative waste water treatment plant is managed and controlled by SCADA system what will allow its optimal performance, fast information on failures, fast and effective service and prolonged lifespan. Intelligent SW control (PLC with HMI) will allow remote centralized management and fast service interventions with the minimisation of personal and service costs.

Keywords:

Environmental protection, membrane bioreactor, mobile container, modern control system, SCADA system, waste water treatment.

ACM Computing Classification System:

Hardware, emerging technologies, analysis and design of emerging devices and systems, emerging tools and methodologies.

Introduction

Environmental protection is one of the key values of Tercial, a member of BOST group. In cooperation with Slovak universities, it has developed a modern and innovative system of wastewater treatment using membrane bioreactors. Water Beast 700 is a modern container wastewater treatment plant with a treatment capacity of 100 m³ per one day, which is sufficient for approx. 700 PE (population equivalents).

Water Beast treatment plants achieve exceptionally high and stable treatment values over a long period. The treatment plants are suitable wherever it is too expensive to build a multi-kilometer long connection to existing sewage networks, in areas with increased environmental protection and where the construction time and the size of the built-up area play an important role.

The usage of innovative waste-water treatment plant is suitable for:

- municipalities,
- industrial objects,
- commercial objects,
- crisis areas,
- areas with an increased level of environmental protection.

1 Treatment Process

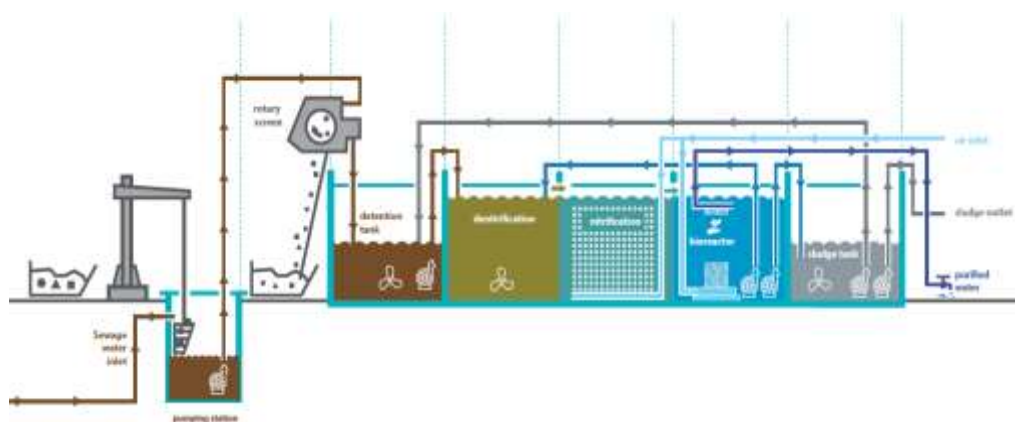


Fig.1. The basic scheme of the treatment process.

1.1 Input pumping station

The input pumping station is used to pump wastewater from the inflow sewerage level to the accumulation section of the process tank.

The pumping station (PS) consists of a shaft with a diameter of 2-2.5 m. Its depth depends on the depth of the input sewerage, inflow unevenness and is fully adapted to the local conditions.

The PS includes a bar screen basket for retaining solids with gaps between individual bar screens of 20 – 25 mm. When the basket is full, it is emptied into a collecting container using a bracket jib crane. Pumps in the pumping station will be designed for a maximum calculation inflow. One pump constitutes a 100 % backup for the other one.

1.2 Mechanical pre-treatment

The mechanical pre-treatment is provided by the bar screen basket in the input PS and subsequently by a rotary screen with openings with a diameter of 0.5 mm. Here, insoluble substances of sizes larger than 0.5 mm are separated from the inflow wastewater. Rotation of the drum pushes impurities into a chute and into an adjacent container. The rotary screen is located above the accumulation section of the process tank.



1.3 Biological treatment in the process container

The process container is divided into sections in which the biological treatment process takes place gradually using activated sludge (specific mixture of micro-organisms), which removes individual components of pollution during the biological treatment process. The tank consists of the following sections:

- accumulation section,
- denitrification section,
- nitrification section,
- MBR section,
- sludge tank.

1.4 Accumulation section

The accumulation tank is used to balance the inflow unevenness during the day, thus ensuring a continuous and uniform treatment process in the following sections. This section contains submersible pumps, which pump water into the next denitrification section. The pump is switched on and off depending on the setting of the level sensor and the level drop in further sections. The tank also contains a submersible propeller stirrer ensuring homogenization of water intended for treatment. The accumulation section also receives back water returning from the sludge dewatering section.

1.5 Denitrification section

The denitrification section follows the accumulation tank and is used to remove nitrogen pollution from the wastewater, namely by converting nitrate and nitrite forms of nitrogen into gaseous nitrogen. At the same time, partial degradation of carbon pollution stemming from the organic substrate takes place here. Correct functioning of the denitrification reactor requires continuous homogenization of its content by the installed submersible propeller stirrer. The inlet of the recirculation, which ensures the return of activated sludge from the membrane bioreactor, also discharges into this section.

1.6 Nitrification section

It follows the denitrification section, into which a mixture of polluted water and activated sludge flows gravitationally over an overflow edge. The nitrification section enables biological removal of carbon pollution, which reduces COD and BOD₅, and, at the same time, oxidation of nitrogen pollution in the form of ammoniacal nitrogen up to nitrates takes place here. This process requires oxidation of treated water. For this purpose, fine-bubble membranes ensuring uniform air-flow across the whole area of the section are located on the tank bottom. Necessary amount and pressure of air are ensured by a set of blowers located in the blowing plant.

1.7 Membrane bioreactor – MBR

Treated water flows into the section by overflowing from the nitrification section. The section contains a membrane bioreactor (Fig.2) embedded with membrane units with a total surface area of 420 m². Cleaned water rid of activated sludge and bacteria is extracted through pores in the membrane walls with a size of 0.04 µm from the inside of hollow fibers into a collecting tank for cleaned water. Water thus cleaned does not contain almost any insoluble substances and most of the bacteria [1], which is why it can be used as service water for irrigation and for the restoration of natural water areas and wetlands.



Fig.2. The membrane bioreactor MBR.

Cleaned water can be used for:

- Cyclical back-flushing of membranes.
- Spraying the rotary screen of mechanical pre-treatment.
- As service pressurized water for secondary use in the treatment plant.
- In the WWTP (Waste Water Treatment Plant) sanitary facility for flushing.

The flow of the mixture of treated water with sludge around the outer walls of the membranes is solved by an aeration system located at the bottom of the bioreactor. The membraneless filtration process follows the following regime:

- 20-25 min. extraction of cleaned water from the membrane walls into the collecting tank.
- 5-7 min. a back-flushing of the membranes with the cleaned water from the collecting tank.
- 1 min. in the last phase of the flushing a chemical is dosed by injecting a sodium hypochlorite or citric acid solution.

The whole process of cleaned water extraction and membrane module back-flushing cycles are programmatically controlled using the PLC system.

Extraction of cleaned water from the bioreactor tank causes sludge densification in the section. Submersible pumps with a backup are located in the section together with the bioreactor. These provide the following functions: the pumps provide the pumping of the returned sludge back to the treatment process in the denitrification section. The recirculation coefficient is adjustable within the range of 2–5 times the WWTP output.

An airlift pump is switched on automatically after the sludge density in the bioreactor section reaches 12-15 g/l and pumps superfluous sludge into the sludge tank (sludge collector).

1.8 Sludge management

The last section in the process tank is the sludge tank, which is divided into two parts with a different volume by a dividing barrier. Superfluous sludge from the MBR (Membrane BioReactor) section is pumped into the first part, whose volume takes up $\frac{3}{4}$ of the sludge collector, and not only gravitational densification of the sludge and the offsetting of sludge water, but also the completion of sludge stabilization takes place here as it is provided with both a stirrer and aeration.

The offset sludge water falls into the other tank part over the barrier and when it is full, it is pumped with the submersible pump into the accumulation tank. Homogenized sludge with dry matter of approx. 20-30g/l, which is monitored with a sludge probe, can be pumped out using a faecal suction truck or pumped into a sludge dewatering line.

2 Constructions and Options

The proposed treatment process is offered in two basic construction forms:

- Water Beast 700 - Container treatment plants with a membrane bioreactor designed for 700 – 2100 inhabitants (100 – 400 m³ of waste water per one day),
- Water Beast 5000 - Wastewater treatment plants with a membrane bioreactor designed for 5 000 – 15 000 inhabitants (800 – 3000 m³/day).

2.1 Water Beast 700

Container WWTPs are delivered pre-assembled. A very short time of delivery and putting the facility into operation is needed (from 3 to 6 months).

They consist of two basic modules, each with dimensions of a transport container for simple transport and assembly. They are equipped with the state-of-the-art treatment technology using membrane bioreactors.



Fig.3. Water Beast 700.

The container tanks are covered. The covers are also used as service platforms for the maintenance and repairs of technological equipment. All the equipment inside the tanks (pumps, stirrers etc.) is adapted to allow its easy and quick replacement. The container tanks may be located on the surface, as half-embedded or fully embedded.

Depending on climatic conditions, the will be provided with suitable thermal insulation. Submersible equipment is already installed in the lower part. A service platform with laid segments of distribution pipelines is located in the upper part. Both parts will be joined together and sealed at the place of assembly. The inner surfaces of the tank and covers are provided with a special zinc-containing coating resistant to the water being treated.

In addition to the basic container modules, we also supply service containers containing supplementary technologies, a control center, and a blowing plant. The treatment plant is pre-assembled and during the on-site assembly it is only necessary to interconnect pipelines, electric distribution lines, process tanks and make a connection to the WW (Waste Water) pumping station.

2.2 Water Beast 5000

Water Beast 5000 offers a solution to minimize construction works and quickly deliver the treatment plant and put it into operation.

Process tanks are circular with inner division of individual tanks. They are made up of metal sheets enameled on both sides, mutually screwed together and sealed. They are placed on a water-resistant reinforced concrete plate.

6m high tanks may be supplied as open or roofed, equipped with thermal insulation or without it. Auxiliary operating facilities consisting of a control room with a sanitary facility, a bioreactor and sludge dewatering control are also delivered fully assembled, at the construction site they just have to be mutually interconnected and connected to the process tanks.



Fig.4. Water Beast 5000.

The technological equipment is supplemented with a sand separator and adapted to the designed output. The operation of this type of treatment plants is fully automatic with the possibility of remote control via mobile devices or PC. We give a WWTP with an output of 1000 m³/day as an example. It consists of three circular tanks with the following parameters:

- The accumulation tank is located in the circular tank itself with a diameter of 8.57 m and height of 5.8 m with a volume of 330 m³. It contains a sand trap, a stirrer and pumps for pumping the treated water into biological treatment tanks. The mechanical pre-treatment and thereafter also the interception of fats and oils of plant and animal origin (if the character of mainly industrial WW requires it) takes place separately before entry into the accumulation tank.
- The treatment process tanks - they include 2 concentric circular tanks, the outer tank has a diameter of 11.14 m and a height of 5.8 m, the inner one 6.86 m. The inner tank with a volume of 211 m³ is used as a denitrification tank. The space in the annular area is divided into 3 parts with dividing walls: the anaerobic section with a volume of 71 m³, the nitrification section 177 m³ and the bioreactor section 106 m³.

2.3 Supplementary technological equipment

Separation of ballast water from wastewater is necessary in a place with a single-pipe system. The equipment – an overflow (OF) – is located in the preliminary shaft ahead of the inflow of the WW into the pumping station.

The OF is a certified finished product allowing a WW volume of Q_{max} to be conveyed into the WWTP and the WW volume to be relieved into the by-pass, thinned in a proportion required by legislation, which will flow to the recipient either through the rain tank or directly.

The filling of the rain tank is enabled by a motor-operated slide, which opens and closes the entry into the rain tank from the by-pass. In the case of torrential rain, the slide opens from the by-pass into the rainwater retention tank. In normal operation, the slide is in the open position into the WWTP, closed into the by-pass. In the case of torrential rain, the inflow into the treatment plant is closed and the inflow into the by-pass or the rainwater retention tank opens simultaneously. The control may be remote or automatic via a rain sensor.

The basic version envisages the transport of aerobically stabilized sludge, gravitationally densified to 20-25 g/l using a faecal suction truck to the nearest big treatment plant for further processing. If it is not possible, we offer to add equipment for sludge dewatering by pressing using a screw press or a screen belt press. The pressed sludge cake contains 20 % of dry matter and its further use must be in accordance with legislation on the handling of sewage sludge. It can be used as a garden or field fertilizer.

Water from the press – the filtrate – flows into the collecting tank and returns to the accumulation section of the process tank via a pump. The equipment is located in a separate container together with a device for inserting and dosing the flocculants into the sludge before the pressing process. Composted sludge can be used as a quality garden or field fertilizer.

The quality of the cleaned WW and its wholesomeness allow its reuse for flushing the technological equipment for WW pre-treatment, sludge dewatering equipment, in sanitary facilities for flushing the toilet, the maintenance of green areas in the WWTP area etc. Further usage of the cleaned WW is possible while using it as service water for agriculture, e.g. for irrigation during the growing season and other purposes. The equipment consists of a pressure water station connected to a distribution pipeline to places of its direct consumption. Cleaned WW not used for the above purposes flows into the recipient, to wetlands etc.

Removal of phosphates is suitable for higher outputs and high pollution of wastewater by phosphate compounds and wherever required by environmental authorities. The treatment is done using the simultaneous coagulation technology. Phosphor is normally coagulated using ferric or ferric-aluminium coagulants, dosed into the denitrification section. The equipment consists of a separate solution reservoir and a dosing pump, which doses the chemical into the denitrification tank in a set ratio.

It is possible to use solar energy on the WWTP by installing photovoltaic cells. Energy gained from them is used for lighting, as a backup power supply for the control system, or to drive part of the technological equipment. The solar system contributes to the reduction of electricity running costs.

2.4 Operating facilities

Operating facilities are used to provide utilities, operating media and the overall operation of the treatment process in the basic configuration. These operating facilities are designed to be located in transport 20' containers with dimensions 6 x 2.4 x 2.52 m and are delivered with the following equipment:

1. Blower operation facility – The equipment in the container provides compressed air necessary for the aeration in the nitrification section, for the bioreactor and airlift pump modules. Three pieces of Roots blowers are located here: for nitrification, for the bioreactor module and one backup blower with an automatic start for one or the other branch. The operation is controlled from a central control room. The blower output is controlled using frequency converters and in the nitrification also based on oxide probe data.

2. Bioreactor automatic control operation facility – The container contains a cleaned water balancing tank, reversing pumps for sucking off water from the bioreactor into the balancing tank. They also provide the flushing of membranes during reverse operation. The output of the pumps is controlled using frequency converters based on pressure and flow sensors. If the set membrane resistance is exceeded, they automatically switch the reverse operation to the back-flushing. An automatic water station is also connected to the balancing tank. This automatic water station provides pressurized water for the rotary screen, a sludge dewatering line and other use of cleaned water for utility purposes. Furthermore, chemical tanks can be found here, which are placed in safety tubs, as well as dosing pumps of chemicals, which inject a dose of a chemical (a sodium hypochlorite or citric acid solution) right at the entry of the back-flushing water into the bioreactor module at selected cycles during the membrane back-flushing.
3. Control room and sanitary facility – Here is the room of the central electric switchgear and control system for the automatic control of the technological process of the WW treatment, the control of external lighting, heating, security cameras etc., with a direct connection to the internet network. Another part houses a sanitary facility with a toilet, shower and a changing room for occasional operators, also a laboratory with basic equipment for taking samples and performing necessary analyses of the WW and sludge.

2.5 Remote control

The latest generation of PLC, a database and visualization system, works under both the Android and iOS systems. After it is connected via the internet, it is any time capable of monitoring the state, correcting the automatic WWTP control or switching the operation to the manual mode. The visualization system provides timely alerts to changes of process values beyond required ranges, which helps prevent emergency situations of the WWTP. For service purposes, it is possible to retrospectively monitor all states, alarms and messages. Remote diagnostics and preventive maintenance thus help you substantially reduce service costs and predict potential emergency situations. We offer the possibility to connect to the manufacturer's dispatching.

Statistical evaluation of selected process parameters representing the amount of cleaned water and energy consumption at selected time intervals goes without saying.

Conclusion

The proposed treatment process with membrane bioreactors offers several advantages in comparison with conventional types of wastewater treatment plants:

- 1/3 built-up area compared to conventional WWTPs;
- low construction costs;
- a very short manufacture, installation and commissioning time (3-6 months);
- usage of cleaned water as service water;
- the possibility of discharge into low-flow watercourses;
- an application for remote control and for checking the condition from a PC, smartphone or tablet;
- saving of costs related to the construction of a system of concrete tanks;
- high treatment efficiency, for some indicators up to 99 %;
- fully automatic and almost unattended operation.

A typical site for embedding a container WWTP with a MBR is an agglomeration of minor municipalities and settlements in mountain areas with recreational facilities or sports facilities, hotels and hostels. This is an opportunity to reuse well cleaned water and also a possibility to retain it in the area. The dewatered stabilized sludge produced from the WWTP is suitable for use in local compost plants and for agricultural purposes in plant production. Due to its high efficiency the treated water can be (re)used also in little watery watercourses even with very high environmental protection level.

▲ Acknowledgement

This paper is supported by the Slovak Research and Development Agency (VEGA 1/0819/17), and the Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic (KEGA 030STU-4/2017).

▲ References

- [1] T. Stephenson, S. Judd, B. Jefferson and K. Brindle, "Membrane Bioreactors for Wastewater Treatment", IWA Publishing, London, UK, ISBN 900222-07-8, 2000.

▲ Authors



Ing. Ján Cigánek, PhD.

Faculty of Electrical Engineering and Information Technology
Slovak University of Technology in Bratislava, Slovakia
jan.ciganek@stuba.sk

He was born in 1981 in Malacky, Slovakia. He received the diploma and PhD. degree in Automatic Control from the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology (FEI STU) in Bratislava, in 2005 and 2010, respectively. He is now Assistant Professor at Institute of Automotive Mechatronics FEI STU in Bratislava. His research interests include optimization, robust control design, computational tools, SCADA systems, big data, and hybrid systems.

