Module 04 : Planning operations

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IWMI
International Water Management Institute

Week 03C: Design technology systems for water recovery

Resource Recovery and Reuse (RRR) Entrepreneurship

Week 3.C module 4: Design technology systems for water recovery

“Welcome to week 3.C of module 4: Design technology systems for water recovery.

This week we are going to look at selected **treatment technologies** that render the wastewater safe for reuse, in a way that valuable nutrients and water are available, without posing a health and environmental risk.

Specifically, I will be talking about primary and secondary treatments of domestic or municipal wastewater, which is water that has been produced at the household level, also called sewage.

Wastewater can be also industrial wastewater, but its content of physical, chemical and biological pollutants changes drastically depending on the industrial activity. Therefore, we will not be covering industrial wastewater treatment, and I suggest that you contact a specialist in case you will be treating this type of wastewater.

As I said, sewage or domestic wastewater is a type of water that is produced by households. It consists mostly of:

- greywater from sinks, tubs, showers, dishwashers, and clothes washers, usually with soap and detergent.
- blackwater, which is the water used to flush toilets, combined with the human waste and toilet paper – depending on hygiene habits.

Domestic sewage contains approximately 99.9% water. The remaining part contains organic and inorganic, suspended and dissolved solids, together with microorganisms. This 0.1% pollutes the water and makes wastewater treatment necessary.

The main parameters to characterize domestic wastewater are:

- Total solids, which can also be suspended and dissolved.
- Organic matter, which is a mixture of proteins, carbohydrates and lipids. We measure it as BOD_5, which is the biochemical oxygen demand, or COD_5, the chemical oxygen demand.
- Total nitrogen, which includes nitrogen, ammonia, nitrite and nitrate. This is an essential nutrient for the growth of microorganisms in biological wastewater treatment.

- Total phosphorus, which exists in organic and inorganic forms.

- Faecal contamination, commonly measured with the indicator E-coli, which represents the presence of faecal coliforms that are present in large numbers in human and animal faeces.

- Another indicator of quality that is particularly relevant for the reuse of wastewater is the number of parasitic Helminth eggs present in wastewater samples.

In this table you can see the typical **concentration range** of domestic wastewater, as well as the **typical** concentration in developing countries. All are measured as mg/L, except E. coli, which is measured as number of microorganisms per 100 mL. Keep in mind that total solids is about 1100 mg/L and BOD around 300 mg/L, while the *E .coli* is typically 10^7 org/100 mL.

This is of course just an example. You will need to take samples of the wastewater you will treat and get actual values for these indicators in a local laboratory.

The aim of wastewater technologies is to decrease these concentrations to a level that is either required for discharging the water into the environment or for the goal of reuse, such as irrigation water or drinking water standards.

When selecting wastewater treatment technologies, it is imperative to define the **goal of reuse**.

For instance, if you are designing a scheme for wastewater reuse for irrigation, you must ask yourself: **what is the type of crop that will be irrigated?** If you are irrigating energy crops, like willows or poplar, the required quality of the wastewater is less than the quality required to irrigate crops that are consumed raw, such as lettuce.

Knowing the goal of reuse will let you identify the treatment objectives. These are usually defined by the standards set in national regulations or international guidelines such as the 2006 WHO Guidelines for the safe use of wastewater, excreta and greywater in agriculture and aquaculture. In there, you will find that the standards of 1000 E. Coli/100 ml and <1 Helminth egg are very safe effluent standards to protect farmers and consumers. I highly recommend that download the WHO guidelines below and read them.

Now, let's look at the components of a typical wastewater treatment system:

- **A pre-treatment step**, which has the aim of removing wastewater constituents, such as oil, grease, sand and trash.

- **A principal treatment step**, which is divided in two: primary treatment and secondary treatment. The aim of the **primary treatment** is to remove the settable suspended solids, while the objective of the **secondary treatment** is the removal of organic matter.

- Finally, the treatment of wastewater might or might not contain a **value addition step,** usually called **post-treatment.** This is where most of the pathogens and nutrients are removed.

These are the technologies that are available to remove oil, grease, sand and trash in the **pre-treatment** step:

- **Grease traps** are chambers made out of brick-work, concrete or plastic, in which grease is trapped on the top. These are very relevant if you are planning to reuse water from restaurants or kitchens that use large amounts of oils.

- **Screens** are inclined screens or bar racks that prevent coarse solids, such as plastics, rags and other trash, from entering the treatment systems. More sophisticated screening processes include rotating screens and comminutors.

- The removal of sand contained in the sewage is done by sedimentation through special units called **grit chambers**. Because of their large dimension and density, sand grains go to the bottom of the tank. There are three general types of grit chambers: horizontal- flow, aerated, or vortex chambers.

As you can see in the figure, grease traps and grit chambers can be combined in one unit.

Alright, that's all about pre-treatment.

Before I continue with principal treatment, I will briefly explain one key design parameter. This is the **Hydraulic Retention Time** or detention time. The **Hydraulic Retention Time** is the time that wastewater needs to spend in the treatment unit for the treatment process to happen under optimal conditions.

Let me give you an example:

Let's imagine that you need to treat 1 cubic meter of wastewater per hour, and the hydraulic retention time is 5 hours. This means that the wastewater needs to spend 5 hours in that unit in order to achieve the optimal conditions for the microorganisms to do their job. This means that the treatment unit should have a volume of 5 m^3.

The important thing for you to keep in mind is: the longer the required hydraulic retention time, the larger the size of the unit you need to construct, which also means higher costs.

As I said before, the principal treatment in wastewater treatment technology is divided in two: primary treatment and secondary treatment.

Within the **primary treatment** settable suspended solids are removed thanks to physical processes. Much of the suspended solids are organic matter in suspension, which means that their removal in a simple **sedimentation tank** implies a reduction in the BOD load that arrives in the secondary treatment, which is usually more expensive.

Sedimentation tanks are also called settlers, clarifiers or settling basins. Their main purpose is to facilitate sedimentation by reducing velocity and turbulence of the wastewater stream. The solids that deposit at the bottom, called sludge, need to be removed periodically to ensure that the unit works under designed conditions.

In order to allow sedimentation, settlers need a hydraulic retention time of 1.5 to 2.5 hours. Sometimes, you will find settlers with a higher retention time, for instance 8 hours. The construction of such units will not only cost more, but such high volumes will also cause organic degradation, which is not the objective of the primary treatment.

Settlers can achieve a significant initial reduction of suspended solids of 55-65% and BOD removal of 30-35%.

Normally, the reduction of E-coli is less than 1 log unit. Which means that the wastewater still contains large amounts of pathogens.

The principal treatment of wastewater also includes a **secondary treatment**.

The main objective of secondary treatment is the removal of organic matter, and this is achieved thanks to the inclusion of a biological step.

In this step microorganisms decompose the organic material under controlled conditions. The idea of the secondary treatment is to accelerate the degradation of the organic matter by ensuring favourable environmental conditions for microorganisms to feed on it.

Different technologies offer these conditions for the microorganisms. Some of them are **extensive** and others are **intensive**.

Extensive treatment options require more land but less energy and skilled labour, while **intensive technologies** require less land but more energy and skilled labour. Intensive technologies are for instance: Activated sludge, trickling filters, rotating biological contactors, Upflow Anaerobic Sludge Blanket Reactor (UASB), amongst others. Because of the complexity of their operation, high costs and dependence on electricity, their use has not been that successful in developing countries and therefore I am not going to explain them further.

I will focus on **extensive wastewater treatment technologies** that are robust and well-established in developing contexts. They are also able to degrade organic pollutants and reduce pathogens, while maintaining nitrogen and phosphorus content, which is key for water reuse in irrigation, forestry and aquaculture.

Another benefit of extensive technologies is the possibility of combining primary treatment, secondary treatment and post-treatment in one unit. These technologies are: waste stabilization ponds, constructed wetlands, floating plants and fish ponds,

Let's start with waste stabilization ponds.

Waste Stabilization Ponds (WSPs) are large, man-made water bodies, that can be used individually, or linked in series for improved treatment. There are three types of ponds: anaerobic, facultative and aerobic maturation.

As you can see here, anaerobic ponds are the smallest and deepest, built to a depth of 2 to 5m. As the receiver of the pre-treated raw sewerage, its main function is sedimentation and stabilization of sludge. With a hydraulic retention time of 1 to 3 days, it can reach a BOD reduction of 40 to 50%.

The facultative ponds are shallower, constructed to a depth of 1 to 2.5m. They require a retention time of 10 to 20 days, which make them larger than the anaerobic ponds. This is where the aerobic microorganisms degrade the suspended and dissolved matter, reaching a BOD reduction of 50 to 70%.

Finally, there is a shallow maturation or aerobic pond, constructed to a depth of less than 1 m. Here, the wastewater is retained for about 10 days, which requires a huge surface. In a waste stabilization pond system, this pond acts as a polishing step, in which remaining suspended solids, bacteria and pathogens sediment.

When designed in series, the waste stabilization pond system does not require a sedimentation tank as primary treatment, since the sedimentation of suspended solids happens in the anaerobic pond.

Here you can see a system of stabilization ponds for the treatment of domestic wastewater for irrigation.

You can see the huge area required for the treatment, which is a consequence of the high retention times in the units.

With a treatment system like this, it is possible to obtain treated wastewater with very low concentration of suspended solids and organic matter, while the nutrients, such as nitrogen and phosphorus are maintained.

Furthermore, the effluent with a concentration of 1000 E.coli per 100 ml of effluent and less than 1 Helminth egg will not pose a health risk to farmers or consumers.

This treatment system is particularly interesting because it doesn't require electricity and the operating costs are low, however the anaerobic pond can create odours, and you need a very large plot of land. Depending on the price of land, the capital costs of this system might make the business unviable. You should also contact an expert, as the system requires expert design and construction.

Let's now take a look at constructed wetlands.

Constructed wetlands are large gravel and sand-filled basins, usually lined with impermeable barrier, that shelter aquatic plants, such as reed or cattails. They simulate the natural occurring processes in natural wetlands, in which particles settle, materials are filtered, pathogens are destroyed, and organisms and plants take up the nutrients.

This treatment technology is particularly suited for warm climates but can also be designed to tolerate cold periods.

Because of its capacity for removal of pathogens and nutrients, constructed wetlands are used as secondary treatment and polishing step.

There are three types of wetlands:

- **Free-water surface constructed wetlands**, which allow water to flow above ground exposed to the atmosphere and to direct sunlight. This type of wetlands is adequate for receiving effluent from stabilization ponds. In these conditions, they occupy an area between 1.5 to 3.0 m^2/inhabitant. One of its disadvantages is that it can facilitate mosquito breading.
- In **horizontal subsurface flow constructed wetlands**, wastewater flows horizontally through the basin of small, evenly sized gravel of a depth of 0.5 to 1 meters, in a way that the filter material filters out particles and microorganisms degrade the organic. The water level is maintained at 5 to 15 cm below the surface to ensure subsurface flow. As clogging is a common problem, the influent should be well settled with primary treatment before flowing into the wetland. Generally, a surface area of about 5 to 10 m^2/inhabitant is required.
- In a **vertical flow constructed wetland**, wastewater is poured or dosed onto the surface from above, 4 to 10 times a day, using a mechanical dosing system. The basin consists of a 20 cm layer of gravel for drainage followed by layers of sand of gravel to a maximum height of 80 cm. The benefit of the vertical flow is better aerobic conditions improving performance. Generally, a surface area of about 1 to 3 m^2/ inhabitant is required. As in the case of horizontal

wetlands, vertical wetlands also require the influent to be well settled in a primary treatment stage before flowing into the wetland.

Constructed wetlands offer great efficiency for the removal of suspended solids and organic matter, while the nutrients, such as nitrogen and phosphorus are maintained.

However, constructed wetlands alone might not be sufficient to achieve the required quality concentration of *E-coli* to protect farmers' and consumers' health. As you can see, the average quality of the effluent is 10^4-10^5 of organisms in 100 ml of effluent, while it should be equal to 1000 or 10^3. Additional safety measures should be used to ensure the reduction of the health risk.

Constructed wetlands are a good option for reuse systems, however you should have sufficient space and technical expertise for its design, construction and operation.

Now, it is time to talk about floating plants ponds.

A **floating plant pond** is a modified maturation pond with floating macrophyte plants, such as hyacinths or duckweed whose roots hang down into the water to uptake nutrients and filter the water that flows by.

To maximize the production of algae a totally aerobic environment is required, which is accomplished with shallow ponds of less than 1 m depth. It is a common practice designing these ponds in the shape of a carrousel, similar to an oxidation ditch.

This technology is particular interesting for reuse as it generates valuable RRR products. For instance, **duckweed** is a fast growing, high protein plant that can be used fresh or dried as fish or poultry feed. Also, **harvested hyacinths** can be used as a source of fibre for ropes, textiles or baskets. Depending on the income generated, the technology can be cost neutral.

Fish can also be introduced in ponds that receive effluents, where they can feed on algae and other organisms that grow in the nutrient-rich water.

Only fish tolerant to low dissolved oxygen levels and other adverse environmental conditions should be chosen. Different varieties of carp, milkfish and tilapia have been successfully used but the specific choice depends on the local consumer preferences.

The fish themselves do not dramatically improve the water quality, but their sale can recover the costs of operating a treatment facility. Under ideal operating conditions, up to 10 000 kg/ha of fish can be harvested. If the fish are not acceptable for human consumption, they can be a valuable source of protein for other high-value carnivores (like shrimp) or converted into fishmeal for pigs and chicken.

It is also possible to combine fish and floating plants in one single pond.

You have now learnt about key technologies available for wastewater treatment for reuse in agriculture, forestry and aquaculture.

Keep in mind that the pre-treatment step produces solid waste and the primary treatment produces sludge that need to be properly collected and treated or disposed.

When assessing which technologies are most appropriate for your wastewater treatment system, you need to ask yourself the following questions. You may download the worksheet below to record your findings.

- What should be the treatment objectives in terms of organic, nutrient and pathogen reduction?
- What suitable technologies are available locally for wastewater treatment? What has been the experience with them?
- What is the level of performance and efficiency of the different technologies?
- Are there resource constraints related to labour, land, energy or other factors of production?
- If there is a break-down in the plant, are capacities and resources available for the timely repair and maintenance?

To learn more about wastewater treatment technologies in developing countries, I recommend you to have a look at the further readings below and read the Compendium of Sanitation Systems and Technologies by eawag.

Furthermore, the publication “Wastewater Characteristics, Treatment and Disposal” by Marcos von Sperling gives a great introduction of all extensive and intensive technologies, their design and capital and operational requirements.

Now that you have learnt about the different technologies for wastewater treatment, it is time to plan your own technology system for reuse in agriculture, forestry and aquaculture. Record your findings in the worksheet below.

The first thing you need to do is to determine the total inflow of wastewater to treat. This is calculated as the average of domestic use multiplied by the number of persons multiplied by 80%. You could also measure the actual water flow in the field.

You should take samples of the wastewater and determine key parameters such as suspended solids, BOD, nitrogen and phosphorus concentrations and E. coli.

As a first exercise, you can take the typical concentration in developing countries as reference presented in this table.

Depending on the goal of reuse, you need to revise national and international standards for effluent reuse, and determine key values of effluent characteristics.

Knowing the removal efficiency required, it is time to select the type of technology.

Knowing the specific hydraulic retention times required by the different technologies, as well as the water inflow, it will be possible to calculate the volume of each technology.

Also, the specification of each technology tells you what is the depth required, what at the end determines the surface required. This is key to knowing how much land you need!

With this new information it is time for you to describe the specifications of each treatment step: what is the type of technology, the capacity of each step and the list of all equipment needed. Record your findings in the worksheet.

In week 4, I will guide you through the planning of your capital and operational resources. I will see you there!"

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Graph sources:

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- Page 27: Waste Stabilization Ponds:
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  Picture Right: http://waterandcarbon.com.au/technology/waste-stabilisation-ponds/
- Page 32: https://www.researchgate.net/figure/Schematic-flow-chart-of-waste-stabilization-pond-Mathura-II_fig4_259875872
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*Information and data were compiled to our best knowledge, but mistakes remain possible. In such a case we apologize and kindly ask for feedback to correct them.