Treatment matrix for reuse of upgraded wastewater

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Abstract In 2003 the Aquarec project sponsored by the European Commission under the 5th Framework Programme was started, aiming at “integrated concepts for reuse of upgraded wastewater with special focus on the European countries”. One of the key elements is the development of a treatment matrix, in which wastewater treatment processes are categorised as a function of the raw wastewater quality and the reuse application and are further characterised with respect to costs, operational critical control points and environmental aspects. The construction of the treatment matrix is based on the reuse options (industrial, domestic, natural and agricultural applications), the water quality requirements, the treatment requirements and the extensive description of the various treatment processes and schemes. In the process of constructing the matrix it can be concluded that the actual knowledge on municipal wastewater treatment is definitely well consolidated until the so-called secondary treatment including biological or physical/chemical nutrients removal; the treatment of this effluent should be accomplished by more advanced techniques. As a consequence of the actual EU rules on water discharges, it makes sense to focus the Aquarec project on the possible refinements of secondary effluent. Great attention must be given to the advanced or tertiary wastewater treatment processes, as a mean to upgrade the effluent to water suitable for reuse.

Keywords Advanced treatment; municipal wastewater; reuse applications; reuse-matrix; treatment train

Introduction
Europe has a long history in water management in general and more specifically in the “small water cycle”; the treatment and distribution of drinking water and the collection and treatment of wastewater are well developed practices. However, the recycling of treated wastewater has not been widely applied in most European countries. But due to the increasing need for protection of water resources, the growing environmental awareness and the public inclination to sustainability the pressure on water recycling is gradually increasing.

Therefore, in 2003 the Aquarec project sponsored by the European Commission under the Fifth Framework Programme was started, aiming at “integrated concepts for reuse of upgraded wastewater”; with special focus on the European Countries. One of the key elements in the Aquarec project is the development of a water treatment matrix in which wastewater treatment process schemes are categorised as a function of the raw wastewater quality and the reuse application and are further characterised with respect to costs, operational critical control points and environmental aspects.

The starting point for building a water treatment matrix is the definition of the conceivable reuse aims. Municipal wastewater can be reused for an industrial, a domestical (household/irrigation), a natural and an agricultural purpose. These reuse options require different kind of water qualities. The dissimilar water qualities are reached by using of specific treatment levels (see Figure 1).

From Figure 1 it can be explained that many different ways of reuse can be envisaged depending on the application of different treatment processes. In most of the situations a chain of treatment processes has to be formed in order to reach the required water quality for reuse.

As a first step all realistic processes involved in these treatment schemes were described and investigated. Special attention is given to the removal efficiencies of constituents that
are important in respect to reuse applications. A basic division has been made between primary, secondary and tertiary treatment processes. As to the processes it can be stated that both conventional and innovative options are included. Detailed information is provided in the Aquarec milestone report M7.1; the review of processes is mainly based on recent literature (see added list).

**Primary treatment processes**

For primary treatment following processes have been selected:

A. Sedimentation; removal of particles by gravity. The removal efficiency can be increased by adding of coagulants.

B. Dissolved air flotation; separation by introduction of fine gas bubbles. In many situations the addition of coagulants is necessary for good process results.

C. Fine screen.

D. Coarse media filtration; in the coarse media the particles are retained. Coagulants can be dosed to enhance the removal of fine particles.

E. Direct membrane filtration; separation of constituents by passing the water through a semi-permeable membrane.

F. Magnetic separation; enhanced flocculation of the magnetic magnetite particles and removal by an electromagnetic field (example SIROFLOC).

G. Actiflo™-process; micro-sand together with flocculants is added to improve setting conditions.

H. A-stage of AB-concept; high rate biological pre-treatment step, sometimes extra chemicals are added.

I. Denitrifying A-step; high rate biological pre-treatment step with the addition of nitrate as electron donator.

J. UASR (Up-flow Anaerobic Solid Retention); sedimentation and bio-adsorption of particles followed by anaerobic treatment.

After describing the alternative pre-treatment processes estimations have been made of the removal efficiencies. The next step has been the selection of the primary treatment processes which will be incorporated in the treatment matrix. Processes A, B, C, E and G have been selected. Figure 2 shows the estimated removal efficiencies of the selected processes.

It can be seen that some processes are quite similar with respect to removal efficiencies; but also great differences do exist.

**Secondary treatment processes**

After primary treatment the wastewater can be treated in secondary processes; also some secondary processes can be directly applied on raw wastewater. Following processes have been investigated:
I. Activated sludge (AS) (+ settling); the transformation of organic matter in sludge flocs in a dispersed growth mass reactor followed by gravity separation, nitrogen removal can be accomplished by nitrification, denitrification and phosphorus removal can be done either biologically or by chemical precipitation.

II. Trickling filters (TF) (+ settling); organic matter is removed by biological processes with sludge growth on fixed media.

III. Rotating biological contactors (RBC); biological treatment by bacteria growing on a fixed surface, which alternatively rotates through the liquid.

IV. Submerged aerated filter (SAF); biological treatment with bacterial growth on fixed media where air is added for oxygen supply.

V. Stabilization ponds (StabP); large basins where bacteria, algae and other micro-organisms grow under the removal of organic matter; sludge has to remain in the ponds.

VI. Constructed wetlands (CW); surface and subsurface flow of wastewater through shallow fields often provided with reed or plants where wastewater is treated by natural processes.

VII. Membrane bioreactors (MBR); combining the intensified activated sludge process with separation of the liquid through membranes.

A first indication of the possible treatment levels is presented in Figure 3.

Secondary treatment processes mainly remove biological constituents and nutrients. Depending on the loading rate the removal efficiency can differ.

**Tertiary treatment processes**

Tertiary treatment processes can be applied after primary and secondary schemes. Mostly their purpose is to eliminate specific components. Following processes have been studied:

1. Media filtration (MedFil); removal of particles by filtration through media consisting of sand or anthracite.

2. Surface filtration (SurFil); removal of particles by filtration through a thin “septum” of filter material based on mechanical sieving.
3. Membrane filtration (MemFil), removal of particles and other components by passing the liquid through a membrane; pore sizes of the membrane can differ widely giving various results (microfiltration, ultrafiltration, nanofiltration, reverse osmosis).

4. Adsorption, removal of soluble components by adsorption onto porous material (mainly activated carbon (ActCar)).

5. Gas stripping; mass transfer of a gaseous component from a liquid into the gas phase by intensive contact; mainly applied for the removal of ammonia.

6. Ion exchange (IonEx); displacement of certain constituents into an insoluble material; followed by regeneration.

7. Advanced oxidation processes (AdvOx); degradation of complex organic pollutants by hydroxil free radicals; examples are ozone/UV and hydrogenperoxide/UV.

8. Soil Aquifer Treatment (SAT); infiltration through large ground areas, further polishing of water quality.

9. Maturation pond (MatP); further polishing of water quality by natural processes.

10. Constructed wetlands (CW) for polishing.

11. Disinfection (Disinf); removal of bacteria and viruses by chemical oxidation, (chloride, ozone), UV or membrane filtration.

The removal efficiencies are given in Figure 4. Because of the high energy consumption gas stripping has been left out of the water treatment matrix.

It has to be remarked that also more than one tertiary process can be applied in the same process scheme.

**Treatment schemes**

With the different primary, secondary and tertiary treatment processes numerous different treatment trains or schemes can be constructed. The possibilities of reuse greatly depend on the requirements set up for the various applications.

In fact, for each reuse application a large number of possibilities for combining the treatment processes exists. From basic considerations a set of logical limitations can be deduced.

- **As to the primary treatment level**
  - Many processes can lead to comparable process results; so, not all primary processes should be evaluated further.
  - Processes based on the solubilization of constituents have to be followed by biological secondary processes.

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removal efficiency: +: 0 – 35 %, ++: 35 – 70 %, +++: 70 – 100 %

**Figure 4** Tertiary treatment processes and their removal efficiencies
Total removal of particles can be realised by (a combination of) primary processes.

- As to the secondary treatment level
  - Biological processes can handle effectively the dissolved organic constituents (soluble COD).
  - Many biological processes lead to comparable results.
  - Nitrogen can be removed almost completely by application of nitrification/denitrification.
  - Advanced particle removal in the primary treatment step only gives limited advantages in the secondary step.
  - Removal of BOD, COD, N and P, if necessary, should be preferably done in the secondary treatment step.
  - Membrane bioreactors include some of the tertiary processes.

- As to the tertiary treatment level
  - Porous media filtration is a common step for pre-treatment when other tertiary processes are applied.
  - Tertiary processes are very specific for certain components.

- As to all processes
  - The sludge produced in the primary and secondary processes requires further and extensive treatment.

The next step, after building the treatment schemes, is the construction of the Reuse Matrix. This Reuse Matrix greatly depends on the existing wastewater treatment infrastructure and the possible applications. So it is a very specific instrument that can vary from case to case. Calculations with the treatment trains can be facilitated by a computer model including all available information on design, costs and operation.

Intermediate comments

In the process of collecting information and comparing different treatment schemes some basic experience has been gained leading to following comments.

1. The actual knowledge about municipal wastewater treatment is definitely well consolidated until the so-called secondary treatments, including biological and physical/chemical nutrients removal. Processes and schemes are well known and planning and management are reliable, whether physical-chemicals or biological treatments are involved. These processes can provide a satisfactory effluent quality for parameters such as BOD, COD, SS, N, P, which are still the basis of the EU standards for effluent discharge.

   Nevertheless, in some cases, the actual wastewater treatment plants needs upgrades and renewals in order to satisfy the new directives.

2. The treatment of the effluent of secondary treatment, is accomplished through more advanced techniques. Rapid filtration and disinfection are nowadays already regarded as traditional and very common in practice, but other processes are applied less frequently. What really makes the advanced treatment “different” is the specificity of the treatment, which has to be calibrated on the water quality requirements.

   The subject spreads in several applications and results cannot be extended to other situations, so that preliminary experimentation becomes of major importance for a good planning.

3. The EU directives discharge limits should be the starting point for further treatment for municipal wastewater for reuse. Many countries indeed will try to accomplish those limits in a near future, therefore that effluent will be the main primary sources for wastewater reclamation in the short term. On the opposite, schemes alternative to the traditional chain can be a feasible option only in the long term.
Typical schemes

Based on the previous matrix and comments the member-partners have developed a set of typical schemes. These schemes have their own strength, are related to specific reuse applications and are mostly represented by many examples in practice.

Without excluding any other possibilities these schemes seem to be representative for the majority of the possibilities in the Reuse Matrix. Shortly these schemes are:

- **“Title 22”**: conventional wastewater treatment, including P- and N-removal, followed by dual media filtration and disinfection by UV or chlorine; the reuse varies from urban applications, green landscaping to industrial usage. This concept exists as standard in the USA.
- **“High quality”**: conventional wastewater treatment, including P- and N-removal, followed by double membrane filtration (MF/UF followed by RO) and final disinfection by UV; eventually also other processes can be applied; the treated water is of so high quality that many applications (industrial, households, etc.) are possible. Examples of this concept are Water Factory 21, Sydney Olympic Park and Torreele (Belgium).
- **“Only disinfection”**: conventional wastewater treatment, followed by chlorination, enabling the reuse of the treated water for irrigation under restricted conditions. Many examples are available all over Europe.
- **“Local MBR”**: small scale treatment of (part of the) wastewater by a package MBR system with reuse of the water in the direct neighbourhood (as toilet flush water). Typical solution for Japanese office buildings is now also introduced in some European sites.
- **“Soil treatment”**: conventional wastewater treatment, including P- and N-removal, followed by infiltration through large ground areas; the final water can be reused for unrestricted irrigation. Examples are present in the Mediterranean area (Israel).
- **“Wetlands”**: conventional wastewater treatment, including P- and N-removal, followed by constructed wetlands as a natural polishing step; reuse can be done in nature conservation or agriculture. Applications are present in Northern Europe (Netherlands) as well as Southern Europe (Spain).
- **“Lagooning”**: treatment of wastewater by lagooning (several types in series), occasionally followed by chlorination; reuse of the effluent by (very) restricted irrigation. Typical application for Mediterranean countries with moderate treatment facilities.
- **“Direct membrane filtration”**: micro- or ultrafiltration of raw wastewater followed by agricultural applications. New concept, which is investigated in several places (Netherlands, China, Israel).

Of course many variations on these basic schemes exist; variations depend on local situations and greatly vary due to the present wastewater infrastructure and regulations. These basic concepts will be extensively studied in the next phase of the project.

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References


