Minimising waste water emissions with special consideration of micropollutants

In a nutshell

SUMMARY
It is best practice to significantly remove micropollutants by implementing tertiary treatment, such as adsorption onto pulverised activated carbon (PAC) or oxidation with chlorine-free oxidising agents (specifically ozone).
Target group
Public administrations responsible for waste water management and urban drainage.
Applicability
This best practice is applicable to public administrations responsible for waste water management, both in new and existing municipal waste water treatment plants; however, for existing plants, there could be space constraints which can be overcome by adapted design of the equipment.
Environmental performance indicators
• Removal efficiency for micropollutants in the adsorption or ozonation stage in terms of COD or DOC[1](%) • Percentage of the annual waste water flow undergoing tertiary treatment for micropollutants removal (%)
Benchmarks of excellence
• The average removal efficiency for micropollutants is higher than 80 % • Micropollutants are removed from at least 90 % of the annual waste water flow

[1] DOC: dissolved organic carbon.

Description

Diffuse and point-source pollution still threaten the status of EU waters, despite the progress achieved (Blueprint, 2012) so far. A particular challenge is the emission of micropollutants[1] for which municipal waste water treatment plants are a major source (Welker, 2004; Abegglen/Siegrist, 2012; JRC, 2012; WHO/UNEP, 2013) as they cannot sufficiently be eliminated by the commonly applied techniques (primary and biological treatment) via biological degradation and adsorption to activated sludge. In addition, the possibilities to prevent the discharge of hundreds of micropollutants at source are limited. As a consequence, the application of end-of-pipe techniques is required. The minimisation of the discharge of heavily or non-biodegradable organic compounds, especially of micropollutants, comprise the following elements:

- to treat at least up to double of the dry weather wastewater influent flow (in case of rain or thawing)

- to treat the wastewater at nitrifying conditions (food-to microorganisms ratio of <0.15 kg BOD_5/kg MLSS x d), and to perform denitrification and phosphorous removal (see the BEMP on energy efficient waste water treatment achieving full nitrification)
- in case of sensitive areas[2], to remove suspended solids by means of sandfiltration (or by submerged membranes) and to significantly remove micropollutants by adequate techniques, such as adsorption to pulverised activated carbon (PAC) or oxidation with chlorine-free oxidising agents (specifically ozone). The removal of mircopollutant is at least for 90 % of the annual waste water flow; this means in case of heavy rain, part of the waste water by-passes the adsorption or oxidation plant.
- to on-line monitor organic compounds (total organic carbon), ammonia, nitrate and phosphorous in case of plant capacities of more than 100 000 inhabitants equivalents or of a daily influent BOD_5-load of more than 6000 kg respectively.

Most experience is available from plants equipped with an adsorption stage using pulverised activated carbon. It is important to note that this adsorption stage is used for the non-biodegradable organic compounds. For this purpose, the easily as well as the heavily biodegradable compounds are to be removed in the biological stage as far as possible. This requires fully nitrifying conditions (for an activated sludge system, the food-to-microorganism ratio is below 0.15 kg BOD_5/kg MLSS x d). In case of removal of the micropollutants by oxidation with ozone, the suspended solids have to be removed as far as possible by sand filtration or submerged membranes. The fact that the removal efficiency of heavily biodegradable organic compounds in an activated sludge system operated under fully nitrifying conditions is significantly better compared to activated sludge systems operated below the aforementioned food-to-microorganism ratio is shown in Figure 1. All the individual organic compounds analysed represent micropollutants.

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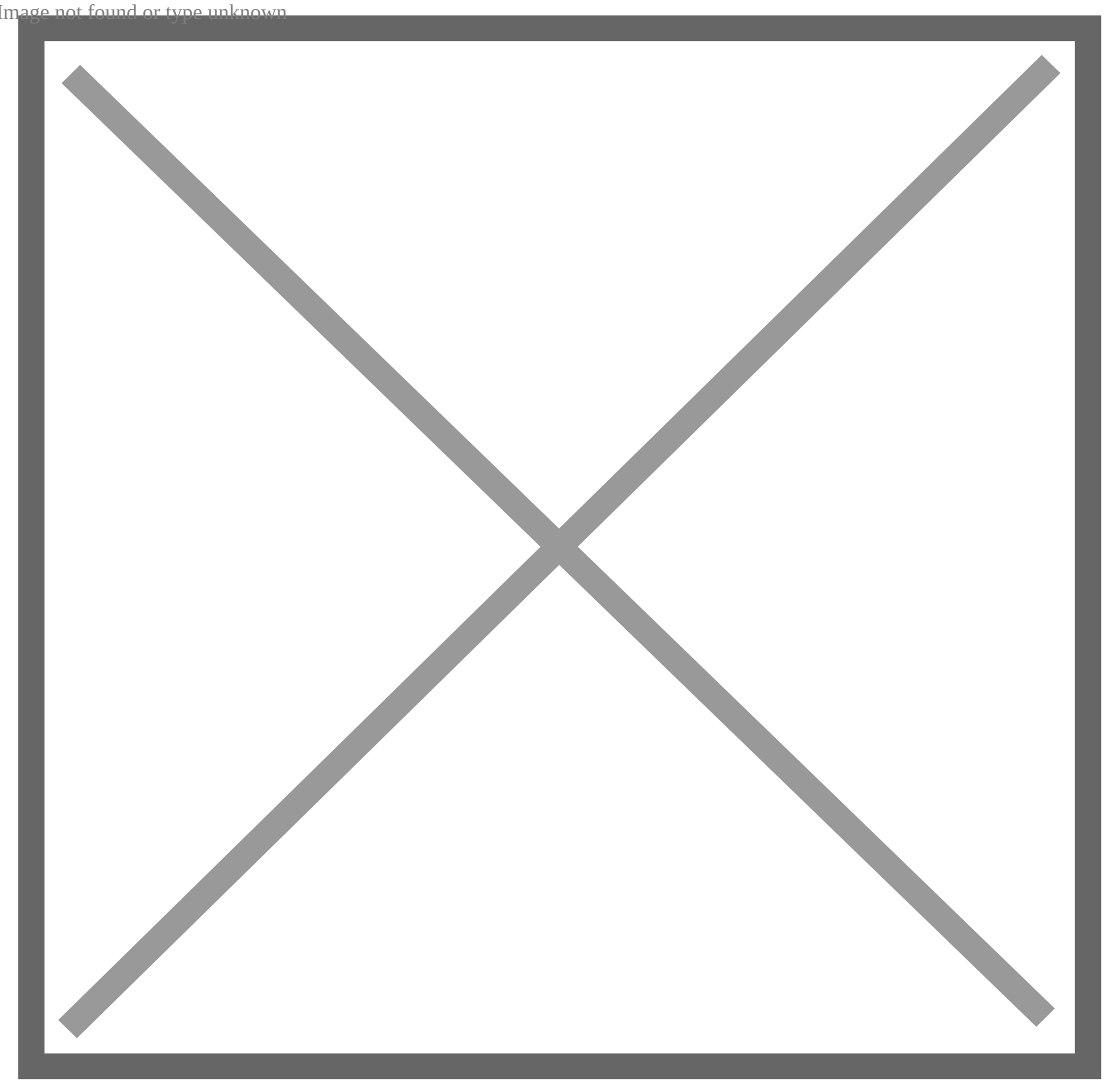

Figure 1: Bioelimination of micropollutants in activated sludge systems operated under fully nitrifying and under non- (or incomplete) nitrifying conditions (Abegglen/Siegrist, 2012, p 74)

The waste water from the biological stage with a BOD_5 content of less than 10 mg O_2/l (practically free of biodegradable organic compounds) is then specifically treated to remove the micropollutants. The currently most relevant techniques are the adsorption to pulverised activated carbon (PAC) in a dedicated reactor or the oxidation with ozone in a cascade reactor. Figure 2 shows the scheme for the adsorption technique. The pulverised activated is automatically added via a silo and a dosage system in a quantity of 10 – 20 mg/l to the contact reactor equipped with stirrers where the adsorption takes place at a retention time of half an hour and a content of activated carbon of about 4 g/l. At or just after the outlet of the contact reactor, a precipitant (usually a iron(III)salt or an aluminium salt; dosage about 2-4 mg Fe or Al/l) is added and also a polyelectrolyte to improve the aggregation of precipitates (dosage about 0.3 mg/l) (Metzger, 2012); another 1 mg Al or Fe is added after sedimentation prior to sand filtration. Then, the PAC is separated by sedimentation (retention time about 2 h) and sand filtration but it is possible to have a filtration only or to use membrane technology to completely remove the PAC from the water phase. Part of the separated PAC is returned to the adsorption stage in order to maximise its adsorption capacity and the surplus is directed to the activated sludge system where it leaves the system with the excess sludge reaching the anaerobic digestor(s). The return of the activated carbon to the biological stage significantly increases the removal efficiency. The final disposal of the laden activated carbon takes place with the anaerobically digested and dewatered, possibly also thermally dried sludge which is co-incinerated in a thermal power plant or a cement plant or in a dedicated sludge incineration plat, all operated in compliance with best available techniques according to the Industrial Emissions Directive.

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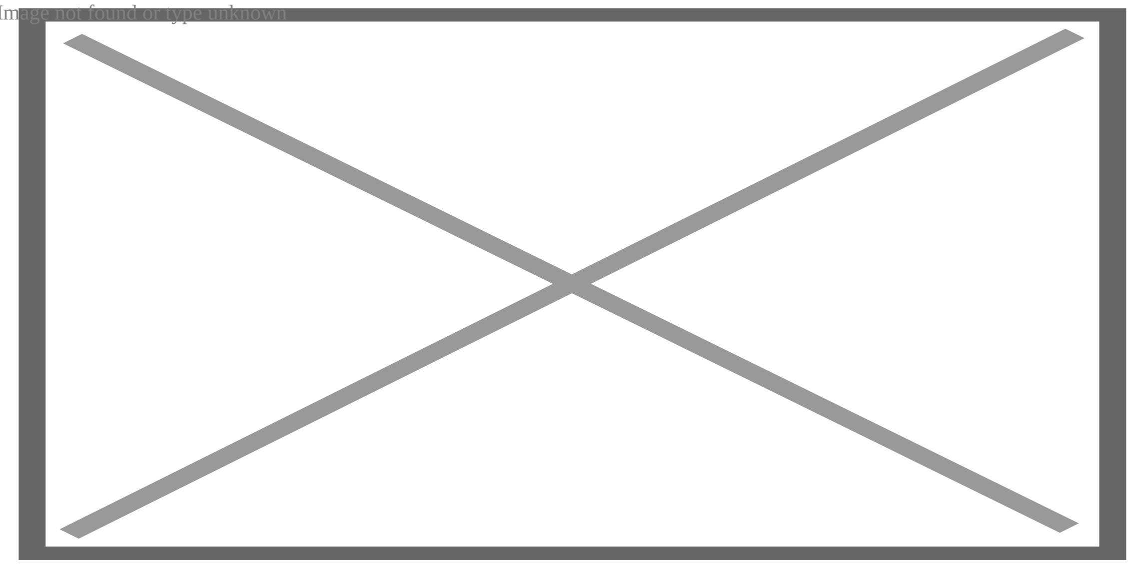

Figure 3: Scheme of an adsorption stage using pulverised activated carbon downstream to mechanical-biological treatment (Abegglen/Siegrist, 2012, p 121)

Another option is to add ozone to the waste water after mechanical-biological treatment (see the scheme in Figure 4). The content of organic compounds and suspended solids should be as low as possible in order to minimise the dosage of ozone. Ozone is produced onsite by means of silent electric discharge from air or oxygen. In a closed ozonation reactor, it is counter-currently added to the waste water flow at an injection depth of more than 4 m to completely dissolve it.

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Figure 4: Scheme of an ozonation stage downstream to mechanical-biological treatment (Abegglen/Siegrist, 2012, p 97)

The appropriate dosage should be proportional to the dissolved organic carbon (DOC) concentration which can be achieved by means of a monitor using a signal at 254 nm (UV light absorption). It is about 0.6 g O_3/g DOC which is usually equal to 4 – 6 mg O_3/l. The oxidation depends on the chemistry of the micropollutant considered and the ozone dosage. As ozone is toxic, ozone detectors are needed and the off-gas with a residual ozone content has to be treated; it can be returned to the activated sludge system or the zone is destroyed. In the oxidation process, the organic compounds are broken down but they are not completely oxidised. Thus, the residual organics are removed in a biologically active sand filter (Figure 4).

[1] Micropollutants are organic compounds which are present in the aquatic environment at concentrations in the range of a few n/l to ?g/l and can have an impact on fundamental biochemical processes (Abegglen/Siegrist, 2012) such as the endocrine systems. Micropollutants comprise a wide range of organic compounds, such as pesticides, biocides, pharmaceuticals, x-ray-contrast media, flame retardants etc.). All the organic priority pollutants of Annex X of the Water Framework Directive (the existing list according to (Decision, 2001) contains 33 pollutants and there is a proposal to add 15 more pollutants (Proposal, 2012)) are considered as a significant risk to or via the aquatic environment, including such risks to waters used for the abstraction of drinking water (Article 16(1) of the Water Framework Directive (WFD, 2000). The endocrine disrupting chemicals are an important part of the micropollutants (WHO/UNEP, 2013). Some of the aforementioned priority chemicals also belong to the endocrine disrupting chemicals.

[2] Sensitive areas as defined in ANNEX II of the Urban Waste Water Directive 91/271/EEC (UWWD, 1991)

Environmental benefits

Most of the micropollutants are reduced with a removal efficiency of more than 80%. This is demonstrated in Figure 5 for the application of PAC. The efficiency for the individual micropollutants depends on their physicochemical properties. For many compounds, the removal efficiency in biological treatment is less than 10 % but more than 90 % with an adsorption stage (dosage of 15 mg PAC/l and return of excess activated carbon to the biological stage). For few micropollutants such as the X-ray contrast agents (Iopromid and Iohexol – see Figure 5), the removal efficiency is less than 80 %, or significantly depends on the PAC dosage and recirculation to the biological stage. It is important to note that the spectrum of micropollutants removed is broad including hundreds of compounds and their metabolites of which many cannot be analysed so far. The residual content of organic compounds is measures with sum parameters such as COD or DOC. The adsorption stage reduces the COD or DOC only by 20 – 30 % but, in general, the removal efficiency for micropollutants is much higher.

The removal of the micropollutants considerably contributes to the minimisation of adverse environmental impacts due to waste water discharge such as the impacts on the endocrine system of aquatic organisms. Further, the micropollutants removed cannot reach drinking water supply systems.

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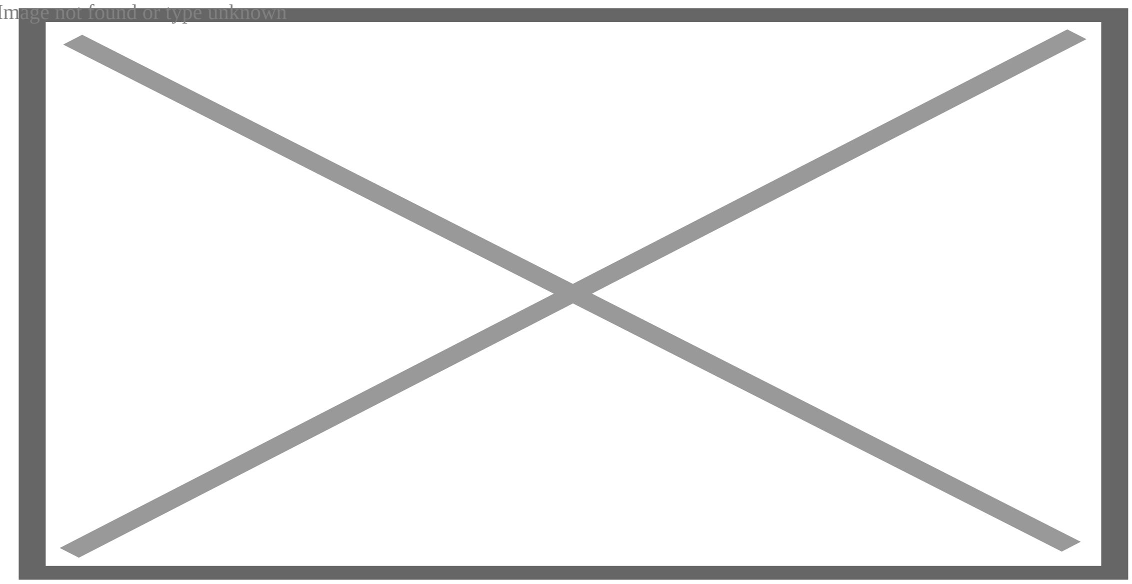

Figure 5: Average elimination rates of different micropollutants using pulverised activated carbon (PAC) (Abegglen/Siegrist, 2012, p 133)

Side effects

The adsorption with PAC requires the production and transport of PAC which is associated with emissions of greenhouse gases and other emissions to air. This impact seems to be minor compared to the removal of micropollutants. In addition, the laden PAC has to disposed of in an environmentally friendly way such as the incineration described.

Concerning ozonation, the energy consumption for producing ozone has to be considered (about 12.5 kWh/kg O_3). With a realistic ozone dosage of about 5 g/m3, the specific energy consumption is about 8 kWh/p.e.[1]/yr which 0.06 kWh/m^3 .which would increase the average electricity consumption of large mechanical-biological municipal effluent treatment plants (> 10 000 p.e.) by about one fourth (UBA, 2009). In addition, unknown oxidation products could create an adverse impact on the natural water. However, detailed investigations did not show evidence for this fear (Abegglen/Siegrist, 2012).

[1] P.e.:population equivalent

Applicability

The technique described is applicable to new and existing municipal waste water treatment plants (Metzger, 2010). For existing plants, there could be space constraints which can overcome by adapted mixing and reaction concepts.

As the adsorption and oxidation technique cover a very broad spectrum of micropollutants, there is no limitation for their application from this perspective. In contrast, as many micropollutants and their metabolites are still unknown or have not been analytically identified yet, it can be expected that the technique also removes most of them.

Economics

According to calculations for the Suisse situation, the operation costs for adsorption plants (including the operation of the sand filter) depend on the size of the plant. For plants with more than 250 000 population equivalents (p.e.), the operation costs are between 10 and 11 Cent/m^3, for plants between 18 000 and 66 000 p.e., the operation costs are between 18 – 30 Cent/m^3 and for small plants (< 10 000 p.e.), the figure is 37 Cent/m^3 (Abegglen/Siegrist, 2012, p 131)

The reported operation costs of real German plants are lower. For the above described municipal waste water treatment plant Böblingen-Sindelfingen, the operation costs are only 5 Cent/m3 (see Figure 13). This figure also contains interest and depreciation, as well as the subsidies received and the lowered waste water levy. If the subsidies received and the lowered waste water levy are not taken into account, the operation costs are 7.5 Cent/m^3.

For the much smaller plant in Kressbronn-Langenargen (30 000 p.e.), the operation costs are between 8 to 9 Cent/m3 (Götzelmann, 2012).

The estimations for the operation costs for the very carefully designed plant Ulm-Steinhäule are 10 Cent/m^3.

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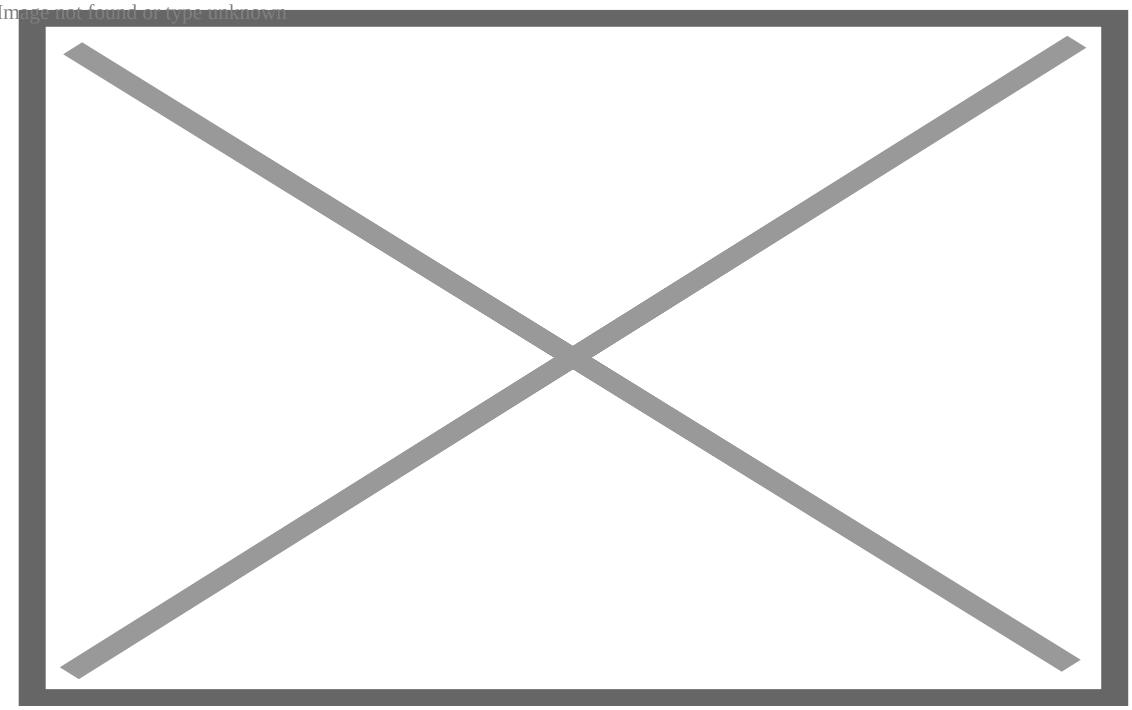

Figure 13: Real operation costs for the removal of micropollutants in the adsorption stage of the municipal waste water treatment plant Böblingen-Sindelfingen (Schwentner, 2012)

For the ozonation plants, the available figures also indicate that the operation costs (ozonation and sand filtration) depend on the size of the plant. For plants with more than 250 000 population equivalents (p.e.), the operation costs are between 6 and 7 Cent/m^3, for plants between 18 000 and 66 000 p.e., the operation costs are between 12 – 23 Cent/m^3 and for small plants (< 10 000 p.e.), the figure is 27 Cent/m^3 (Abegglen/Siegrist, 2012, p 107).

Driving forces for implementation

There are no legal requirements but voluntary initiatives to protect the aquatic environment. The very first plants in Albstadt-Ebingen, Albstadt-Lautlingen and Hechingen (all in the Southwest of Germany) have been designed and built with respect to the combined treatment of domestic sewage and textile waste water in order to remove residual colour and heavily or non-biodegradable textile chemicals (Schönberger/Schäfer, 2003). In all three cases, the receiving water bodies are small and sensitive.

Most of the latest plants were designed and built due to small and sensitive natural water bodies such as small rivers or lakes (Lake Constance). However, the Mannheim plant discharges the treated waste water to River Rhine; nevertheless one line of the treatment plant (for about 18 % of the total annual influent) is treated (see Table 3).

Reference organisations

The adsorption of heavily or non-biodegradable organic compounds, such as micropollutants, is a proven technique and is successfully applied for more than 20 years. As mentioned above, it was first applied for the combined treatment of textile waste water and domestic sewage. Now, it is more and more applied to tackle the problems of micropollutants. The known available plants are compiled in Table 3. Where available, information concerning the size, the maximum flow, the percentage of annual waste water flow treated, the date of start of operation and the investment costs are given.

Table 3: Known municipal waste water treatment plants which were or will be retrofitted with an adsorption stage, status, status: August 2014 (KOMS, 2014)

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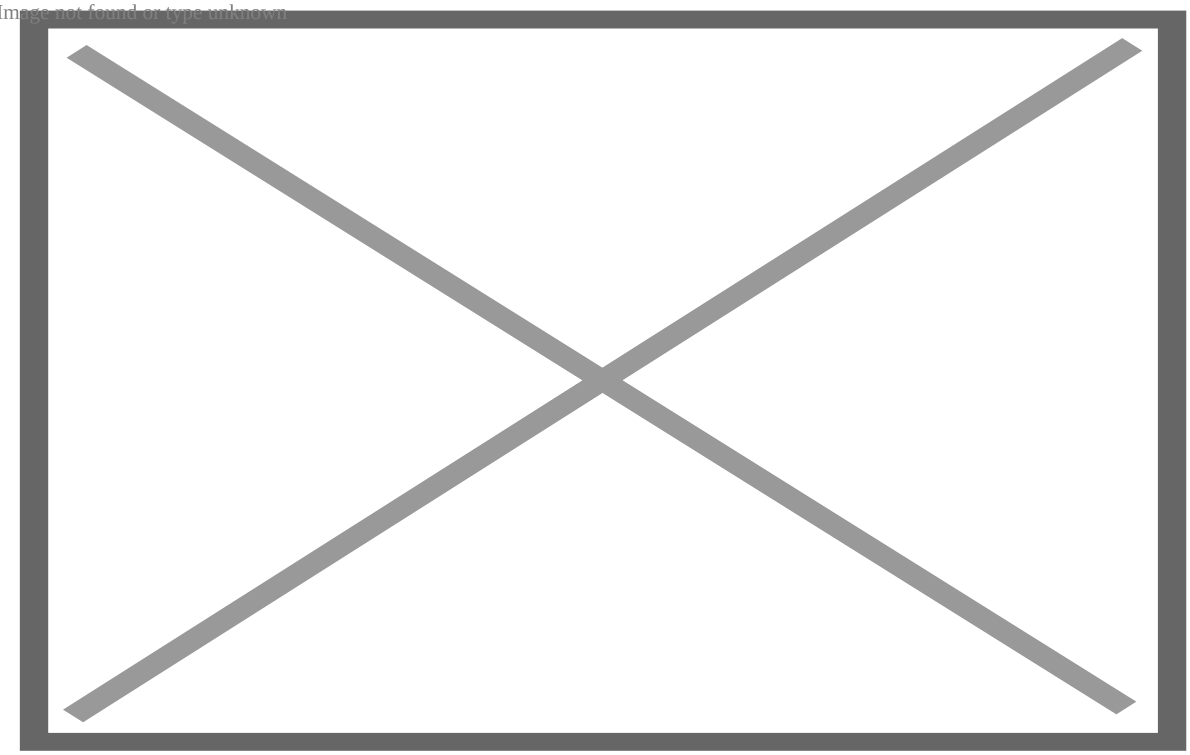

So far, the ozonation technique was mainly installed in Italy where there are about 100 plants. In many cases, they were erected at municipal waste water treatment plants which treat domestic sewage and textile waste water. The biggest plats were installed in Prato and Fino Mornasco (Italy).

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