Chapter

VoxSton—A New Water Clarification System

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Abstract

A new water clarification system for industrial and communal wastewater is presented here. The system consists of two centrifugal separators, a screw separator and two vortex flow flotation units. It can separate the solids like fibers out of the sludge and press them to dry matter content of up to 30 percent and clean the sludge water for recycling and discharge to nature. The clarification system can, in most cases, treat process and communal sludge continuously or daily basis directly from outlets of the wastewater to be treated to finish without equalization and precipitation. The objective is to recycle the process and wastewater, and to collect different ingredients for reuse as much as possible, and to prevent microbe growth. The new system saves in energy and space as well as in operational costs by roughly 50 percent compared to present advanced systems. The capital costs are estimated to be lower too. The new treatment or part of it has been applied for purification of various water matrices from city and industrial wastewaters to natural lake waters.

Keywords: water treatment, water purification, flotation, particle removal, recycling, separation, clarification, integrated clarification, pharmaceutic residues removal, radon removal

1. Introduction

A new industrial process and communal wastewater clarification system VoxSton developed by SansOx Ltd. and Rannan Teollisuuskone Oy in Finland is presented in this chapter. The system consists of two centrifugal separators, a screw separator and two vortex flow flotation units. It can separate the solids like fibers out of the sludge and press them to dry matter content of 30 percent, and clean the sludge water for recycling and discharge to nature.

The first test runs have been conducted process phase by phase with real pulp and paper process sludge successfully. The treatment or part of it has been applied for purification of various water matrices from city and industrial wastewaters to refreshing of natural lake waters. The special feature of the system is that the industrial and communal sludge can be treated in most cases continuously or daily basis directly from the liquid outlet to finish without equalization and precipitation in terms of hours instead of days and weeks. Separation and recycling potential is presented in **Figure 1**. The water treatment technology discussed here is able to fulfill the most separation demands presented in the figure. Removal of the separated ingredients

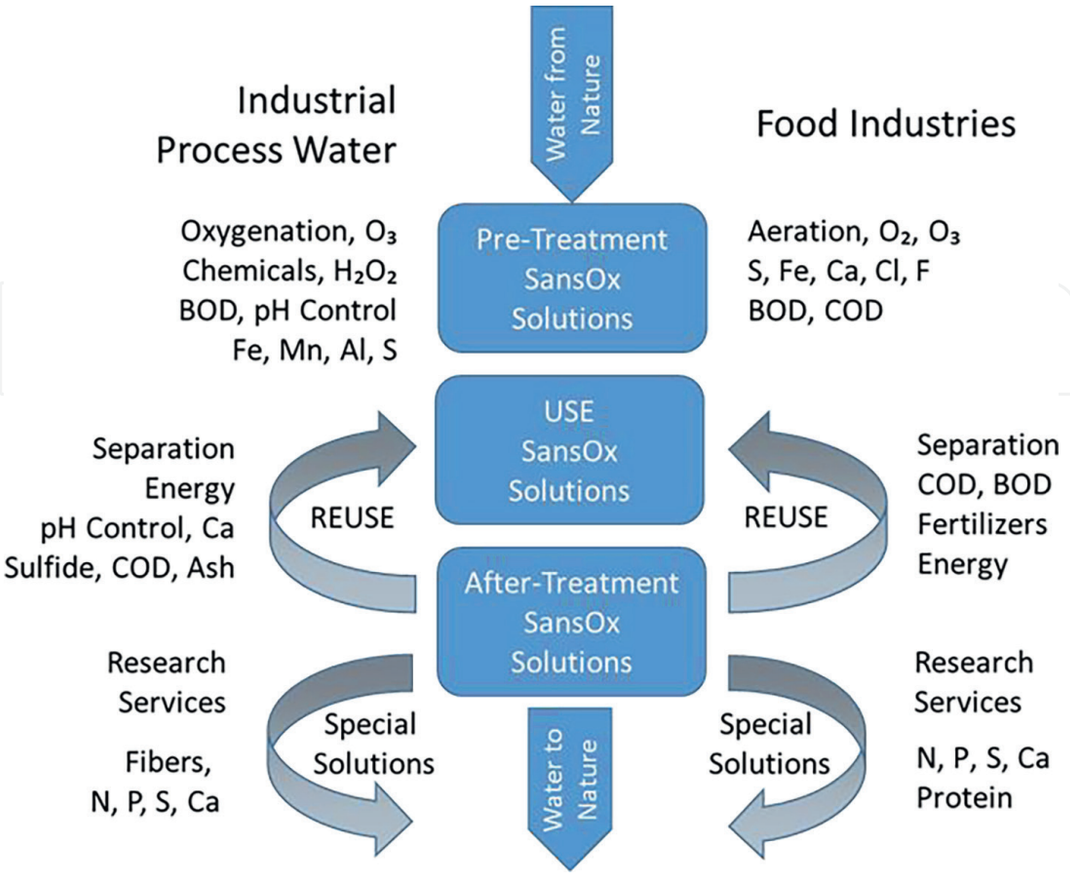

Figure 1.
Industrial recycling economy.

for recycling might need dedicated filtering. The most challenging separation and removal cases have been dealt with radon gas, pharmaceutic residues and disinfection of a hospital wastewater.

The new system saves in energy and chemicals, and in space as well as in operational costs roughly 50 percent compared to present advanced systems. The treatment process is integrated and fast. Use of chemicals has been reduced significantly due to molecular activation and efficient mixing in hermetic tube condition. For example CO_2 consumption was reduced to 1/5 by OxTube in a Ca removal case. The capital costs are estimated to be lower too. The main benefits of the new treatment system are presented in **Table 1**.

2. Flotation theory in brief

Solids removal of the new process water treatment system VoxSton is based on centrifugal and screw separation. Separation and removal of soluble ingredients are based on OxTube separation, molecular activation, and flotation in tube and cell condition. Flotation bubbles are generated by OxTube in VoxFlot water intake and fed them to bottom of the cell. The design principles of the VoxFlot are based on the flotation theory that is preferred here in brief [1–3]. The OxTube treatment and VoxFlot flotation are described in Chapter 3.

P&P Process Water of 5000 m^3/d			**Cost Estimation 2016**	
Item	**Conventional Process**		**Novel VoxSton Process**	
Investment	2.9 to 4.3 M€	580 to 860 €/m^3	2.5 to 3.4 M€	500 to 680 €/m^3
Operation Costs	1050 €/d	0.21 €/m^J	680 €/d	0.14 €/m^3
Maintenance Costs	340 €/d	0.07 €/m^3	170 €/d	0.04 €/m^3
Less Energy Cons.	7000 kWh/d	1.4 kWh/m^3d	3600 kWh/d	0.72 kWh/m^3d
Space	3850 m^2		1400 m^2	
Less CO_2 + removal	High energy consumption		Low energy consumption	
Odor Control	Difficult		In control by Efficient Oxygenation	
COD and BOD	Slow, high energy consumption		Fast and low energy consumption	
Disinfection	Chlorine and UV used		Ozone with air into OxTube	
Microbe Growth	Difficult to eliminate		Easy to eliminate with aeration	
Chemicals Removal	Difficult		Possible, verified with drugs residues	

Table 1.
Conclusions on the comparison of the novel VoxSton and present industrial process water treatment systems of the same capacity.

The mechanisms for the bubble-particle attachment are very complex and consists of three steps; collision, attachment (adsorption) and detachment (desorption). The collision is achieved by particles being within the collision tube of a bubble and this is affected by the velocity and radius of the bubble. The collision tube corresponds to the region in which a particle will collide with the bubble.

The attachment of the particle to the bubble is controlled by the induction time of the particle and bubble. The particle and bubble need to bind and this occurs if the time in which the particle and bubble are in contact with each other is larger than the required induction time. This induction time is affected by

- the fluid viscosity,
- particle and bubble size, and
- the forces between the particle and bubbles.

The detachment of a particle and bubble occurs when the force exerted by the surface tension is exceeded by shear and gravitational forces. These forces are complex and vary within the cell. High shear will be experienced close to the impeller of a mechanical flotation cell and mostly gravitational force in the collection and cleaning zone of a flotation column.

The attachment of the bubbles to the surface is determined by the interfacial energies between the solid, liquid, and gas phases. This is determined by the Young-Duprè equation [1]

$$'\Upsilon_{lv}\cos\theta = \left('\Upsilon_{sv} - '\Upsilon_{sl}\right) \tag{1}$$

where:

- Υ_{lv} is the surface energy of the liquid/gas vapor interface,
- Υ_{sv} is the surface energy of the solid/gas vapor interface,
- Υ_{sl} is the surface energy of the solid/liquid interface,
- θ is the contact angle, the angle formed at the junction between gas, solid, and liquid phases.

A common quantity used to describe the collection efficiency of a flotation process is *flotation recovery R*. This quantity incorporates the probabilities of collision and attachment of particles to gas flotation bubbles [2, 3].

$$R = \frac{N_c}{\left(\frac{\pi}{4}\right)\left(d_p + d_b\right)^2 H_C} \tag{2}$$

where:

- $N_c = PN_c^i$ is the probability of the particle being collected, where P is probability coefficient and N_c^i the number of possible particle collisions
- d_p is particle diameter
- d_b is bubble diameter
- H is a specified height within the flotation at which the recovery was calculated
- c is the particle concentration

3. Description of VoxSton

The concept of the new industrial and communal sludge and water treatment called VoxSton consists of the following phases and devices:

1. SaoxFuge centrifugal separator with a screen shelter flange for enhancement of solids content from 0.5 to 5 percent in concentrate fed to the screw separator.
2. Milston screw separator for solids separation of dry matter content up to 30 percent.
3. VoxFlot vortex flotation process for floggulation, flocs separation and cleaning of the water coming from SaoxFuge and Milston separation. The flotation foam can be fed to the screw separator or to a drying area.

4. Final phase might be filtering, e.g., sand filtering. OxTube Treatment is identified by measures to enhance filtering, e.g., iron and manganese removal, efficiency. Reaction gases can be removed by VoxFlot Flotation or by a separate gas remover.

The entire concept is presented in **Figure 2**. The devices can be installed according to an integrated treatment process principles. Number of pools, tanks and pumps can be reduced, and energy and chemicals saved. Microbe growth, smell and uncertain phenomena can be eliminated by speeding up the process lead time. Of course, the process quality and recycling will improve significantly.

Present processes can be improved by the pretreatment and the secondary treatment that could be similar to the concept in **Figure 2**. These kinds of retrofits have been completed in present wastewater treatment and water intake facilities even without additional pumps and energy consumption. The secondary treatment from a sediment pool or from any other still water vessel requires normally an additional pump.

3.1 SaoxFuge centrifugal separator

Separation efficiency of SaoxFuge is based on centrifugal force and sediment effect that depends on the liquid viscosity and the specific gravity difference. The liquid flows a spiral path among the SaoxFuge pipe and a strong centrifugal force is created. The centrifugal acceleration depends on the flow speed and curve radius; it could be up to 1000 G. The liquid flow in the SaoxFuge can be pressurized up to 10 bar that makes the flow smoother, and reasonable high flow speed without turbulences is possible. The liquid flow turns to a spinning mode which is compensated by a counter vortex flow in SaoxFuge intake. The SaoxFuge Separator is presented in **Figure 3**.

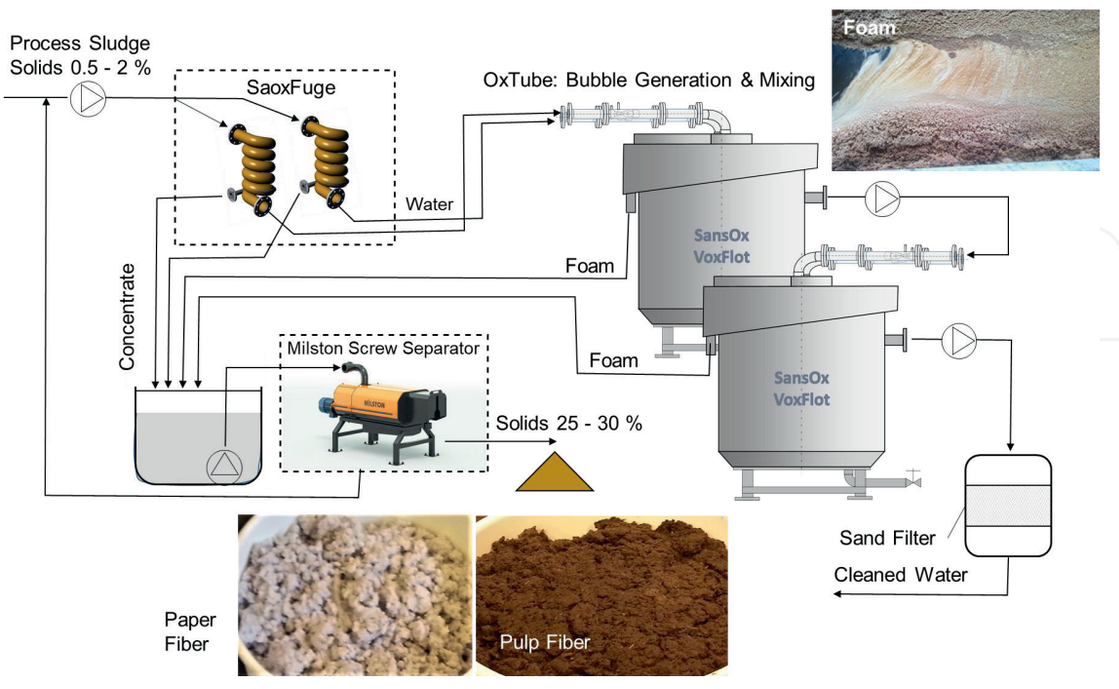

Figure 2.
Conceptual illustration of VoxSton process water treatment. In the most cases the process water can be treated from process outlet to finish continuously or daily basis without equalization and precipitation in terms of hours.

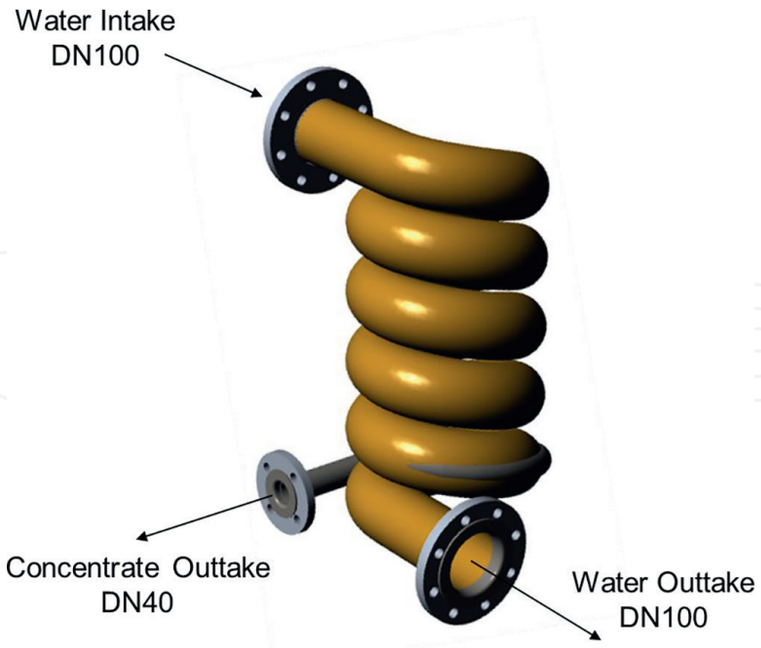

Figure 3.
SaoxFuge DN100 centrifugal separator is simple and reliable, no moving parts. Separation is a continuous and even process.

3.2 OxTube water treatment and bubble generation

A new hermetic water treatment called OxTube Integrated Clarification and some of its applications are presented briefly here. There are many ways and combinations to apply this new water treatment technology. In order to understand the OxTube phenomena from industrial water clarification point of view the basic principles and some related examples are presented in this context.

OxTube treats the water in hermetic flowing condition. It separates soluble ingredients from the water, splits molecular and ionic structures, activates molecules, and clarifies the water. These treatment functions happen within a second or less in its seamless process of the hermetic tube condition. OxTube sucks air in its nozzle zone, generates bubbles and mixes them evenly in the water to be treated. The other gases and chemicals can be mixed evenly with the water flow in the nozzle zone. The meeting or collision probability of the molecules, particles and bubbles is high. Desirable chemical reactions follow immediately and they are well controlled in the hermetic condition. Compressed air can be fed into the nozzle or after, if more bubbles are needed.

The principle of OxTube water treatment is presented in **Figure 4** with a functional prototype visually. The entire clarification process is very well controlled due to its hermetic procedure. Its foam generation efficiency in flotation is illustrated in **Figure 5** in raw water intake from a lake to industrial processes. **Figure 8** shows visible bubble generation, biomass split and flotation in a lake refreshing which is similar to purification of industrial waters. Measured aeration and oxygenation efficiency is presented in **Figure 6**.

OxTube efficiency on separation of soluble ingredients, molecular activation and clarification is shown visibly with Swiss Alpen tap water in **Figure 7**. Separation and activation can be illustrated by OxTube treatment without air suction, and the integrated clarification within a second with air suction left and right, respectively.

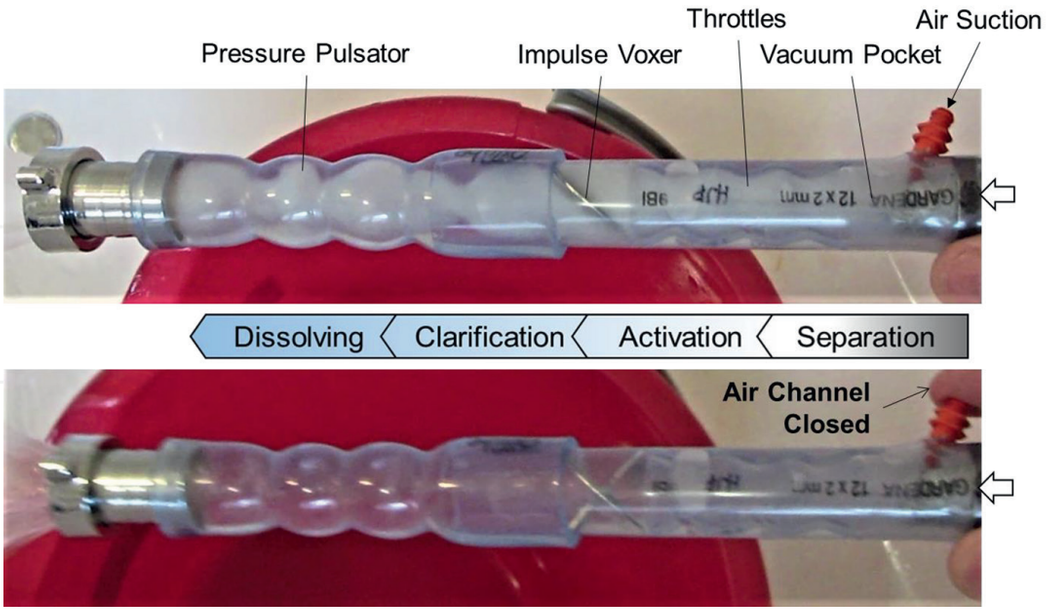

Figure 4.
OxTube water treatment process illustrated visually with air suction. The seamless process of separation with bubbles, activation, and clarification is performed within a second. The water is all the way an even mixture of small air bubbles, water and separated substances with air suction (upper picture). Collision probability of molecules, particles and bubbles is extreme high.

Figure 5.
Result of the efficient reaction of OxTube aerated lake water and related foam generation on the surface without additional flotation bubbles.

The water temperature and pressure are kept exactly the same in this trial. Turbidity of 0.0 NTU has been achieved in clarifications.

OxTube water treatment technology has been applied successfully in removal of pharmaceutics, radon gas, calcium, manganese and iron from various water matrices, and disinfection with ozone of a hospital wastewater. More than 40 different pharmaceutical residues in total over 24 μg/l were removed 90 percent by OxTube Integrated

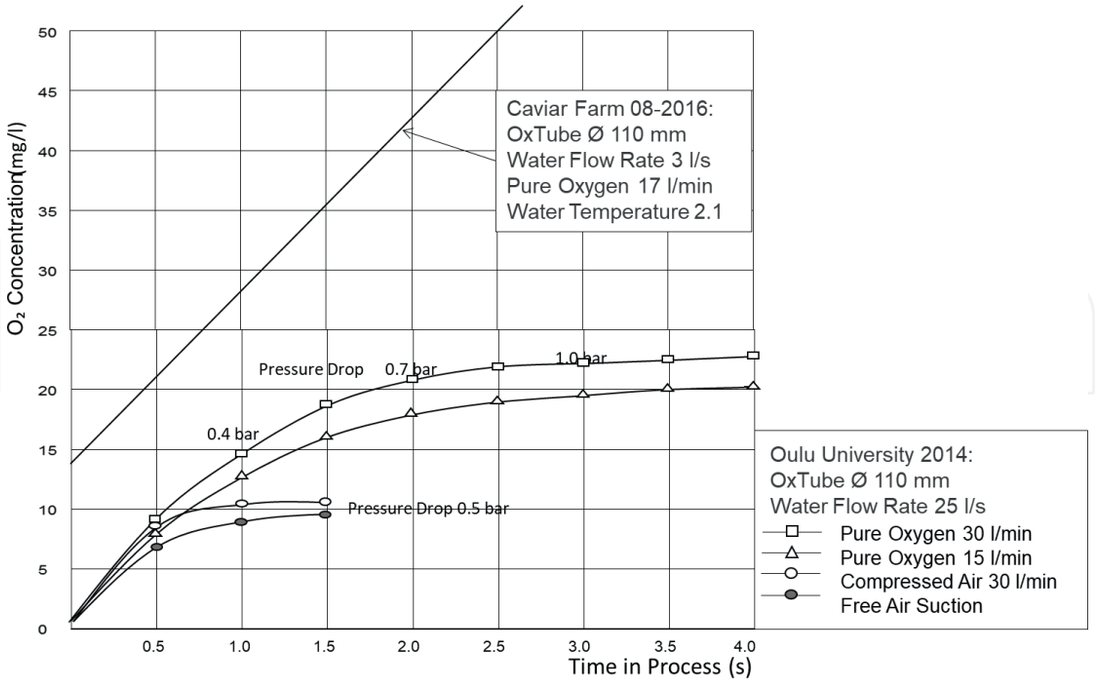

Figure 6.
Gas dissolving performance of the OxTube DN100. O_2 concentration of 100% was reached continuously within a second/Oulu university [4]. The highest O_2 concentration achieved continuously in an OxTube DN100 installation 2016 is 55 mgO_2/l at 2.1°C.

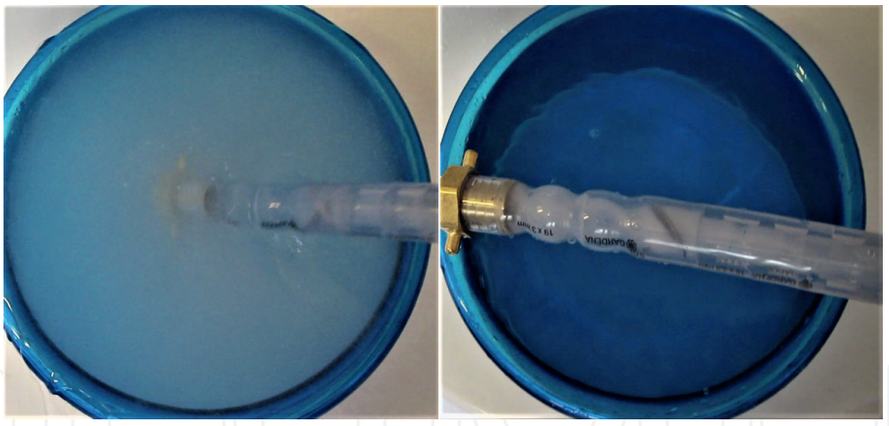

Figure 7.
Efficiency of OxTube water treatment with air; left Swiss Alpen tap water after the soluble ingredients separation and molecular activation, right the integrated clarification at the same condition. The separation, activation, clarification and replacement dissolving are performed seamlessly within a second in OxTube.

Clarification within a second in one through run [5]. Radon removal from 57 to 8 Bq/L is achieved continuously in five installations of ground water intakes at Water Plants in The Philippines. Disinfection of a hospital wastewater with ozone is shown in **Table 2** [5, 6]. Viruses were reduced over 60 percent without any gas and chemicals feed. Microbe growth can be reduced or even eliminated by OxTube oxygenation with clean air. Further, microbes and particles can be removed by VoxFlot flotation.

OxTube can be installed in various positions in present treatment processes and facilities. Calcium removal was improved up to 100 percent and CO_2 consumption reduced to 1/5 just by installing one OxTube in the present industrial water treatment facility of a can manufacturer.

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Disinfection of Hospital Waste Water/THL Summary April 3, 2018												
Sample	***E.coli* PMY/ml**	**Log-red**	**Reduction %**	**MS2 PFU/ml**	**Log-red**	**Reduction %**	**T °C**	**EC µS/cm**	**pH**	**Turbity NTU**	**O_3 Res mg/l**	**O_2 mg/l**
Test Water	2			1			12,8	283	7,73	0,68	0,03	10,26
Inoculum	2,500,000			870,000								
0 mgO_3/l	1,700,000		32,00	340,000		60,92	12,4	285	7,88	0,46	0,02	11,65
1,43 mgO_3/l	<0,001 (MR.)	>9,23	99,99,999,994	<2 (MR.)	>5,27	>99,9995	13,2	285	7,81	0,31	0,10	>20
1,27 mgO_3/l	<0,001 (MR.)	>9,23	99,99,999,994	<2 (MR.)	>5,27	>99,9995	12,6	294	7,83	0,27	0,14	>20
1,11 mgO_3/l	<0,001 (MR.)	>9,23	99,99,999,994	<2 (MR.)	>5,27	>99,9995	12,9	288	7,73	0,44	0,10	>20
0,95 mgO_3/l	<0,001 (MR.)	>9,23	99,99,999,994	<2 (MR.)	>5,27	>99,9995	14,3	279	7,84	0,37	0,10	>20
0,79 mgO_3/l	<0,001 (MR.)	>9,23	99,99,999,994	<2 (MR.)	>5,27	>99,9995	14,0	289	7,85	0,44	0,08	>20
0,61 mgO_3/l	<0,001 (MR.)	>9,23	99,99,999,994	<2 (MR.)	>5,27	>99,9995	14,0	287	7,74	0,40	0,07	>20

Reduction of 100% of E. coli and MS2 achieved with O_3 feed within 0.7 second [5, 6].

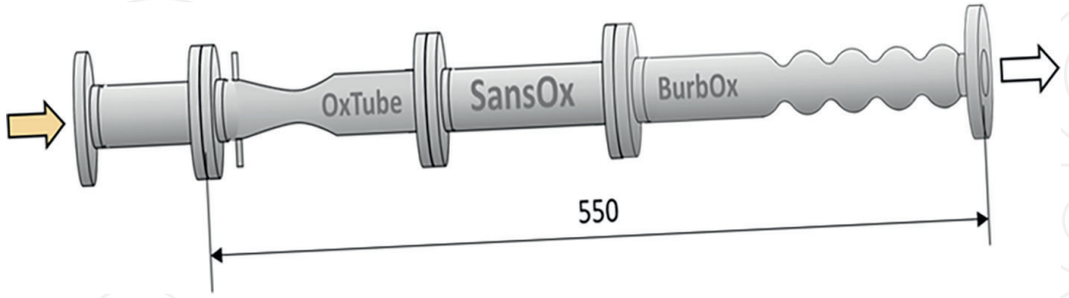

Table 2.
High molecule and microbe collision probability can be shown by the disinfection tests completed at Savonia University of Applied Sciences in Kuopio Finland.

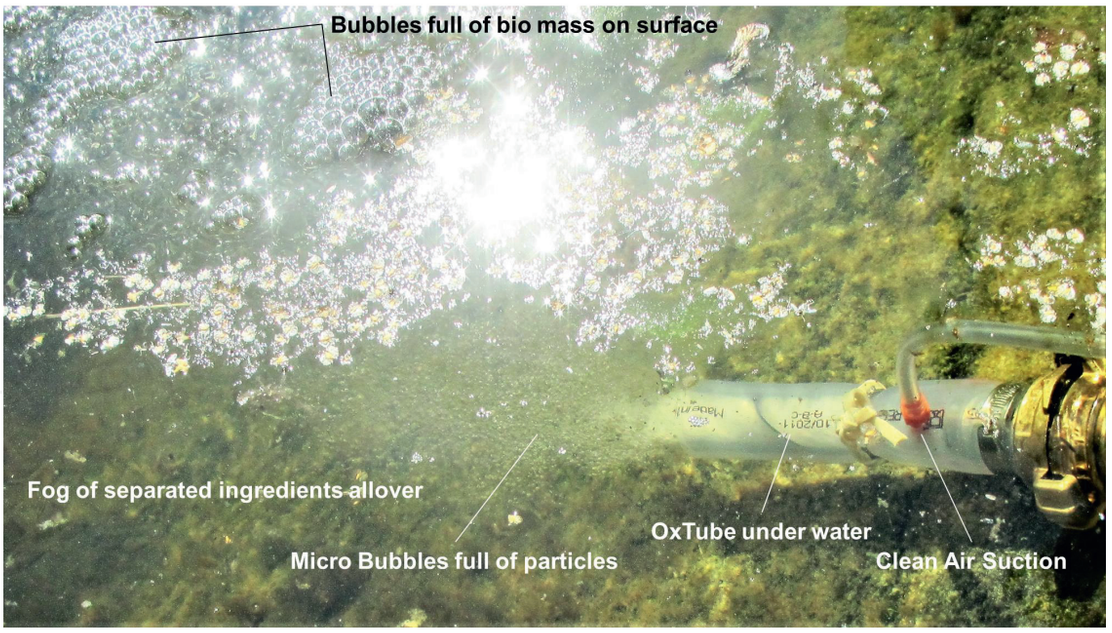

Figure 8.
Natural water refreshing by OxTube integrated water clarification visibly. OxTube separates soluble ingredients, activates molecules, and generates air bubbles for the high collision flotation in tube. Split bio mass attaches on bubbles, and mass floats are formed on the surface easy to scribe out. The turbid lake water turned clear within 5 days. Turbidity of 0.0 NTU has been achieved in some purification cases.

OxTube clarification and flotation capabilities have been applied in refreshing of natural waters and their ecosystem. OxTube creates in its tube condition an efficient flotation with high collision of bubbles and bio particles. Turbidity of 0.0 NTU has been achieved in some wastewater purification cases with retention of some hours after the OxTube treatment. There is a flotation effect in the tube flow after bubble generation. This OxTube Flotation is a new innovation and it can be named as Tube Flotation. The natural water clarification by OxTube is shown visibly in **Figure 8**.

3.3 Milston screw separator

Milston is a compact and efficient screw separator verified with various sludge and slurry separations. It is available as a fixed installation and mobile applications, manual or completely automated. Particularly, Milston products are robust and reliable, easy to maintain and keep clean by internal washing system. Milston Hero 1 and its test results of P&P sludge separation are presented in **Figure 9**. The water, after solids separation, can be fed into the water treatment process as presented in **Figure 2**.

Milston Screw Separator can be used in various positions of industrial as well as other sludge processing. Content of solids should be at least around 5 percent. The concentration enhancement can be performed by SaoxFuge centrifugal separator.

3.4 VoxFlot flotation

Vortex Flotation Separation developed by SansOx is a unique separation method in which the liquid flows with the particles continuously in a vortex path, the gas bubbles are formed in inlet of the liquid flow by OxTube, and in the vortex flotation flow before the flotation cell. The bubbles are evenly distributed in the flow. In the flotation cell bubbles spin and flow cross the vortex liquid flow in optimal angle, the particles in the vortex

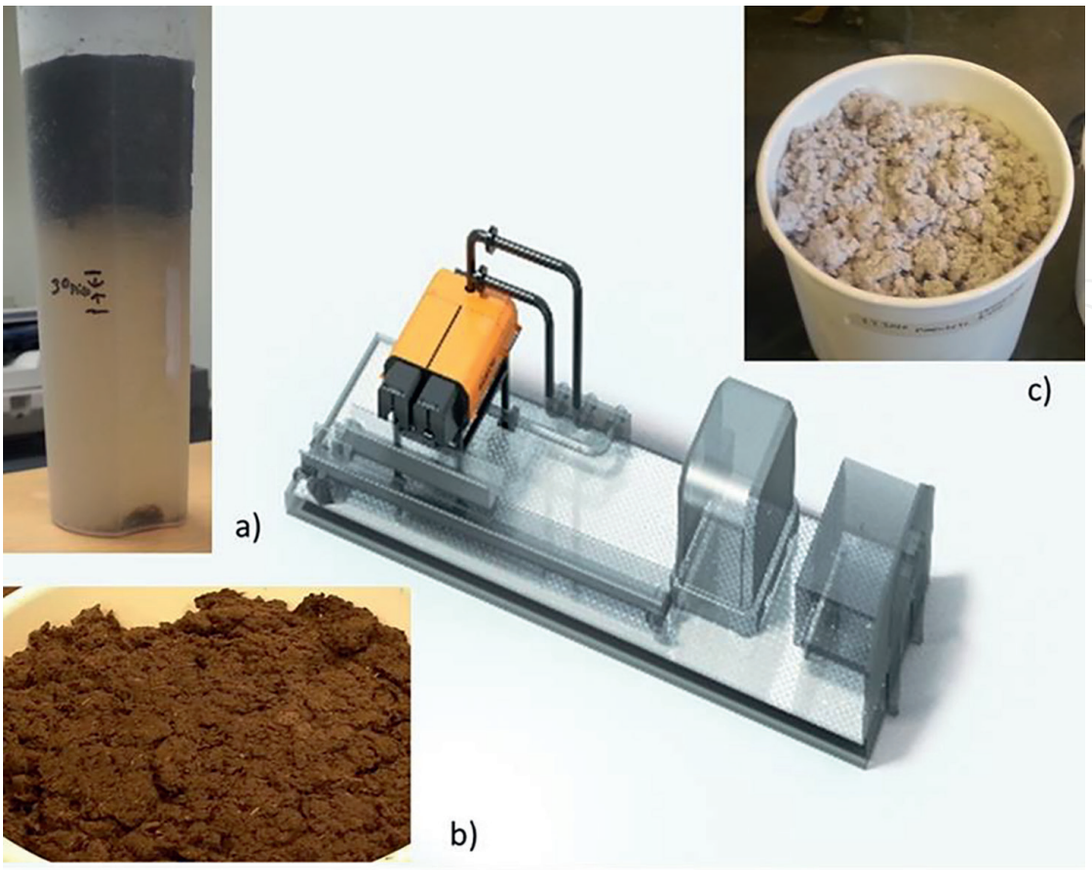

Figure 9.
Milston HERO 1 slurry separation capacity up to 75 m³/h; a) pulp sludge left above, b) separated pulp sludge left beneath, c) separated paper sludge right above.

flow stick gently on the spinning gas bubbles and are transferred to the cell surface. The Vortex Flotation Separation by SansOx is named as VoxFlot. The concept and principle of the VoxFlot are presented in **Figures 10–12**. The flotation cell is compact and small in size. The bubbles are generated evenly by OxTube into the water flow before entrance to the cell and they function all the way with high collision probability and attachment.

The liquid is treated before the vortex flotation phase in the VoxFlot cell by the OxTube of SansOx, **Figures 10** and **11**. The OxTube treatment consists of ingredients separation, molecular activation, bubble generation, chemicals feed and mixing. Aeration and additional compressed air feed if needed for additional air bubbles can be performed. The treatment is done continuously and fast in terms of seconds by the OxTube process that mixes chemicals, e.g., coagulants, dissolves gases, e.g., oxygen into the liquid, and generates lots of flocs and bubbles of air and reaction gases directly into the flowing liquid. Meeting or collision probability of bubbles and particles is high in the tube condition of OxTube. The treatment supports flotation theory referred briefly in Chapter 2 in all its aspects.

3.4.1 Superior performance of VoxFlot

The design principles of the VoxFlot are based on the flotation theory presented in Chapter 2, and experiences of the new and present systems, and particularly verified separation and dissolving performance of the OxTube. A special focus has been set on the collision probability, bubble generation, ingredients separation, molecular

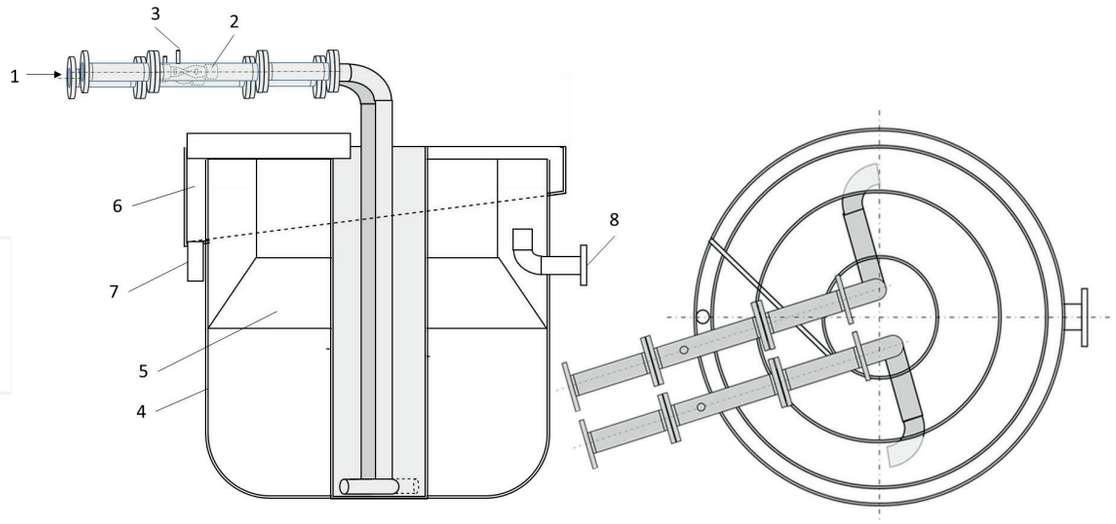

Figure 10.
VoxFlot flotation; 1. Liquid intake, 2. OxTube bubble generator and dissolver, 3. Air intake, 4. Flotation cell, 5. Bubble trap, 6. Foam collector, 7. Foam outtake, 8. Cleaned water outtake.

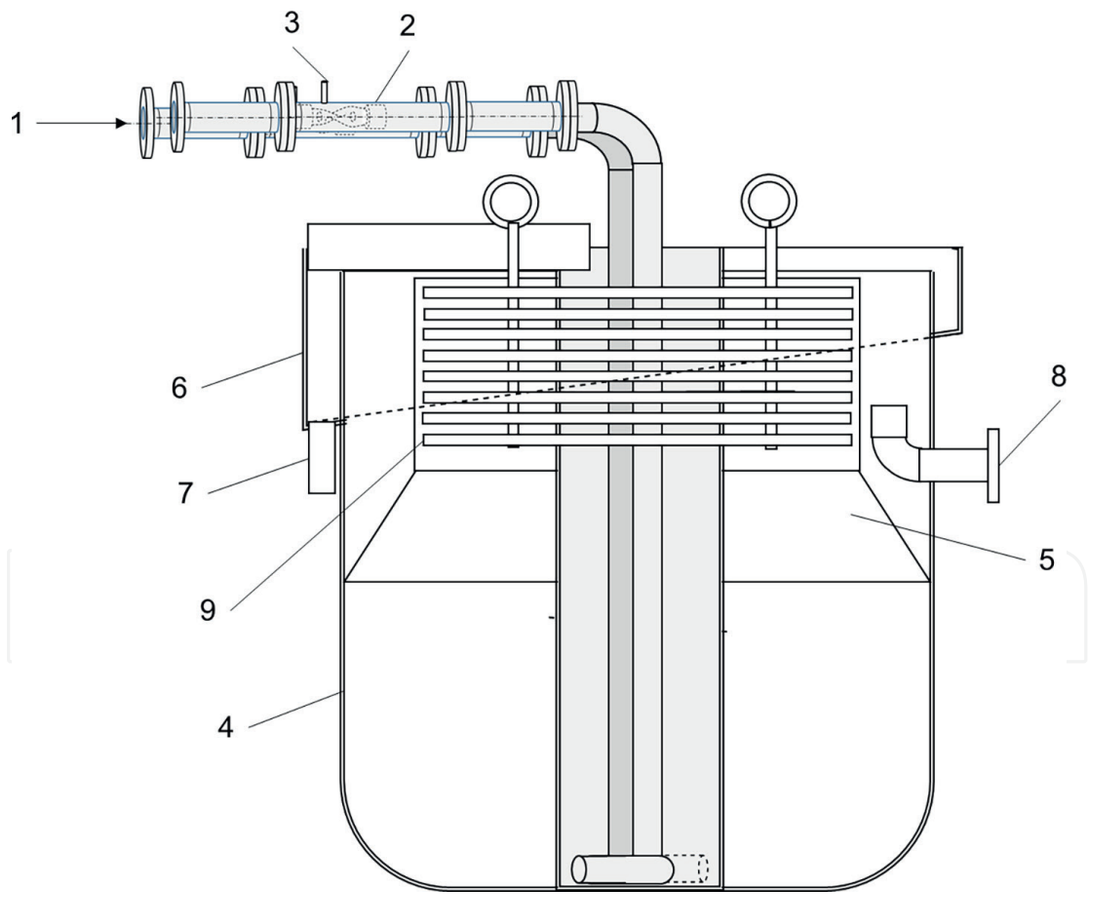

Figure 11.
VoxFlot flotation with lamella calcium removal; 1. Liquid intake, 2. OxTube bubble generator and dissolver, 3. Air intake, 4. Flotation cell, 5. Bubble trap, 6. Foam collector, 7. Foam outtake, 8. Cleaned water outtake, 9. Lamella.

activation and even mixture of bubbles and particles. The process is streamlined, all kinds of unnecessary delays have been eliminated. The superior performance of VoxFlot is based on the following features:

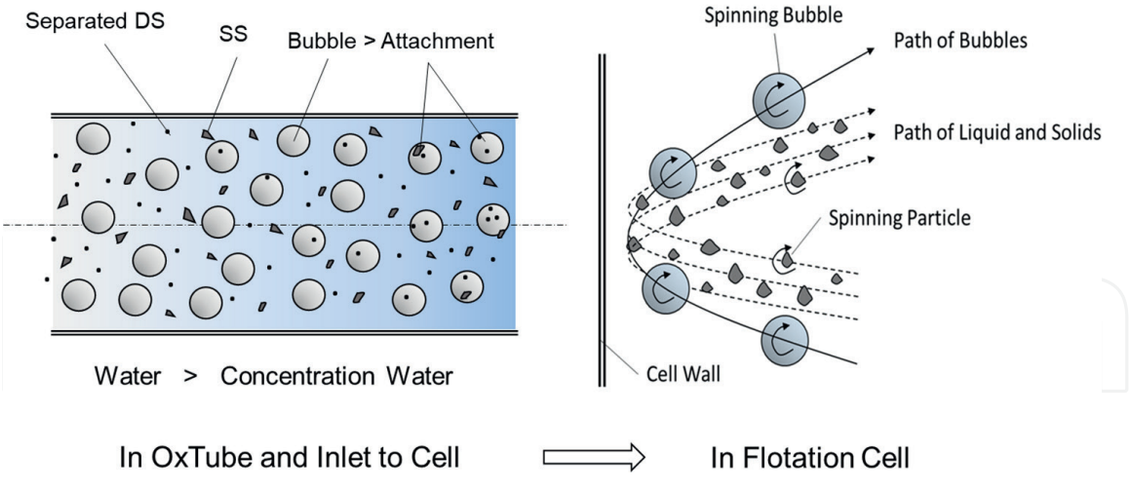

Figure 12.
OxTube generates bubbles and even mixture in the hermetic tube condition. Meeting probability of particles and bubbles is high. The vortex flow into the cell through the bubble trap causes a spinning effect of bubbles and solids that increases attachment.

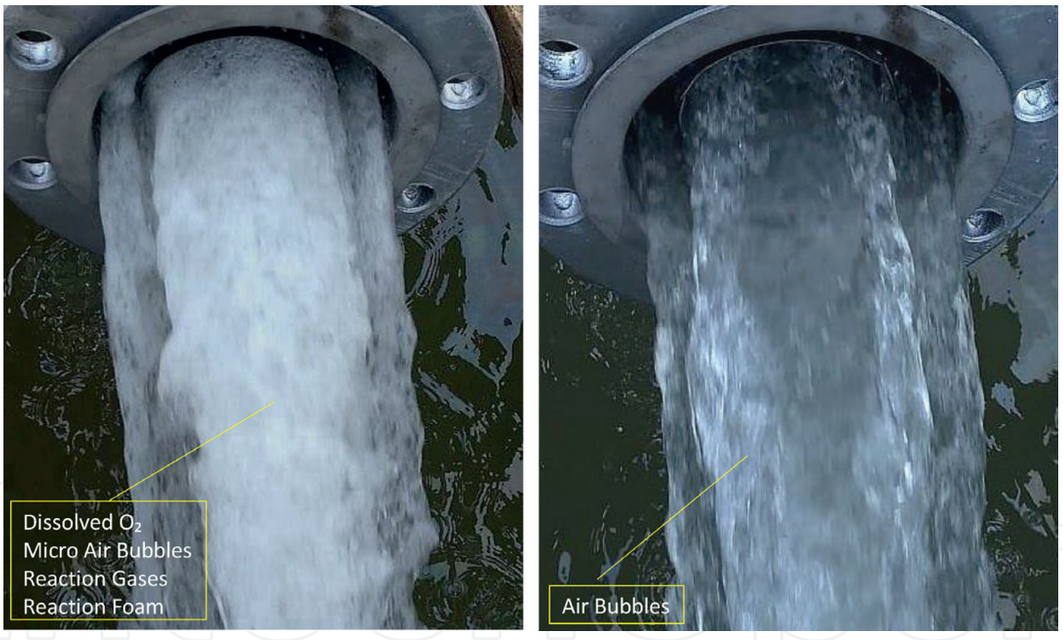

Figure 13.
Left OxTube aerated water flow and right non-OxTube aerated water flow. OxTube aeration creates high concentration of dissolved O_2, immediate reaction and huge amount of bubbles of 0.1 mm diameter in average. The surface tension and viscosity of the liquid is reduced significantly [7].

- Bubbles are generated in OxTube in the liquid flow evenly which enhances the meeting or collision probability of bubbles and particles, **Figures 4, 12**, and **13**.

- OxTube separates dissolved ingredients and activates molecules which increases performance, and decreases energy and chemicals consumption, **Figure 7**.

- Chemicals if needed can be fed in OxTube together with air or separately.

- The bubbles are evenly distributed, number of the bubbles is huge and their size is small and controllable, **Figures 8**, **12**, and **13**.
- There are mixture of air and reaction gas bubbles in the liquid flow that increases attachment performance; **Figures 4**, **8, 12**, and **13**.
- Additional compressed air can be fed into the liquid flow in order to generate larger bubbles.
- Surface energy of the solid/gas interface Υ_{sv} is increased by bubbles and the spinning effect caused by the vortex flow; the attachment of solid to gas is increased; Eq. (1) and **Figure 12**.
- Surface energy of the solid/liquid interface Υ_{sl} is reduced by gas dissolving; surface tension and viscosity of the liquid are lowered by 10 to 14 percent, and the attachment of solid to gas is increased; Eq. (1), test runs and **Figures 5–12**.
- The vortex flow turns bubbles and solids toward the main stream that reduces impact of shear and gravitational forces on the detachment; **Figure 12**.
- The collection efficiency of the flotation process (flotation recovery R) is increased by high collision probability N_c, small bubble size d_b, and high density of air and reaction gas bubbles; **Figures 12** and **13**, and Eq. (2).
- The vortex flow in the flotation cell generates the spinning effect of the bubbles and solids that increases the attachment and collision performance, **Figure 12**.

3.4.2 Main economic benefits of VoxFlot

VoxFlot flotation system has significant economic benefits compared to the present systems as follows:

- Bubble generation is performed in the main flow in OxTube just after the water intake; compressed air is reduced or not necessary which reduces energy consumption.
- The flotation cell size is reduced into a half or more due to the vortex flow and bubble trap which reduces capital costs and floor space, **Figures 10–12**.
- The vortex flow keeps the flotation cell clean for longer which reduces service costs.
- There are no rotational nor moving elements, e.g., impellers in mixing/dissolving.
- OxTube treatment and the vortex flow prevent growth of bacteria population (**Table 2**), BOD, fermentation and sediment retention on the bottom and wall.
- COD is reduced fast by the efficient aeration, reasonable high oxygen concentration, and by the continuous treatment process.
- Lamella for Ca removal can be integrated into VoxFlot Unit, as shown in **Figure 11**.
- The main economic benefits are summarized in **Table 1**.

4. Conclusions

Water itself is a clean element and present everywhere in the natural processes and ecosystems. It is heavily loaded in process and wastewaters as well as in the nature on earth and ecosystems. The water can purify itself or leave its load by evaporation powered by sun energy. Water circulation can be said as the largest transportation system globally.

The VoxSton system removes many ways the entire or partial load of various water matrices and treats the water for recycling and discharge to nature. It is an integrated water clarification system that separates soluble ingredients, activates molecules, generates flotation bubbles evenly in the water flow, presses solids for recycling and treats the water for recycling and discharging to nature.

The VoxSton industrial process and wastewater treatment system is efficient and it can in the most cases treat the liquid from the process to finish continuously or daily basis. It can be installed directly into the liquid flow without equalization and precipitation.

The VoxSton or its parts can be applied in purification of various water matrices. It has been applied in water intake, industrial processes, various wastewater purifications, fish farms, refreshing of natural waters and pretreatment at water plants. The most challenging cases have been removal of pharmaceutical residues from city wastewater and radon from intake of ground water at water plants, and disinfection of a hospital wastewater.

The new process water treatment system VoxSton is an integrated and fast. It saves in energy, chemicals and space as well as in operational costs roughly by 50 percent compared to present advanced systems. The capital costs are estimated to be lower too.

The main benefits of the VoxSton compared to present industrial water treatment systems are presented in **Table 1**.

Note

VoxSton concept for process waters of P&P Industries has been published first time in 2016 in China [8, 9]. The basic concept remains the same but its subsystems of OxTube and VoxFlot are developed further applicable for many other water matrices.

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