The ACTIDisk® process for water reclamation: an experimental performance assessment

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Abstract The ACTIDisk® process, as a combination of the Actiflo® and the Hydrotech Discfilter processes, was experimentally tested to determine its ability to reliably produce effluents with low levels of total suspended solids (< 5 mg/l) and turbidity (< 2 NTU). Studies were conducted in two demonstration plants and one full-scale water reclamation plant. The ACTIDisk® process can achieve an effluent total suspended solids limit of 5 mg/l with a reliability ranging from 83% to higher than 90%; similarly, it can achieve a turbidity limit lower than 2 NTU with a reliability ranging from 81% to more than 90%, as a function of actual operating conditions. An ACTIDisk® process treating a water with total suspended solids lower than 35 mg/l can produce an effluent with total suspended solids ranging from 3.2 to 3.7 mg/l. The ACTIDisk® process removes 91% (90th percentile) of particles larger than 1 µm, 87% (90th percentile) of particles larger than 2 µm, and 98% (90th percentile) of particles larger than 10 µm. Experimental results confirm that the ACTIDisk® process can reliably produce an effluent in conformity to total suspended solids (10 mg/l) and turbidity limits (2 NTU) of proposed Spanish water quality criteria for reclaimed water.
Keywords Water reclamation; ballasted sedimentation; microscreen filtration; particles removal

INTRODUCTION

Recent drought episodes and increasing water demands for agricultural and landscape irrigation in Spain, particularly in coastal Mediterranean areas, have resulted in an unprecedented search for new water sources, with higher reliability than those currently available (Iglesias, 2005). Furthermore, the steady progress of sanitation programs throughout coastal areas has resulted in larger flows of high quality wastewater treated effluents, which are normally discharged through submarine outfalls to protect beaches and coastal areas. The priority has been raised to develop new treatment methods and technologies for water reclamation and reuse that can turn those treated effluents into water flows suitable for different beneficial uses, either as a substitute for surface waters currently used, or as water sources to satisfy new water demands (Mujeriego and Asano, 1999).

Spain has no national quality standards for water reclamation and reuse. However, some Regional governments have been applying preliminary quality guidelines, mostly based on the recommendations proposed by the World Heath Organization (1989). A set of quality standards for water reclamation and reuse has been recently proposed by the Spanish Ministry of the Environment, which is expected to be approved during 2007. Aside from the absolute limits required for helminth eggs and E. coli concentrations, as well as for residual turbidity and disinfectant levels, the proposed regulation emphasizes the need for high reliability of reclaimed water quality. The ACTIDisk® process has been proposed by VEOLIA as a practical innovative means to achieve a highly reliable removal of suspended solids and turbidity, before the final disinfection step (Sanz *et al*., 2007). The ACTIDisk® process combines the Actiflo® process (Haarbo *et al.*, 1998; Plum *et al.*, 1998; Jiménez *et al.*, 1999) with the Hydrotech Discfilter microscreening process (Bourgeous *et al.*, 2003; Persson *et al.*, 2006; Asano *et al*., 2007). Two demonstration projects have been conducted using the ACTIDisk® process to reclaim secondary effluents.

OBJECTIVES

The main objectives of the two ACTIDisk® demonstration projects were: 1) to evaluate the ability of the process to achieve a suspended solids concentration lower than 10 mg/l and a turbidity lower than 2 NTU, in accordance to the quality requirements of the proposed Spanish regulations for unrestricted irrigation with reclaimed water, 2) to determine the reliability level of the ACTIDisk® process when reclaiming a secondary effluent, and 3) to evaluate the use of particle size distribution as a process performance indicator for water to be subsequently disinfected.

METHODS

Demonstration studies

An ACTIDisk® demonstration study was conducted at the WWTP of El Prat de Llobregat, Barcelona, Spain during May and June 2004. The main objective of the experimental study was to determine the ability of the system to achieve low levels of suspended solids and turbidity. The two individual processes (Actiflo® and Discfilter) were first tested independently to assess their specific efficiency, and then their combined operation was evaluated. A second ACTIDisk® demonstration study was conducted at the WWTP of Castellón de la Plana, Spain, during May of 2005. Four test series were conducted using different operating conditions, with particular interest in reclamation of influents with a high load of suspended solids and with different particle size distributions. The ACTIDisk® process was selected as the water reclamation process at the El Prat de Llobregat water reclamation plant (300,000 m^3/day), followed by UV light disinfection. Results obtained after the start-up phase of El Prat water reclamation plant were used to confirm the performance efficiency of the ACTIDisk® process under full scale and conventional operating conditions. The quality parameters used were suspended solids, turbidity, COD, BOD and total phosphorous.

Demonstration plants

Two mobile plants were used to evaluate the treatment performance of the ACTIDisk® process. A mobile Actiflo® plant was built in a 40 feet container with a maximum capacity of 80-120 m^3/h, and a mobile Hydrotech Discfilter with a maximum capacity of 50-70 m^3/h. The Actiflo® had a lamella water surface of 1 m^2, and the lamellar overflow velocities ranged from 80 to 120 m/h. The Hydrotech Discfilter had a total effective surface area of 5.6 m^2, and was operated at 60% submergence. Figure 1 shows the two mobile plants of the ACTIDisk® process.

Figure 1. Overall view of the ACTIDisk® demonstration plant at Castellón WWTP.

Reagents added for operating the ACTIDisk® were coagulant, microsand, and polymer. The coagulant used was polyaluminium chloride (17.0±0.5 expressed as Al_2O_3). Coagulant dose was calculated according to previous trials; standard dose was fixed at 7.8 mg Al/l, with a maximum dose of 17.8 mg Al/l, and a minimum dose of 4.6 mg Al/l. The largest dose was only used during episodes of poor quality of secondary effluent. The microsand had an effective size of 130 µm and a uniformity coefficient of 1.5, and was 98% pure silica (SiO_2). Anionic polymer Hydrex 6161 doses were set in accordance to previous trials: normal dose was set at 0.6 mg/l, with a maximum value of 1 mg/l. This polymer it is made of a high molecular weight polyacrilamide.

To simulate episodic increases of total suspended solids, water with high total suspended solids concentration was extracted from a secondary clarifier of the nearby activated sludge plant and pumped to the head of the demonstration ACTIDisk® plant. Algae and biofilms were detected during the cleansing of secondary clarifiers channels. This simulation strategy was integrated into the demonstration study as to provide episodic high loads of total suspended solids in the influent.

Water samples were collected at the two individual ACTIDisk® steps (Actiflo® and Discfilter). Water analyses at El Prat de Llobregat demonstration plant (May and June 2004) included turbidity, total suspended solids, total phosphorous, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), particle size distribution and total coliforms. Water analyses at Castellón demonstration plant (May 2005) included total suspended solids, turbidity, particle size distribution, dissolved organic carbon (DOC), and water transmittance at 254 nm.

Full scale plant

The water reclamation plant of El Prat de Llobregat is based on the ACTIDisk® process and includes a 3-line Actiflo® process, with a maximum treatment capacity of 4,800 m^3/h and an overflow velocity of 120 m/h. After lamellar settling, water flows through 10 Hydrotech Discfilter microscreens with a mesh size of 10 µm. Each Discfilter has a treatment capacity of 1,440 m^3/h. The treatment capacity of El Prat de Llobregat water reclamation plant is 300,000 m^3/day. The Actiflo® process uses polyaluminium chloride, an anionic polymer, and 130-150 µm effective size microsand for coagulation, enhanced-flocculation and lamellar clarification. Operation of the start-up phase of the water reclamation plant was provided by the FCC-SPA-Aqualia consortium. Water analyses during that phase (August to November 2006) included turbidity, total suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5) and total phosphorous.

RESULTS AND DISCUSSION

El Prat de Llobregat demonstration plant

Table 1 summarizes the removal performance of the ACTIDisk® process based on turbidity, total suspended solids, total phosphorous, COD, BOD_5 and total coliforms. The results indicate that the ACTIDisk® process was able to reliably achieve a low turbidity (< 2 NTU) and a low suspended solids concentration (< 5 mg/l). The effluent turbidity and suspended solids concentrations were very close to those originally established. The Discfilter microscreening process is able to achieve the turbidity and suspended solids reduction required with a reliability higher than 90%.

Figures 2 and 3 show the particles removal performance of the ACTIDisk® process based on particle size probability distributions. The figures show that the ACTIDisk® process was able to effectively remove 83% (50^{th} percentile) and 91% (90^{th} percentile) of particles with a diameter larger than 1 µm, and 94% (50^{th} percentile) and 96% (90^{th} percentile) of particles with a diameter larger than 10 µm. Particles with diameter larger than 1 µm are mainly removed by the Actiflo® process with an efficiency of 82% (50^{th} percentile) and 90% (90^{th} percentile); the Discfilter microscreen process does not significantly affect the number of particles larger than 1 µm (see

Figure 2). Removal of particles with diameter higher than 10 µm takes place on both processes: a partial reduction is effected by the Actiflo® process 78% (50th percentile) and 86% (90th percentile), and then a subsequent significant reduction is achieved by the Discfilter process (see Figure 3).

Table 1. Summary of ACTIDisk® removal performance at the El Prat de Llobregat demonstration plant (May-June 2004). Ranges indicate minimum and maximum values.

Quality parameter	ACTIDisk® inlet	Actiflo® outlet	ACTIDisk® outlet	Reduction, %
Turbidity, NTU	12.0 – 43.6	1.2 – 2.1	0.8 – 1.7	92 - 97
TSS, mg/l	15 - 56	2.9 – 5.1	<2 – 3.7	81 - 94
Total P, mg P/l	0.94 – 3.32	0.12 – 0.25	0.11 – 0.31	74 - 94
COD, mg O_2/l	57.6 – 112.3	<30 – 54.9	<30 – 52.0	36 - 67
BOD_5, mg O_2/l	9.0 – 10.0	<3.0 – 4.0	<3.0 – 4.0	56 - 80
Total coliforms, CFU/100 ml	2.3E+03 – 6.0E+06	3.2E+04 – 3.0E05	7.0E+03 – 3.0E+05	39 - 99

Castellón demonstration plant

Figure 4 and 5 shows total suspended solids and turbidity removal performance of the ACTIDisk® process based on probability distributions. Influent total suspended solids to ACTIDisk® ranged from 21 mg/l for the 50th percentile and 83 mg/l for the 90th percentile, while those for turbidity ranged from 8.2 NTU for the 50th percentile and 39 NTU for the 90th percentile. The probability distributions obtained indicate that ACTIDisk® can provide an effluent turbidity lower than 2 NTU in 87% of the samples and a total suspended solids concentration lower than 5 mg/L in 92% of the samples. The Actiflo® process can provide a turbidity lower than 2 NTU in 68% of the samples and a total suspended solids lower than 5 mg/l in 47% of the samples, provided that total suspended solids at the ACTIDisk® inlet are lower than 35 mg/L in 68% of the samples. The Discfilter process is very effective in reducing turbidity and total suspended solids, and more particularly in removing suspended solids. According to those probability distributions, an ACTIDisk® process receiving a suspended solids concentration of 35 mg/l in 68% of the samples would produce an Actiflo® effluent with a TSS of 7.2 mg/l, and an ACTIDisk® effluent with a TSS de 3.2 mg/l. It may be noted that the limit of quantification for the total suspended solids analysis is 2 mg/l.

Particle size distribution analysis indicate that the ACTIDisk® process was able to effectively remove 90% (50th percentile) and 87% (90th percentile) of particles with a diameter larger than 2 µm (see Figure 6) and 98% (50th percentile) and 99% (90th percentile) of particles with a diameter larger than 10 µm (see Figure 7). Similarly as it was obtained in the El Prat de Llobregat demonstration plant, the reduction in the number of particles with a diameter higher than 2 µm takes mainly place in the Actiflo® process, with levels of 84% (50th percentile) and 90% (90th percentile), while the Discfilter has a insignificant contribution to the filtration process (see Figure 6). However, the reduction in the number of particles with diameter higher than 10 µm takes place partially in the Actiflo® process, with 92% (50th percentile) and 98% (90th percentile), followed by a minor contribution by the Discfilter process (see Figure 7). However, the Discfilter contribution in the removal of particles with a diameter larger than 10 µm is likely the reason for the higher reliability achieved in suspended solids removal, in contrast with that achieved in turbidity removal.

Table 2 summarizes the statistical variation of water transmittance at 254 nm after the coagulation and flocculation taking place in the Actiflo® process. The results show an improvement in water transmittance at 254 nm. Also, coagulation and flocculation partially remove dissolved organic carbon, by adsorption reactions onto the flocs generated (see Table 3). The Discfilter process does not significant improve the water transmittance at 254 nm achieved by Actiflo®, but it does contribute with a limited improvement in DOC removal.

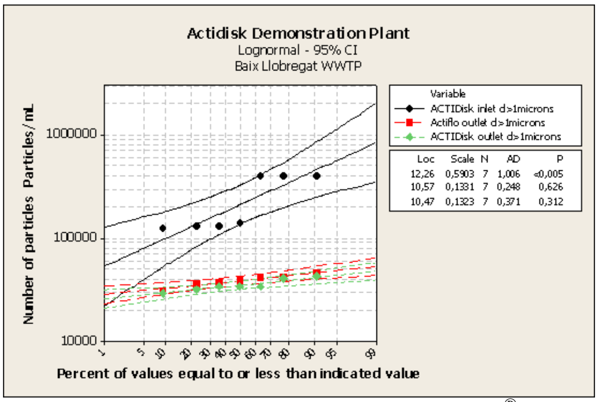

Figure 2. Probability distributions of ACTIDisk® removal performance for particles with diameter higher than 1 μm at El Prat de Llobregat demonstration plant.

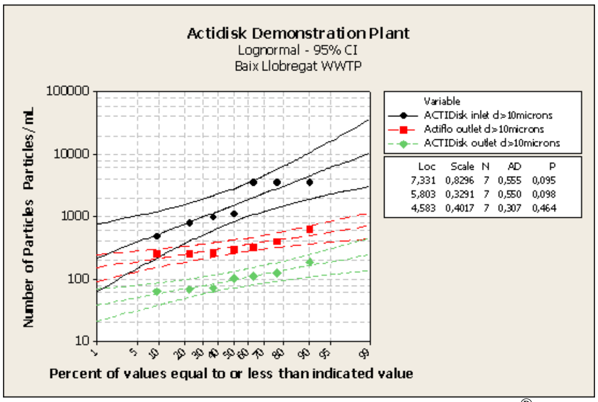

Figure 3. Probability distributions of ACTIDisk® removal performance for particles with diameter higher than 10 μm at El Prat de Llobregat demonstration plant.

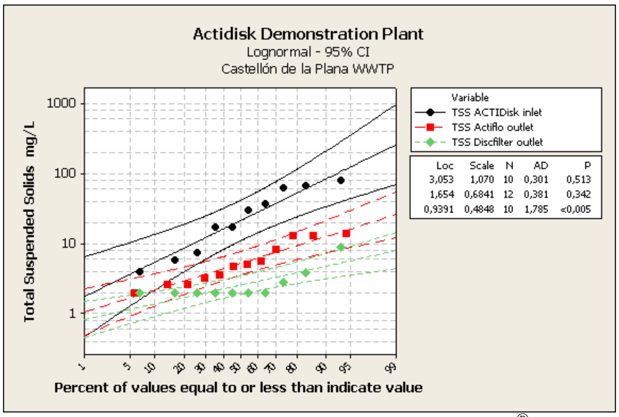

Figure 4. Probability distributions of ACTIDisk® removal performance for total suspended solids at Castellón demonstration plant.

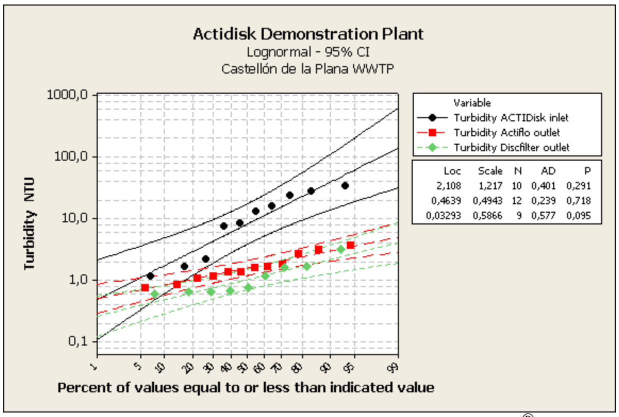

Figure 5. Probability distributions of ACTIDisk® removal performance for turbidity at Castellón demonstration plant.

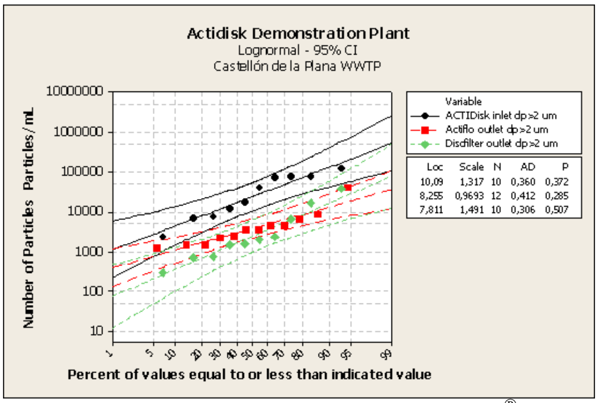

Figure 6. Probability distributions of ACTIDisk® removal performance for particles with diameter higher than 2 μm at Castellón demonstration plant.

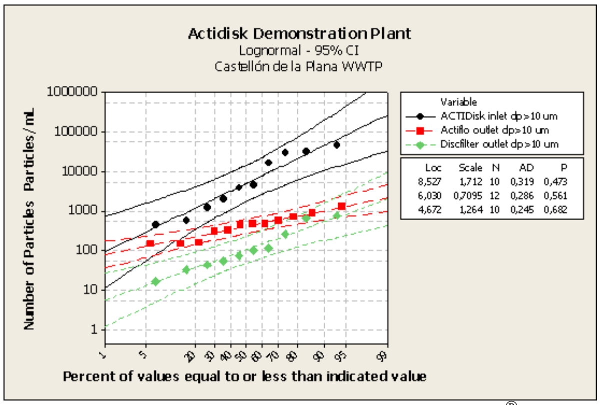

Figure 7. Probability distributions of ACTIDisk® removal performance for particles with diameter higher than 10 μm at Castellón demonstration plant..

Table 2. Changes of water transmittance (%) at 254 nm achieved by the ACTIDisk® process at the Castellón water reclamation plant (May 2005).

Values	ACTIDisk® inlet	Actiflo® outlet	ACTIDisk® outlet
Minimum	55.0	63.1	63.1
Maximum	67.6	74.1	74.1
10^{th} percentile	57.3	64.9	64.4
50^{th} percentile	66.1	69.2	70.8
90^{th} percentile	67.6	74.1	74.1

Table 3. Changes of dissolved organic carbon DOC achieved by the ACTIDisk® process at the Castellón water reclamation plant (May 2005).

Values	ACTIDisk® inlet	Actiflo® outlet	ACTIDisk® outlet
Minimum	11.0	8.6	8.6
Maximum	25.0	19.0	17.0
10^{th} percentile	11.0	8.7	8.6
50^{th} percentile	13.0	10.5	10.5
90^{th} percentile	25.0	19.0	16.5

Full scale plant: Baix Llobregat Water Reclamation Plant

Figures 8 and 9 show the total suspended solids and turbidity removal performance of the full scale ACTIDisk® process, under conventional operating conditions during start-up phase; a total of 41 samples were obtained. The probability distributions indicate that ACTIDisk® can provide an effluent with turbidity lower than 2 NTU in 81% of the samples and total suspended solids lower than 5 mg/l in 84% of the samples. The 90^{th} percentile values were 2.6 NTU and 5.5 mg/l. Total suspended solids at the influent of ACTIDisk® were 15.4 mg/l for the 50^{th} and 69 mg/l for the 90^{th} percentile. The influent turbidity to ACTIDisk® was 7.7 NTU for the 50^{th} percentile and 38 NTU for the 90^{th} percentile. According to the probability distributions, an influent to the ACTIDisk® with total suspended solids of 35 mg/l for a 76^{th} percentile would result in an effluent with 3.7 mg/l of total suspended solids.

Table 4 shows the removal performance of the ACTIDisk® process in terms of chemical oxygen demand COD, biochemical oxygen demand BOD_5, and total phosphorous. Removal performance at the 90^{th} percentile was 56% for COD, 86% for BOD_5, and 40% for total phosphorous.

Table 4. Removal performance of the ACTIDisk® at the El Prat de Llobregat water reclamation plant based on 41 samples (August November 2006).

Quality parameter	Range	ACTIDisk® inlet		Range	ACTIDisk® outlet	
		50^{th} percentile	90^{th} percentile		50^{th} percentile	90^{th} percentile
COD, mgO_2/l	29-193	52	125	10-81	36	55
BOD_5, mgO_2/l	1-37	7.0	25.5	1-4	2.0	3.5
Total P, mg P/l	1-7.5	3.0	4.7	0.1-1.7	0.6	1.4

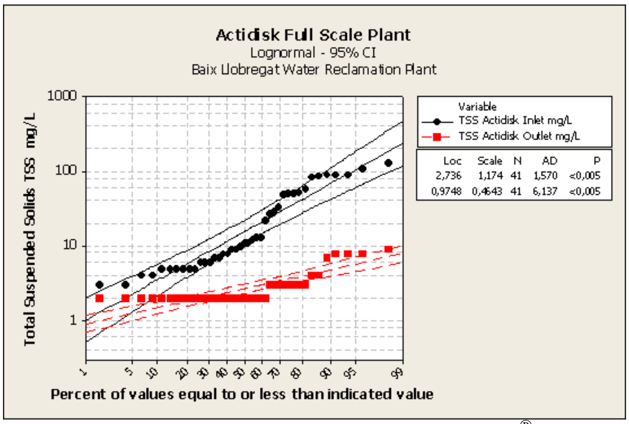

Figure 8. Probability distributions of ACTIDisk® removal performance for total suspended solids at full scale plant Baix Llobregat Water Reclamation Plant.

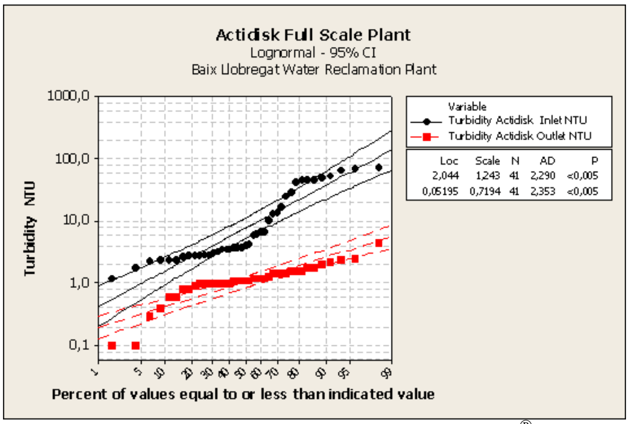

Figure 9. Probability distributions of ACTIDisk® removal performance for turbidity at full scale plant Baix Llobregat Water Reclamation Plant.

CONCLUSIONS

The ACTIDisk® process, as a combination of the Actiflo® and the Hydrotech Discfilter processes, has been experimentally tested to determine its ability to reliably produce effluents with low levels of total suspended solids (< 5 mg/l) and turbidity (< 2 NTU). Experimental results from two demonstration plant studies and one full scale plant follow-up study have been used to assess the ACTIDisk® removal performance using probability distributions.

The ACTIDisk® process can achieve an effluent total suspended solids limit of 5 mg/l with a reliability ranging from 83% to more than 90%, as a function of actual operating conditions. Similarly, it can achieve a turbidity limit lower than 2 NTU with a reliability ranging from 81% to more than 90%, as a function of actual operating conditions. It has been estimated that an ACTIDisk® process treating an influent water with total suspended solids concentration not higher than 35 mg/l can produce an effluent with a total suspended solids ranging from 3.2 to 3.7 mg/l.

The ACTIDisk® process is able to remove 91% (90th percentile) of particles with a diameter larger than 1 µm, 87% (90th percentile) of particles with a diameter larger than 2 µm, and 98% (90th percentile) of particles with diameter larger than 10 µm.

The higher removal efficiency and reliability for total suspended solids, as compared to that of turbidity, can be explained by the effective contribution of the Diskfilter process in removing particles with diameter higher than 10 µm (pore size of the microscreen cloth). As turbidity is highly dependent on smaller size particles, the efficiency and reliability of turbidity removal will have to be mostly assured by the Actiflo® process.

Finally, the experimental results obtained at the full scale water reclamation plant were in accordance with those previously obtained at the two demonstration plants and confirm that the ACTIDisk® process can reliably produce an effluent that conforms to the total suspended solids (10 mg/l) and turbidity limits (2 NTU) included in the proposed Spanish water quality criteria for reclaimed water.

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