RETENTION OF FINE PARTICLES IN COMBINED SEWER OVERFLOWS USING INTELLISCREEN TECHNOLOGY: EXPERIMENTAL RESULTS AND PRACTICAL IMPLICATIONS

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Introduction

Efficient wastewater treatment remains a central challenge in environmental engineering and sustainable water management. In many urban areas, combined sewer systems collect domestic, industrial, and stormwater in a single network. During heavy rainfall, hydraulic overloading often leads to combined sewer overflows (CSOs), releasing directly into receiving waters untreated or partially treated wastewater, when the wastewater treatment plant (WWTP) has systems for that such as screens or sedimentation pods. These discharges introduce suspended solids, organic compounds, nutrients, and micropollutants, which significantly impair water quality [1–3]. Filtrable solids (AFS63 0.45 µm – 63µm) pose a particular challenge here, as heavy metals and organic pollutants mainly accumulate on them.

Developing reliable and adaptable treatment methods for the dynamic conditions of the combined sewer system is essential, due to the rapid fluctuations in flow rate, pollutant concentration and particle composition during rainfall events. Although conventional mechanical treatment technologies, including coarse screens, sedimentation tanks, and sand filters, are effective for large and settleable particles, they are frequently inadequate for fine particles and micropollutants [4, 5]. Thus, there is a growing need for advanced pre-treatment systems at discharge points in sewer systems that maintain high separation efficiency (≥70–90% for particles <1 mm) under variable hydraulic (e.g., sudden increases in flow velocity and water level) and load conditions (e.g., variations in solid concentration, organic content, and particle size distribution).

Mechanical pre-treatment is a key stage in WWTPs, as it protects downstream biological and chemical processes from excessive solids and hydraulic overloads. The screening process is crucial for the prevention of clogging and operational disturbances by removing coarse and fine particles. In WWTPs, screens are usually vertically arranged at the plant inlet, whereas in combined sewer systems, horizontal step screens (HSR) are installed at overflow structures to retain solids before discharge into receiving waters. Conventional HSRs typically operate at a fixed cleaning speed, meaning that the raking mechanism moves at a constant rate and interval, regardless of the actual hydraulic and solids load. As a result, these systems cannot adapt to rapidly changing hydraulic or pollution conditions during storm events.

The IntelliScreen technology, developed by HST Systemtechnik GmbH, represents an innovative, smart variant of the HSR. Since it addresses the above limitations through adaptive control: instead of operating at a constant speed, IntelliScreen continuously adjusts its cleaning frequency and screen movement based on real-time measurements of water level, flow, and head loss. This works as follows: instead of fixed-speed operation, IntelliScreen continuously adjusts cleaning frequency and screen motion based on real-time measurements of water level, flow, and head loss. This enables the controlled formation of a filter cake, a thin layer of retained solids that enhances fine particle retention. This layer acts as a secondary fine filter, significantly improving the retention of small particles that would otherwise pass through. By controlling the filter cake's thickness and cleaning intervals, the system maintains hydraulic stability while achieving enhanced fine particle separation under dynamic inflow conditions.

Recent advances in automation and digital monitoring have enabled the implementation of such intelligent systems. Yet, little experimental evidence exists on their particle retention efficiency and impact on wastewater quality under real operational conditions.

This study aimed to fill that gap by comparing the performance of an IntelliScreen and a conventional HSR screen at the Hof WWTP (Germany). The evaluation focuses on particle retention, changes in COD and turbidity, and the hydraulic behavior associated with the filter cake formation. In particular, the flow rate reduction caused by the developing filter cake was monitored, as this effect is directly linked to the reduction of flow going through, which means also an improved pollutant retention. Overall, the results contribute to a better understanding and optimization of adaptive screening technologies for municipal wastewater treatment.

Materials and Methods

Experimental Setup

The experiments were conducted at the Hof wastewater treatment plant (WWTP) in Bavaria, Germany, a facility with a capacity of approx. 230.000 PE, using a specially designed container-based test facility installed upstream of the inlet channel. For comparative testing under the same hydraulic and wastewater conditions, the system includes both operation mode: conventional with constant cleaning speed and the innovative IntelliScreen unit, that varies the cleaning speed and formed a filter cake layer. A regulating valve system was integrated downstream to allow partial throttling of the outflow. By slightly restricting the discharge, the water level upstream of the screen increases, leading to a higher hydraulic head difference across the screen surface. This promotes the deposition and accumulation of suspended particles on the screen bars, thereby facilitating the controlled formation of the filter cake required for evaluating the IntelliScreen's adaptive performance.

Influent water was taken out of the channel and pumped through an inlet pipe with flow measurement, allowing adjustment of flow rate and water level. Sensors continuously measured flow (m^3/h), water level (m), turbidity (NTU), conductivity (µS/cm), pH, and nitrate concentration (mg/L).

Results

The gradual formation of a filter cake increased the head loss across the screen, which was automatically compensated by adaptive cleaning control. Once established, the filter cake enhanced fine particle retention but slightly reduced hydraulic capacity. As excessive build-up, turbulence at the screen surface increased, occasionally disturbing stable cake formation. These observations indicate that maintaining an optimal hydraulic balance is essential for efficient and continuous IntelliScreen operation.

The experiments confirmed that IntelliScreen can reliably generate a stable filter matrix on the screen bars, which acts as a dynamic filtration layer. Two main retention mechanisms were identified:

1. Hydraulic retention effect – The longer the filter matrix remains on the screen surface, the denser it becomes. This increased density leads to a significant reduction in flow capacity, directing a higher proportion of polluted combined wastewater toward the WWTP rather than discharging it untreated through stormwater overflows.
2. Particle retention effect – Depending on the structure and porosity of the filter matrix, several grab samples showed a significant increase in retention efficiency for particles smaller than 4 mm. These fine particles, which typically bypass conventional screening systems, were effectively captured within the matrix.

The results demonstrate that IntelliScreen contributes significantly to reducing particle discharge, including fine solids and potential microplastic fractions, into surface waters. By maintaining adaptive control over the filter matrix and optimizing screen cleaning intervals, the technology supports current water management objectives for mitigating pollution from combined sewer overflows.

Further investigations are planned to validate these findings under extended operational conditions and to develop specific control strategies for balancing hydraulic performance and particle retention.

Discussion

The potential of adaptive screening technologies, such as IntelliScreen, to improve mechanical pre-treatment in municipal wastewater systems is demonstrated by the results of the initial experimental series. In particular, the reliable formation and control of a filter matrix represent a decisive improvement over conventional fixed-speed screen.

The experiments indicated that adaptive control of screen cleaning intervals allows the formation of a stable filter layer without compromising hydraulic safety. Even though increased matrix density enhances fine particle retention, it also increases head loss, which is a critical equilibrium. The IntelliScreen system effectively balanced this trade-off by adjusting the cleaning frequency in real-time, thereby preserving hydraulic functionality and operational stability.

Such adaptive operation directly addresses one of the main limitations of conventional screens, which operate at a constant speed independent of flow and load conditions [5]. The ability to modulate cleaning based on head loss and level measurements minimizes both energy consumption and overflow risk.

The observed retention of particles <4 mm confirms previous observations by Müller-Czygan and Stolz [6, 7],who reported that filter cake formation can significantly increase particle separation efficiency. The filter matrix acts as a secondary filtration barrier, enhancing the removal of suspended solids and particulate COD beyond the geometric limit of the screen openings.

Conclusion

The IntelliScreen technology at the Hof WWTP was shown to facilitate the formation of a filter matrix, thereby significantly improving the mechanical pretreatment of wastewater overflow before entering WWTP, as evidenced by the aforementioned experiments. By decreasing flow, IntelliScreen was able to retain more particles and particulate COD in the receiving water body when compared to traditional fixed-speed screens.

The results confirm that filter matrix development plays a dual role (1) Hydraulic retention, by reducing overflow discharge during high inflow events, and (2) Particle filtration, by improving solid and organic matter separation efficiency during normal operation.

Overall, the research substantiates the assertion that IntelliScreen represents a substantial advancement in the field of digitalized wastewater treatment by integrating process automation and adaptive mechanics. This technology directly impacts the sustainable management of urban water systems by enhancing particle retention and minimizing pollutant discharge during combined sewer overflows.

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ELECTROCHEMICAL MEASUREMENT OF COD/TOC USING A PHOTOCATALYTIC CELL

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1. Introduction

Reliable monitoring of organic load is essential for the efficient operation and design of wastewater treatment processes. In particular, the Chemical Oxygen Demand (COD) and the Total Organic Carbon (TOC) are key parameters that determine the sizing of waste water treatment plants and the required oxygen supply. Since aeration units account for a major portion of the total energy consumption, a rapid and reliable determination of organic carbon is crucial for optimizing process control and energy efficiency.

In Germany, COD analysis is standardized according to DIN 38409-41 and DIN ISO 15705, both relying on wet-chemical oxidation of organic pollutants with potassium dichromate. Although these methods are robust and well established, they require toxic reagents, extensive sample preparation, and provide results only after several hours. Consequently, they are poorly suited for continuous monitoring or process automation.

To overcome these limitations, alternative electrochemical and photocatalytic approaches have been investigated in recent years, aiming at reagent-free, real-time determination of organic carbon. The present study explores a novel concept based on the electron-Doppler effect in