

Article

A Fundamental Study on the Extraction of Particulate Organic Carbon from Municipal Wastewater Treatment Plants

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Abstract: In line with the strategy of transforming existing municipal wastewater treatment plants (WWTP) from disposal facilities into systems for using domestic wastewater (WW) as a source of energy and raw materials, a concept consisting of chemical, physical, and biological steps has been set up as a pilot project in WWTP Bösau, Stuttgart, Germany. The key part of the entire process is based on the use of advanced microsieving (MS) to eliminate remaining particulate organic carbon (POC) (mg/L) from the effluent of the primary sedimentation tank (PST). Therefore, in the primary stages of this project, it was necessary to have a broad vision and a true understanding of the particle size distribution (PSD) of municipal WW. As a novel approach, in the present study, the conventional PSD method was optimized by implementing certain modifications, and the tests were conducted in situ. The modified PSD analyses facilitated in-depth investigations of solid–liquid separation at WWTPs and showed that drying samples in the oven can result in a 20% to 30% deviation in the POC (mg/L) removal results. In addition, the idea of the substitution of PSTs with an MS was supported by the results of this study. It was determined that an MS with a pore size of 45 μm to 63 μm can provide the same elimination efficiency as a PST. Another significant outcome of this study was the introduction of suitable mesh sizes for the MS which were coupled with PST in order to extract the maximum amount of POC (mg/L) from the municipal WWTPs without the addition of any chemicals. The results revealed that up to 90% of the TSS (mg/L) and 70% of the COD (mg/L) can be removed if an MS with a mesh size between 4 μm and 20 μm is coupled with a PST.

Keywords: particle size; sieving; primary sedimentation; particulate organic carbon; TSS (mg/L); COD (mg/L)



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1. Introduction

Natural water pollution has seen a significant rise since the exponential increase in population growth and urbanization, and this can mainly be attributed to the establishment of sewer systems and the discharge of untreated domestic sewage [1–4]. The objective of using WWTPs is to properly dispose of domestic sewage in order to protect natural waters and achieve good hygienic conditions. In fact, the main aim of implementing WWTPs is to reduce both settleable solids and organic load to maintain hygienic conditions and sufficient levels dissolved oxygen in natural waters. More recently, nutrient removal (nitrogen and phosphorus) has been implemented to inhibit eutrophication and save the environment [5,6]. Finally, since the beginning of this century, micropollutant removal has been introduced in some countries due to the nature of its impact [7]. Thus, end-of-pipe treatment has been improved step by step. As the energy consumption for treatment increased, measures to minimize it were introduced. The anaerobic digestion of primary and excess sludge combined with electricity generation from biogas represents the first utilization of wastewater as an energy source [8]. Today, wastewater is understood as a source of energy and chemical raw materials [9]. A rising number of studies have also

focused on using novel technologies, such as mesoporous materials, hollow fiber composite membranes, and polyethersulfone ultrafiltration membranes, to remove a variety of organic and inorganic pollutants [10–12]. Against the background of the conventional approach, the tendency to change WWTPs into energy sources rather than purification streams is steadily increasing across the globe. WWTP BÜsnau, Stuttgart, Germany, is not an exception in this regard. The intention at this WWTP is to remove much greater quantities of suspended solids (SS) in the primary steps of treatment with the help of a PST and an MS, and finally to use these materials for the recovery of energy and chemicals. The residual load for biological treatment is thereby lowered and thus the energy consumption required for aeration is significantly reduced. Prior to biological treatment, ammonium, an energy-rich substance, will be recovered. As a consequence, simpler biological treatments can be designed in the form of cost-effective methods such as trickling filters. As indicated, the primary and fundamental step of the project is to significantly increase the separation of POC in the primary treatment steps. For this purpose, PSD analyses can be used to select the appropriate design processes, e.g., the type and size of the mesh used for the MS in order to extract the maximum amount of POC for energy and chemical recovery. Increasing attention has been given to the size distribution of wastewater solids by researchers over the past several years [13,14]. This is likely because a true understanding of PSD can have a decisive impact on the pollutant removal efficiency of WWTPs. A succession of techniques has been developed to determine PSD, such as sieving, light scattering, microscopic investigation, and a few others. It should be understood that employing a variety of approaches to specify particle size distribution can result in entirely distinct outcomes [15,16]. Certain classification methods are known for identifying the distribution of particle size in wastewater. Typically, four size classes [17] are employed to illustrate wastewater components, namely, settleable solids, supracolloidal solids, colloidal solids, and dissolved solids. However, since wastewater substances include a broad range of particle sizes [18,19], a unanimous agreement has not been reached among researchers concerning the exact distribution of particles in wastewater. Therefore, results tend to differ according to the type of wastewater used [20,21]. Since multiple researchers [22–27] have used different classifications for the same fractionations, defining the best analytical method or the most reasonable particle ranges for the PSD of municipal wastewater is not easy [28]. The processes that may occur within the sedimentation processes in WWTPs are characterized by their high sophistication [29]. Therefore, comprehensive techniques or measurement methods are still not capable of precisely analyzing wastewater particles, either qualitatively or quantitatively [17]. As a result, the present study, by introducing a modified PSD analysis, aims to thoroughly explore PSD in municipal WWTPs and produce unambiguous results which incorporate almost all particle ranges and can be reliably applied to future investigations. The conventional PSD approach was optimized using three distinct methods of analysis: wet (T1), dry analysis at room temperature (T2), and dry analysis at 105 °C (T3). The current study makes significant contributions to the field of wastewater treatment for the following reasons. Firstly, conducting the PSD analyses *in situ* allowed us to obtain accurate information about the size distribution of the particles without affecting their original size. Secondly, it proposes the coupling of PST and MS, which has never been practiced before. This method is cost-effective and enables the practicing of load-independent methods in which the conventional activated sludge tank can be removed. By applying this concept, high amounts of POC can be extracted from municipal WWTPs, leading to significant energy savings and increased gas and electricity production via anaerobic digesters.

2. Materials and Methods

2.1. Materials

A small-scale sieving machine from Retsch (Haaan, Germany) was employed at BÜsnau municipal WWTP (10,000 population equivalents) for analyzing PSD in the PST_{in} and PST_{out}. The mesh size of the stainless steel sieves varied from 2 mm to 20 µm. Municipal

wastewater was used in the sieving machine after preliminary separation (5 mm bar rack followed by a sand trap). From the effluent of the sand trap into the inlet of the sieving machine, wastewater was pumped using a peristaltic pump at a flow rate of approximately 30 L/h. Afterwards, the effluent of the last sieve was filtered off with consecutive paper filters of pore sizes ranging from 2 μm to 15 μm . The detailed material used and the actions taken for conducting this test are summarized in subsequent subsections.

2.1.1. Stainless Steel Sieves

The selected sieves from Retch (Haaan, Germany) are as follows: 2 mm, 500 μm , 250 μm , 125 μm , 63 μm , 45 μm , and 20 μm , respectively.

2.1.2. Ash-Free Colour-Coded Quantitative Filter Papers

Since there is no stainless steel sieve smaller than 20 μm available on the market; the effluent from the sieve 20 μm should have been analyzed by different paper filters. So, the ash-free colour-coded quantitative filter papers from Sartorius (Göttingen, Germany), with pore sizes varying from 15 to 2 μm , were used.

2.1.3. Membrane Filter

For determination of the rest residue of filterable matters below 4 μm and above 0.45 μm , the effluent from the filter 2–15 μm was again filtered off by a 0.45 μm filter made by the Sartorius (Göttingen, Germany). It should be noted that this approach was not conducted gravimetrically but rather by compressed air (4 to 6 bars).

2.1.4. Scales

The scales that were applied in this study in order to weigh the mass of retained material by the stainless steel sieve or the paper filters were distinct. Sartorius scales (Göttingen, Germany) with an accuracy of 0.01 g were applied for the stainless steel sieves, and the scale from Precisa (Dietikon, Switzerland) with an accuracy of 0.0001 g was used for measuring the ash-free color-coded filter papers as well as membrane filters.

2.1.5. Sieving Machine

The sieving machine used was from Retch (Haaan, Germany).

2.1.6. Peristaltic Pump

A peristaltic pump, MCP (type: p3/filter3), was used for discharging the wastewater from the flow channel to the top of the sieves.

2.1.7. Measuring Cylinder, Funnels and Beakers

Glass or plastic measuring lab cylinders were used for taking the samples (100 mL and 1 L). Moreover, nine funnels and nine beakers were prepared in order to keep the paper filters and also collect the filtered material.

2.1.8. Ultrasonic Machine

Since the finer particles trapped by the pores of the stainless steel sieves cannot be detached by hand or simple washing methods, the ultrasonic machine from BANDELIN Electronic GmbH and Co. KG (Berlin, Germany) was applied for this purpose.

Remark: For more information about conducting each specific part, please refer to the Supplementary Information.

2.2. Methods

First, all the needed material was prepared one day before the test. The filters and sieves were dried in the oven one day before the test. All the sieves and filters were weighed right before the test, and then the test was conducted for exactly one hour. During the test, checks for any leakages from the ventilation aids and the hoses were conducted. Sufficient

samples were taken for determining TSS (approximately 1 L) and filterable substances (200 mL for each measurement) every 20 min. When the test was completed, all the sieves were detached, transported to the lab, and immediately weighed and put in the lab to be dried. So, at this time, the first values for the sieving test were recorded. Meanwhile, the very fine fraction of SS was determined by means of membrane filtration (applying the standard method: DIN 38409-2). Measurements for the weight of the sieves and filters were accomplished after 24 h, 48 h, and 72 h, which correspond to T1, T2, and T3 samples, respectively. TSS (mg/L) was measured at least three times using a 0.45 μm membrane filter (applying standard DIN 38409-2). During the filtration process using paper filters, samples were taken for COD (mg/L) and TOC (mg/L) and analyzed according to DIN 38409-41 and DIN EN 1484, respectively. The individual specimen contained at least 50 mL of filtered material. Moreover, two more samples were prepared. The first one was for the sample filtered with a 0.45 μm -membrane filter, and the second one was for either PST_{in} or PST_{out} according to the selected type of analysis. After completion of the test, the stainless steel sieves were cleaned gently by hand in order to remove coarse particles. Afterwards, the ultrasonic machine was used to remove finer particles. Eventually, dry matter content and the loss on ignition were determined by applying standards DIN EN 12880 2000 and DIN EN 12879 2001, respectively. For more details, Figure 1 illustrates the piping and instruction design (PID) for the primary treatment step of WWTP in BÜsnau, Stuttgart, along with the points chosen for in situ PSD analyses. It is worth noting that the PST's hydraulic retention time (HRT) ranged from 1 to 5 hours depending on the inflow rate. As a result, all studies were attempted at 11:00 a.m., when the availability of SS in WWTP BÜsnau was very high.

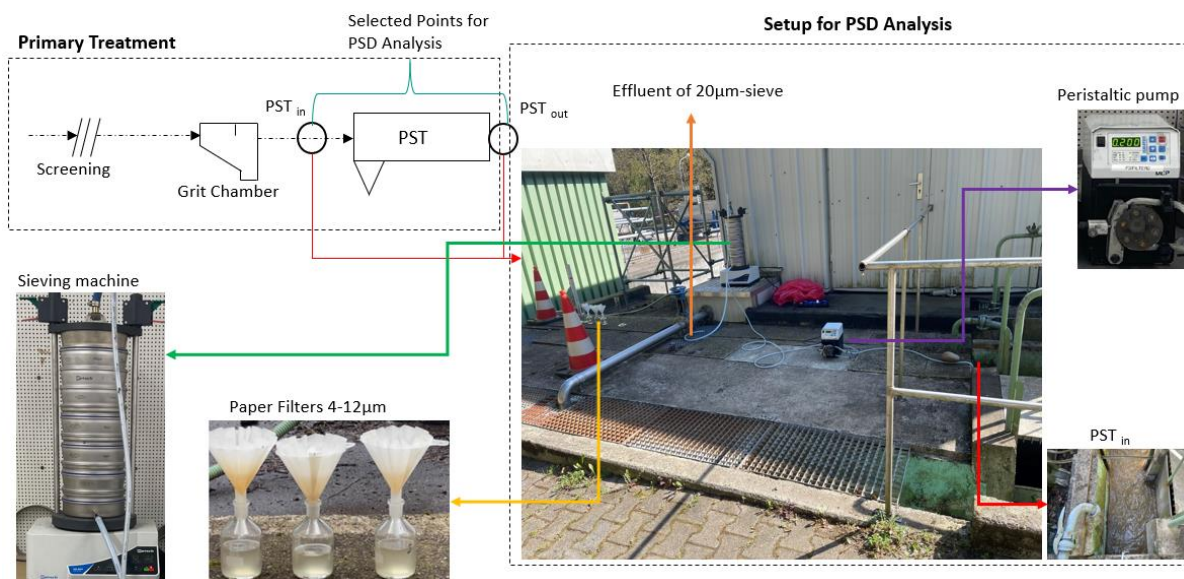


Figure 1. PID of primary treatment step of WWTP BÜsnau, Stuttgart, Germany, along with detailed setup for PSD analyze (1 h < HRT in PST < 5 h).

2.3. Interpretation of Data

For determining the concentration [mg/L] of TSS over a specific sieve (TSS_x) and the cumulative removal efficiency (RD_x) of different fractions, Equations (1) and (2) were applied, respectively.

$$\text{TSS}_x = W_D / V_{F'} \quad (1)$$

where W_D is the weight [g] of detained particles equal to or bigger than mesh size x , and V_F [L] is the total volume of the filtered sample.

$$RD_x (\%) = \sum_i^n W_D / V_F \times 100 \quad (0.45 \mu m \leq i \leq 2 \text{ mm}), \quad (2)$$

where W_D is the weight [g] of detained particles equal to or bigger than mesh size x , and V_F [L] is the total volume of the filtered sample.

Moreover, in order to determine the removal efficiency for COD (mg/L) of a specific sieve, Equation (3) was applied.

$$RC_x (\%) = \left[\frac{C_{in} - C_{out}}{C_{in}} \right] \times 100, \quad (3)$$

where C_{in} and C_{out} are the concentrations of COD (mg/L) in the inflow and outflow of the sieve X , in the given order.

3. Results and Discussion

The literature review revealed that the deviations obtained in PSD analyses could stem from the following points:

- No attention was paid to the particle breakage issue caused by sample transport to the lab for dry sieving or by pump propellers for wet sieving;
- There was no consideration of the hourly or daily variation of wastewater flows;
- Different analytical methods and categories, and even sometimes irrelevant ones, were chosen for the distribution of particles in municipal WWTPs;
- Grab samples were taken for the distribution test analyze instead of using mixed samples or conducting the test in situ;
- There was a lack of data or knowledge about the exact performance of PSTs on the removal of specific fractions of suspended solids present in wastewater.

In this study, we attempted to minimize all the factors mentioned above in order to make it easy so that the values and ranges can be applied with confidence to further studies. The parameters of total suspended solids (TSS), chemical oxygen demand (COD), and organic/inorganic portion were analyzed not only for the inflow of the primary sedimentation tank (PST_{in}) but also for the outflow of the primary sedimentation tank (PST_{out}) in order to gain a profound understanding of fractionation in municipal WWTPs. The results obtained are discussed in the subsequent sections in detail.

3.1. Solids Distribution in the Influent of PST

Solids in wastewater are described as particles, flocs, and aggregates. They differ according to shape and size. Even though bigger SSs are detectable in wastewater, the vast majority of them are of very small sizes [30]. Solids in wastewaters are typically classified by non-specific parameters such as SS, total solids (TS), volatile solids (VS), etc. [31]. The SS parameter has been applied to be a satisfactory index for cutting-edge processes such as trickling filters [32], membrane filtration [33,34], and the activated sludge process [35] in water and wastewater treatment. By introducing PSD for the inflow and outflow of PST in Figure 2 and Figure 3, respectively, the mechanism of solid sedimentation by PST can be better understood. Experimental outcomes showed that around 70 to 90% of receiving solids and particles after the grit and grease chamber are equal to or bigger than 20 μm , of which 70% belong to T3 and 90% to T2. These findings are in agreement with work conducted by Izdori et al. [25]. Since fine particles can be removed by simultaneous settling [36] with large particles, both percentiles can be realized depending on the hourly or daily variation of receiving SS concentration, weather conditions, and retention time. Simultaneous settling occurs when faster-sinking particles meet slower-sinking particles due to factors such as a decrease in velocity in the wastewater. Particles from a region with a higher flow velocity reach an area with a slower flow velocity, but their movement

is not immediately slowed down, so they encounter other particles whose movement is already slower and settle together because of inertial forces. In places with high levels of turbulence, this procedure is particularly crucial. The capillary merging of individual particles also contributes significantly to the simultaneous settling process [37].

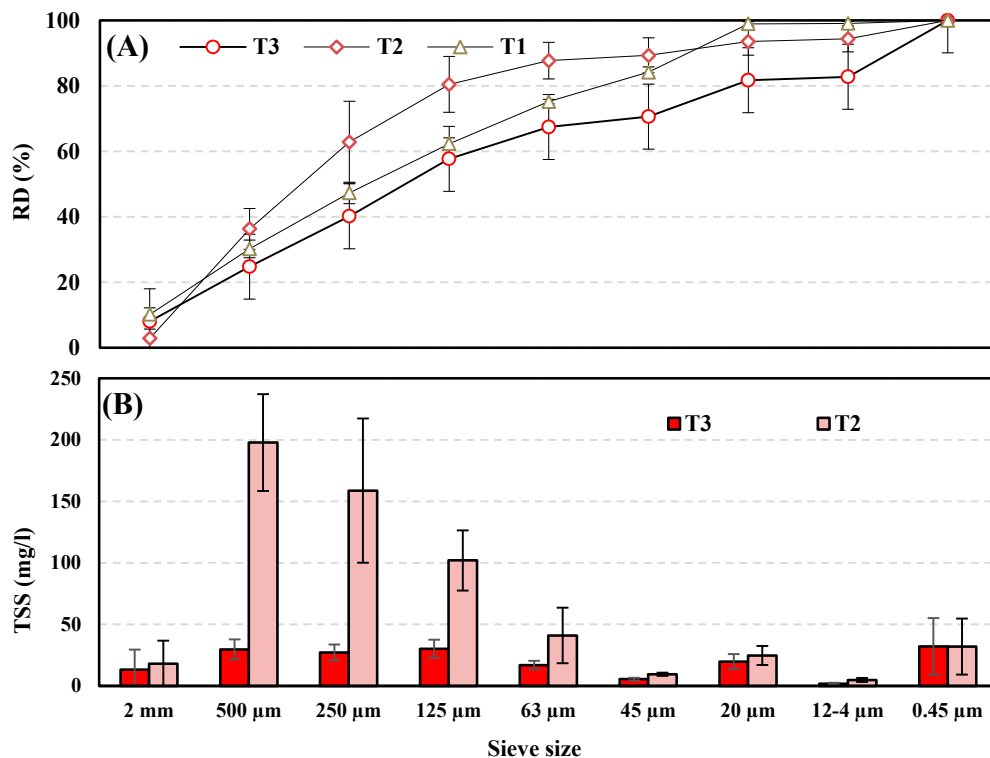


Figure 2. TSS (mg/L) removal (A) and concentration (B) versus different mesh sizes of sieve—PST_{in}.

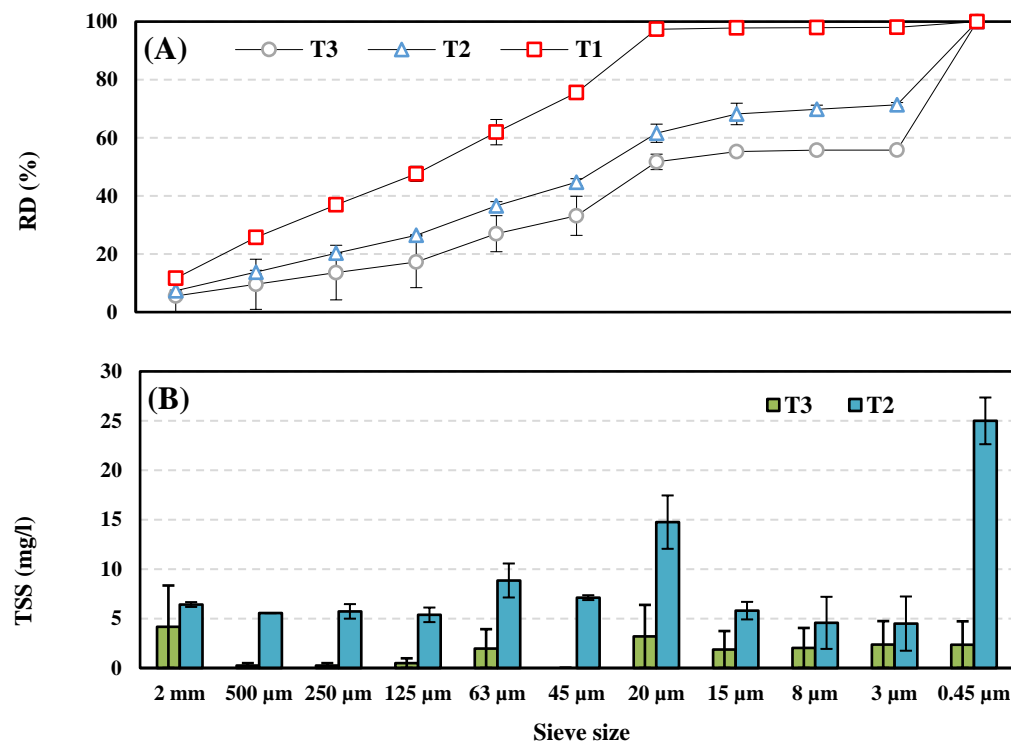


Figure 3. TSS (mg/L) removal (A) and concentration (B) versus different mesh sizes of sieve—PST_{out}.

The substitution of PSTs with an MS with the same removal efficiency could also be seen in Figure 2. According to the European norm, PSTs can remove about 50% of TSS (mg/L). So, according to these results, an MS with a pore size of 45 to 63 μm can provide the same removal efficiency, even with low maintenance costs and the capability of being adjusted to population increases. The PSD analyses applying three distinct measuring methods could also provide advantageous information on the type and nature of sewage solids. For instance, analyzing the material obtained by sieving showed that most of the particles retained by sieves 125 μm and bigger, and even partially by sieve of 63 μm , stem from toilet paper (approved by visual observation and loss of ignition). A comparison of the results of this study with works conducted in this area reveals that the settling process by PSTs can be reasonably projected by assessing the fraction of particles.

3.2. Solids Distribution in the Effluent of PST

The same approach was applied for determining the SS concentration in the effluent of PST. Figure 3 shows the measurement of TSS (mg/L) for the effluent of PST for different days. Considerable differences can be noted between the concentration of TSS (mg/L) in the influent and the effluents of PST. The findings are in line with the outcomes of the study conducted by Vicuini [38]. Based on the measurements carried out, particles sizing from 2 mm to 125 μm can be rarely found after PST. This means that these particles are easily removed by PST during the sedimentation process. In addition, the above results proved that toilet paper is a dominant organic component of TSS (mg/L) received from wastewater. However, our optical observation showed no traces of toilet paper after PST. This could be due to the particle's geometry; irregularly shaped particles (mainly coarser) settle faster than regularly shaped ones (mainly finer) because rotation during the settling process shifts their area perpendicular to the direction of travel. Therefore, gravitational forces cause particles to settle more rapidly, facilitating their removal through primary sedimentation tanks. By introducing an MS as an alternative for PSTs, toilet paper, which is mainly cellulose, can be readily extracted from raw wastewater. This information is highly valuable for supporting ideas such as using cellulose fibers as flocculant material to enhance the removal of organic SS (mg/L) in PSTs by their cationic or anionic charging by chemical or catalytic reaction [39], and the production of activated carbon from fibers taken from wastewater screenings [40]. By doing so, an increase in biogas yield and a decrease in the energy consumption of biological treatment steps are expected due to the availability of more primary sludge. Realizing this concept will bring us one step closer to the dream of looking at municipal wastewater as a resource rather than a waste stream.

Figure 3 illustrates that ca. 50 to 70% of TSS (mg/L) remaining after PST can be removed if the MS mesh size is selected between 15 and 4 μm . In contrast, studies conducted by Remy et al., Köngsepp et al., and Vaananen et al. [41–43] mainly observed the removal of solids from raw wastewater using drum or disc filters, with mesh sizes predominantly ranging from 100 to 400 μm but with the help of chemicals such as ferric chloride and aluminum chloride or sulfate. However, the idea of coupling a PST with an MS in order to extract a higher amount of POC (mg/L) out of municipal WWTPs without any chemical addition is being introduced for the first time in this study. The results indicate that around 80 to 90% of TSS (mg/L) can be removed if an MS with a mesh size between 4 and 20 μm is coupled with a PST.

3.3. COD (mg/L) and TOC (mg/L) Removal for the Influent and Effluent of PST

The PSD-COD fractions serve as the fingerprint for the biodegradability of wastewater [32]. It is essential to comprehend how each treatment step changes the distribution of COD (mg/L) fractions in that unit and how this influences the downstream treatment stages for an integrated treatment process [44]. Figure 4 demonstrates the correlation between PSD and TCOD (mg/L) fractionation as an index for biological treatability by drawing a correlation between particulate organic matter and total COD (mg/L) or TOC (mg/L) amounts. Results acquired through PSD-TCOD (mg/L) analyses depict distinct

illustrations for municipal sewage. PSD-TCOD (mg/L) fractionation analyses specify the size interval consisting of both the soluble COD (mg/L) and the particulate range above 0.45 μm . Primarily, one of the basic understandings of designing and modeling PST has been the introduction of several COD (mg/L) fractions following PSD [45]. If TCOD (mg/L) is picked up for the PSD analyses, the major part of COD (mg/L) appears at the size ranges above 0.45 μm , and only a relatively small quantity is in the soluble range (<0.45 μm). However, this ratio changes marginally for the influent and effluent of PST. The TCOD (mg/L) ratio is divided into about 65% particulate and 35% soluble COD (mg/L). Results of this part revealed that treatment of raw WW only by using a PST can effectively eliminate a major part of particulate COD (mg/L). Moreover, the COD (mg/L) profile demonstrated in this study is in line with some of the values outlined by Levine et al. [17], who reviewed multiple studies on PSD for different types of domestic sewage. In this study, significant fractions (about 50%) of TCOD (mg/L) were shown to be in size intervals of >15 μm , presumably due to the high availability of organic material in this range. Part 3.4 of this study will be dedicated specifically to this context.

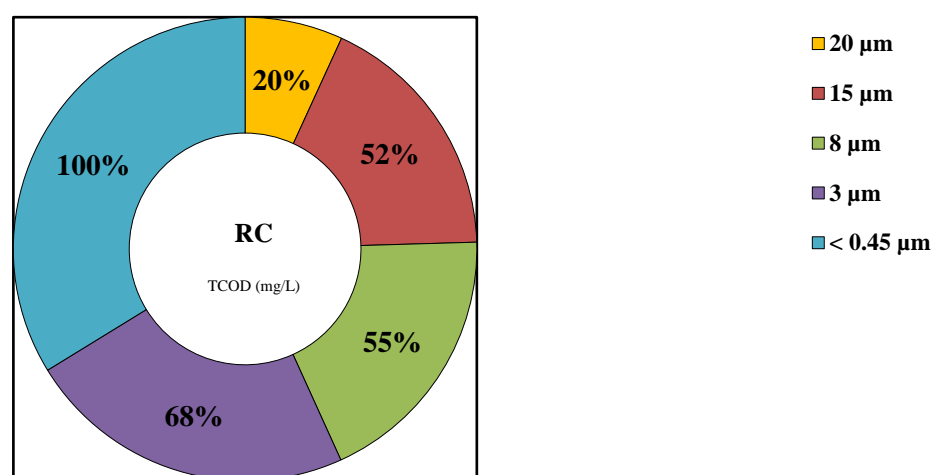


Figure 4. TCOD (mg/L) removal efficiency versus different mesh sizes of sieve—PST_{in} and PST_{out}.

Remark: Multiple experiments were performed to determine TOC (mg/L) variation for PST_{in} and PST_{out}; however, due to a blockage of the sampling needle, TOC measurement could not be completed successfully, and so its results were not reported in this study.

3.4. Organic and Inorganic Portion of the Influent and Effluent of PST

The organic and inorganic compositions of solids in municipal wastewater and domestic primary effluent are understood only to some extent. Defining the total amount of organic or inorganic matter in wastewater is essential for developing a clear understanding of treatment processes. Some researchers, such as Raunkjer et al. and Kunwar et al., [46,47] have documented that organic matter in wastewater is represented by COD, TOC, and BOD fractions. However, a more explicit classification based on soluble/particulate fractionation and PSD analyses is labor intensive; therefore, it has received limited attention. It is clearly seen in Figure 5 that the particulate solids were dominantly organic, but the dissolved solids were greatly inorganic (for instance, neutral salts such as sodium chloride (NaCl) or sodium sulfate (Na₂SO₄)). The largest group of organic matter found in the studied municipal wastewater was toilet paper, which consists of cellulose fibers. Our observations agree with the findings of work conducted by Hong-huang et al. [19]. Results of this study also indicated that treatment by PST was extensively more efficient in decreasing the concentration of particulate organics than in reducing the concentration of soluble organics. Nevertheless, the organic material share of the particulate matter is reduced by decreasing particle size. For instance, this ratio drops from 100% to 70% if the particle

size reduces from 2 mm to 10 μm , presumably due to the lack of availability of cellulose fibers in smaller fractions. It is clear from the results that most of the organic matter is in particulate form and is suitable to be extracellularly hydrolyzed prior to any metabolism by bacteria. The primary and microsieved sludge could be used for hydrolysis; therefore, a meticulous specification of particulate organic or inorganic matter in wastewater could help us enhance solid–liquid separation and further planned biological processes. According to this study’s observations, the organic contents (Figure 5) differed based on PSD brought into comparison with measured COD (mg/L) (Figure 4) in the corresponding fractions. In favor of solid–liquid separation, PSD analyses guide us towards the better design and operation of biological treatment steps such as the biological hydrogen production process or activated sludge [26]. For instance, the batch reactor for POC hydrolysis could be designed with a higher retention time and volume if wastewater were mainly composed of large particles with slow hydrolysis rates.

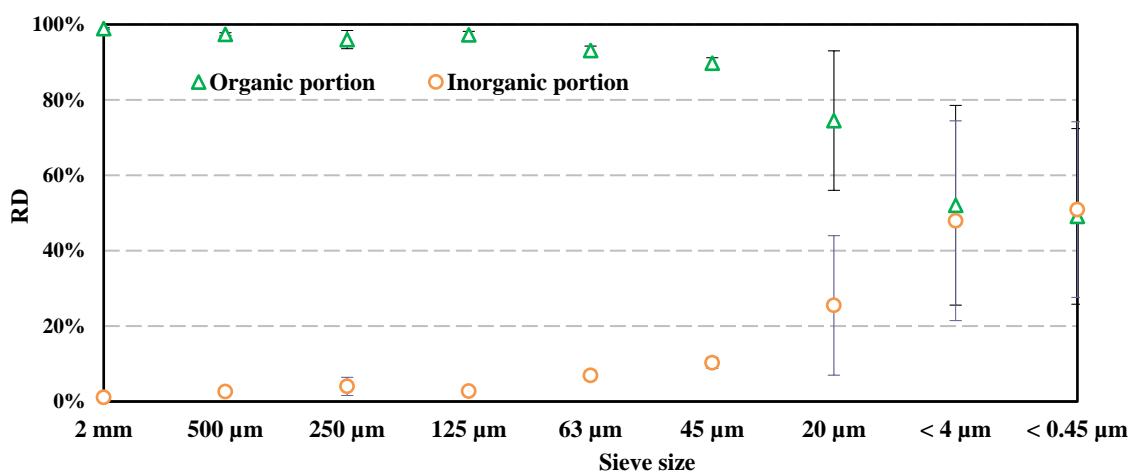


Figure 5. Removal rates for organic-inorganic contents versus different mesh sizes—PST_{in} and PST_{out}.

Remark: The deviation observed in the results of <20 μm samples can be due to scale errors resulting from the low amount of sample available after being ignited in the oven.

3.5. Optimal Measuring Method and Classification

As far as the applied method is concerned, three different methods were applied in this study, including two dry methods (T1 and T2) and one direct measurement (wet method/T3). A comparison between T1 and T2 applied based on the TSS (mg/L) removal efficiency of PST is presented in Figure 6. T1 was excluded from the analyses due to the high discrepancy of its results with the other two methods. Indeed, the samples contain a high amount of water; so, by taking them into consideration, the wrong conclusion can be drawn. As shown in Figure 6, both dry methods followed the same pattern for TSS (mg/L) removal efficiency. However, the results showed a 20–30% discrepancy for TSS (mg/L) removal depending on the method applied. So, it is important to note that when choosing the best mesh size for MS, TSS (mg/L) removal can be underestimated or overestimated depending on method applied. The bigger the mesh size, the higher the deviation. This 20–30% discrepancy in the results presumably stems from the evaporation of volatile organic matter due to the samples drying in the oven compared to drying conditions at room temperature. The literature survey showed that no study conducted on PSD considered this an important factor. So, the question is whether dry analyses at room temperature can be substituted for, or considered an alternative to, the oven drying method for purposes such as TSS (mg/L) measurements. In addition, based on the results of this study, the rational classification for PSD in municipal wastewaters is suggested as follows: settleable solids $\geq 100 \mu\text{m}$, 100 μm > supracolloidal solids, colloidal solids $\geq 0.45 \mu\text{m}$, and dissolved solids < 0.45 μm , in given order.

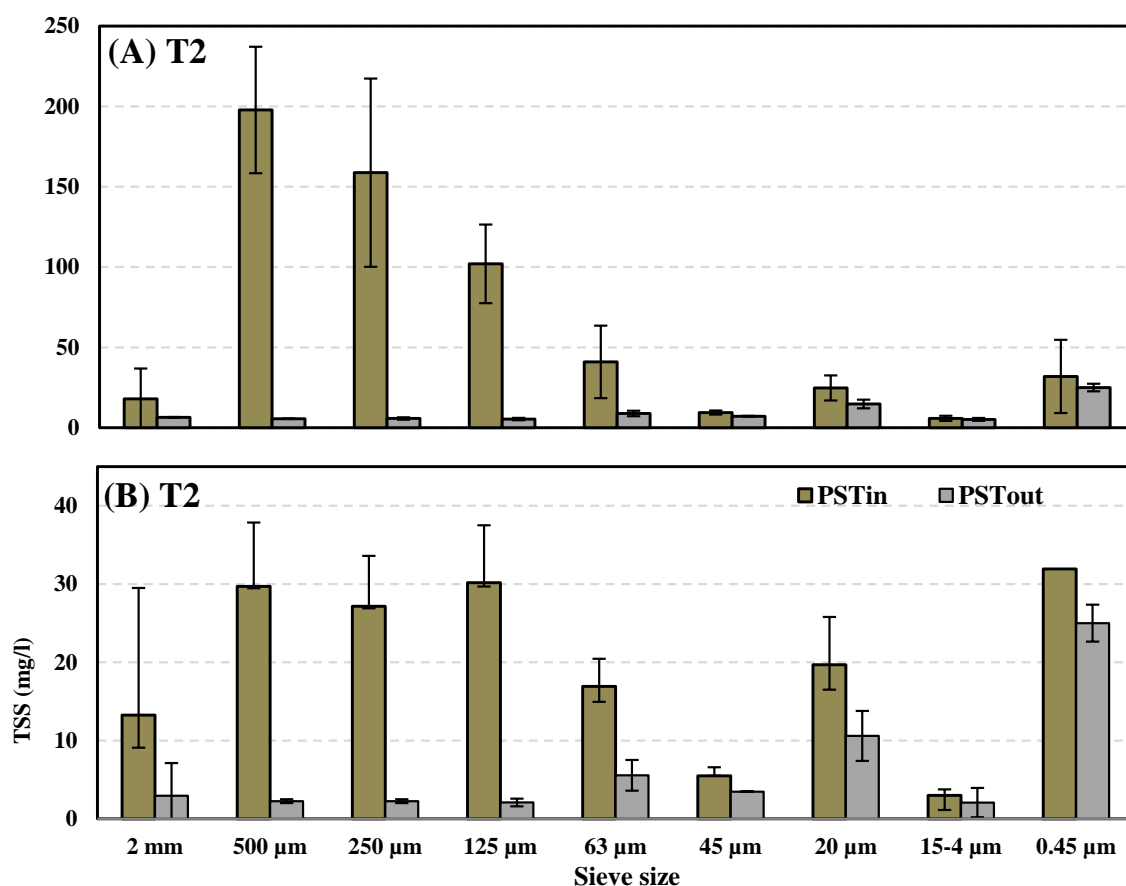


Figure 6. TSS (mg/L) removal rates of PST—T2 (A) and T3 (B).

4. Conclusions

In this study, the conventional PSD method was creatively modified for analyzing POC (mg/L), TCOD (mg/L), and the organic and inorganic portions of PST_{in} and PST_{out}. Based on the obtained results, the following conclusions can be drawn:

- In-depth investigations on solid–liquid separation at WWTPs can be realized by applying the modified PSD analyses introduced in this study to select the prevailing compositions of the organic matter entering biological treatment steps;
- By conducting PSD analyses, it was observed that drying the samples in the oven can result in a 20–30% deviation from the POC (mg/L) removal results. The bigger the sieve size, the higher the deviation. Therefore, for PSD analyses, it is recommended to dry the samples at room temperature rather than in the oven;
- The idea of substituting PSTs with an MS can be supported by the results of this study. According to the results obtained, an MS with a pore size of 45 to 63 μm can provide the same elimination efficiency as a PST, even with a low maintenance cost and the capability of being adjusted by population growth;
- By introducing suitable MS as an alternative for PSTs, toilet paper (cellulose fibers) can be readily extracted from raw wastewater and used for flocculants and activated carbon production;
- When retrofitting the existing WWTP was being considered, the idea of coupling PST and MS showed itself to be a potential option. The results showed that approx. 50 to 70% of POC (mg/L) in the effluent of PST can be removed if it is coupled with an MS with a mesh size selected between 4 and 20 μm. TCOD (mg/L) of wastewater before PST showed it to be about 65% particulate and 35% soluble. Since there is a direct correlation between particulate COD (mg/L) and POC (mg/L), by removing the dominant part of POC, which was found to be organic and made of toilet

paper, a significant fraction of COD (about 50%) could be removed by the suggested arrangement;

- The recommendations for the classification of PSD in municipal wastewaters are as follows: settleable solids $\geq 100 \mu\text{m}$, $100 \mu\text{m} >$ supracolloidal solids, colloidal solids $\geq 0.45 \mu\text{m}$, and dissolved solids $< 0.45 \mu\text{m}$, in the given order.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/w15101861/s1>.

Author Contributions: Conceptualization, B.A.L. and P.M.; methodology, B.A.L. and P.M.; software, B.A.L.; validation, B.A.L., P.M. and H.S.; formal analysis, B.A.L.; investigation, B.A.L.; writing—original draft preparation, B.A.L.; writing—review and editing, B.A.L. and H.S.; visualization, B.A.L.; supervision, P.M. and H.S. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest: The authors state that they have no known competing financial interest or personal tie that would appear to have influenced the work disclosed in this study.

Abbreviations

Symbol	Definition	Symbol	Definition
BOD	Biochemical Oxygen Demand	Na_2SO_4	Sodium sulfate
$^\circ\text{C}$	Degree Celsius	Out.	Outflow
COD	Chemical Oxygen Demand	P	Phosphorus
DOC	Dissolved Organic Carbon	PID	Piping and instruction design
EU	European Union	PST_{in}	Inflow of primary sedimentation tank
Fig.	Figure	PST_{out}	Outflow of primary sedimentation tank
h	Hour	PSD	Particle size distribution
H	Hydrogen	POC	Particulate organic carbon
HRT	Hydraulic retention time	PST	Primary sedimentation tank
In.	Inflow	SS	Suspended solids
L	Liter	TSS	Total suspended solids
m^3	Cubic metre	TS	Total solids
mg/L	Milligrams per liter	VS	Volatile solids
mL	Milliliter	WW	Wastewater
Min	Minutes	WWTP	Wastewater treatment plant
N	Nitrogen	μm	Micrometer/Micron

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