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Should Rheological Properties of Activated Sludge be Measured?

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Abstract:
The core of activated sludge monitoring lies in the biological analyses. Anyway, the knowledge of sludge physical characteristics is crucial for a proper management of WWTPs (Waste Water Treatment Plants). One of these physical features is viscosity that, notwithstanding its valuable role has not yet become a routine analysis. This study examined the evolution of rheological properties of two sludges alongside the "purification route" (from the biological reactor up to the sludge treatments). It could been shown that sludges behaved like non-Newtonian fluids and dry solids content strongly affected viscosity values, which reached relatively high values. Microscopic observation of flocs was carried out. Both the sludges revealed similar features, in particular an over-proliferation of filamentous bacteria. This work showed how rheological measurements can be a tool to obtain information on microbiological composition of activated sludge and how it could be related to settleability properties.

Key words:
activated sludge, rheology, filamentous bacteria, viscosity, waste water

1 INTRODUCTION

The activated sludge (AS) process is so far the most common biological method used worldwide for wastewater treatment. Water contamination is removed through biomass activity leading to the unavoidable generation of a large amount of biosolids (waste sludge), which has to be managed. Despite its small volume more than 40% of the wastewater treatment cost is spent on sludge treatment and disposal processes [1]. In order to improve sludge handling (e.g. pumping, transporting, mixing, and dewatering operations) and to reduce costs consequently a proper technical design and management of biosolids treatment and reuse/disposal facilities is needed. This requirement can be fulfilled mainly through the knowledge of physical characteristics of sludge [2]. In addition, sludge physical together with biological properties heavily affect also the solid-liquid (i.e. sludge-treated water) separation process [3], which occurs in final clarifiers and whose efficiency influences the overall plant performance.

One of the most important sludge physical characteristics is the rheological behavior, which is capable to interfere with reactors hydrodynamics, oxygen transfer (i.e. design of aeration systems), and sludge pumping (i.e. recycle flows), transportation (i.e. pressure losses in pipes), and conditioning/dewatering [4–6] with evident consequences on the operating costs [7]. As well known, rheology describes the deformation of a body under the influence of stress and the determination of shear stress τ as a function of shear rate $\dot{\gamma}$ enables to characterize the flow behavior of a fluid. Sewage sludge rheology has been extensively investigated in recent years [8] and, thus, AS (as well as granular, anaerobic, and membrane bioreactor sludge) is classified as a non-Newtonian fluid, which means that shear stress is not linearly related to shear rate. From a structural point-of-view at high shear rate the motion of the particles prevents the particle-particle bonding and leads to a more dispersed suspension behaving more like a fluid. On the contrary at lower shear rates,individual particles can aggregate in clusters being able to form a rigid network and the slurry can be considered as a solid [9]. Viscosity (shear stress/shear rate ratio μ) is the main characteristic summarizing flow behavior: The greater the viscosity, the more viscous and less flowable is the fluid, which means that the molecules in higher viscous liquids are more strongly bound to each other, and thus less freely moveable [8].

Different factors can affect the evolution of AS viscosity: dry matter content, a "non-specific" parameter described by Total Suspended Solids (TSS) concentra-

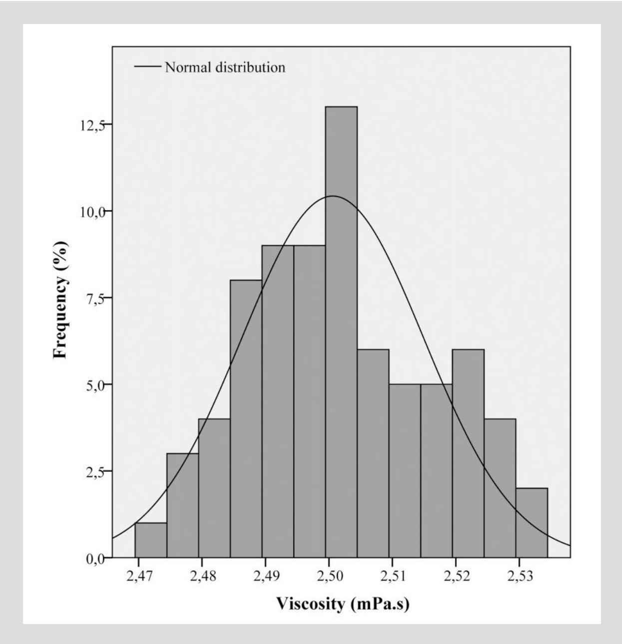

Figure 2: Statistical analysis, reporting frequencies diagram of viscosity measurement on a 4 gTSS/L sample.

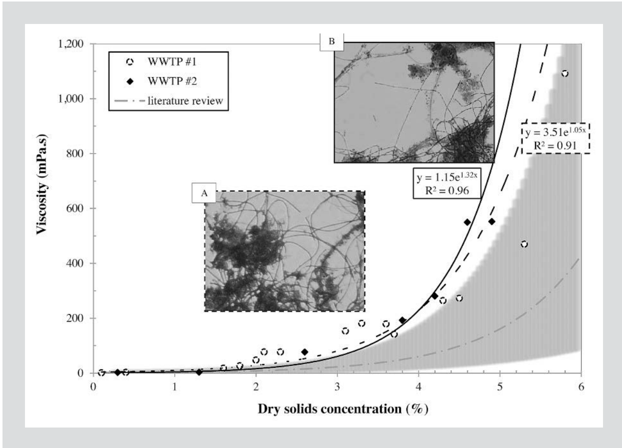

Figure 3: Viscosity increase as a function of dry solids concentration for two tested sludges, with details of floc observation (Gram stain, 1000 x magnification), and comparison with literature data (filled area representing its variability). Open circles, dotted line, and picture a: #1 WWTP. Filled square, solid line, and picture b: #2 WWTP.

expected [19] the relationship between viscosity and TSS was accurately represented by means of a power law as demonstrated by the high values of R^2. Similarly, Herschel-Bulkley parameters (K and m) showed the same strong dependence on TSS: An increase of solids concentration was responsible for an increase of consistency index and on the contrary for a reduction of the flow index meaning a switch from dilatant ($m > 1$) to pseudoplastic ($m < 1$) fluid (Figure 4). Moreover, as a further outcome, both tested sludges displayed very similar behaviors: the parameters of μ/TSS power law were comparable to those reported in the available literature, in particular close to the highest values. Several works [3, 8, 9, 12, 20, 21] were taken into account to generate the "literature review" pattern represented in Figure 3 together with the maximum and the minimum: Its high variability (filled area) is a consequence of viscosity measurement "sensitivity" (to the use of different devices, protocols, ...) as reported in the Introduction (Section 1).

The reason of this trend was successfully sought in sludge biological characteristics. From the macroscopic point of view, the Sludge Volume Index (SVI, an empirical indication of sludge settleability in the final clarifier) assumed alike values equal to 325 and 275 mL/g for #1 and #2 WWTP, respectively. Such values represent a straight warning towards possible critical situations (e.g. the onset of bulking phenomena). Likewise, the microscopic observation of AS revealed that both the plants were characterized by middle dimension flocs (150 – 500 μm) with a high level of filamentous bacteria. These features directly affect the physical behavior of sludge at the macroscopic scale, since filamentous bacteria colonize each floc (which is the morphological and functional unit of activated sludge process itself) and form bridges among flocs. Within this context, detected filament types were *M. parvicella* (Type 021N, Type 0041) for #1 WWTP and *M. parvicella* (Type 0092, Type 0914) for #2 WWTP. The dominant filament *M. parvicella* synthesizes oils, thus worsening sludge settleability. Also *Zooglea sp.*, which is strictly related to EPS production and the main onset of the so-called viscous bulking consisting in increased volume and tendency to flotation was detected in both plants. Within the Figure 3 two typical pictures captured during floc observation are reported displaying *M. parvicella* detected with Gram stain at 1000 x magnification.

4 CONCLUSION

In this work, the main rheological properties of AS were measured at different concentrations, thus simulating different stages of WWTPs, i.e. from biological reactor up to the digested sludge. A strict and defined protocol was carried out involving both the experimental measurement and the data processing: This is a key point for tests consistency and data comparability. Milestones for the rheological analysis were the determination of the rheogram (both upload and download cycle) together with the hysteresis area and the calculation of the viscosity at a set shear rate. As result, two sludges showed a quite similar rheological trend: i) both evidenced a non-Newtonian behavior, perfectly fitting with Herschel-Bulkley model, ii) a clear hysteresis loop was determined, as wider as higher the solid concentration, and iii) viscosity was determined at 100 s^{-1} shear rate with values of a few mPas for AS in the biological reactor up to hundreds of mPas for a digested sludge. In conclusion, the solid content was the driving factor affecting rheological characteristics. In particular, the viscosity increased with dry solids concentration in sludge according to an exponential law which means a heavy boost of viscosity along the sludge treatment line. The viscosity was used as a tool to provide information also on the microbiological characteristics of AS and specifically to qualita-

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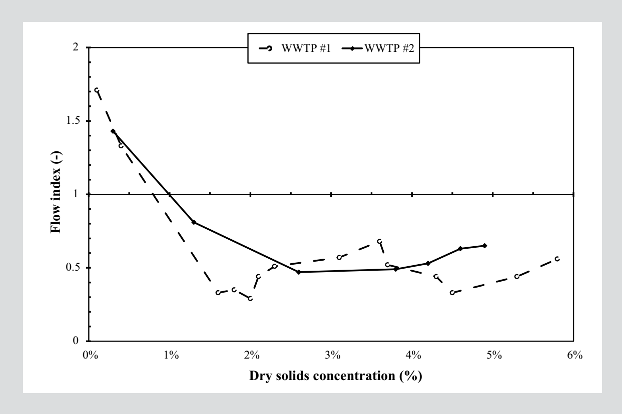

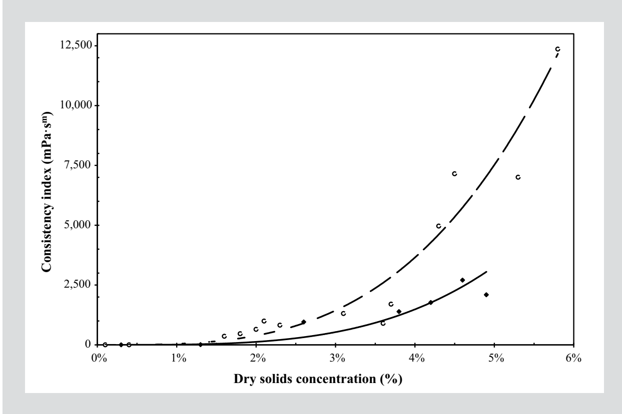

Figure 4: Flow index reduction (left) and consistency index increase (right) as a function of dry solids concentration of sludge.

tively foresee the amount of filamentous bacteria. Both tested sludges were characterized by elevated viscosity values, which corresponded to an over-proliferation of filamentous microorganism. Finally, as general outcome, this research evidenced that viscosity is a useful parameter whenever assessing CAS systems, and should be measured in order to properly design plant features (such as reactors, pipes, ...) and to obtain information on sludge settleability properties together with the traditional microbiological analysis of AS flocs.

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