Experimental assessment of the effect of Organic Matter on the flocculation of freshwater sediments.

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Abstract: In this work, the shear rate, the concentration and type of organic matter were related to the flocculation processes in samples of the longest river in Mexico, the Usumacinta river, and compared with the performance of samples extracted of aquaculture tanks at the "Centro Acuícula El Zarco", which was theorized to be organically differently composed. It was concluded that the river contained a heavy charge of Dissolved Organic Matter (DOM), which is one of the main property of rivers. On the other hand, El Zarco samples contained a heavy charge of Particulate Organic Matter (POM) due to the biological activity and algal presence.

The sediments of the Usumacinta river have a strong relation with the breakup and stabilization of flocs diameters, attributable to the presence of Humic Substances (HS) in the DOM. On the contrary, the El Zarco sediments tends to form bigger flocs diameters under the same hydrodynamics conditions. In addition, the estimation of the floc size is another index to relate to the organic matter charge and the annular flume hydrodynamics.

The results confirmed that according with the concentration and type of organic matter the flocculation processes are affected. The El Zarco sediments prove conclusions of previous studies where the presence of POM like algae enhanced the adhesion capacity between particles due to the influence of extracellular polymeric substances (EPS), the results show that the initial diameter of these flocs increase by 28%. At opposite the sediments of the Usumacinta River proved being rich in DOM, confirming that this river freshwater contains HS and hence stabilizes the flocs diameters which increase in less amount

Keywords: Cohesive sediments; flocculation; organic matter; freshwater; rotating annular flume

1. Introduction

The cohesive sediments transported by rivers in the form of aggregates is a complex matrix of microbial communities and organic and inorganic material [1].This process is called flocculation which is a dynamic and complex process in which physical, chemical and biological conditions interact [2].

Lately, flocs in natural environment have been characterized by their diverse composition consisting of inorganic and organic materials, xenobiotic substances, oil droplets and pore space and water. The interest in the effect of the organic matter concentration in flocculation processes has become relevant due to the imminent climate change, rising global temperature and anthropogenic activities which affect freshwater and estuaries, triggering variations in the characteristics of water, modifying the organic matter concentration in the stream. These modifications influence flocculation and hence the final deposition of the sediments.

Different forms of Organic matter are present in freshwater environments; solid particles in suspension like plant detritus, death microorganisms, excreta, living organisms (algae and bacteria) that can be measured by the POC (particulate organic carbon), also DOC (dissolved organic carbon) in the form of organic molecules like sugars, aminoacids, humic acids. The type of OM present in flocs can enhance the flocculation process, for example the polymeric substances (EPS) are crucial in the polymeric bridge aggregation mechanism [3]. Also Deng et al.[4] show an aggregation mechanism consisting in the formation of polymeric networks built by microorganisms. Flocs with high content of OM favour growth of phytoplancton and invertebrates communities that produce EPS [5-6].

In this research samples from two sources of cohesive sediments with different kind and composition of organic matter were analyzed in order to contrast the effect of the OM in the flocculation mechanisms. Samples of cohesive sediments from the longest river in Mexico, the Usumacinta river, were compared with samples extracted of aquaculture tanks at the “Centro Acuícola El Zarco”, Two different measurements of OM was performed with the samples, Particulate Organic Carbon (POC) by gravimetric method using samples filtered in 0.7 µm.meshes and Dissolved Organic Carbon (DOC) using a TOC analyser.

Experiments in a Rotating Annular flume (RAF), with plexiglass walls to allow optical techniques, were performed in order to analyse the flocculation mechanism of the sediments. A Particle Tracking Velocimetry (PTV) equipment was used, consisting of laser sheet that illuminates the flocs used as tracers and a CCD digital camera that captures images. It was possible to obtain the change in flocs diameter during long term experiments.at different shear rates and to relate those changes with the Organic Matter content and type of the samples..

2. Materials and Methods

2.1. Sampling campaigns

Suspended cohesive sediments were sampled in the Usumacinta River in Centla, Tabasco, upstream from the confluence with the Grijalva river (see figure 1). Chichicastle station with coordinates 18° 18.36’ N and 92° 26.69’ E, is located in the Usumacinta river 24 km upstream the rivers junction at Tres Brazos.

During the months of November and December 2023 a sampling campaign was launched. Suspended sediment concentration profiles were obtained at different water columns in the cross-sections defined at the sampling site. At least three vertical profiles were taken at the sample site, and point samples were obtained with a Van Dorm bottle each 50 cm. In addition, at each sampling site, when taking the vertical samples, 50 L were collected for the rotating annular flume (RAF) analysis [7].

Also, 50L samples of water and sediments were obtained from El Zarco aquaculture tanks. It is a trout production plant located midway between Mexico City and Toluca at an elevation of 2850 msnm.

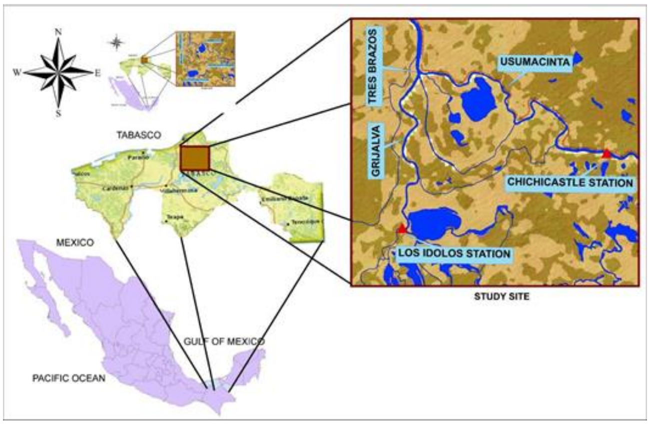


Figure 1. Usumacinta River sampling station.

2.2. Organic Matter measurements of the samples

POC

A gravimetric test was conducted to measure the Total Suspended Solids (TSS) and the Particulate Organic Carbon (POC), known in this test as Volatile Suspended Solids: VSS. The test was performed using glass fibre filter with a pore size of 0.45 µm. Each sample was repeated three times to ensure reliable results.

The procedure followed the Standard Methods for the Examination of Water and Wastewater, especific procedures are described in [8].

DOC

The samples were analysed in a TOC analyser model TOC – L of the branch Shimadzu. In these tests were measured Total Carbon (TC), Inorganic Carbon (IC), Organic Carbon (OC) (also called Dissolves Organic Matter: DOM) and Total Nitrogen (TN).

Samples from the study sites were poured in 250 ml plastic bottles. A 10 mL aliquot of each sample was transferred to centrifuge tubes and centrifugated at 4,000 RPM, causing smallest particles settled into the bottom of the tubes. Subsequently, the tubes were placed in the autosampler of the TOC analyser, which was programmed to obtain the results.

2.3. Flocculation experiments

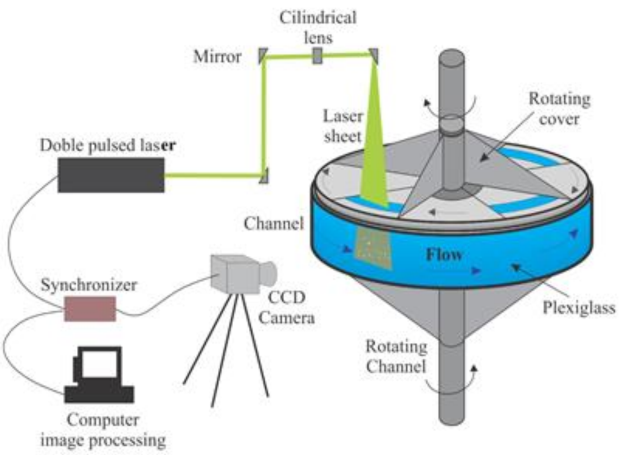
The sediment characteristics, like floc size variation in time and settling velocity for different floc diameters of the river and from El Zarco, were obtained in the RAF. The hydrodynamic conditions prevailing in the river were reproduced (same u*) and the flocculation process was studied during long range experiments in the RAF. The Rotating Annular Flume (RAF) is made of Plexiglass and has a 1.3 m diameter and a flume cross section of 15 cm x 15 cm (figure 2).

A laser sheet was introduced from above using a double pulsed Nd:Yag laser (15 mJ), high speed CCD cameras JAI (250 fps and resolution and 1600 x 1400 pixels) were mounted laterally to the channel and synchronized by means of a NI-PCIE-1430 card with laser pulses. Both cameras were equipped with 50 mm NIKKON lenses

The cohesive sediments were analyzed during 2 hour long experiments and images were taken each 15 minutes. The PTV method was used which implies two procedures. The first one improves image quality through spatial filtering. The second procedure is detecting particles in each pulse.

Experiments in the RAF using samples from El Zarco and Usumacinta river were performed at shear rates similar to those encountered in the field.

Figure 2. Rotating annular flume (RAF) and PTV set-up.



3. Results

Figure 3 summarizes the results of the Total Carbon Analyzer (TOC) for the samples of the Usumacinta River and from El Zarco. It can be observed that the Dissolved Organic matter (DOM) is larger in the Usumacinta river samples than in El Zarco.

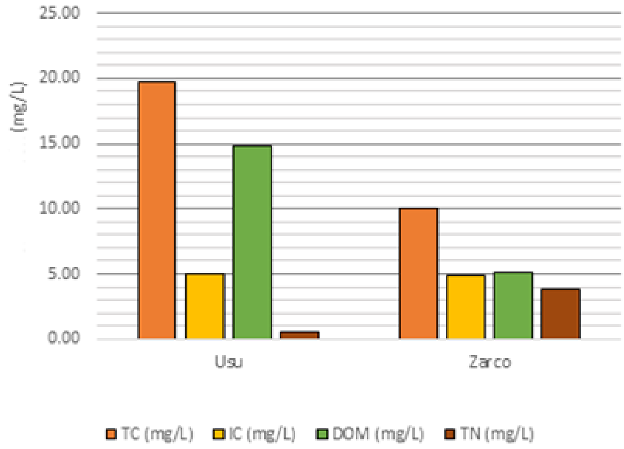


Figure 3. Total Carbon (TC), Inorganic Carbon (IC), Dissolved Organic Matter (DOM), and Total Nitrogen (TN) Results from TOC Analyzer for both Samples.

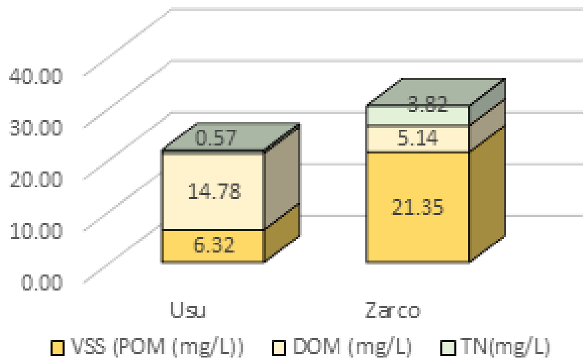


Figure 4. Organic matter in the Usumacinta River and El Zarco. Sum of VSS, DOM and TN.

Figure 4 presents the results of Particulate Organic Matter measurements. It is observed that POM concentration is 3.4 larger in the El Zarco flocs than in the usumacinta river flocs.

Results obtained in the Rotating annulaer flume (RAF) are presented in figures 5 to 8 for the El Zarco samples. It show the change in flocs diameter at different times during te experiments. It can be observed that using a shear velocity of 3.2 cm/s the floc diameter increases by 25% in average (figure 5).

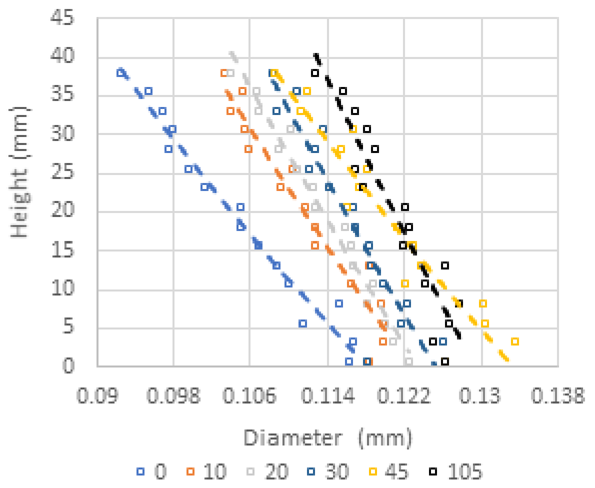


Figure 5. Average Diameter vs. Height for El Zarco sediments in experiments

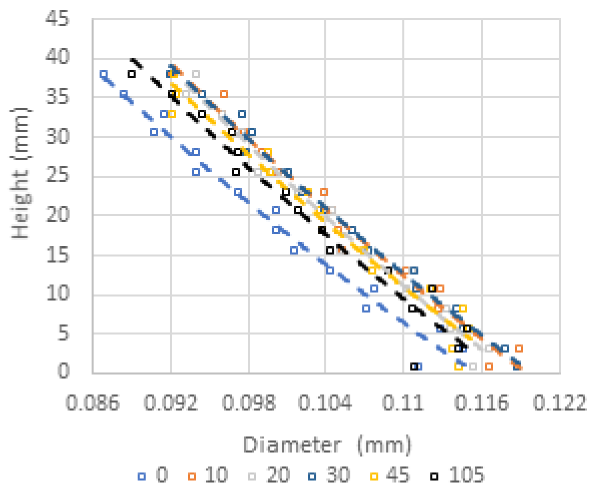


Figure 7. Average Diameter vs. Height for El Zarco sediments in experiments

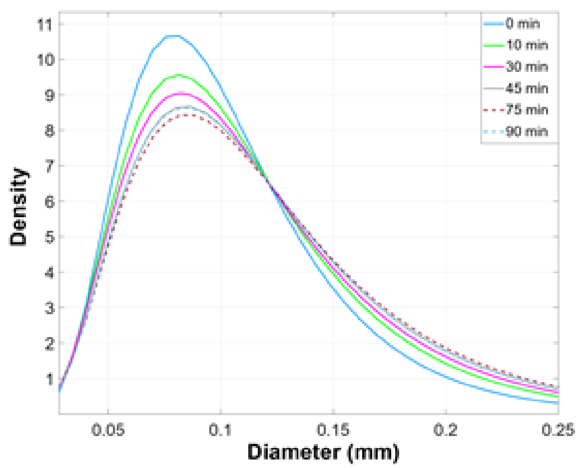


Figure 6. Log – normal curve for El Zarco sediments in experiments

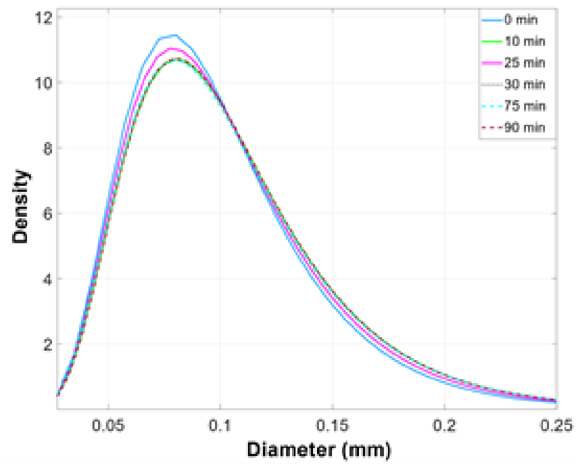


Figure 8. Log – normal curve for El Zarco sediments in experiments

When the shear velocity is increased to 4.4 cm/s the increase in flocs diameter is reduced by the effect of floc breakage. The average increase is only 6% (figure 7).

In the case of the El Zarco samples when the flocs diameter (df) change with respect to the initial diameter of the flocs (d0) is plotted against the time of the experiments (figure 9), it is observed that for moderate shear velocity (3.2 cm/s) there is a continuous increase in floc diameter, but for large shear velocity (4.2 cm/s) there is flocs breakage after 30 minutes.

Results from Rotating Annular Flume (RAF) are presented in figures 10 to 13 for the Usumacinta river samples. It show the change in flocs diameter at different times during te experiments. It can be observed that using a shear velocity of 3.2 cm/s the floc diameter increases by 15%. In average(figure 10).

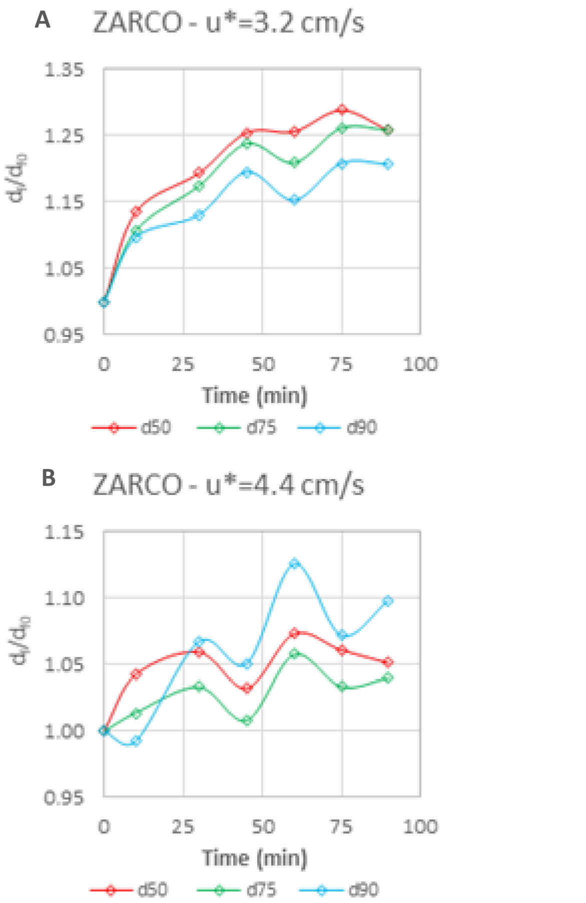


Figure 9. Characteristic diameter for El Zarco River sediments in experiments a) and b)

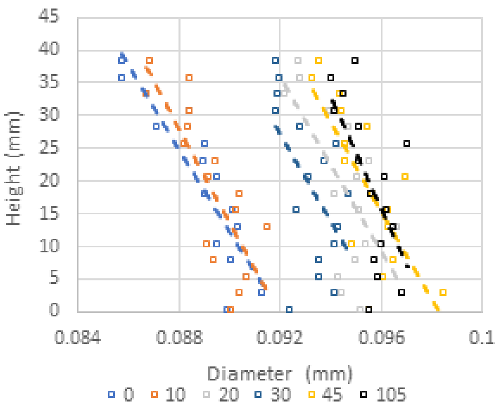


Figure 10. Average Diameter vs. Height for Usumacinta River sediments in experiments

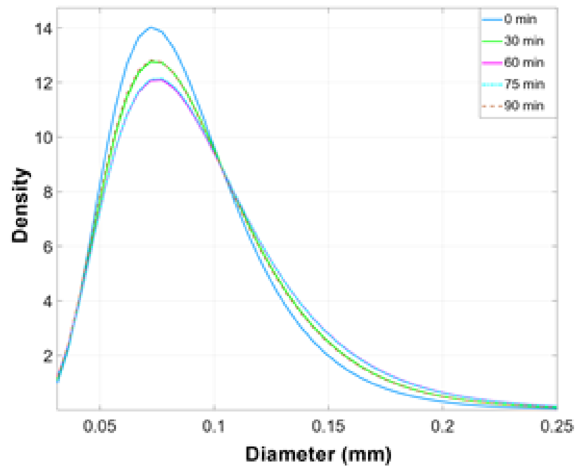


Figure 11. Log – normal curve for Usumacinta River sediments in experiments

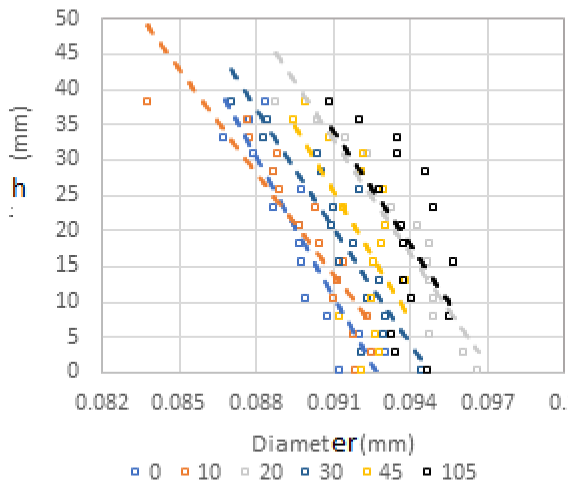


Figure 12. Average Diameter vs. Height for Usumacinta River sediments in experiments

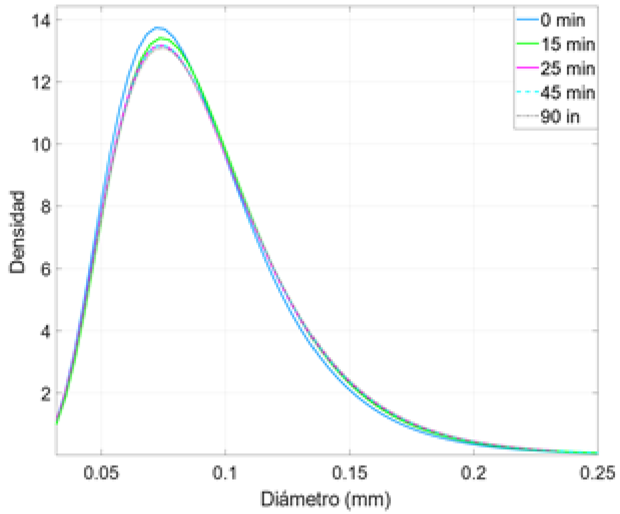
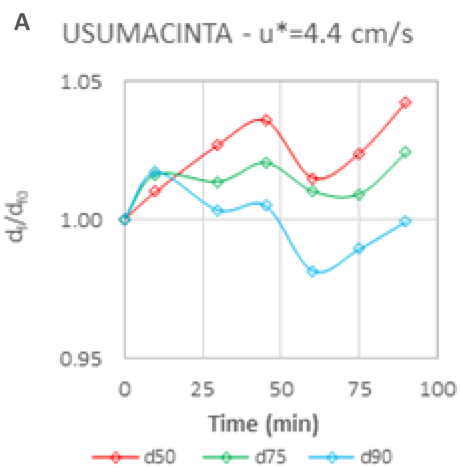


Figure 13. Log – normal curve for Usumacinta River sediments in experiments

In the case of the usumacinta river samples when the flocs diameter (d_f) change with respect to the initial diameter of the flocs (d_0) is plotted against the time of the experiments (figure 14), it is observed that for shear velocity (3.2 cm/s) there is a continuous increase in floc diameter, but for large shear velocity (4.4 cm/s) there is flocs breakage after 30 minutes.



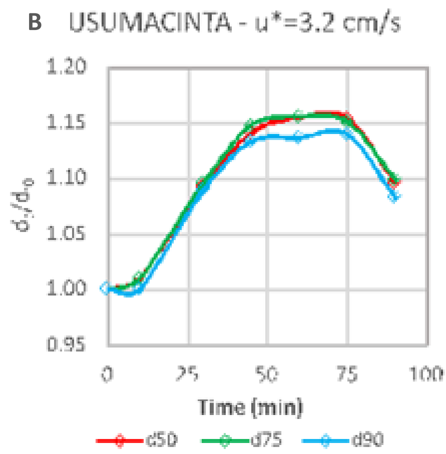


Figure 14. Characteristic diameter for Usumacinta River sediments in experiments a) and b)

4. Discussion

Figure 15 shows that In the case of U*=3.2 cm/s, the larger growth of flocs diameter was for the El Zarco sediments (until 28%) of the initial diameter) in contrast with the Usumacinta river sediments where the growth is only 15% of the initial diameter. This result shows the effect of Organic Matter in particulate form (POC) which is much larger in El Zarco sediments than in Usumacinta river sediments.

The characteristic of some alagae ,like the mucilage layer that surrounds the cells of S. convergens increase their effectiveness in being adhered to by clay particles [9]. Previous studies have suggested that the aggregation between clay particles, bacteria and algae is due mainly to the presence of extra celular polysaccharides [10-11].

In the case of U*=4.4 cm/s, the larger growth of flocs was for El Zarco sediments (until 8% of the initial diameter) in contrast to the Usumacinta River sediments where the growth is only 5% of the initial diameter. The effect of turbulence in flocs breakage is present in this larger shear rate. The OM effect is still present but the larger amount of DOC in Usumacinta river sediments difficult the growth of flocs during the experiments.

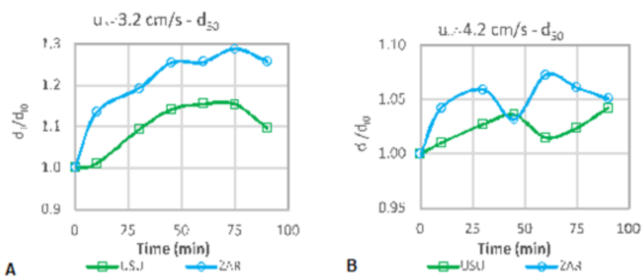


Figure 15. Characteristic diameter for Usumacinta River and El Zarco sediments in experiments A) y B)

Results show that when shear rate is moderate (u*=3.2 cm/s) the relationship between suspended solids and OM is important for flocculation as stated by [12]. El Zarco sediments aggregated in larger amount than Usumacinta river sediiments which is related with the larger POC of the formers.

The presence of algae and EPS in the El Zarco sediiments prove that the large polymeric chains created by them enhance the flocculation [4].

5. Conclusions

Flocculation experiments, performed in a Rotating Annular Flume, of freshwater sediments from different environments; a large river near its mouth (Usumacinta river) and an aquaculture tank for trout growth, demonstrated the contrasting effect of the type of Organic Matter. In the river case the larger amount of DOM inhibits large growth of flocs and in the aquaculture tank the larger presence of POM enhances the flocculation by the mechanism of polymeric bridges.

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