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A Miniature Wastewater Cleaning Plant to Demonstrate Primary Treatment in the Classroom

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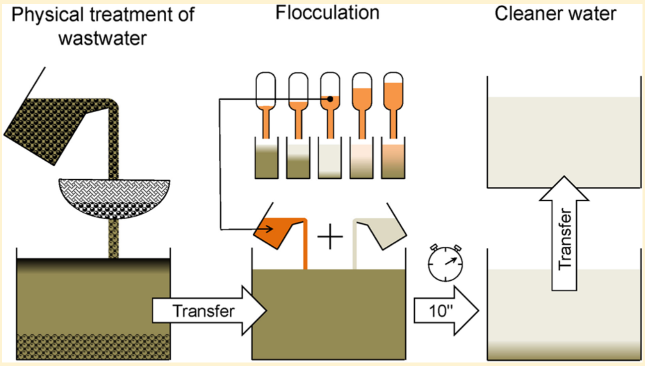
Supporting Information

ABSTRACT: A small-scale wastewater cleaning plant is described that includes the key physical pretreatment steps followed by the chemical treatment of mud by flocculation. Water, clay particles, and riverside deposits mimicked odorless wastewater. After a demonstration of the optimization step, the flocculation process was carried out with iron(III) chloride and a cationic polyelectrolyte and lasted less than 10 s for 7 L of wastewater. This experiment is primarily targeted toward high school students to give a real world demonstration of solution and colloid chemistry, but is also useful for a more general audience. The demonstration has already been successfully presented to 700 visitors.



KEYWORDS: *Elementary/Middle School Science, High School/Introductory Chemistry, General Public, Environmental Chemistry, Public Understanding/Outreach, Colloids*

INTRODUCTION

As water is flowing freely out of the water taps of industrialized countries, hundreds of liters of water per person per day are injected into sewer systems (e.g., 400 L/(day × person) in Geneva). In Switzerland, 95% of this water is treated in wastewater treatment plants (WWTP) before being released into the environment where one relies on natural processes for the final cleanup. Modern WWTP act in several steps: during the Primary Treatment, solid debris, oily matter, and colloidal clay particles are removed; the Secondary Treatment consists of feeding the dissolved organic matter to microbial cultures which then settle out; and finally, the Tertiary Treatment removes dissolved nitrogen and phosphorus species.

This demonstration is targeted primarily to high school students accompanied by their teachers to appreciate a real world application of colloid and solution chemistry. The Chimiscope (the chemistry outreach demonstration platform at the University of Geneva, Switzerland[1,2]) designs 1-h visits for the edutainment of the general public or for out-of-school activities of visiting classes. The module "Environment | Chemistry" offers a complement to the education provided by the teacher at the appropriate education level. As part of this effort, this demonstration was created to allow for the visualization of the Primary Treatment of a water cleaning process using synthetic wastewater, omitting the microbial purification step. Since the U.S. National Environmental Education Act of 1990 encourages teachers to provide basic knowledge in environmental engineering, which encompasses water treatment,[3] the demonstration is also useful for a more general audience, for example in combination with a filtration experiment that can illustrate the production of drinking water.[4] Depending on the age of the students, any explanation given by the demonstrators should be adapted to the scientific education level of the group.

This demonstration is repeatable, its reagents can readily be stored, it requires minimal cleanup, it can be carried out in a 15 min time frame, and it is visually compelling: it is therefore more useful for such pedagogical purposes than prior reports. Despite the importance of colloid science in applied chemistry,[5,6] previous reported demonstrations were either slow[7] or had limited visual interest.[8] In this demonstration, to enhance the visual impact, red clay and dark river deposit-based mud flocculated with iron(III) chloride and the commercially available polymeric flocculant Ensola 8561 are used to demonstrate the principles of wastewater treatment. Importantly, the flocculating polymer, a linear cationic polymer based on acrylamide, is used industrially in WWTP.[9] The demonstration articulates the consecutive steps in the evolution of a batch of dark muddy water to its final release in the environment.

MATERIALS AND METHODS

Hardware and Reagents

Figure 1 shows the minimum necessary materials needed for this demonstration. A full description of the hardware and reagents can be found in the Supporting Information.

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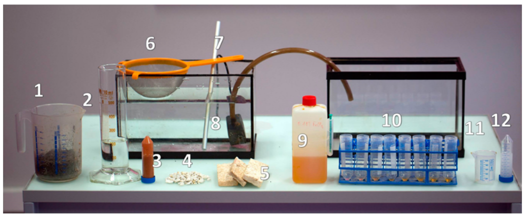

Figure 1. Minimum materials and reagents for the experiment: 1, beaker with 500 mL of riverside deposits; 2, clear water; 3, clay suspension; 4, gravels; 5, polystyrene blocks; 6, kitchen sieve; 7, bar for manual stirring; 8, aquarium pump; 9, $FeCl_3$ 0.1 M; 10, rack for 50 mL tubes containing an increasing dose of iron(III) chloride 0.1 M (0.1 to 1 mL); 11, beaker to measure and pour the iron(III) chloride; 12, diluted polyelectrolyte solution (Ensola 8561). Two recipients are also needed: we use here two 12 L aquarium tanks.

Wastewater

For the demonstration, a wastewater model system was prepared by combining some gravel, 10 L of water, 500 mL of Arve riverside deposit, and 40 mL of sonicated clay. Some vegetable or mineral oil can be added to simulate the oily residues, although oil adds difficulty to the cleaning. Instead, we use polystyrene packaging blocks to simulate supernatant oil (see Figure S3).

■ HAZARDS

The artificial wastewater is made from nontoxic materials and does not present any health threat. The flocculants may irritate skin and eyes. Their handling requires the use of protective goggles, chemical barrier gloves, and a lab coat. Moreover, in the case of spillage of the polymeric flocculants, the surface can become slippery, but the material can be readily absorbed with absorbent paper and any spill residue can be cleaned with soapy water.

■ DEMONSTRATION

Sieving

The initial purification step involves the demonstrator pouring the model wastewater through the kitchen sieve to retain rough solids (Figure 2) into the first aquarium. It is further useful to combine a volume of tap water with the model wastewater to demonstrate that WWTP utilize a single process to treat both reasonably clean water and significantly contaminated water (see Figure S4). (Note, if using polystyrene blocks as the oil simulant, they must be added post sieving, whereas oil can be added before sieving.)

Figure 2. Beaker containing gravel and part of the wastewater (here, clay) is poured into the kitchen sieve in order to retain the gravel.

Decantation/Oil Removal

The second purification step includes a decantation to remove the sediment that passed through the sieve (typically, sand-like residues) after allowing them to settle at the bottom of the aquarium tank. The oily residues (here the polystyrene) form a layer on the top of the water. Thus, to separate muddy water from in between the sediment and oil layers, an aquarium pump is used with the intake submerged to just above the sediment layer with the output being pumped into a receiving tank. The sedimentation (physical step of the treatment) of the incoming water is a reasonably rapid process. In wastewater treatment plants, the material deposited on the bottom is evacuated through an Archimedes' screw. Here, on the other hand, the material will remain on the bottom of the tank after pumping the supernatant water to the next aquarium tank (see Figure S5). The polystyrene blocks remain on top, analogous to the oily residue.

Flocculation

The third purification step must remove the remaining suspended residue from the wastewater. This is accomplished using chemical flocculating agents. Flocculation comprises the aggregation of charged colloids suspended in solution. Here, the negatively charged species (mostly clay) are aggregated by the positively charged flocculant. While a small dose does not provide sufficient treatment, an excessive dose also prevents effective formation of flocs. Thus, one must determine the optimal concentration above the Critical Coagulation Concentration, CCC, and below the Critical Resuspension Concentration, CRC.

To ensure complete reaction, the partially purified wastewater should be vigorously stirred. Just as in a real wastewater treatment plant, the water must be tested to determine the optimum quantity of flocculant to be added. Here, we demonstrate the optimization of iron(III) chloride as the flocculant. Eight wastewater samples (45−50 mL each) should be extracted (manually or with a pump) from aquarium tank #2 into Falcon tubes preloaded with varying aliquots of 0.1 M aqueous $FeCl_3$ (see Figure 3 and caption). The tubes are then shaken vigorously. The extract/flocculant samples should be placed in a rack for parallel observation to demonstrate the effect of increasing flocculant concentration.

As shown in Figure 3, below 1 mM, there are particles left in suspension, while above 1 mM the excess of iron(III) chloride

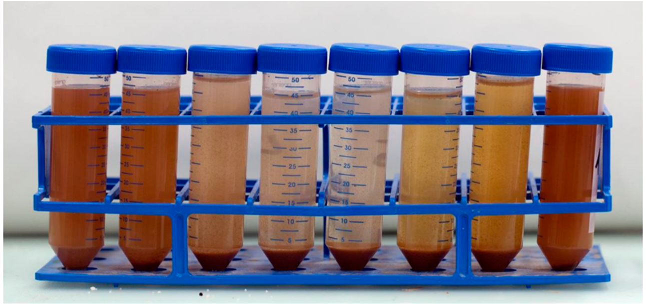

Figure 3. Effect of iron(III) chloride addition on the flocculation of the mud of the second tank. The final concentrations in the tubes are, from left to right, 0, 0.2, 0.6, 0.8, 1, 1.2, 1.4, and 2 mM $FeCl_3$ in the 50 mL samples.

is visible first through a more yellow solution, and subsequently through a resuspension of the colloids. Thus, for our artificial wastewater, the optimal dosage is 10 mL of the 0.1 M iron(III) chloride solution per liter of muddy water. The volume of the remaining wastewater should be 7 L for the preparation described here, and the proportional amount of $FeCl_3$ solution necessary for maximal flocculation (here 70 mL) is then slowly added to the suspension in the aquarium tank under vigorous stirring (see Figure S7). After a stirring period of ca. 30 s, 30 mL of the industrial flocculant (see Figure S8) is added to create large flocs (more than 2 mm diameter). After flocculation, the stirring is stopped and the residue is allowed to settle (see Figure 4), resulting in a clear supernatant. When only aggregated with iron(III) chloride, the flocs are small (less than a millimeter in diameter).

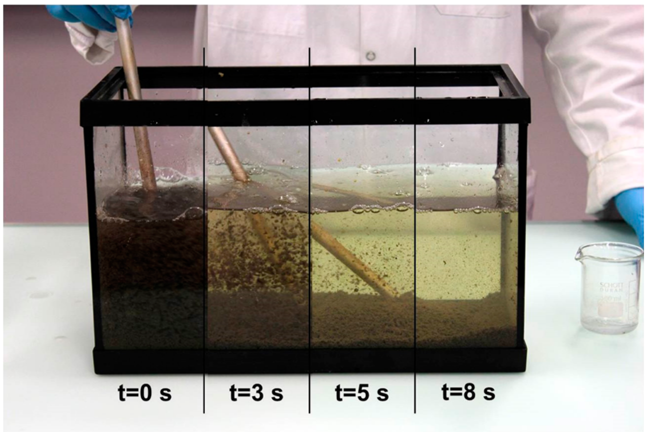

Figure 4. Evolution over time of the visual quality of the water when the stirring is stopped. The residual yellow color is due to a slight excess of iron(III) chloride.

The clear solution can then be transferred to a final reservoir using a pump mounted on a floating device made of polystyrene to separate the purified water from the flocculant residue. (See Figure S9 for the difference before/after flocculation.) The water would now be ready to be sent through microbial treatment to consume residual organic matter, before being released as clean water into the environment.

CONCLUSION

This small, rapid, and reliable demonstration including the required chemical flocculant optimization provides a useful wastewater treatment plant model that can be used to introduce the students to different issues relative to wastewater treatment. This experiment has been conducted by a dozen different demonstrators and performed in front of approximately 700 students aged 12 to 25 since 2014, in both English and French. It was also presented to decision-makers in Environmental policy from different countries at the science fair of an international conference and has been featured on Swiss Television.[10] The quick flocculation of the wastewater is dramatic and visitors regularly describe this step as "impressive", clearly providing visual illustration of a process too often taken for granted. We believe that similar demonstrations can easily be set up with locally harvested mud.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00291.

Detailed "Hardware and Reagents" section and additional pictures (PDF)
Movie of the flocculation step (MPG)

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Notes

The authors declare no competing financial interest.

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