

Ohmsett Wastewater Treatment and Response to High Volumes of Cement Runoff

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Abstract

Management and proper treatment of hazardous materials on large-scale construction sites present logistical and personnel challenges. These efforts are further complicated in high precipitation areas where large volumes of wastewater runoff are generated daily. Storage, treatment, and removal of large volumes of wastewater can become costly with internal man-hours or external treatment services. The development of low-budget, on-site methods can be advantageous to meet project goals and regulatory limits.

Ohmsett, The National Oil Spill Response Research and Renewable Energy Facility, is an environmental test tank in New Jersey. It spans 203.3 meters (667 feet) in length, 19.8 meters (65 feet) wide, and 3.4 meters (11 feet) deep totaling 9.8 million liters (2.6 million gallons) with the water depth being near an operational height of 2.44 meters (8 feet). During the recent tank refurbishment, the Ohmsett staff removed over 2.1 million gallons of wastewater for temporary storage or in-line treatment determined by total suspended solid loads in cement runoff containing silicon dioxide (sand) and calcium sulfoaluminate (cement).

Chemical treatments of cement runoff include application of coagulants and flocculants to destabilize suspended particles and increase the particle size to allow settling. Water quality parameters can be used to measure effects of treatment methods and determine the ability of the treatments to decrease dissolved and particulate suspended solids at a range of particle sizes. Coagulation and flocculation treatments of cement runoff were successful to remove suspended solids to below regulatory limits at laboratory scales (liters) and mesoscales (10^2 L). The effectiveness of suspended solid removal was largely influenced by the temperature and pH of wastewater, and will be considered primary controls on future large-scale treatment efforts (10^3 L) at the Ohmsett facility. High suspended solid loads are a mechanical and biological threat to wastewater treatments, therefore, the development of effective on-site treatment methods at Ohmsett will be useful for future refurbishments and other large-scale construction and testing facilities.

1 Introduction

Resurfacing the Ohmsett test tank during 2021-2022 required the application of MortarCrete® (TNEMEC Series 217) over the tank floors, walls, and walkways. MortarCrete is composed of crystalline silica (quartz) or silicon dioxide (SiO_2), a known human carcinogen (IARC, 2012), and calcium sulfoaluminate ($\text{Ca}_4(\text{AlO}_2)_6\text{SO}_4$) solids dissolved in formaldehyde (MortarCrete SDS, 2018). Calcium sulfoaluminate or CSA differs from ordinary Portland Cement (OPC) as it sets and hardens rapidly, has a low risk of shrink or cracking, and is resistant to sulfate.

However, CSA has been found to have a coarser pore volume than OPC and requires the addition of supplementary cementitious materials (SCMs) to decrease the pore diameter of CSA cement paste (Ke et al., 2021). The incorporation of quartz to CSA in MortarCrete reduces pore diameter thus increasing resistance to air and aqueous compounds such as chloride, which was

found to have penetrated Ohmsett tank walls and caused rust damage to the rebar structure.

Resistance of these cement paste compounds to environmental conditions leads to their persistence when suspended in water. Quartz, used as SCM, is commonly nanometer-size lengths to increase the strength of concrete (Schoepfer & Maji, 2009). Cement runoff is generated from a variety of sources in the environment including highways, bridges, and construction sites. Large volumes of cement runoff are generated as stormwater during high precipitation events containing a variety of pollutants and heavy metals (Barrett et al., 1998). Much of the particulate load gathered during storm events can be captured in the initial volumes, however, most retention technologies are not able to remove small particles/solids (<20 μm) from suspension (sediment) (Li et al., 2006). These small suspended solids are of particular concern due to large surface area to volume ratios allowing adsorption of pollutants to surfaces (Langmuir, 1997).

Chemical treatments for these suspended particles include coagulation, a chemical process involving the destabilization of stable suspended particles and flocculation, a physical process with the goal of settling by increasing particle size (Maria, 2016). These treatment methods are particularly important for colloids, small particles with a negative surface charge and 1 nanometer (nm, 10^{-9} meters) to 200 nm diameters (Pabasara, 2017). Chemical treatment of coagulant is successful when the colloidal suspension becomes destabilized, losing repulsive (stable) capabilities in solution and allow for the agglomeration of small particles which increases settling (Bratby, 2016).

Aluminum coagulants have been tested effective at removing fine particles in urban runoff using low-intensity dosages to meet state discharge limits (Trejo-Gaytan et al., 2006). High dose coagulation techniques have also been applied (Kang et al., 2007) but require additional pH regulation following treatment. During addition of coagulants, small particle destabilization is often accompanied with lower pH and changes in redox potential which can be optimized to reduce the amounts of solids in solution (Sansalone and Kim, 2008). Inorganic coagulants have been used in conjunction with organic polymers, (DeWolfe and Foundation, 2003) which have the ability to increase particle sizes (flocculation) during sequential rapid and slow mixing cycles. Powdered activated carbon (PAC), an organic compound commonly used for removing organic material in wastewater (Newcombe, 2006), may increase flocculation in suspension through adsorption of particles to surface.

Categories of particles in cement runoff can vary but can be classified using standard water quality methods and definitions. Total suspended solids (TSS) are particles present in the water column that are larger than 2 microns, while dissolved solids (TDS) are smaller in particle size (Fondriest, 2014). Although a portion of the total solids (TS) includes heavy particles, such as gravel and sand, those such as silt and clay that do not settle, are examples of TSS. TSS exists as nonsettleable solids or colloids if small particle size falls in the range of 1-200 nm and retains insolubility (Pabasara, 2017). Size fractions of solids can be summarized as: TS (settleable) > TSS (> 2 μm , suspended and insoluble) > TDS (< 2 μm , suspended solids – soluble > colloids (< 1 μm , suspended solids - insoluble) > salt (dissolved).

To determine presence of these size particles, multiple approaches are required. Turbidity is a measurement used to determine the presence of suspended solids in a solution. It utilizes the incidence of light scattering when emitted light comes in contact with a sufficiently sized particle to change its course of travel at specified angles (USGS, 2017). Increased turbidity will result in increased source light deflection and less source light taken up or absorbed by the particle (Figure 1).

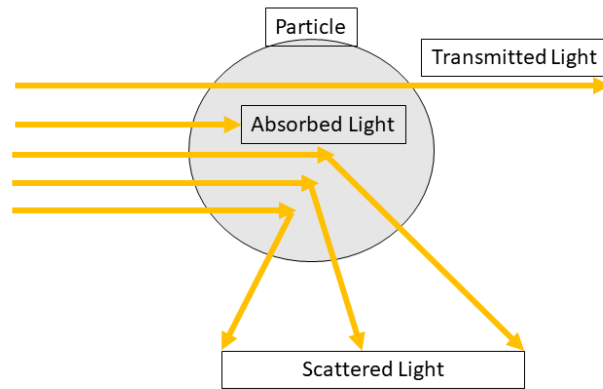


Figure 1 Light scattering, absorption, and transmission from a turbid particle

Nephelometric Turbidity Unit (NTU) and Formazin Nephelometric Unit (FNU) are the most common units of measurement for turbidity meters and are determined by wavelength used and the angle at which the beam is detected (USGS, 2017). For this study we used NTU and smaller ($< 2 \mu\text{m}$) particles unable to be detected using incident light (e.g., TDS) that can be measured electrochemically. Conductivity is the ability of water to pass electric current through dissolved solutes (salts). As TDS measurements can also detect ionized (positive or negative) and neutral colloids (IC Controls, 2014) it is possible to have a low conductivity water sample but high colloidal TDS.

Quartz behaves as a colloid and can be dispersed in water and exist as negatively charged particles that require expensive filtering equipment (osmosis filtration) to remove it from water (Oh et al., 2018). CSA particles tend to exist in sizes greater than $1 \mu\text{m}$ depending on the composition of silica and other minerals (Jeong et al., 2017). At these sizes, CSA particles can be filtered. However, they are present in a lower percentage weight than background quartz (neutral, $< 1 \mu\text{m}$) (MortarCrete SDS, 2018) passing through most filtration units. These materials were used during the Ohmsett tank refurbishment and thought to be present in the cement runoff (rainwater) collected and stored in large volume (10^3 L) frac tanks. Quartz and CSA in MortarCrete are synthesized for high stability. However, chemical treatment of particles can change pH, electrochemical conditions (oxidation-reduction potential (ORP), and particle element ratios (Gao et al., 2002), causing particles to destabilize and increase susceptibility to settling. Laboratory and field method development efforts were undertaken to effectively treat cement runoff (rainwater) from the Ohmsett tank. Chemical treatment methods using metal coagulants (aluminum sulfate) and organic polymer flocculants (powdered activated carbon) were developed at laboratory and mesoscales in order to meet municipal water quality criterion needed for future large-volume discharge of treated water to the sewage authority.

2 Objectives

In order to develop treatment methods and discharge treated cement runoff compounds from the solution, the Ohmsett staff's objectives were to 1) to remove the suspended solids in cement runoff to low turbidity levels in laboratory; 2) to optimize treatment methods for field applications; 3) to develop on-site cement runoff treatment at mesoscale volumes and; 4) to

design cement runoff treatment methods for a large-scale (10^4 L) capacity. As the treatment processes are affected by the temperature, pH, and oxidation-reduction potential (ORP), these parameters were monitored throughout laboratory and field activities. Target characteristics for treated cement runoff included 1) low turbidity levels (<100 NTU); 2) parts per million (10^{-3} g/L) total dissolved solids concentrations and; 3) a pH 6 – 9 range.

3 Methods

3.1 Laboratory Coagulation and Flocculation Tests

Water quality was assessed using the following parameters: temperature, turbidity, TDS, pH, and oxidation-reduction potential (ORP). Turbidity was measured using an OakTon T-100 Turbidimeter by single-point measurements and calibration of four nephelometric turbidity unit standards. Total dissolved solids (TDS), pH, and oxidation-reduction potential (ORP) were measured using a 6PFC^E Ultrameter II (Myron L Company). TDS was measured electrochemically and calibrated using three sodium chloride standards (2027, 3740, and 7860 ppm). pH measurements were calibrated using three standards 4.00, 7.00, and 10.01, and ORP calibrated indirectly from pH = 7.00 standard. Salinity (by conductivity) was measured with YSI Model 30-10 FT calibrated with three sodium chloride (1,000, 7,000, and 10,000 μ S) standards. Temperature was recorded with each water quality measurement to monitor potential effects of laboratory and field conditions. All calibrations were performed and check standards were performed daily to ensure accuracy of the measurements.

Coagulation and flocculation tests included pH adjustments of basic (pH = 9) cement runoff to destabilize colloidal material and the addition of flocculants to allow settling of suspended solids. Laboratory chemicals were chosen based on previous literature, ability for treated wastewater to meet municipal water quality standards, and applicability for treatment of cement runoff at mesoscale and large volumes at the Ohmsett test facility. Optimal dosages of chemicals were determined by municipal sewage water quality standards. Initial efforts of cement runoff laboratory treatment were conducted using glass beakers, stir plates, and stir bars. Small volumes (~ 200 mL and ~ 3.5 L) of wastewater were collected from temporary storage units (frac tanks). In Figure 2, observable results following the addition of coagulant hydrochloric acid (HCl) and sodium sulfate (NaSO_4) (primary chemical treatment) for destabilization of colloids can be seen in the experimental treatment (left) relative to the control (right). These experiments were conducted to test the ability of acidic pH and sulfate (SO_4^{2-}) to destabilize colloidal material and to increase flocculation of cement runoff.

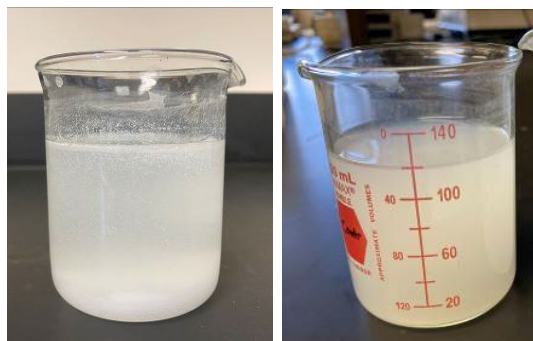


Figure 2 Laboratory pH Destabilization and Sulfate Addition

The application of a commercial coagulant “Drop Out” (aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3$)) was tested at slightly larger volumes (3.5 L) following previous treatments (secondary chemical treatment) in the Ohmsett laboratory. In Figure 3, commercial “Drop Out” was added and the formation of pin-floc was observed (left). Following the additions of “Drop Out,” powdered activated carbon (PAC) was added to test its ability to react and bind to particles to allow settling of suspended solids bound to PAC (tertiary chemical treatment) (right).

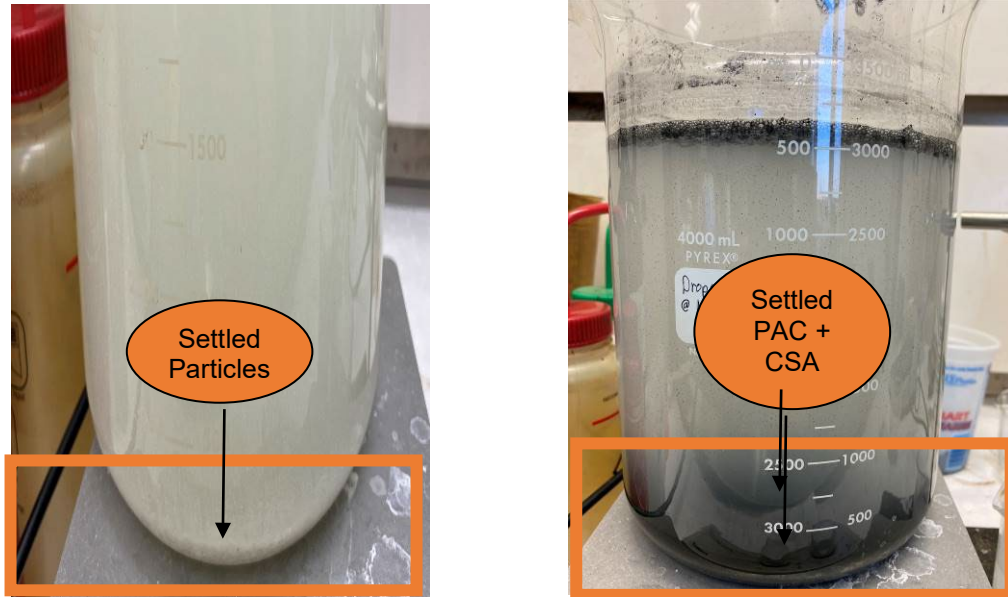


Figure 3 Commercial “Dropout” coagulant and PAC

3.2 Mesoscale Treatment Tests

Medium volume (~2,000 L) tests were conducted in order to pump sequential batches of cement runoff to the local sewage authority. In Figure 3, cement runoff was removed from temporary storage in a frac tank (Figure 4, left) to an induction tank (center, $\sim 10^4$ L). Due to high initial pH and low salinity, pH neutralization and destabilization of colloids was performed using hydrochloric acid and the addition of rock salt (primary chemical treatment). Once a pH was near neutral (pH 7-8), cement runoff was treated with powdered activated carbon (PAC) in ~2,000 L sequential batches (secondary chemical treatment). To induce contact of PAC with CSA/quartz particles, fast mixing and slow mixing cycles were performed manually using shovels (right) followed by a fast mixing cycle with air generated from a double diaphragm pump. Following chelation of suspended particles, PAC and bound particles were allowed to settle.



Figure 4 Primary wastewater treatment phase of cement runoff with PAC

Due to low temperatures, persisting high TDS levels, and small pin-floc formed during primary treatment; a secondary dilution treatment was necessary prior to final (tertiary) treatment. In Figure 5, following the PAC settling, treated wastewater was pumped from the induction tank to a 2,000 L cylindrical tank (top left) using a double diaphragm pump (top right) at ~1,000 L intervals with a low flow rate (20 – 40 L/min). Here treated wastewater was diluted using ~1,000 L from a freshwater tote (bottom left). To remove carryover PAC from transferred wastewater, a 100 µm mesh was placed around the metal cartridge filter (bottom right).



Figure 5 Secondary wastewater treatment phase of cement runoff with PAC in dilution tank

From the dilution tank, wastewater was fed into dual granular activated carbon (GAC) tanks (tertiary wastewater treatment) with four ports numbered to show flow path (Figure 6). Release of treated wastewater to the Township of Middletown Sewage Authority (TOMSA) was controlled by a release valve, with a flowrate of 40 – 80 L/min measured using a turbine flowmeter. Water was collected at the point of discharge and measured for water quality parameters.

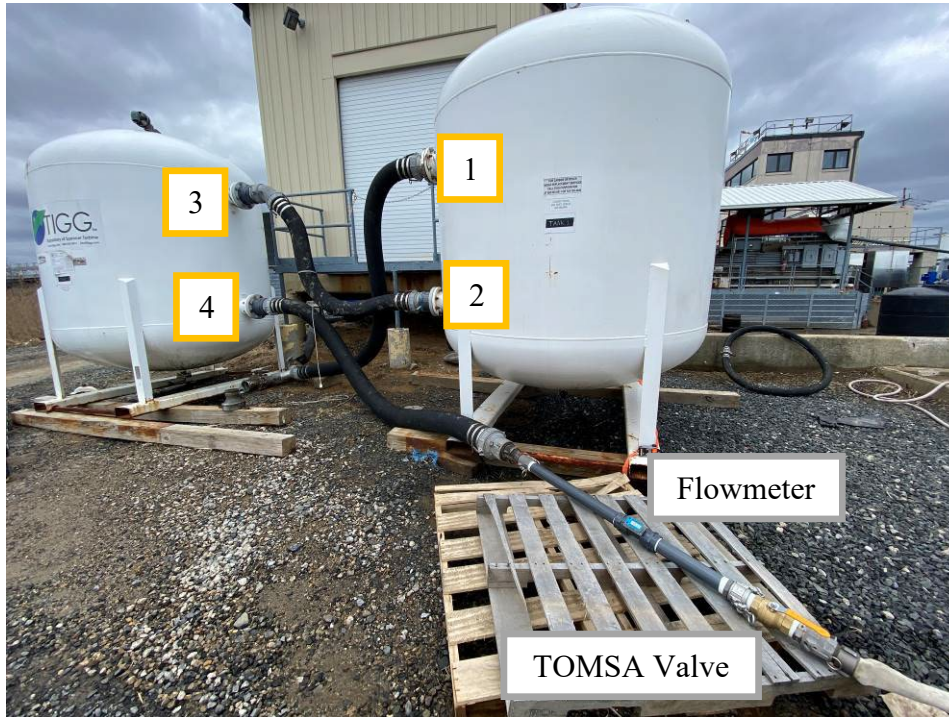


Figure 6 Tertiary wastewater treatment phase of cement runoff with dual-GAC tanks

4 Results

Destabilization of colloid particles in alkaline wastewater (pH 8.8) was performed using concentrated (12 M) hydrochloric acid (HCl) with a final concentration of 0.16 M to reach pH 1.6. However, the addition of HCl dissolved suspended particles (silt) (988 to 968 NTU) increased the concentration of the dissolved solids fraction (2.18 to 13.4 ppt) (Table 1). In addition, HCl addition dissolved TDS to the dissolved salts fraction, increasing the salinity of the solution. Coagulation and flocculation of silicate and aluminosulfate compounds were tested using an addition of sodium sulfate (Na_2SO_4 , 2.2 M). Destabilization of colloids and settling of pin-floc were successful relative to control (Figures 2 and 3) as turbidity levels were decreased by a factor of 2 (Table 1). However, as seen in the HCl addition, TDS concentration increased substantially with sodium sulfate addition, thus impacting TSS concentrations.

Table 1 Laboratory pH Destabilization and Sulfate Flocculation of Cement Runoff

| Treatment | pH | Turbidity (NTU) | TDS (ppt) | Salinity (ppt) | ORP (mV) |
|---------------------------------|------|-----------------|-----------|----------------|----------|
| Runoff | 8.88 | 988 | 2.18 | 1.1 | 195 |
| HCl | 1.6 | 968 | 13.4 | 14 | 693 |
| Na ₂ SO ₄ | 1.6 | 968 | 13.4 | 14 | 693 |
| Steady state | 2.5 | 453 | 88.6 | 38.3 | 441 |

Treatment of cement wastewater runoff was to neutralize pH to allow commercial “Drop Out” coagulant (aluminum sulfate) to act on suspended solids at its optimum pH range of 7.5-7.8. Initial addition of sodium sulfate and sea salt elevated pH and salinity (Table 2) to increase buffering capacity of wastewater (cement runoff suspended in rainwater) before HCl. Following “Drop Out” addition and mixing, a slight decrease in turbidity was observed (946 to 805 NTU). However, once powdered activated carbon was mixed in to allow contact with CSA/quartz particles and allowed to settle, the turbidity of cement runoff decreased approximately by a factor of 10.

Table 2 Laboratory Treatment of Cement Runoff

| Treatment | pH | Turbidity (NTU) | TDS (ppt) | Salinity (ppt) | Temp (°C) | ORP (mV) |
|------------------------------------|------|-----------------|-----------|----------------|-----------|----------|
| Runoff-Untreated | 9.02 | 985 | 2.3 | 2.4 | 15.4 | 100 |
| Sodium sulfate + sea salt + mixing | 9.60 | 978 | 10.69 | 11.8 | 16.6 | 70 |
| Hydrochloric acid + mixing | 7.54 | 946 | 16.98 | 18.1 | 17.1 | 157 |
| “Drop Out” + mixing | 7.17 | 805 | 17.18 | 18.7 | 18.9 | 205 |
| PAC + mixing | 6.82 | 75.1 | 17.14 | 18.4 | 19.8 | 263 |
| Steady state | 6.94 | 84.1 | 17.11 | 18.4 | 19 | 302 |

The slow addition of dry PAC to cement wastewater lowered turbidity levels from 931 to 268 NTU (Table 3). TSS, estimated as 3 NTU = 1 mg/L, would yield 89 mg/L of TSS after primary treatment. This concentration is below the TOMSA daily average discharge concentration limit of 250 mg/L. The pH of wastewater was also lowered to near neutral and within the expectable range of sewer discharge (pH 6 – 8). Total dissolved solids remained high throughout primary treatment and following treatment methods were aimed at lowering these concentrations.

Table 3 Primary Treatment of Cement Runoff – Induction Tank

| Treatment | pH | Turbidity (NTU) | TDS (ppt) | Salinity (ppt) | Temp (°C) | ORP (mV) |
|-------------------|------|-----------------|-----------|----------------|-----------|----------|
| Runoff | 9.09 | 931 | 2.73 | 2.8 | 12.8 | 208 |
| Slow mixing cycle | 7.75 | 708 | 2.78 | 2.8 | 14.0 | 200 |
| Fast mixing cycle | 7.30 | 268 | 2.87 | 482 | 11.2 | 268 |

Secondary and tertiary treatments of wastewater yielded low turbidity and TDS discharge levels to TOMSA. The pH varied little throughout treatments, however, temperatures of discharge lowered from 9.2 to 7.7 °C (Table 4).

Table 4 Secondary and Tertiary Treatment of Cement Runoff – TOMSA Discharge

| Treatment | pH | Turbidity (NTU) | TDS (ppt) | Salinity (ppt) | Temp (°C) | ORP (mV) |
|---------------------------|-----|-----------------|-----------|----------------|-----------|----------|
| Primary treatment | 6.8 | 465 | 2.88 | 3.1 | 9.2 | 214 |
| Secondary (dilution) tank | 7.0 | 6.8 | 0.239 | 0.0 | 7.7 | 231 |
| Steady state | 7.0 | 3.2 | 0.237 | 0.2 | 7.8 | 260 |

5 Discussion

Laboratory and mesoscale treatments of CSA/quartz particles yielded beneficial results for on-site treatment of cement runoff. Lowering turbidity (factor of 10) and TDS levels following primary, secondary, and tertiary wastewater treatment phases, respectively, are most supportive of this claim. Temperature governs the speed and effectiveness of PAC treatment as the binding of CSA particles to PAC was improved in laboratory temperatures. Temperature also serves as an indicator of sequential batches of treated wastewater in tertiary treatment. It was observed during discharge to TOMSA that the effluent had a lower temperature than the newly treated wastewater, indicating the effluent was likely composed of water already present in the GAC filters.

Future efforts of large-scale volumes of cement runoff will be performed using a frac tank treatment induction system (Figure 7). The frac tank will contain cement runoff from the Ohmsett wave/flow tank and chemical treatments will be added from the treatment-induction tank. Laboratory results indicate that adding a sulfate-containing flocculate (“alum”) (e.g., “Drop Out”) prior to PAC, increases the removal of CSA/quartz particles from wastewater. A similar approach will be executed in frac tanks-treatment induction system where a coagulant will be added to destabilize CSA/quartz particles prior to binding to PAC.

Low budget applications of coagulation and flocculation methods to cement runoff in wastewater will allow the potential of on-site treatments methods of cement runoff at the Ohmsett facility and at large-scale construction sites. These efforts can greatly reduce outside contracting treatment costs and allow for appropriate funds to be focused on the restoration and repair of infrastructure of the Ohmsett tank and construction sites during refurbishment periods.

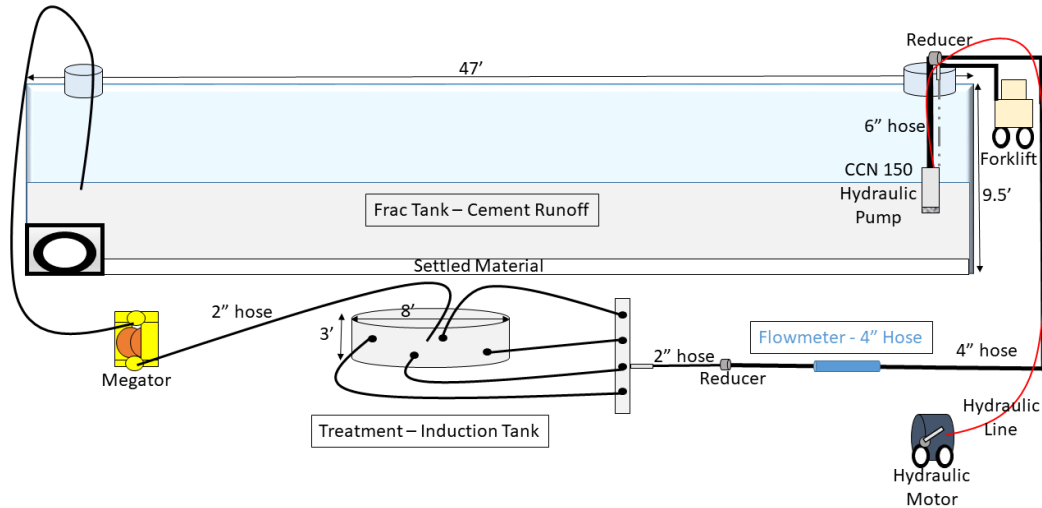


Figure 7 Frac tank-treatment induction system

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