CHANGES IN SEPTIC TANK EFFLUENT DUE TO WATER SOFTENER USE

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ABSTRACT

The compatibility of home water softeners and septic tanks is of concern for the on-site wastewater treatment community. Research has shown that high sodium levels in activated sludge plants can lead to deflocculation and poor effluent quality. Therefore, it is logical to assume that high sodium levels that result from the exchange of calcium and magnesium for sodium in home softeners could give rise to poor effluent quality from septic tanks, leading to shortened lives of drain fields. Additionally, the release of regeneration discharges to the septic tank might further damage performance. This study was undertaken to investigate the effect home ion-exchange softeners have on septic tank performance. A column study was set up and varying levels of sodium were added to wastewater influent and these were fed to columns that contained solids collected from operating septic tanks. In addition, slug influent solutions, which mimic regeneration flow, with varying amounts of excess sodium were investigated. To reinforce the lab column experiments, data were obtained from private septic tanks to determine the effluent quality from septic tanks both diverting and receiving the regeneration flow. Also utilized were graduated cylinder experiments, where the effect of sodium on grease flocculation was determined, and batch anaerobic digestion studies, which determined the effect sodium has on the production of gases and the degradation of solids.

The study showed that the addition of sodium to septic tanks is likely to impact the effluent quality of sewage discharged from a septic tank to a drain field. The common way of measuring ion concentrations for comparison in this study was to obtain the monovalent to divalent ratio (M/D Ratio). This is simply the concentration of the sodium ions in solution divided by the concentrations of magnesium and calcium, on an equivalent weight basis (all other monovalent and divalent ions were negligible). Slug solutions of high levels of salts (Septic Tank Effluent M/D = 11), mimicking regeneration wastes from water softeners with an inefficient regeneration cycle, increased the effluent solids, COD and BOD. However, if the regeneration wastes contained the same amount of calcium and magnesium, but a smaller amount of sodium (Septic Tank Effluent M/D = 5), the negative effect on these effluent characteristics was greatly lessened. In an optimum case with a regeneration solution containing a minimal amount of excess sodium (Septic Tank Effluent M/D = 3), the effluent characteristics were often actually more favorable than in similar situations where the regeneration wastes were diverted (Septic Tank Effluent M/D = 2). The case studies reinforced these data, showing that sodium concentrations correlated with an increased discharge of solids to the drain field. The studies on grease flocculation as well as anaerobic digestion suggest that these processes are not affected by the sodium level. Overall, it appears that the use of home softeners with septic tanks may have an effect on solids discharge to the drain field and the level of impact will depend on the level of hardness in the water, whether the regeneration waste is discharged to the septic tank, and the amount of excess sodium present in regeneration wastes.

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1. INTRODUCTION

Home water softeners have become a necessity in homes that use wells as a water source. On-site wastewater treatment is also frequently necessary because many of these homes are in rural locations where sewer connections are not available. The softening process removes calcium and magnesium from the water using ion exchange technology, replacing them with an equivalent concentration of sodium. The exchange resin in the water softener has a limited capacity and eventually becomes saturated with calcium and magnesium. The resin must then be regenerated using an excess amount of sodium. This waste regenerating solution, consisting of sodium as well as the calcium and magnesium removed from the saturated resin, requires disposal. The simplest disposal method is to discharge the regenerant solution to the septic tank. The combination of home ion exchange softeners and septic tanks raises several questions with regard to this practice. First, by exchanging calcium and magnesium for sodium, the discharge to the septic tank will contain a large concentration of sodium and very little calcium and magnesium. Higgins and Novak (2007 a) have shown that high concentrations of Na can lead to deflocculation in activated sludge systems. Higgins and Novak (2007 b) also proposed that when the monovalent to divalent cation ration exceeds two, effluent characteristics in activated sludge system will deteriorate. Therefore, it is reasonable to suggest that by combining septic tanks with ion exchanges, it is possible that for poor quality discharges from septic tanks to the drain field will occur. In addition, if the regenerating solution is discharged to the septic tank, additional ions are added and this can also impact effluent quality from the septic tank.

Many industry leaders believe that the brine produced by regeneration of the exchange resin within the water softener has a negative effect on the ability of the septic tank to settle solids and treat waste water. This has led to several states passing laws or suggesting practices that promote the inclusion of a separate tank for the collection of regeneration waters (Harrison and Michaud, 2005). This tank solely collects regeneration waters and they are not discharged, but rather are pumped out and hauled away. This could be a good practice, but there is little research to suggest that this process is necessary (Harrison and Michaud, 2005). This could mean that the extra costs associated with the installation of an extra tank and associated piping as well as the extra maintenance costs are unnecessary. Furthermore, there has been limited research that suggests addition of the brine solution could actually improve septic tank performance.

The water from the regeneration of septic tanks includes an abundance of sodium, but also a large amount of calcium and magnesium. Sodium has been shown to inhibit settling and increase deflocculation of settled solids, two things that are a detriment to septic tanks (Murthy et al., 1998). Magnesium and calcium, however, have been shown to have the opposite effect on settling, which would actually be a benefit to the operation of a septic tank (Murthy et al., 1998). This research, while not specifically considering septic tanks, suggests that addition of regeneration waters to a septic tank could benefit overall performance, provided the benefit gained from the calcium and magnesium does not outweigh the detrimental effects of the sodium ions. The concentrations of these constituents could be affected by the time between regeneration cycles. Some softeners regenerate on a planned schedule, while some others operate based on the household water usage. The softeners that regenerate on a planned schedule could regenerate too early in some situations (e.g. when a household is away on vacation), which would send an abundance of sodium to the septic tank without the correlating calcium and magnesium (due to the decreased water use). However, a demand based system takes these variances into account as they only regenerate when the resin has been calculated to be saturated, based on water usage and average water hardness. This difference in operation systems presents another variable in the question of the effect water softeners may have on septic tanks.

This study was designed to investigate the effect of water softener usage on septic tank performance. This was achieved through the use of column studies (which will act as lab-scale septic tanks) oil flocculation tests, anaerobic digestion studies, and case studies of operating septic tanks. The objective of this research was to determine the relative performance of a septic tank under the different conditions that can develop with water softener use. Simulated septic tank discharges were considered both with and without the discharge of regenerant. Measured parameters included gas production, grease flocculation, and effluent characteristics (such as COD, BOD, total and volatile suspended solids, and total and volatile solids) seen in septic tanks under the diverse conditions created by different practices in water softener use.

2. LITERATURE REVIEW

2.1 OVERVIEW OF HARDNESS

Many rural residences in the United States utilize wells to provide ground water for their household water needs. These waters are often prone to high hardness levels. In natural waters, hardness is caused by the abundance of calcium and magnesium ions in solution (Davis, 2011). Hardness levels are often described on an equivalent basis (in mg/L as $CaCO_3$), with classifications of 150 – 300 mg/L as $CaCO_3$ being labeled as “hard” and concentrations of greater than 300 mg/L as $CaCO_3$ being labeled as “very hard” (Davis, 2011). Typically, any water with a hardness above 150 mg/L as $CaCO_3$ is recommended for softening (Davis, 2011). While there is no inherent health risk associated with water hardness, it can cause aesthetic and intended use issues (Skipton, et al., 2008). These include: hindering soap from lathering, leaving a scum or ring in fixtures which contain standing water (e.g. the bathtub or toilet), and can also leave a white scale on objects exposed to heated water (e.g. tea kettles) (Davis, 2011). The issue of most concern with regard to hard water pertains to its impact on water heaters. When water enters a water heater, it increases in temperature. When water is heated, the solubility changes and calcium carbonate will precipitate, leaving a white scale on surfaces. In the case of water heaters, the scale is left on the heating element in the water heater (Skipton, et al., 2008). As the scale builds up, it becomes harder for the element to heat the water, which leads to decreased efficiency and therefore increased energy costs (Skipton, et al., 2008). This can require the homeowner to replace the heating elements regularly to ensure hot water is available when needed. The inconsistent hot water and the costly nature of energy costs and replacement of water heaters is a major reason that households choose to remove hardness before use. Ion exchange water softeners are the most popular device used for this purpose.

2.2 OVERVIEW OF WATER SOFTENERS

2.2.1 OVERVIEW OF ION EXCHANGE PROCESS

Ion exchange softeners take advantage of the increased affinity of divalent cations (Ca^{++} and Mg^{++}) over monovalent cations (Na^{+}) for oppositely charged ion functional groups (Skipton, et al., 2008). Therefore, if water containing calcium and magnesium is passed through a charged media that contains monovalent ions, the calcium and magnesium will have a greater affinity for the media and will displace the monovalent ions and take its place on the media (ion exchange resin). In ion exchange water softeners, the resin is typically polystyrene beads that are saturated with sodium (Skipton, et al., 2008). Sodium is an element with a positive charge of one (monovalent cation). As the hard water encounters the resin, calcium and magnesium (divalent cations) displace the sodium and attach to the beads. The sodium expelled from the softener in the water and the hardness ions stay attached to the resin (Skipton, et al., 2008). Water softeners are rated as to how much hardness they can remove (Skipton, et al., 2008). After prolonged use of a water softener, the resin eventually runs out of exchange sites for the hardness ions and must be regenerated (Skipton, et al., 2008).

2.2.2 OVERVIEW OF REGENERATION OF RESIN

Once the resin is saturated with hardness ions (calcium and magnesium), it must be regenerated to return it to its original state, saturated with sodium ions. To accomplish this, a brine solution is passed through the resin (Skipton, et al., 2008). The high concentration of sodium displaces the hardness ions attached to the resin, causing them to release from the resin while the sodium in the brine solution takes their place on the exchange sites (Skipton, et al., 2008). The waste brine solution, or “regenerant” contains the hardness ions that have been removed from the resin as well as the excess sodium that was needed to drive the hardness removal process (Skipton, et al., 2008). Some of the sodium from the original brine solution is left on the resin to provide the water softening unit with the ability to soften water as discussed above (Skipton, et al., 2008). Since the waste from this regeneration process contains a high salt concentration, its disposal has been a topic of debate.

2.2.3 TYPES OF WATER SOFTENING UNITS

There are four different types of water softening units and the distinction between all four has to do with the unit's approach to the regeneration cycle. The first and simplest is classified as "semi-automatic" (Skipton, et al., 2008). These units require an operator to trip a switch, which sends the unit into its regeneration cycle (Skipton, et al., 2008). While stoichiometric calculations can give the operator a good guess as to when to regenerate, variances in water quality as well as other variables can cause the assumption to be inaccurate, which can result in either regenerating too early (causing inefficiency, increased water use, and increased waste brine solution to deal with) or regenerating too late (resulting in hard water being in the household distribution system and the associated problems). A slightly more advanced type of water softener is labeled as "automatic" (Skipton, et al., 2008). These softeners no longer require an operator to initiate the regeneration cycle, but instead use a timer to determine when the resin will be saturated, and therefore when regeneration is needed (Skipton, et al., 2008). The time setting can be ascertained through the use of stoichiometric calculations, but changes in water quality as well as water use can lead to the same problems experienced with semi-automatic units. A third and very advanced type of softener is classified as a "demand-initiated regeneration" unit, or a "DIR unit" (Skipton, et al., 2008). These units keep track of the water usage and then trigger regeneration based on several factors, including: amount of water used, electrical conductivity of the resin, or by monitoring the hardness of the effluent (Skipton, et al., 2008). Once one of these parameters reaches a set level, the regeneration process is started (Skipton, et al., 2008). These units can be extremely accurate and lead to a diminished chance of the problems associated with semi-automatic and automatic units. Also, due to concern over the handling of waste regenerant, these units can be very attractive because they limit the amount of regenerant that is used. The fourth type of water softening unit is labeled as an “off-site regeneration” unit (Skipton, et al., 2008). With these, the water softener is portable and taken from the home to a separate facility to be recharged, while another unit is left in its place (Skipton, et al., 2008). Since the regenerant is dealt with off-site (and presumably as industrial waste), these units were not considered for this experiment.

2.3 OVERVIEW OF SEPTIC SYSTEMS

As with water softeners, many rural homes have septic systems due to their remoteness in relation to municipal waste collection systems. There are four defined functions of a septic system: to receive wastewater, to separate solid materials from wastewater, to provide treatment of wastes, and to dispose of treated water (Toor, et al., 2012). While many types and configurations of these systems exist, they most commonly have two parts: a collection tank and a drain field (Toor, et al., 2012). The collection tank is where all household wastes are expelled to. Here, the waste undergoes different processes (e.g. the settling of solids and the degradation of constituents by microbes) (Toor, et al., 2012). These processes allow for the separation of solids and treatment of wastes (Toor, et al., 2012). After treatment, the effluent is released into the drain field, which is basically where the treated water is dispersed and released into the soil to undergo further, less intensive treatment (Toor, et al., 2012). Altogether, these systems provide a very simple solution to rural waste management, as long as the system is properly designed and also functioning correctly. The quality treated water from septic systems can often be quantified by the use of several different tests (Toor, et al., 2012). These include biochemical oxygen demand (BOD), total suspended solids (TSS), and analysis of other constituent concentrations (e.g. fecal coliforms or nitrogen) (Toor, et al., 2012). If the septic tank does not properly treat the waste stream, then it can lead to problems in the drain field. This could mean that essentially untreated waste could be released into the ground, resulting in an environmental problem, or the drain field itself could become plugged with solids that were not settled as expected. The effect that the large concentrations of constituents in brine water (particularly sodium) might have on the treatment abilities of a septic system are a main reason for the debate over how the waste regenerant from water softeners should be dealt with. If it is going to cause problems in the septic system, then it should be diverted to a separate tank, but this comes at increased cost and maintenance needs to the homeowner.

2.4 DISCUSSION OF THE EFFECT OF MONOVALENT AND DIVALENT CATIONS ON WASTE TREATMENT

2.4.1 OVERVIEW OF MONOVALENT AND DIVALENT CATIONS

A charged ion can be referred to as an “anion” or a “cation” (Jensen, 2003). Anions hold a negative charge while cations hold a positive charge (Jensen, 2003). These can be further broken down into groups detailing the intensity of the charge on the ion. The two most common types of this classification are “monovalent” (meaning the ion has a single charge) and divalent (which means the ion has a charge of two). For instance, sodium is a monovalent cation, since it has a positive charge of one (+1) and calcium is a divalent cation, since it has a positive charge of two (+2). A useful statistic when dealing with the effect ions are having on a solution can be the “monovalent to divalent ratio,” or “M/D,” for short. Through research, the M/D ratio of a wastewater has been shown to affect the efficiency of certain treatment processes (e.g. settling time), which can in turn have a large effect on the quality of the effluent stream from the treatment location.

2.4.2 EFFECT OF M/D RATIO ON TREATMENT PROCESSES AND EFFLUENT QUALITY

Changes in ion concentration of wastewater streams has been directly associated with the treatment properties of that waste water. Lab trials set up by Murthy et al. (1998) have shown that the addition of calcium and magnesium to a sludge decreased the time it took to settle out when compared to the control or to either constituent separately (Murthy et al., 1998). Further lab studies by Murthy et al. (1998) concluded that the effluent quality from activated sludge reactors was positively influenced by the presence of the divalent cations, calcium and magnesium (Murthy et al., 1998). This was judged by the “chemical oxygen demand,” or “COD” of the effluent (Murthy et al., 1998). As more of these divalents were added, the COD in the effluent appeared to decrease, which would support the earlier finding that these constituents aided in settling times (Murthy et al., 1998). Furthermore, Murthy et al. conducted analyses on the M/D ratio of these sludges and found that a higher M/D ratio resulted in higher effluent COD concentration (Murthy et al., 1998). This data serves as reason to consider the addition of regeneration waste to a septic tank as beneficial to the waste treatment process. Depending on the actual M/D of the waste (e.g. depending on how much sodium was concentrated in the waste as well as how much calcium and magnesium was washed off the resin), there is a possibility it could also serve as a settling aide as in these experiments by Murthy et al. (1998).

Further research has shown that excess sodium can lead to deteriorating effluent characteristics in activated sludge systems (Higgins and Novak, 1997 c). This research examined M/D ratios in activated sludge and showed that sodium can be a detriment to settling ability when the M/D ratio exceeds two (Higgins and Novak, 1997 c). This same research went even further to show that this effect of sodium could be reversed with the addition of calcium and magnesium, as long as the M/D ratio was reduced below two (Higgins and Novak, 1997 c). Once again, even though this research considered only activated sludge, this study is exceedingly important because it incorporates the same ions that are involved in water softening and also details the settling of solids, which is an important function of on-site septic systems. An extension of this study went further to show that an imbalance in cations in activated sludge systems can be a detriment to normal operation due to the effect the imbalance has on the solids (Higgins and Novak, 1997 b). In this study, it was recommended that cations be added to activated sludge systems that were having settling problems (Higgins and Novak, 1997 b). If this is extrapolated to on-site systems, a dose of regeneration wastes with minimal salt could serve as a cation dose, which could increase settling, thereby increasing effluent quality. Another study on activated sludge once again found a correlation between an M/D threshold of two and decreased settling characteristics (Novak, et.al., 1998). This study was also able to show that additions of sodium ions considerably weakened floc strength, which would be the reason for the decreased settling ability (Novak, et.al., 1998). This simply further reiterates the importance of divalent cations in an activated sludge system, which could correlate with their necessity in an on-site septic system. These findings are again reiterated in further studies (Higgins and Novak, 1997, a). Clearly, the role of calcium, magnesium, and sodium has been substantiated in activated sludge systems, so a similar role of these ions should be assessed in on-site wastewater treatment systems.

2.4.3 EFFECT OF PRESENT DATA ON CURRENT REGULATIONS AND RECOMMENDATIONS

Many states have enacted legislation to regulate the disposal of regeneration wastes from water softeners. The state of Delaware released a memo in 2009 to water treatment system installers detailing that no system installed after March 11, 2002 could discharge regeneration wastes into the septic system (State of Delaware Department of Natural Resources & Environmental Control, 2009). Similarly, the state of Rhode Island released a “Best Management Practices” in May 2012 that clearly states that discharge of regeneration waste to a dry well is recommended over discharge to a septic system (Rhode Island Department of Environmental Management, Office of Water Resources, 2012). An opinion piece in the Fall/Winter 2007 edition of *Small Flows Magazine* details how systems receiving the regeneration waste seem to accrue a thick layer of slime inhibiting proper functionality (Gross and Bounds, 2007). It is further discussed in the same article that the high sodium concentration of the brine water may inhibit microbial activity (Gross and Bounds, 2007). However, a paper was presented at the NOWRA convention in 2005 that produced evidence quelling the main fears about regeneration waste discharge to septic systems (Harrison and Michaud, 2005). Information was presented in this article from NSF international that contradicted the thought that brine solution was a detriment to microbial activity (Harrison and Michaud, 2005). This article by Harrison and Michaud went on to suggest that analysis of the available experiments drew no negative conclusions as to the effects of collecting regeneration wastes in septic tanks (Harrison and Michaud, 2005). Clearly, there is a difference in opinion over whether or not to collect regeneration wastes in septic tanks. Different sources site different data that have different conclusions. Quite a few states have chosen to err on the side of caution and pass legislation that prohibits regeneration waste entering septic tanks. Since there is a very healthy debate on the subject, more research in the area would be a welcome occurrence.

3. MATERIALS AND METHODS

3.1 PART I: COLUMN STUDY

3.1.1 EXPERIMENTAL SETUP

The decision was made to try to mimic septic tanks in a laboratory setting to allow for maximum control of the situation. Pieces of standard PVC pipe 5 feet in length and 6 inches in diameter were cut to serve as the lab scale tanks. A "clean-out" cap was put on one end to seal the pipe and allow access for cleaning at the end of the experimental run. Holes were drilled and tapped for sampling spigots. These spigots were placed every 6 inches from the top of the pipe and ceased at 8 inches from the bottom of the pipe. After the first two experimental runs, it was decided to add influent below the top FOG layer in the pipe. To do this, another hole was drilled and tapped in between the 3rd and 4th spigots (counting from the top). An elbow attached to a pipe and a funnel was inserted and run up the side of the pipe to allow for influent addition.

There were 5 of these column set ups, each designed exactly alike. Each column was given a specific experimental scenario pertaining to hardness level treated and/or whether or not the water softener regenerant was diverted. An example of the scenario with differing hardness levels would be the study that began on September 19th, 2011 where the five columns simulated septic tanks receiving waste from houses that softened water containing 0, 100, 200, 300, and 450 mg/L hardness as $CaCO_3$, but also a situation where all regenerant was diverted. An example of the other type of experimental variance would be the study that began on March 29th, 2012 where the 5 column scenarios all simulated septic tanks serving houses with a water hardness of 450 mg/L as $CaCO_3$, but one went unsoftened, one received softened water, but no regenerant, and the other three received softened water with regeneration waste containing varying levels of sodium (or varying "sodium overshot"), which simulated water softeners of varying efficiency.

Once the columns were set up, the specific experimental levels, as detailed above, were chosen. What follows is a table detailing exactly what scenarios were simulated on each run.

Date Experiment Started	**Conditions Investigated**	**Column 1 Treatment**	**Column 2 Treatment**	**Column 3 Treatment**	**Column 4 Treatment**	**Column 5 Treatment**
September 19th 2011 (Run 1)	The Effect of Water Softener Usage on Septic Tank Effluent	0 mg/L treated hardness as $CaCO_3$	100 mg/L treated hardness as $CaCO_3$, Regen diverted	200 mg/L treated hardness as $CaCO_3$, Regen diverted	300 mg/L treated hardness as $CaCO_3$, Regen diverted	450 mg/L treated hardness as $CaCO_3$, Regen diverted
October 24th, 2011 (Run 2)	The Effect of Regeneration Wastes on Septic Tank Effluent	0 mg/L treated hardness as $CaCO_3$	100 mg/L treated hardness as $CaCO_3$, Regen undiverted	200 mg/L treated hardness as $CaCO_3$, Regen undiverted	300 mg/L treated hardness as $CaCO_3$, Regen undiverted	450 mg/L treated hardness as $CaCO_3$, Regen undiverted
November 28th, 2011 (Run 3)	The Effect of Sodium in Regeneration Wastes on Septic Tank Effluent	0 mg/L treated hardness as $CaCO_3$	450 mg/L treated hardness as $CaCO_3$, Regen diverted	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with slight sodium overshot	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with moderate sodium overshot	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with large sodium overshot
March 28th, 2012 (Run 4)	The Effect of Regeneration Wastes with Greater Sodium Concentrations on Septic Tank Effluent	450 mg/L untreated hardness as $CaCO_3$	450 mg/L treated hardness as $CaCO_3$, Regen diverted	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with slight sodium overshot	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with moderate sodium overshot	450 mg/L treated hardness as $CaCO_3$, Regen undiverted with large sodium overshot

Table 3-1. Detail of Experimental Scenarios During Each Column Run

Septic tank waste was collected from neighborhood tanks (but only one was used for each experimental run to limit unknown variables), then mixed (to ensure similar consistency), and then distributed among the five columns to a depth of 4 feet and 10 inches (allowing 2 inches of clearance above the water line). In later runs, salt additions were also initially distributed to each column based on the experimental scenario being modeled and the expected steady state values of the ions of primary concern (e.g. sodium, calcium, and magnesium). This was not done in earlier runs because the time to steady state was not foreseen to be very long, but after examining data from the first few runs, it was apparent the initial addition of salts would yield pronounced differences sooner. Tin foil caps were placed on top of each column to limit any effect light may have on the "septic tanks." After waste distribution and salt amendments, the columns were allowed to settle for several days before testing commenced.

After settling, the columns were operated in such a way that modeled real life septic tank use. Wastewater was gathered from the Blacksburg Wastewater Treatment Plant and used as influent for the columns (or, in other words, served as a simulated effluent from a household). A volume of 3.8 L of influent was added to the column each day to allow the columns to have a 7 day detention time, which was felt to be fairly average for a typical home. The influent received salt additions that were calculated based on the specific experimental scenario being modeled. Extra equivalents of sodium chloride were also added to the influent to account for the calcium and magnesium that was inherently present in the wastewater from the treatment plant.

To make room for the daily influent addition, 3.8 L was also removed from the columns every day. Depending on the day of the week, this effluent would undergo certain tests to evaluate its quality and, therefore, the effectiveness of the "septic tank" in treating waste before being released into the "drain field." Effluent was collected from at the 3rd port from the top of the column (or 18 inches below the water line). It was felt that this was a good distance below the FOG layer and also simulated normal septic tank operations well (where the effluent is released from a "quiescent zone" in the upper middle of the tank).

The columns were operated for three weeks initially, and then the runs were expanded to eight weeks once the initial experiments were analyzed. It was felt that, after looking at the data from the first few runs, it would be beneficial to extend the run time since some promising results were just starting to appear towards the end of the three weeks.

On the final day of testing, samples were collected and analyzed from the 3rd, 5th, 7th, and 8th ports (numbered from the top of the column). This was thought to show any differences that might be seen at different depths, and also provided assurance that the columns were mixing the salt additions throughout. Also on the final day, each column was dumped into a plastic barrel and mixed. The mixture was then sampled and placed in a 1 L graduated cylinder. This showed both that the columns all contained similar solids levels and also allowed for better examination of the clarity of the quiescent layer in the middle of the tank.

3.1.2 EXPERIMENTAL ANALYSIS

The samples were periodically analyzed for each of the following characteristics:

- Total Solids (TS) and Total Volatile Solids (VS)
- Suspended Solids (TSS) and Volatile Suspended Solids (VSS)
- Chemical Oxygen Demand (COD)
- Biochemical Oxygen Demand (BOD)
- Protein content
- Polysaccharide content
- Analysis for ion concentration via Ion Chromatography (IC)

All TS, VS, TSS, VSS, COD, and BOD testing was done in accordance with Standard Methods for the Examination of Water and Wastewater. All solids testing was conducted three times per week (Mondays, Wednesdays, and Fridays). Likewise, samples for COD were collected and preserved on these days. A typical COD test encompassing all present samples was typically run once per week. Samples for IC were collected out of the leachate that passed through the filter paper used in measuring TSS and VSS. This was done because it was a fast and easy way to clean the sample before sending it to the IC machine. Like the COD samples, the IC samples were amassed over a week and then run all at once. Testing for BOD concentration took place twice per week. In the early runs, BOD testing was troublesome and acceptable results were not obtained until later runs. This is discussed in further detail in the results section. Analysis for protein and polysaccharide content took place once a week during the first few runs. Upon examination of this data from the first runs, it appeared this test was not yielding any useful comparative data, so later runs were not analyzed for proteins and polysaccharides. Protein analysis was conducted using the Lowry method and polysaccharide testing utilized the phenol-sulfuric acid method.

In addition to these parameters, another test was conducted using wastewater filters. Real PVC wastewater filters, such as those used as a final treatment for effluent leaving a septic tank, were obtained from an effluent filter manufacturing company. These filters were then cut to similar sizes and inserted into 5 separate apparatuses designed to distribute flow throughout the filter area. The filter was inserted into a coupling which was then adapted to a hose with a funnel. The filter then sat upside down in a 5 gallon bucket, with the funnel end sticking out of the top of the bucket. Of the 3.8 L of daily effluent, 2 L were collected from each column and poured through the corresponding apparatus (one apparatus per column). The filters then remained submerged throughout the entire experiment with the excess wastewater being removed from the collection bucket by dipping. At the end of the run, the filters were removed and weighed. When compared with the initial weight of each filter, this allowed for an analysis of the potential filter fouling that would have occurred in each scenario.

3.2 PART II: GREASE STUDY

The effect of water softener discharge on grease flocculation was also to be studied. Initially, this was to take place as a daily addition of lard to each column's influent. However, this method proved to be troublesome. The grease would stick to any implement, and then began to plug the influent line of several columns. This parameter was then redesigned to take place as a separate experiment.

On the final run (begun on March 28th, 2012), five 1 L graduated cylinders were filled with composite samples from each column as described above. However, this time 900 mL of sample were added to 100 mL of cooking oil that was already in the cylinder. The cylinders were then mixed and allowed to settle and separate over time. The amount of oil that rose to the top was inspected at regular intervals and recorded for comparison between the columns. Once all oil had risen to the top, the cylinders were re-mixed and then the process began again. This occurred 4 times until enough data had been gathered.

3.3 PART III: ANAEROBIC DIGESTION STUDY

3.3.1 EXPERIMENTAL SETUP

Sludge was collected from the Christiansburg Wastewater Treatment Plant. The sludge was then divided and added to 1 L Erlenmeyer flasks as follows: 400 mL primary (unthickened) sludge, 200 mL secondary (thickened) sludge, 60 mL sludge from the plant's anaerobic digester (for use as a seed). The proper sodium chloride amendments were also added to each flask to obtain monovalent to divalent (M/D) ratios of 1, 3, 5, 10, and 20. These digesters were then capped with rubber stoppers and Tedlar bags and placed in a room at 37° C constant temperature. Stir plates and stir bars were utilized to ensure proper constant mixing. Gas was collected and measured for different characteristics and the sludge was analyzed at the end of the digestion period. It should be noted that due to a spill and subsequent shortage of sludge, the digesters modeling the M/D ratios of 3 and 20 only contained about 450 mL of sludge, while the others were able to get the proper amount. These digesters were allowed to run for three weeks.

3.3.2 EXPERIMENTAL ANALYSIS

The collected gas was released as needed to allow for minimal pressure buildup. The collected gas volume was measured with a syringe before the gas was allowed out of the bag. The gas was also analyzed for concentrations of hydrogen sulfide, methanethiol, dimethyl sulfide, and dimethyl disulfide using mass spectrometry. This quantification of these constituents occurred once a week during the experimental run.

3.4 PART IV: CASE STUDY

Case studies were also organized with the help of the Water Quality Association. These took place mainly in New York, although a few samples were sent from Kansas and North Carolina. In the Kansas and North Carolina studies, industry professionals took samples from the "quiescent zone" of septic tanks as directed and mailed them overnight to the lab. Information was then collected as to the household's use of a water softener and treatment of regeneration wastes (e.g. is the waste diverted or sent to the septic system, etc.). In the lab, these samples were then analyzed for COD, TS, VS, TSS, and VSS using the aforementioned methods. Samples to determine ion concentration via IC were also collected and run to determine the levels of calcium, magnesium, and sodium that septic tank was being exposed to. This data was then compared to other case study samples and the comparisons were then related back to the column study data to see how well the lab study mimicked real world data. Since only a few samples were received from Kansas and North Carolina, they were omitted from inclusion in the case study dataset, which now includes samples solely from New York.

The New York case study was somewhat different than the other case studies. In Naples, New York, the managers of Aquasource maintain a septic system and water softener at an apartment complex. There are two apartment buildings on the property, each at maximum occupancy. Each building has its own septic tank, but both buildings are served by the same water softener. The regeneration waste from this softener can be diverted into any tank the operator wishes. Initially, the regeneration waste was collected in one tank while the other tank caught only the effluent from one apartment building. Sampling procedures were communicated to the Aquasource team and regular samples from both tanks were sent to the lab twice a month. These samples were then analyzed for the same parameters as the other case study samples. This provided an excellent side-by-side trial to compare to the lab results. Also, the fact that the sampling was performed by professionals in the field of water softeners and septic tanks provided reassurance that the experiment was carried out with great attention to detail.

4. RESULTS AND DISCUSSION

4.1 PART I: COLUMN SEPTIC TANK STUDY

4.1.1 OVERVIEW OF STUDY

As stated in section 3, there were several different types of experimental set ups for each run of the column study. This investigation used multiple runs to mimic a variety of septic tank conditions. In Figure 3-1, a description of the treatment for each column and each separate run is provided. The results are comparable across runs. It is important to note that the first two runs were considerably shorter than the last two runs (3 weeks vs. 8 weeks). Initially, it was thought that a run time of 3 weeks was adequate to reach steady state. However, after seeing the results from the first two runs, extra time was added and thought to yield more useful data, so the change was made to the initial protocol. Below are descriptions of the results seen in each run of the column study.

4.1.2 FIRST RUN: THE EFFECT OF WATER SOFTENER USAGE ON SEPTIC TANK EFFLUENT

As stated above, the first two studies were much shorter than the final two. Run 1 represented an operational condition where the regeneration wastes from the water softener were not discharged to the septic tank. In effect, the Run 1 data indicate the impact of discharging softened water to a septic tank. Run 2 represents situations with the same water hardness as Run 1, but the regeneration wastes were discharged to the septic tank.

The first run lasted 3 weeks. The pertinent results of the testing over that period can be seen below. COD and VSS provided the most useful data so additional graphs for these parameters were provided. The final 5 results for these two analyses were averaged and graphed. This was meant to show what was happening with the effluent at the end of the run while limiting the impact of possible outliers in the data. Furthermore, each entire data set for VSS and COD was plotted against both the M/D ratio of the column and the sodium concentration to see if any correlation existed. The analysis for protein content and polysaccharide content did not yield useful data. No BOD data was provided for this run.

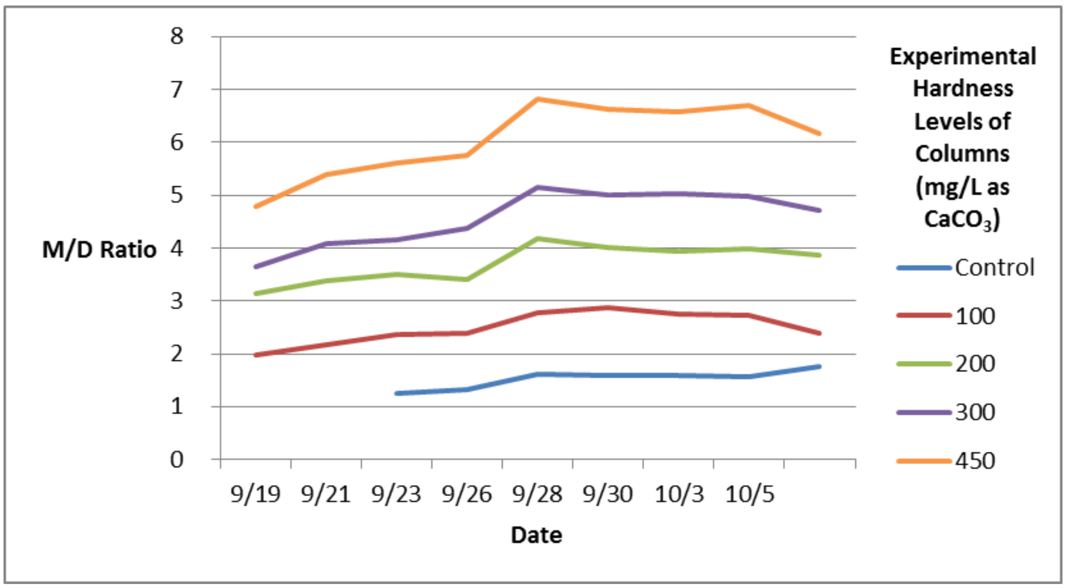

Figure 4-1. M/D Ratio of Column Effluent During the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

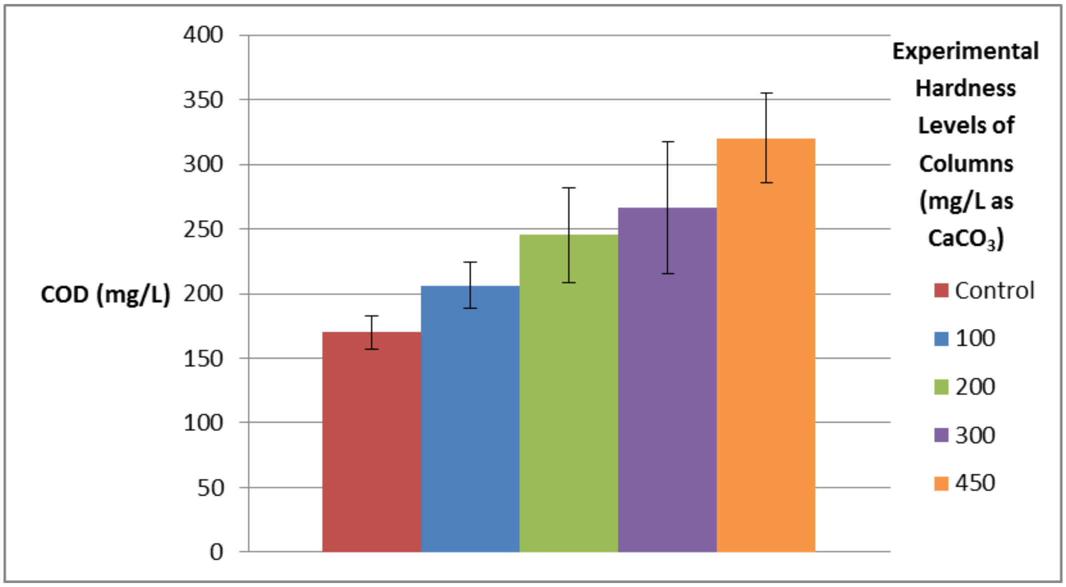

Figure 4-2. Final Five COD Measurements of Column Effluent During the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent) Averaged with Standard Deviations

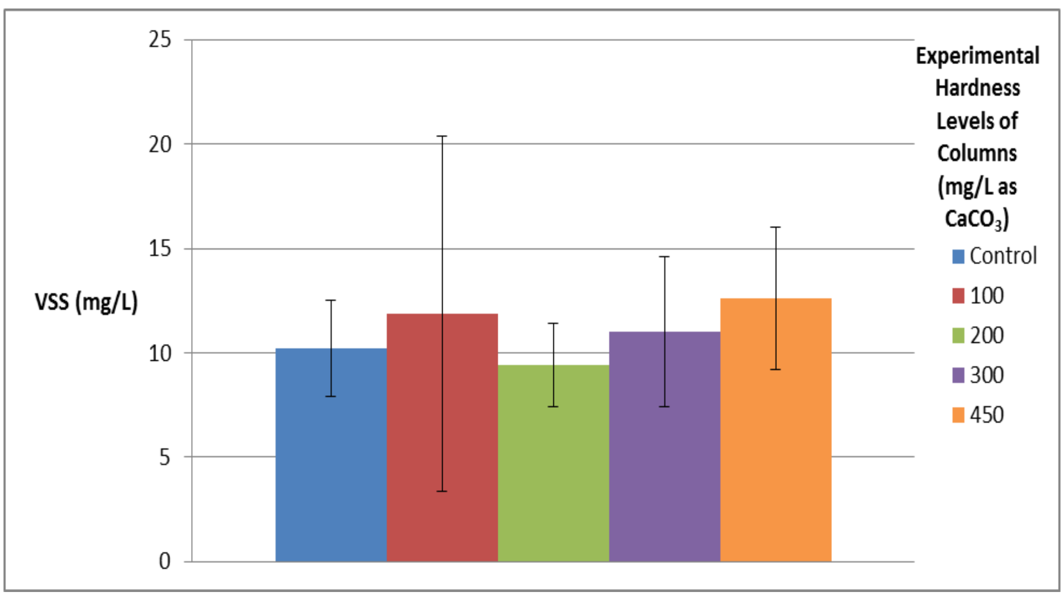

Figure 4-3. Final Five VSS Measurements of Column Effluent During the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent) Averaged with Standard Deviations

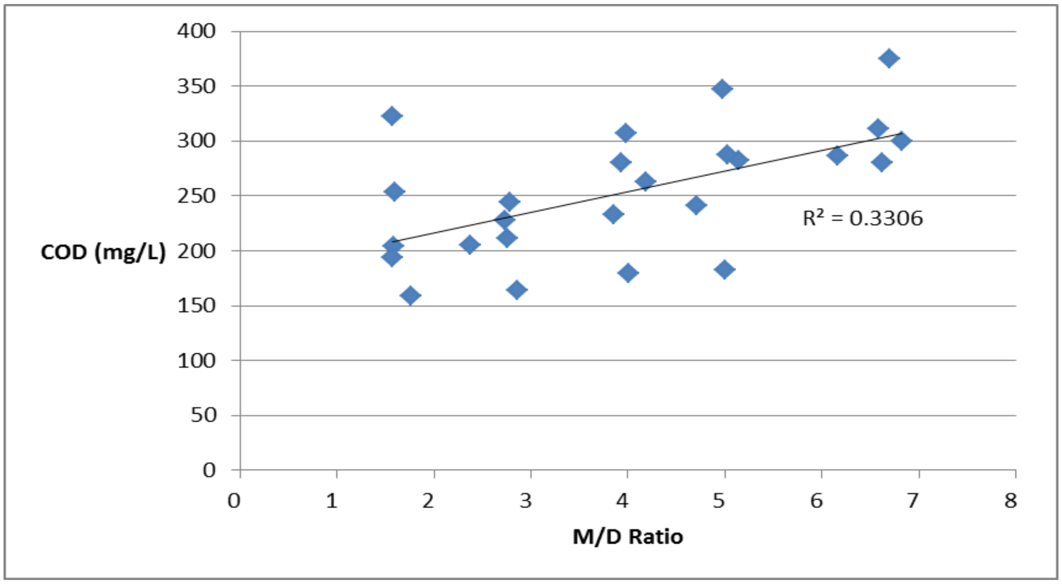

Figure 4-4. R^2 Correlation of M/D Ratio and COD Measurements of Column Effluent of the Final Five Complete Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

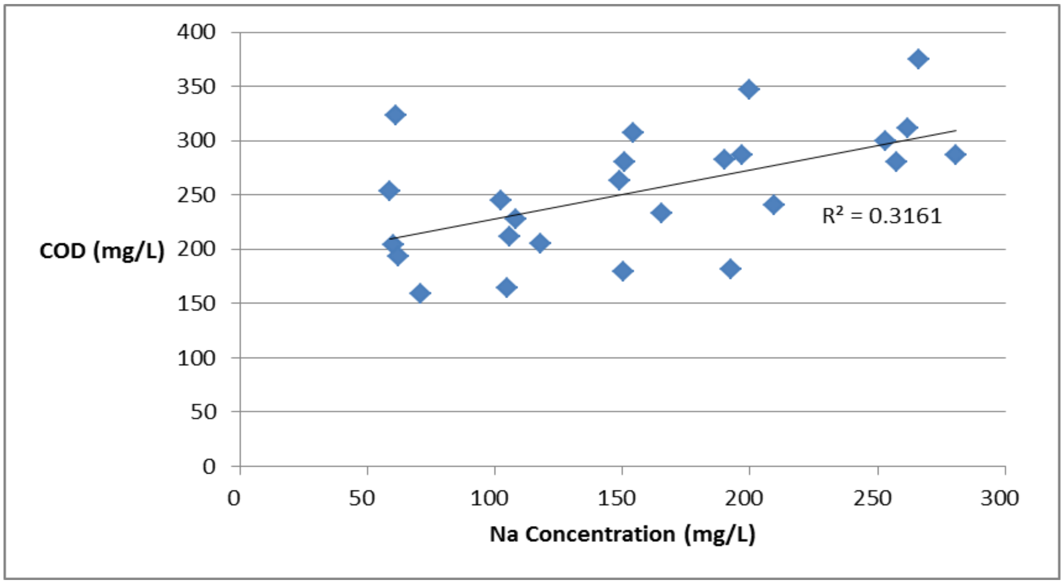

Figure 4-5. R^2 Correlation of Sodium Concentration and COD Measurements of Column Effluent of the Final Five Complete Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

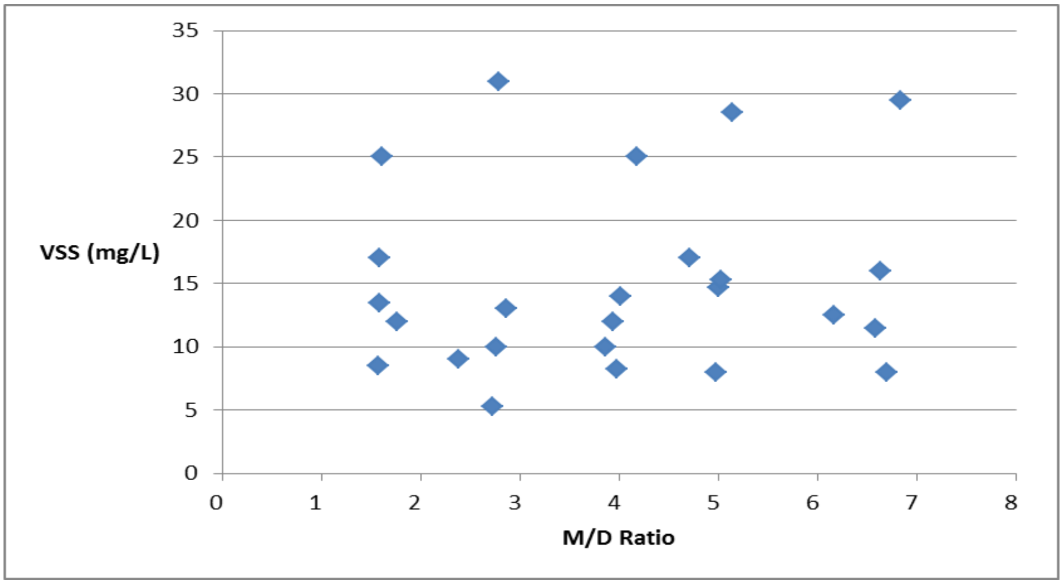

Figure 4-6. Correlation of M/D Ratio and VSS Measurements of Column Effluent of the Final Five Complete Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

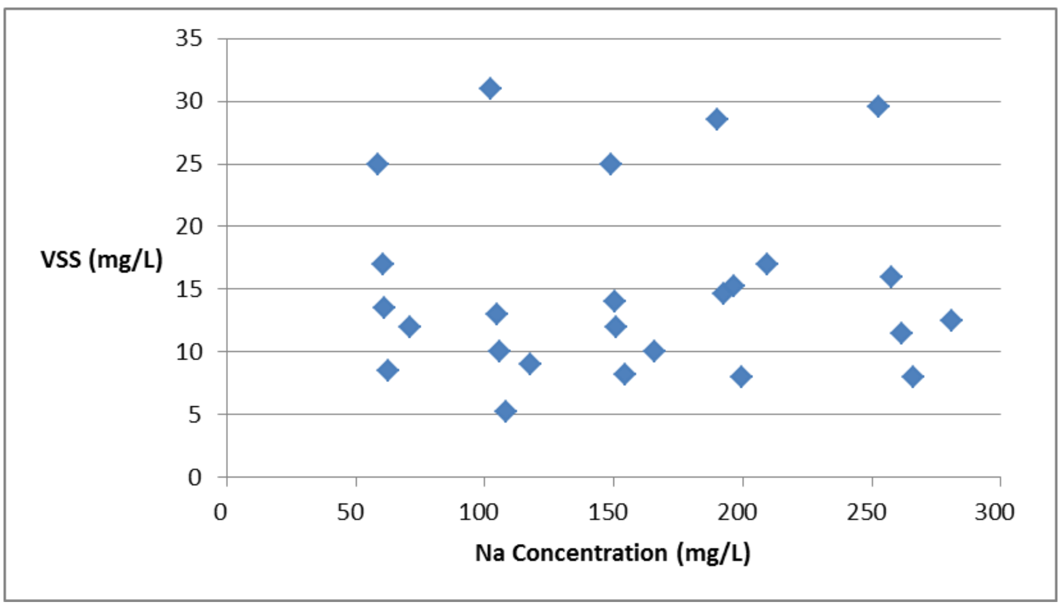

Figure 4-7. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of the Final Five Measurements of the First Run (Determining the Effect of Water Softener Usage on Septic Tank Effluent)

The M/D ratio for the first run followed the expected trend, with the columns representing waters with higher hardness having a greater M/D ratio. The COD results had a very interesting stair-step pattern, but when these results were correlated with both M/D ratio and sodium concentration, only a slight relationship was shown. The pattern of VSS was not as clear, but did have a general upward trend as hardness level increased. When these data were correlated with M/D ratio and sodium concentration, however, no relationship could be determined via the R^2 value. The COD results were promising for this run, but the rest of the data gave somewhat mixed results. It was determined that the second run would include the same levels of hardness, but would represent situations where the regeneration waste was allowed to enter the septic tank.

4.1.3 SECOND RUN: THE EFFECT OF REGENERATION WASTES ON SEPTIC TANK EFFLUENT

As stated above, the second run detailed a corollary to the first run. The pertinent data for this run is shown in the figures below. Once again, protein and polysaccharide testing yielded results with minimal differences. Also, BOD testing was again compromised during this run. The results for COD and VSS were averaged and displayed like the results from the previous run. The correlation plots were also constructed to determine any relationships between COD or VSS and M/D ratio or sodium concentration. This was the first run where effluent filters were available, so the initial and final weights were measured to provide insight into possible filter fouling. The results of the weight change were graphed and are shown below.

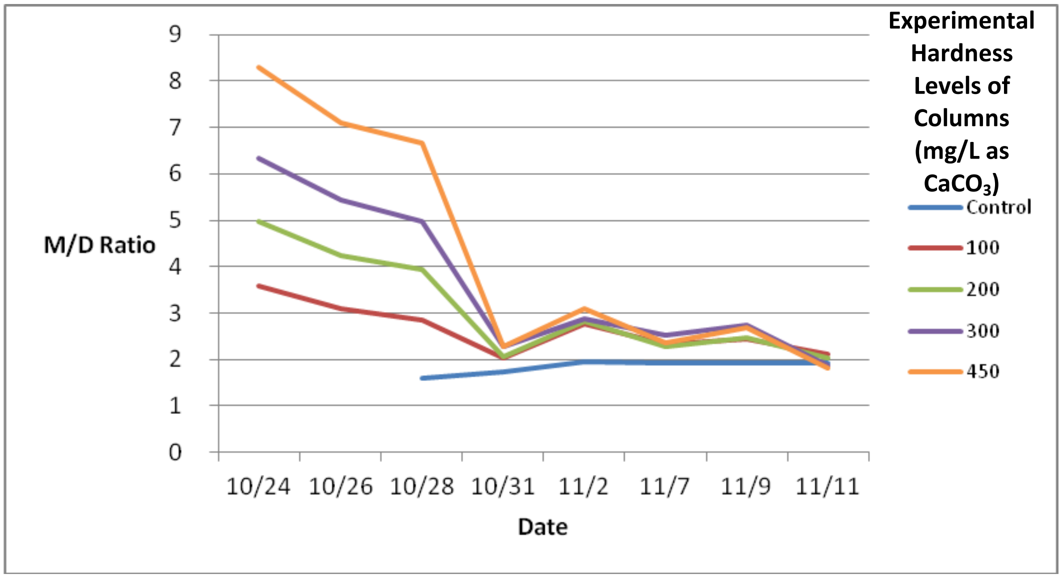

Figure 4-8. M/D Ratio of Column Effluent During the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

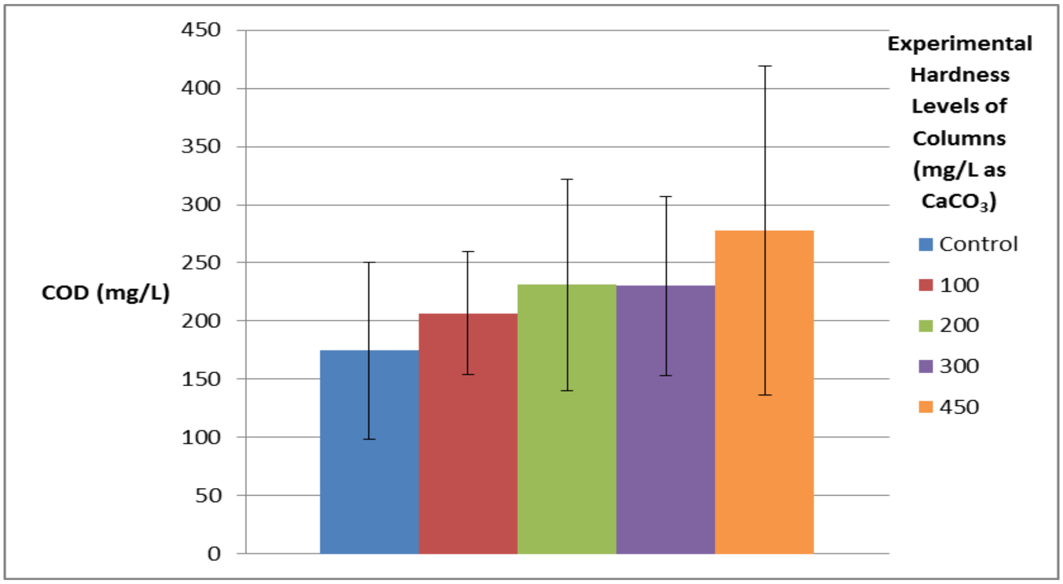

Figure 4-9. Final Five COD Measurements of Column Effluent During the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

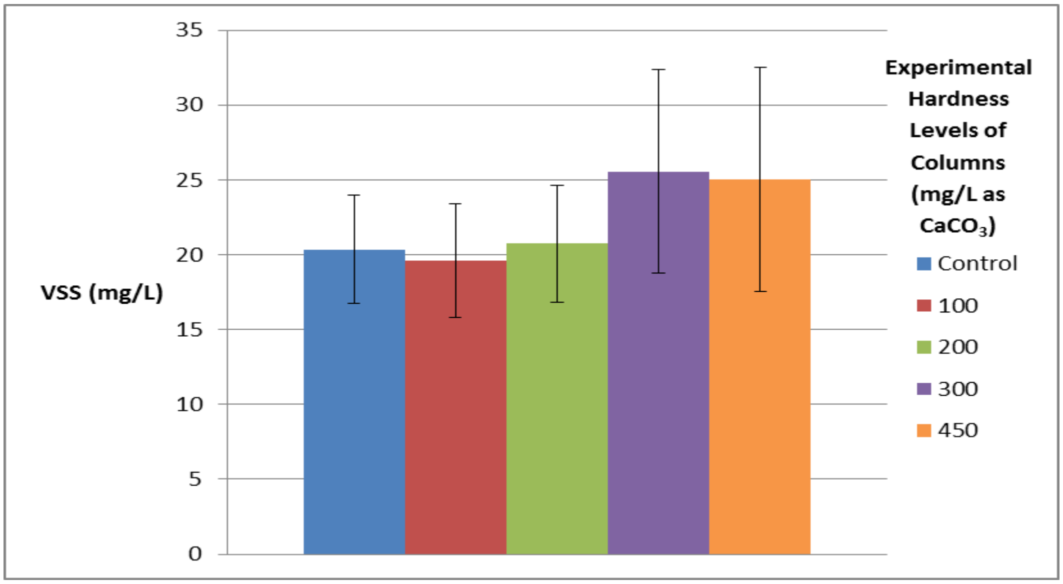

Figure 4-10. Final Five VSS Measurements of Column Effluent During the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

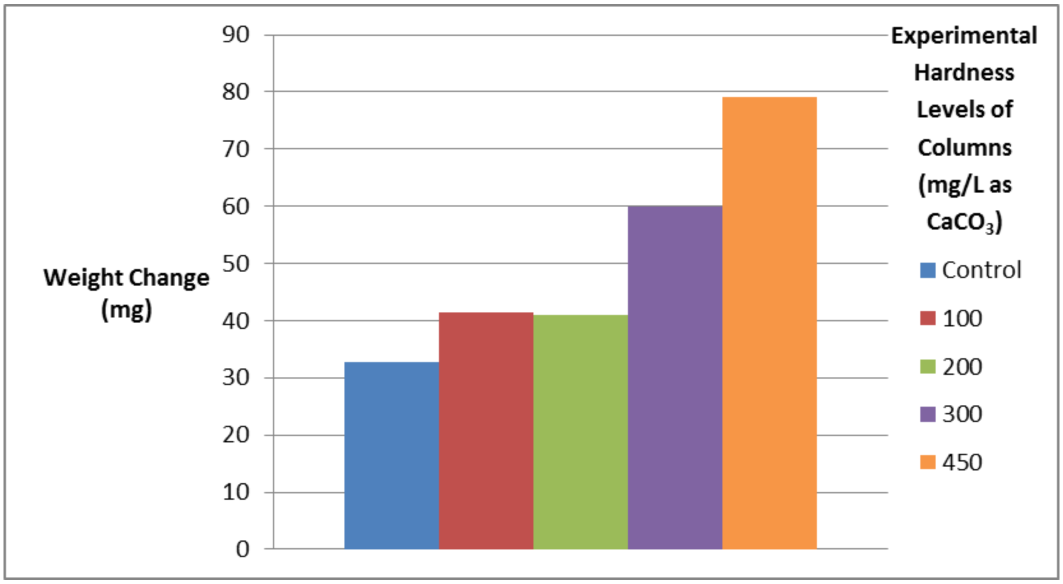

Figure 4-11. Overall Weight Change of Effluent Filter Weights Over the Course of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

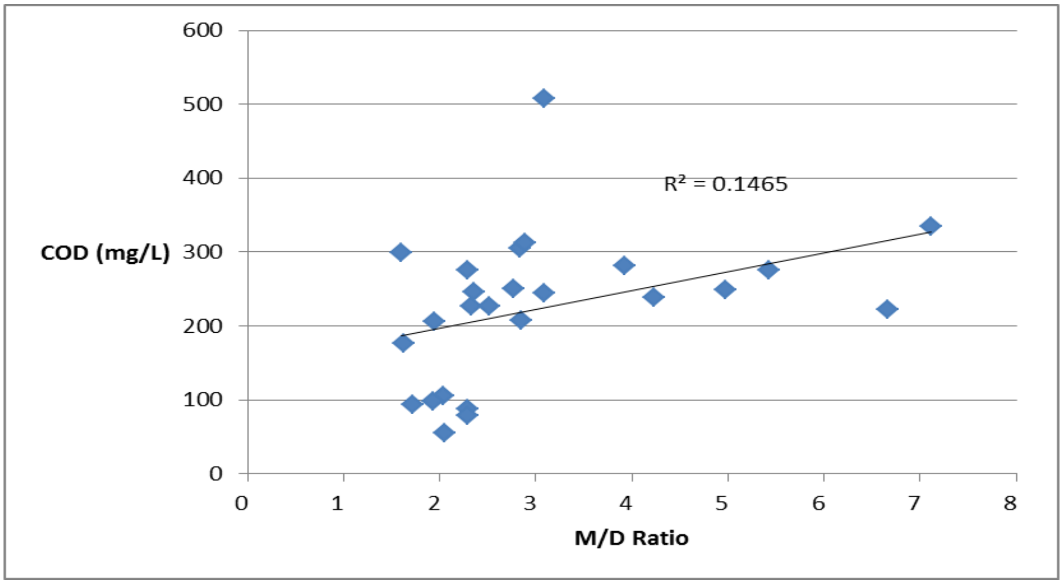

Figure 4-12. R^2 Correlation of M/D Ratio and COD Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

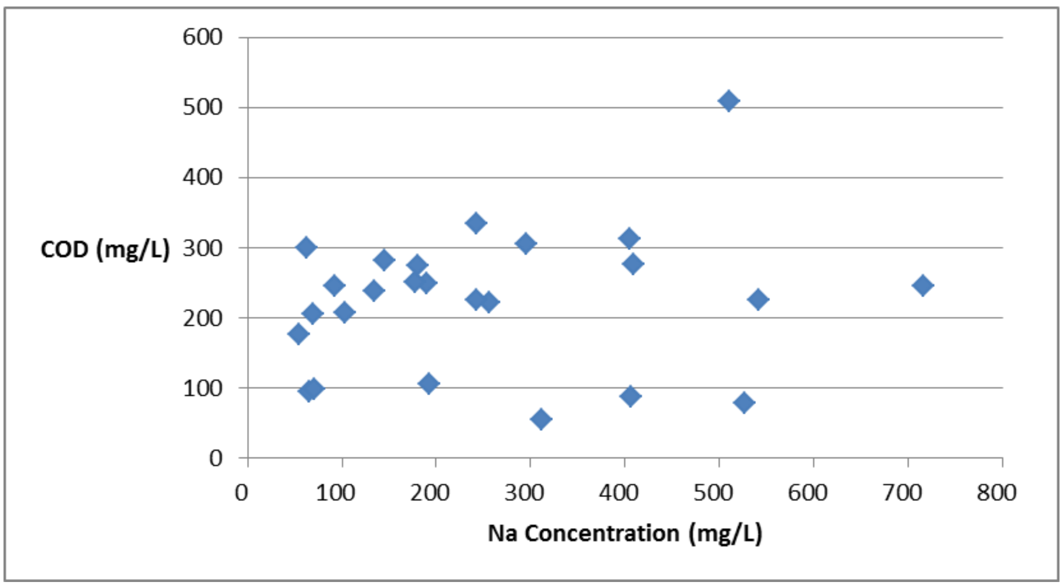

Figure 4-13. Correlation of Sodium Concentration and COD Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

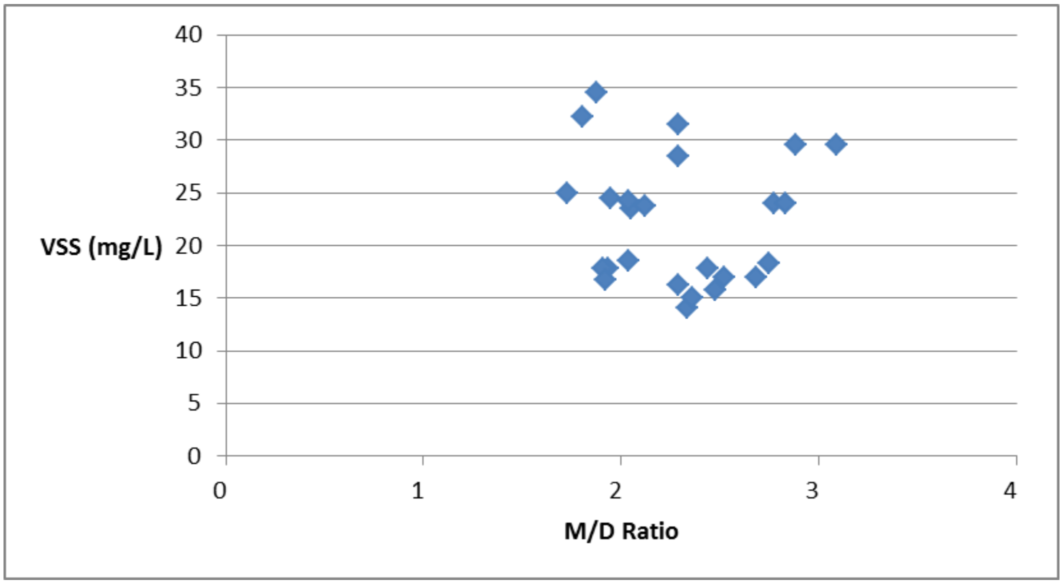

Figure 4-14. R^2 Correlation of M/D Ratio and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

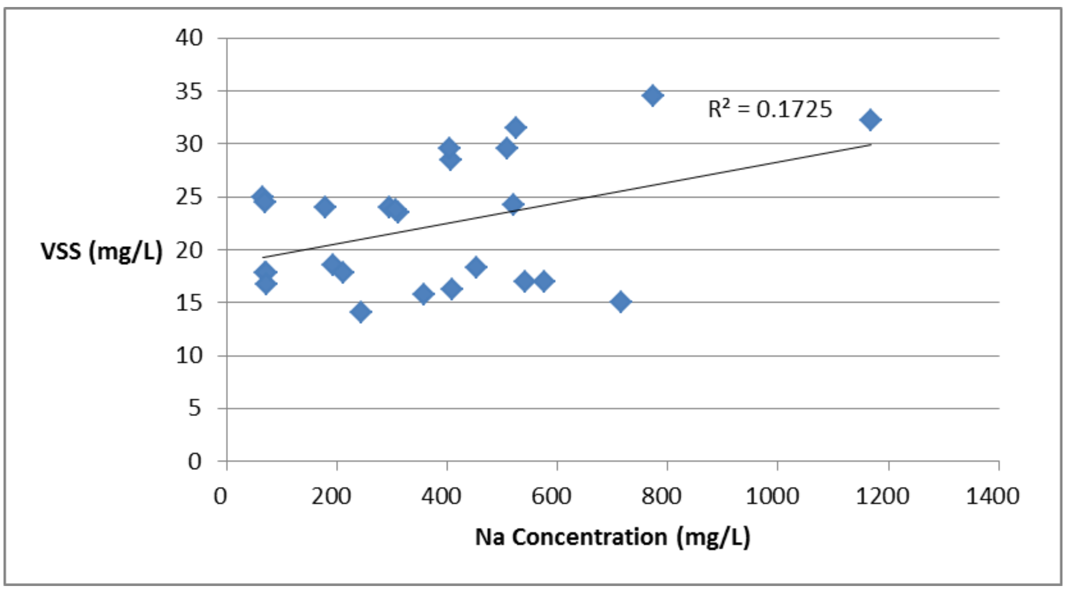

Figure 4-15. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Second Run (Determining the Effect of Regeneration Wastes on Septic Tank Effluent)

Much like the first run, COD analysis yielded a stair-step pattern, of which the highest of hardness levels was at the top of. When these data were plotted against M/D ratio and sodium concentration, a weak relationship to M/D ratio was seen, while no relationship could be inferred with sodium concentration. The VSS analysis did not show values that clearly stepped from one level to another, but instead showed more of a “high-end, “low-end” scenario where the first 3 columns had similarly lower VSS and the last 2 columns had comparably higher VSS. Like COD, when these data were correlated with M/D ratio and sodium concentration, a weak relationship was seen with M/D ratio and no relationship was seen with sodium concentration. The filter fouling quantification was extremely interesting. It showed that those columns with higher hardness (and therefore those receiving more sodium) had filters with a higher weight change at the end of the run. This means that the filter fouling could be said to be greater in these columns than in those with lower sodium. Filter plugging can be a large problem in septic tanks, so this result was deemed to be very important. The M/D ratio of each column followed what was expected. It is interesting to see in the graph of the M/D ratio that the M/D ratios of the columns in this run are fairly even. This is because a solution of simulated regeneration waste was added in this run. This solution, like the sodium level, was calculated based on the theoretical hardness level each column was representing. Also, the “sodium overshot” added to the regeneration waste was constant between the columns. So, every column stayed around the same M/D ratio throughout the run. The “sodium overshot” was changed in subsequent runs to represent systems that had both a more and less efficient regeneration cycle.

4.1.4 THIRD RUN: THE EFFECT OF SODIUM IN REGENERATION WASTES ON SEPTIC TANK EFFLUENT

The third run marks the beginning of the longer runs. This run lasted 8 weeks instead of 3. This was also the first run to change the “sodium overshot” in the regeneration waste, rather than the treated hardness level of the influent, which was held constant at 450 mg/L for columns 2 – 5.

Column 1 received no salt additions whatsoever. This run, as well as the fourth, were essentially looking at differences in efficiencies of water softener's regeneration cycles. All pertinent data, including the final 5 day averages of COD and VSS are shown below. Protein and polysaccharide testing failed to produce useful results again and the BOD results were once again compromised. Correlation plots were once again made for the most useful statistics (COD and VSS). For run 3, the filter fouling data was also compromised as several of the filters fell on their side, creating a greater weight change due to collected solids than would have occurred if they were standing upright.

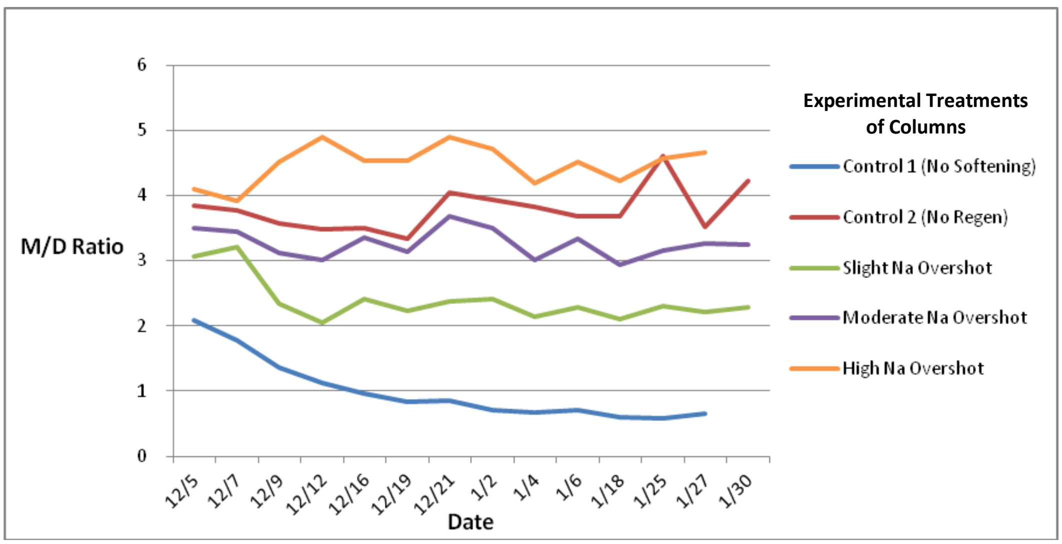

Figure 4-16. M/D Ratio of Column Effluent During the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

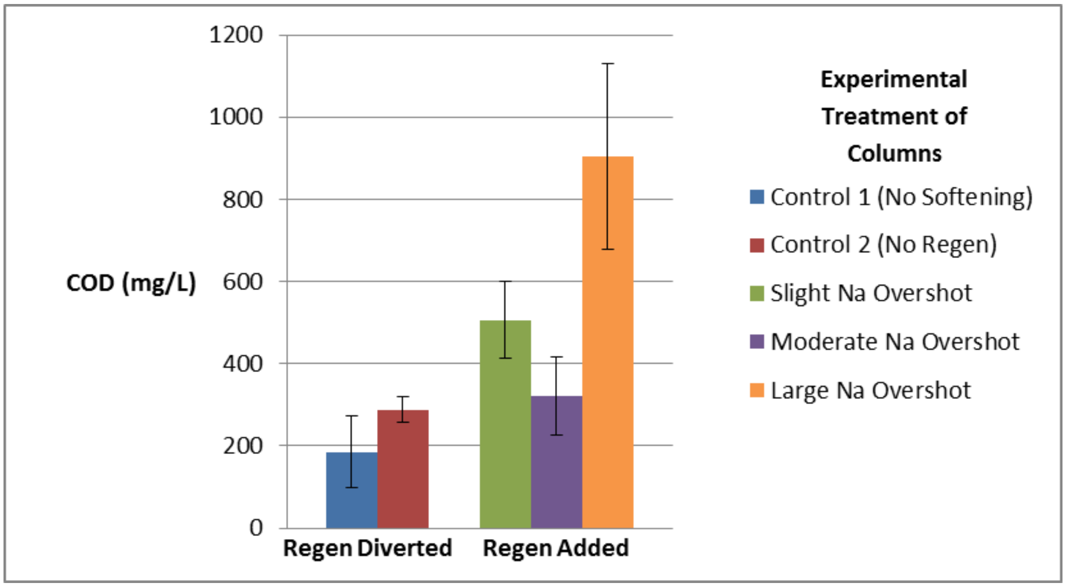

Figure 4-17. Final Five COD Measurements of Column Effluent During the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

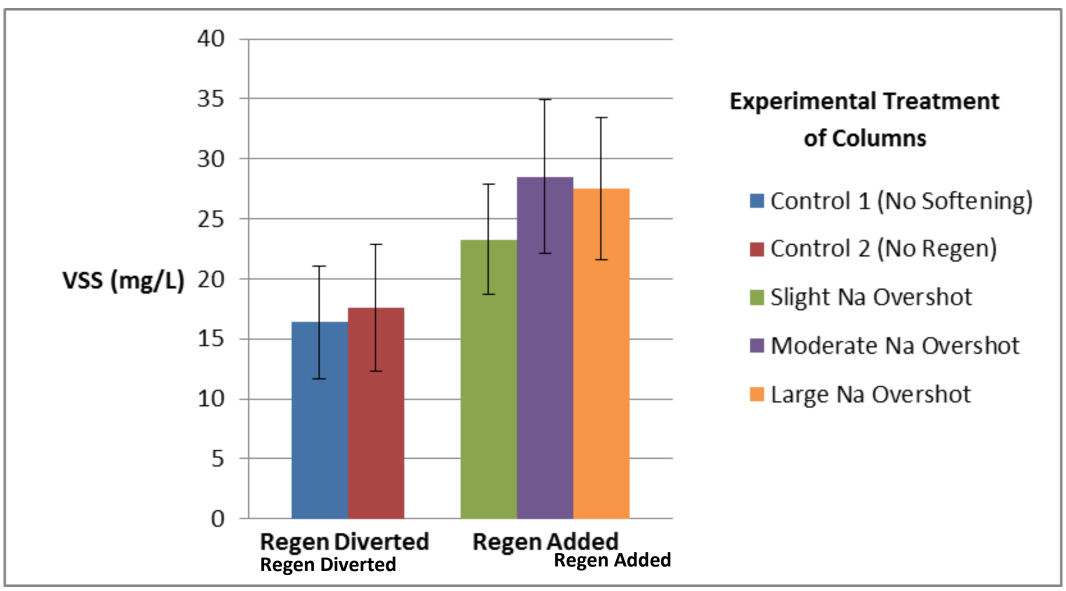

Figure 4-18. Final Five VSS Measurements of Column Effluent During the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent) Averaged with Standard Deviations

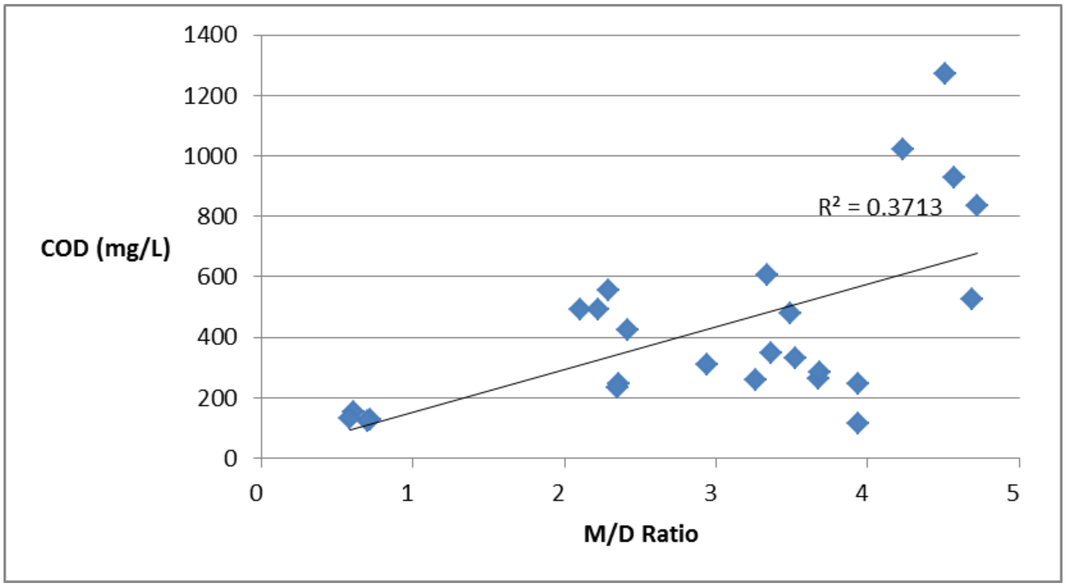

Figure 4-19. R^2 Correlation of M/D Ratio and COD Measurements of Column Effluent of Final Five Complete Measurements of the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

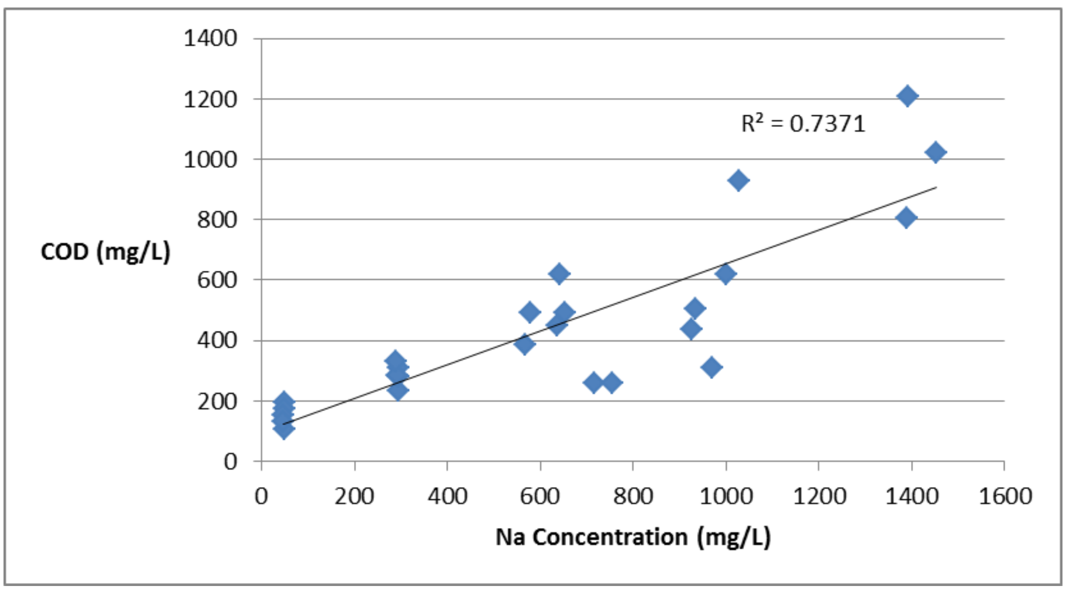

Figure 4-20. R^2 Correlation of Sodium Concentration and COD Measurements of Column Effluent of Final Five Complete Measurements of the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

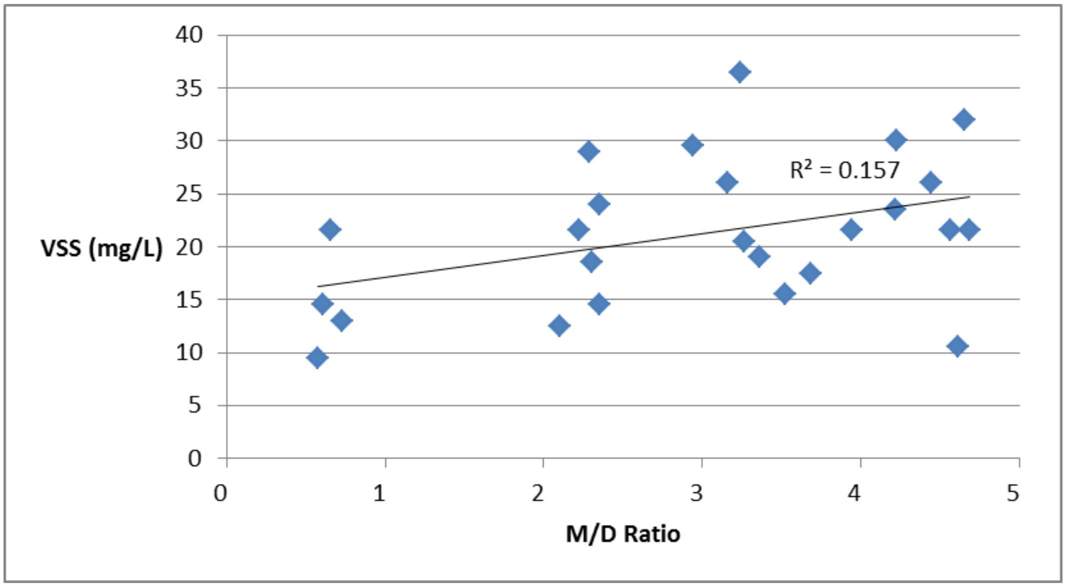

Figure 4-21. Correlation of M/D Ratio and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

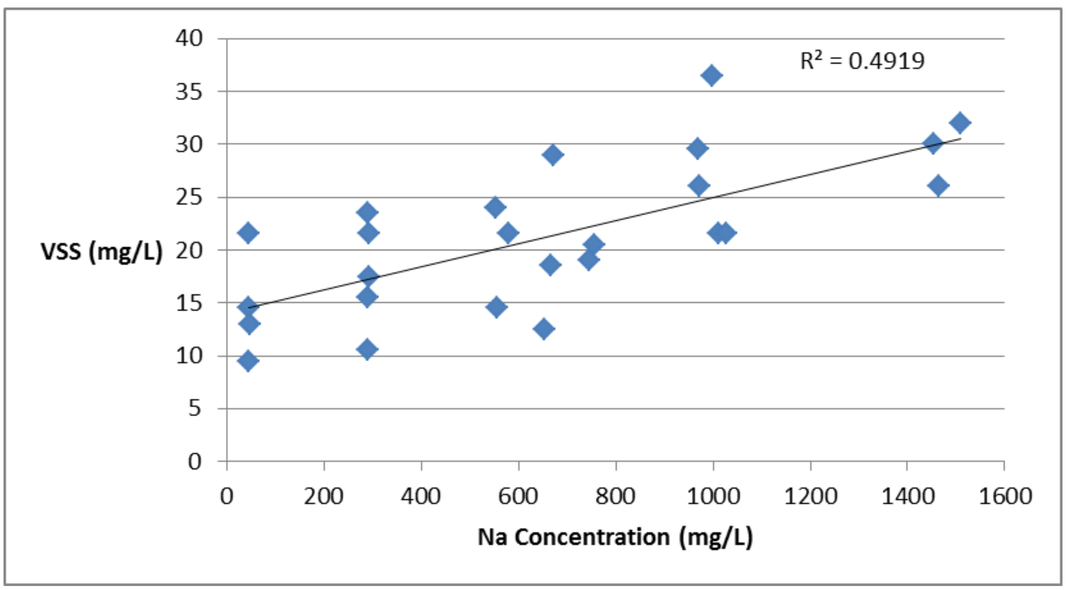

Figure 4-22. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Third Run (Determining the Effect of Sodium in Regeneration Wastes on Septic Tank Effluent)

As can be seen in the first graph, the M/D ratios vary widely, but this was intended as the columns with the higher M/D ratios were representing situations where an abundance of sodium was introduced into the septic tank during the regeneration cycle. The important things to note on these graphs are the peaks that occur throughout the run. This is indicative of the slug of regeneration waste being added. The COD results produced a somewhat upwards trend, though the effluent from the "Slight Sodium Overshot" column had a COD that was out of place. The VSS data were once again very close to a stair-step pattern, with the columns that were receiving the most sodium yielding the highest VSS concentrations. The correlation plots showed, however, that the VSS concentration did not have a relationship with either the M/D ratio or the sodium concentration. The correlation plots for COD were different, however. The COD concentration was shown to have a weak relationship with the M/D ratio, but a moderate relationship with the sodium concentration (R^2 = 0.5). A possible confounding variable with COD measurements could have been the chloride ion concentration. All salts were added in chloride forms, which led to a very high concentration of chloride in the effluent. Chloride is known to interfere with COD testing and that fact could have influenced the results from COD testing, especially in the third and fourth runs, where the salt additions were much greater than those of previous runs. This could be an explanation as to why the COD concentrations seem extraordinarily high. A fourth run was planned to further explore the results seen here.

4.1.5 FOURTH RUN: THE EFFECT OF REGENERATION WASTES WITH GREATER SODIUM CONCENTRATIONS ON SEPTIC TANK EFFLUENT

The fourth run was designed much like the third run, but the "overshots" of sodium were doubled in the fourth and fifth column, in hopes to greatly pronounce any differences. Pertinent data is shown in the figures below. All data presented is the same as the previous runs, except for BOD data. The BOD data was not compromised during the fourth run, so it is shown below.

The overall TSS data is shown below because of the appearance of spikes in the data. The COD and VSS 5 day averages, as well as all correlation plots, are below as well.

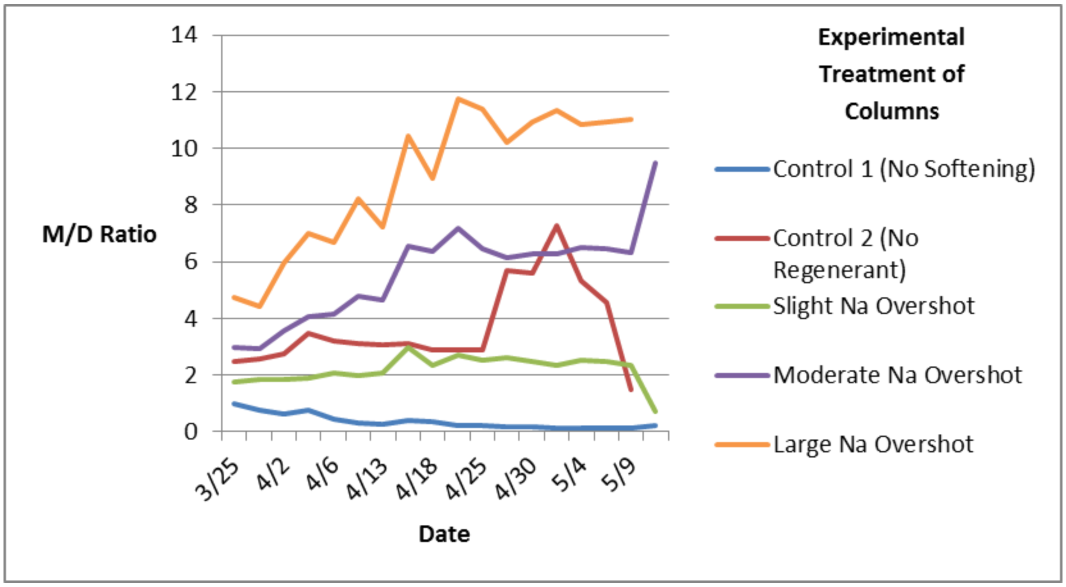

Figure 4-23. M/D Ratio of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) with Outliers Removed

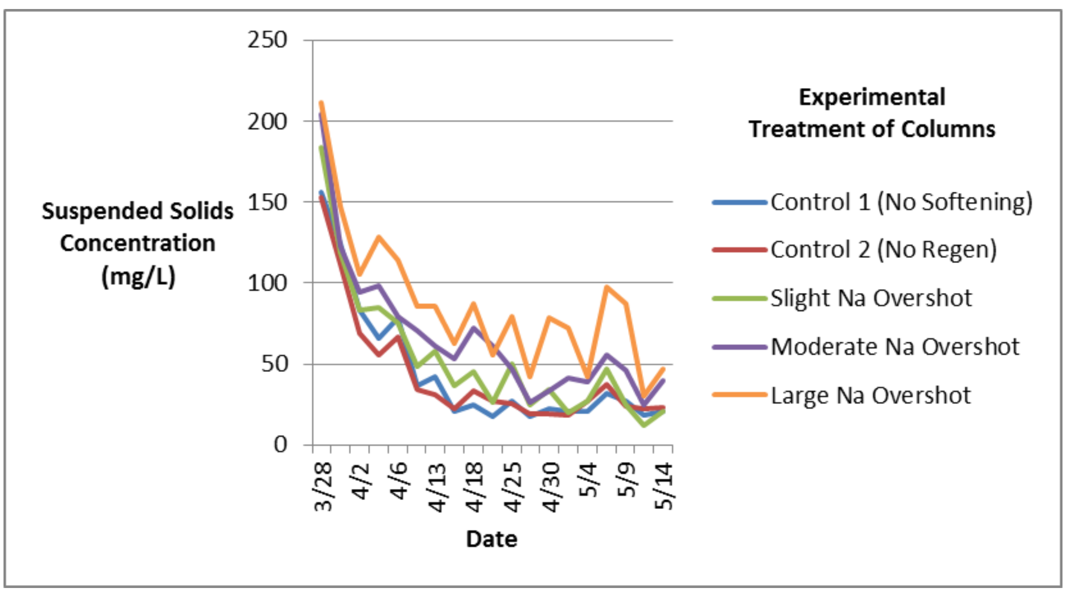

Figure 4- 24. Total Suspended Solids Concentration for the Entire Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

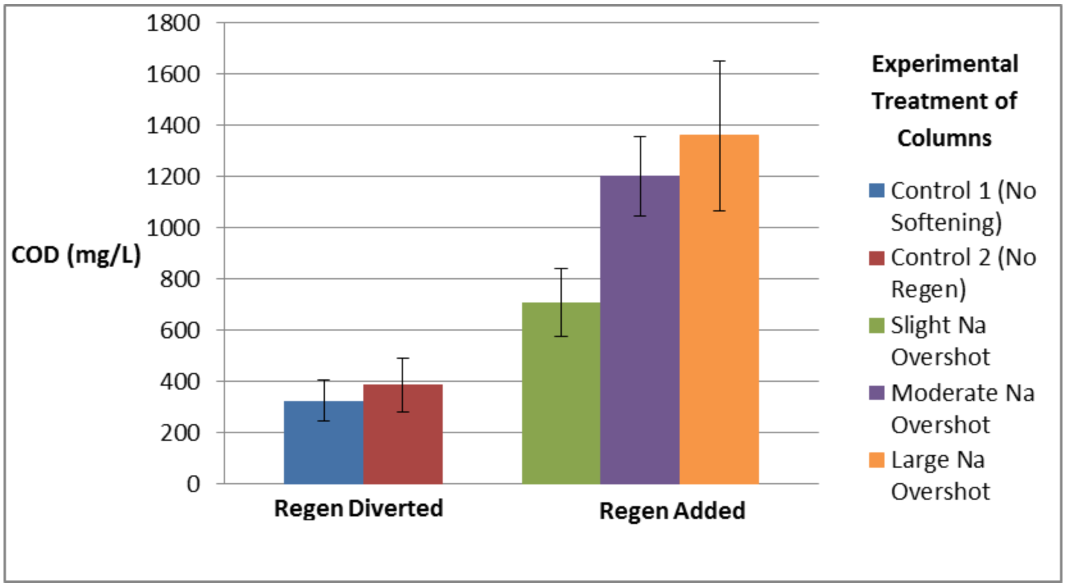

Figure 4-25. Final Five COD Measurements of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) Averaged with Standard Deviations

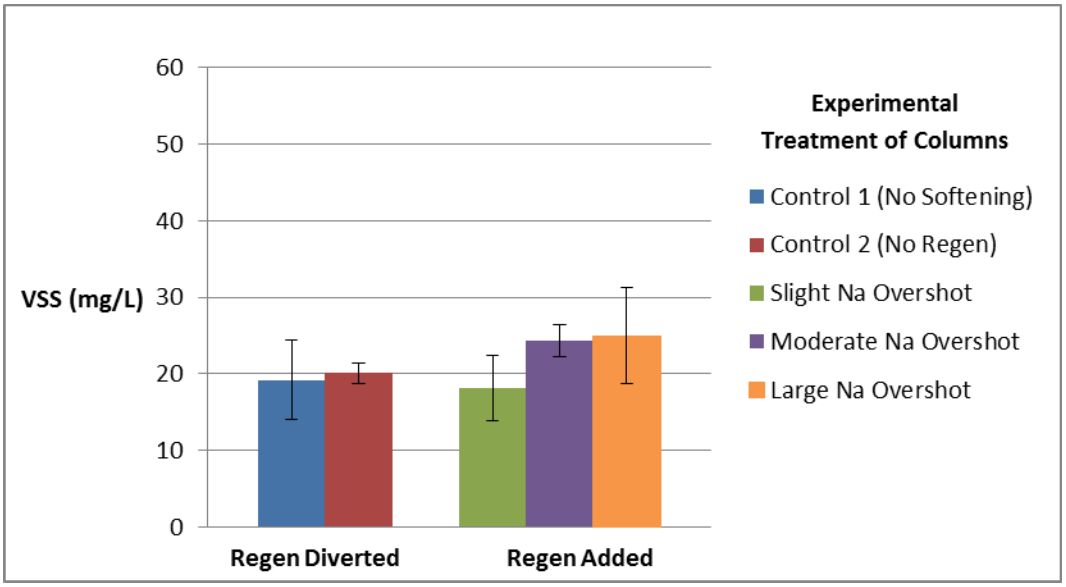

Figure 4-26. Final Five VSS Measurements of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) Averaged with Standard Deviations

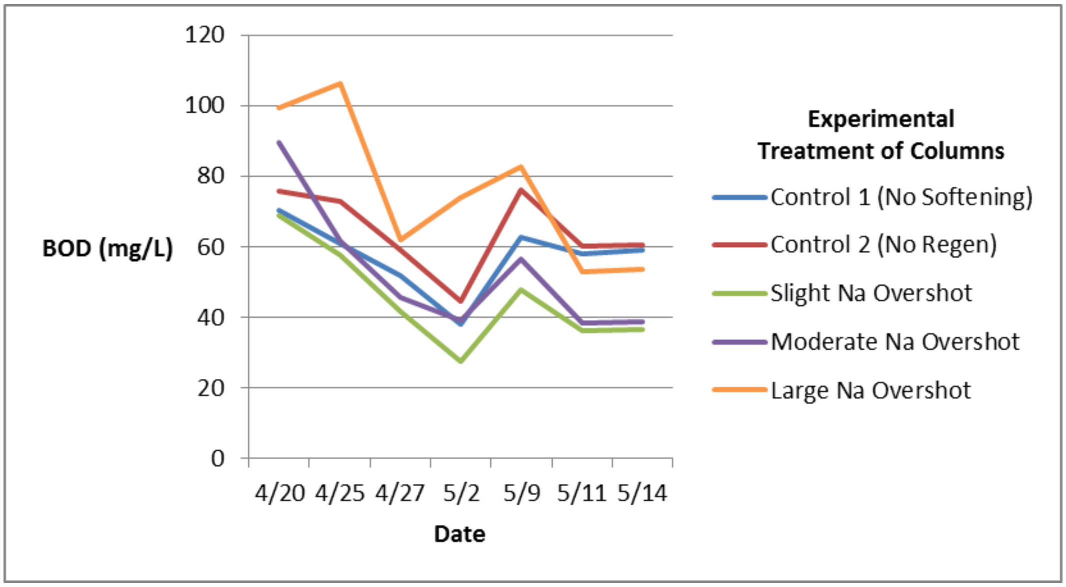

Figure 4- 27. Effluent BOD for the Entire Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

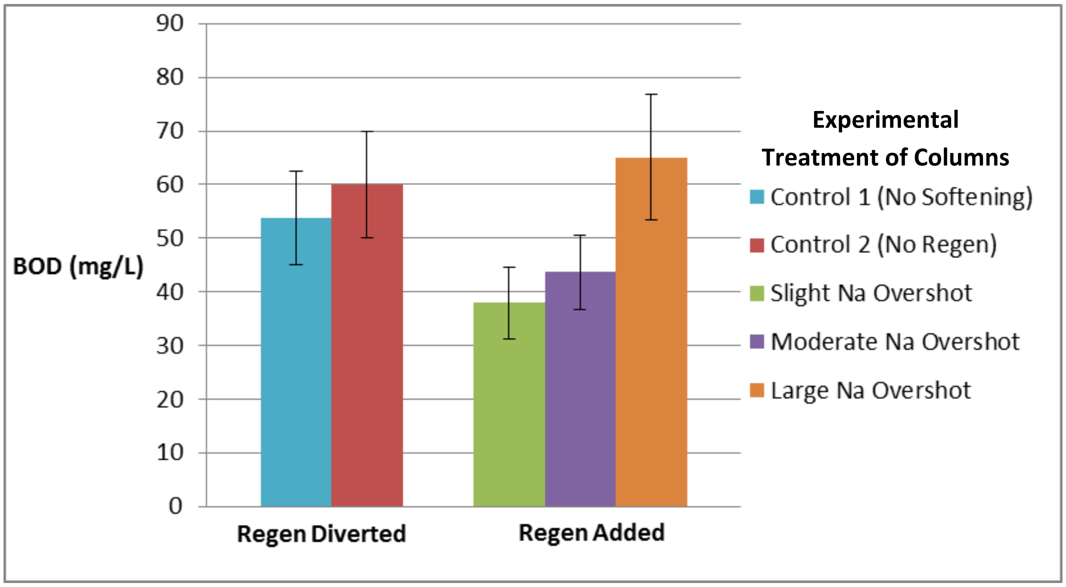

Figure 4-28. Final Five BOD Measurements of Column Effluent During the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent) Averaged with Standard Deviations

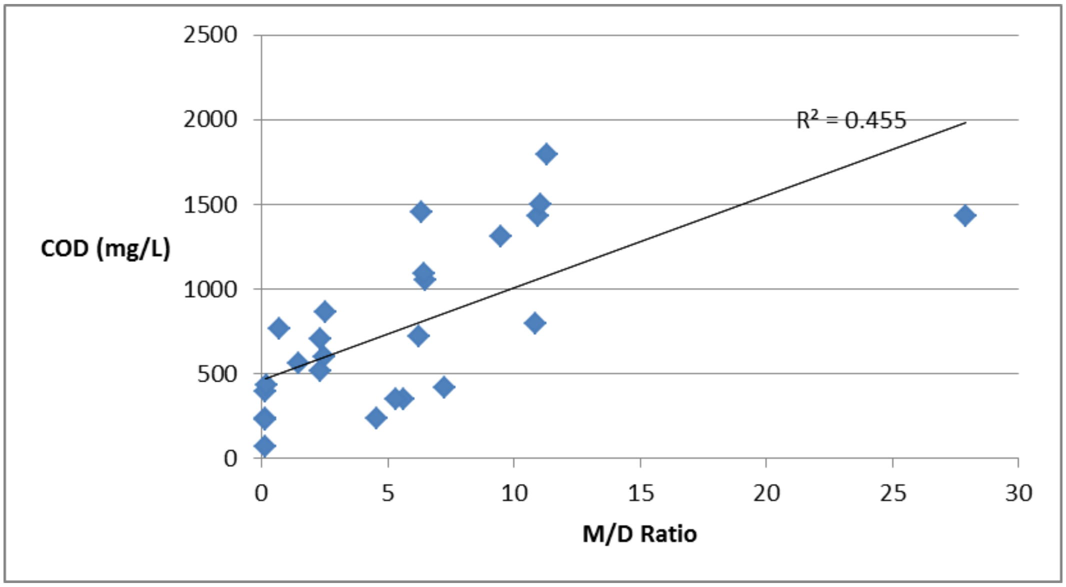

Figure 4-29. R^2 Correlation of M/D Ratio and COD Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

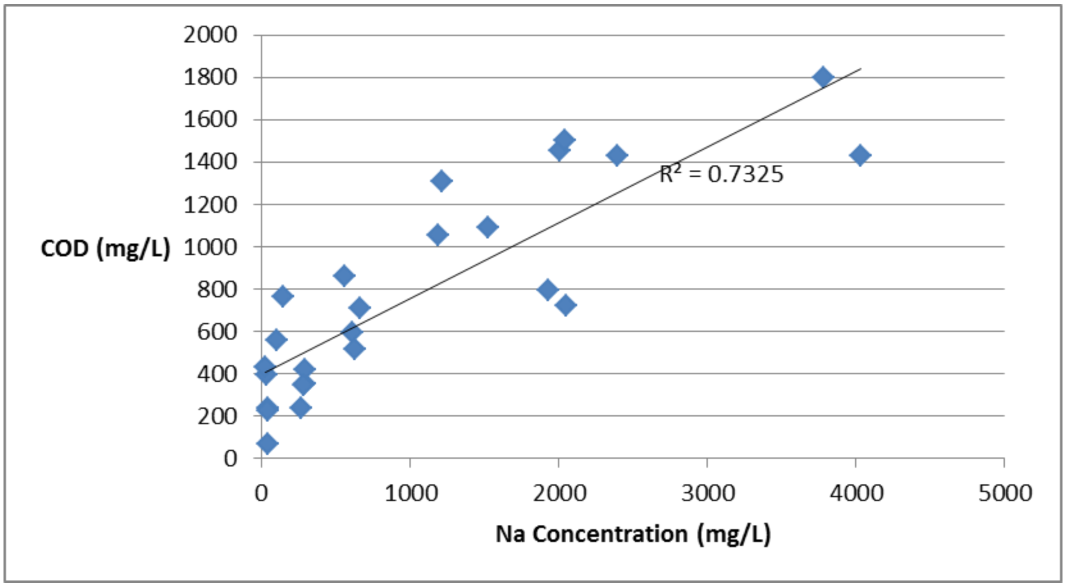

Figure 4-30. R^2 Correlation of Sodium Concentration and COD Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

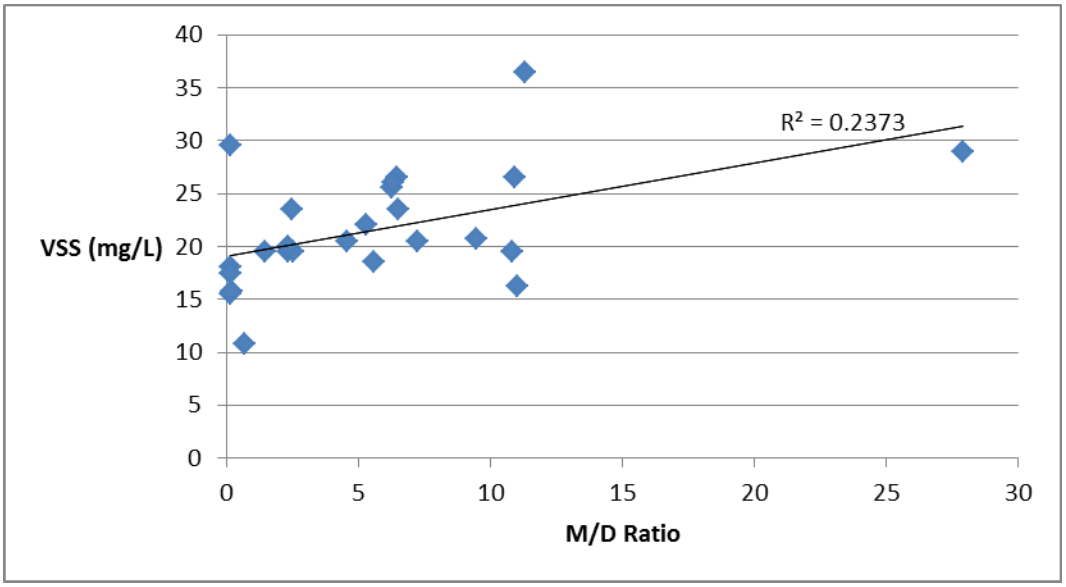

Figure 4-31. Correlation of M/D Ratio and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

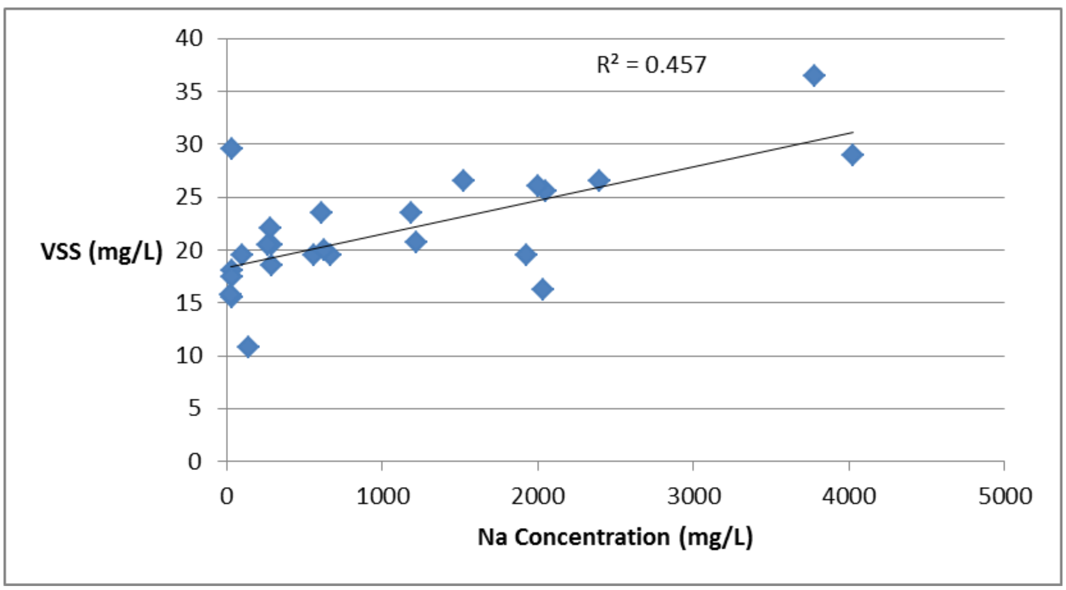

Figure 4-32. Correlation of Sodium Concentration and VSS Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

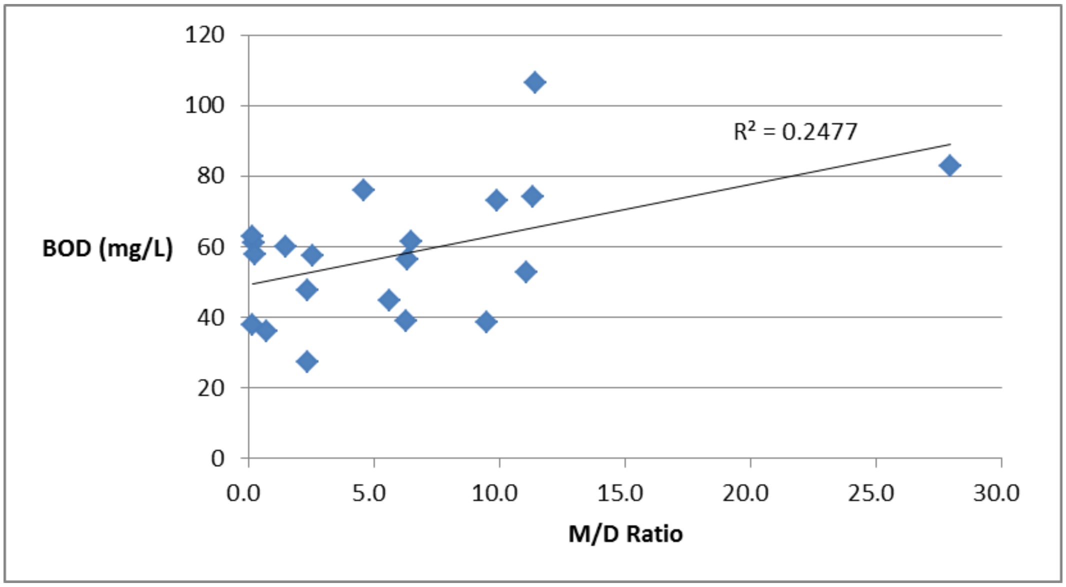

Figure 4-33. R^2 Correlation of M/D Ratio and BOD Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

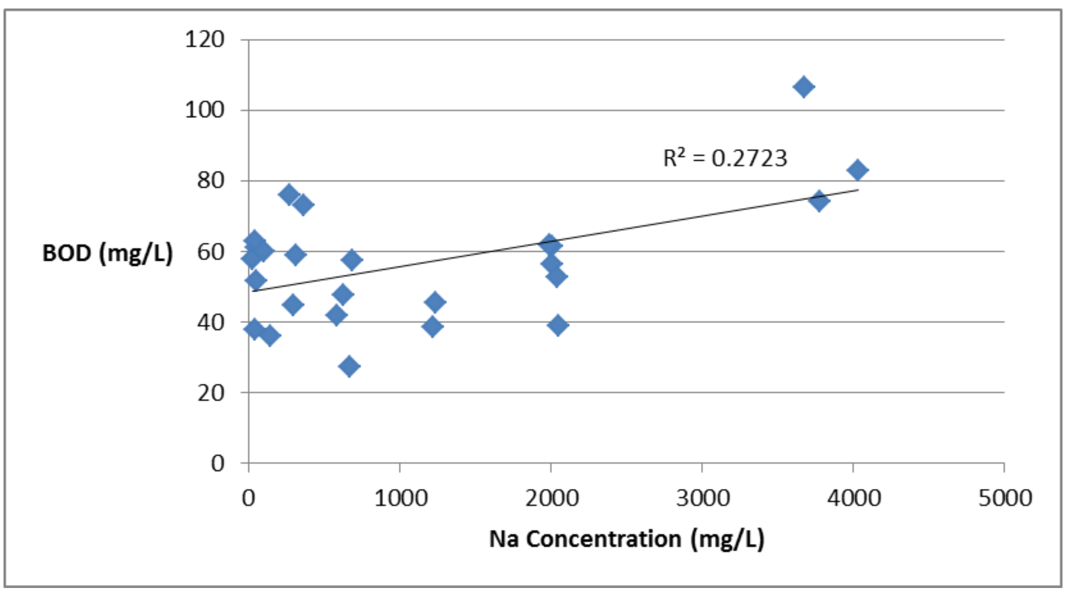

Figure 4-34. R^2 Correlation of Sodium Concentration and BOD Measurements of Column Effluent of Final Five Complete Measurements of the Fourth Run (Determining the Effect of Regeneration Wastes With Greater Sodium Concentrations on Septic Tank Effluent)

The M/D ratio once again followed the expected trend, with a few unexpected spikes along the way. This has been attributed to possible experimental error. As in the third run, the peaks can be seen on this graph that denote slugs of regeneration wastes. The COD results showed a clear stair-step pattern again, with the columns with higher sodium being on the upper end of COD concentration. The overall TSS data is shown here, as well, to demonstrate the possible impact the salt slugging is having. The spikes in the graph denoting higher TSS occur as frequently as the salt slugging in the regeneration waste is added. The VSS data showed a slight stair-step pattern, but the difference overall seemed somewhat trivial. The final 5 day average results for BOD produced a very interesting trend: The column receiving regeneration wastes with a "Slight Sodium Overshot" had the lowest BOD. This could be an example of the divalent cations counteracting the negative effect of the sodium. Even more interesting is that there appears to be a limit to this benefit, as the effluent from the "Large Sodium Overshot" column had the highest BOD of all. The same trend can be seen over the entire BOD data set: the "Slight Sodium Overshot" treatment yields the lowest BOD concentration for the entire run. When these data were correlated to the M/D ratio and the sodium concentration, VSS was shown once again to have no relationship with either. The COD data had a weak relationship with the M/D ratio, but a much stronger relationship with the sodium concentration. This supports the correlation seen in the third run, but the possible influence from the abundance of chloride ions must again be noted. The correlation of the BOD data showed weak relationships with both M/D ratio and sodium concentration, which supports what is seen in the overall BOD data graph.

4.2 PART II: GREASE STUDY

The grease study was conducted after the fourth run with some remaining stock from the columns. The grease (in the form of cooking oil) was added to graduated cylinders containing samples from each column. The contents were then mixed and the separation habits were observed. No differences between columns were noticed. In all graduated cylinders, the grease had risen to the top by the beginning of the next day and they all seemed to do so somewhat uniformly. This continually happened over the four times the cylinders were mixed. No data is displayed for this test, as no differences were discerned.

4.3 PART III: ANAEROBIC DIGESTION STUDY

4.3.1 GAS PRODUCTION

Over the three weeks of the anaerobic digestion study, accumulation of gas in the Tedlar bags was measured. No consistent differences were seen between the different experimental levels, but the gas production did slack off as expected with any batch digestion study. Some bags are suspected of having holes in them, as the sporadic zeros for measured gas content would suggest. When the possible leaking bag was replaced with a new bag, gas accumulation resumed. The graph for the gas accumulation is shown below.

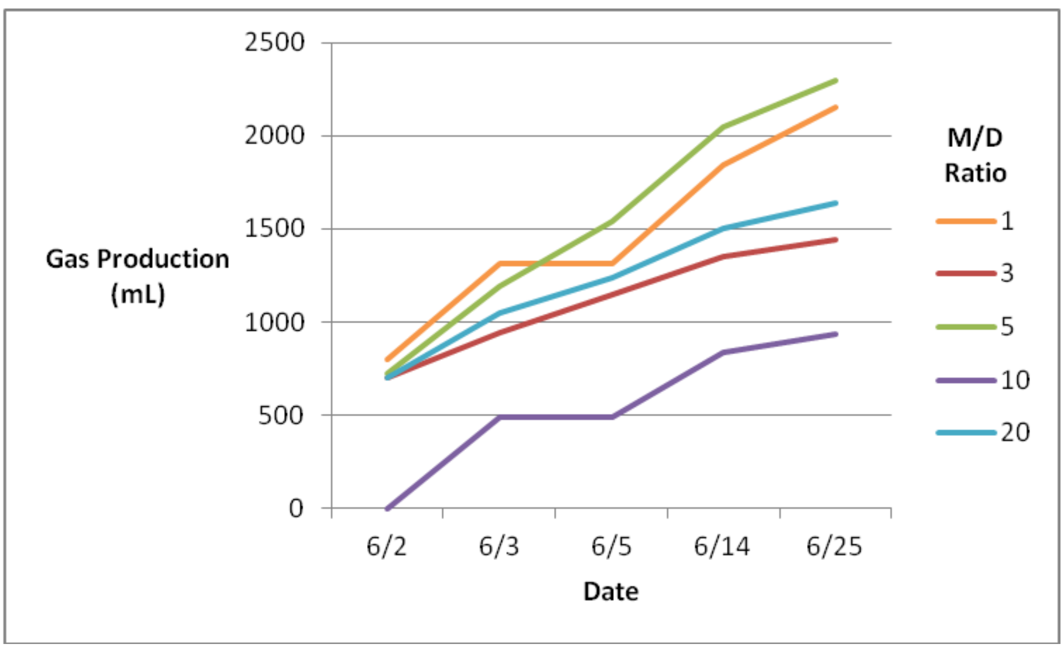

Figure 4-35. Total Gas Production of Anaerobic Digestion Study

4.3.2 GAS CONCENTRATION

The gas collected in each Tedlar bag was analyzed for methanethiol, dimethyl sulfide, dimethyl disulfide, and hydrogen sulfide concentration once during each of the three weeks of testing. On the first testing day, there was not gas in two of the bags, so only 3 experimental levels could be tested. The analysis showed a very interesting trend where certain constituents were higher in situations with a lower M/D ratio and vice-versa. This trend was very promising, but did not reappear in subsequent testing during the second and third week. Also, some of the graphs for dimethyl sulfate and dimethyl disulfate are too small to notice any trends. The differences between the data in these places, however, are trivial. Data for the concentrations of each gas during the entire run are shown below.

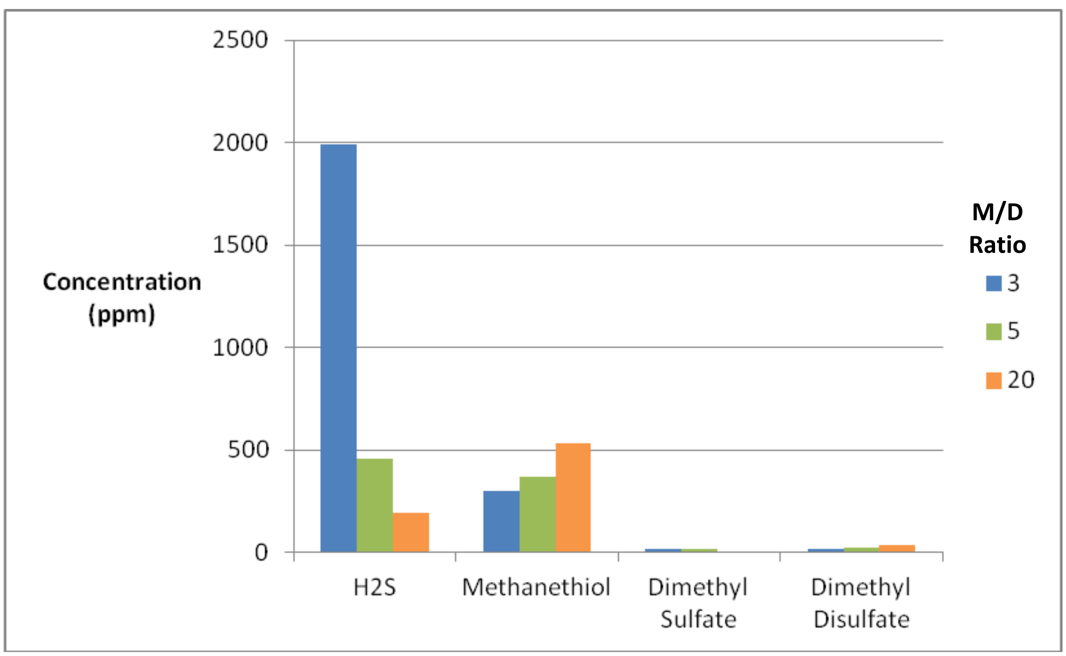

Figure 4-36. Gas Sample Concentration After 1 Week of Accumulation

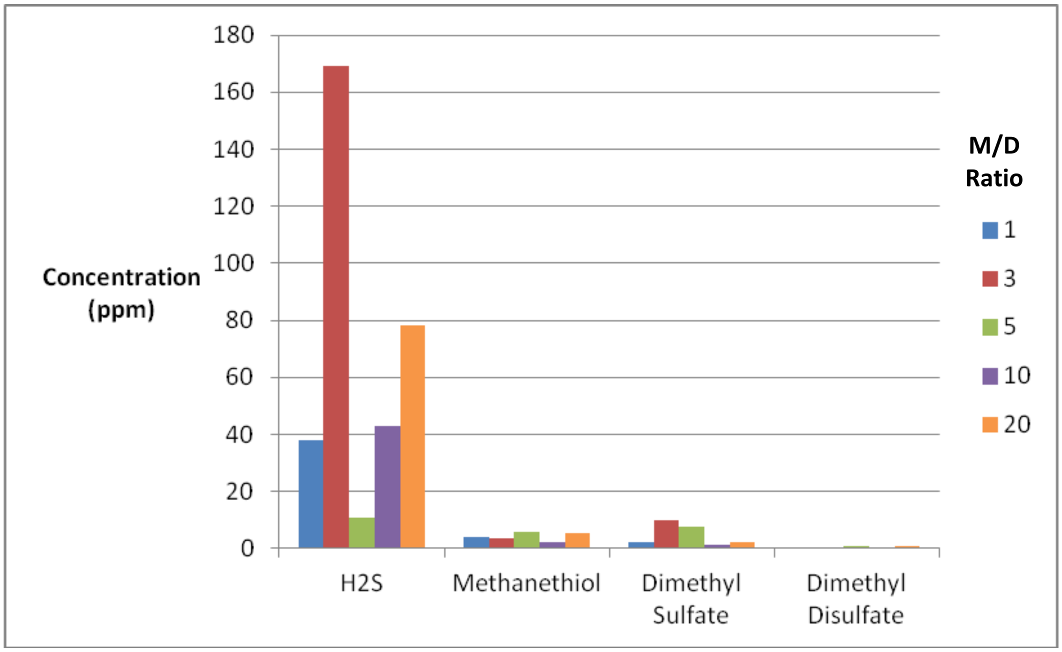

Figure 4-37. Gas Sample Concentration After 2 Weeks of Accumulation

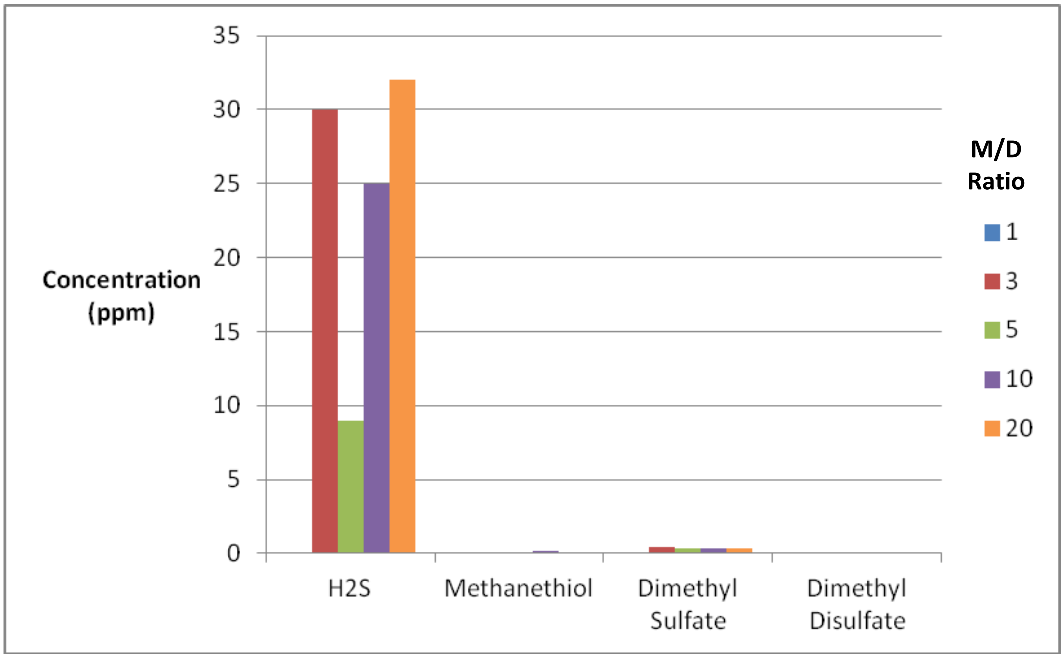

Figure 4-38. Gas Sample Concentration After 3 Weeks of Accumulation

4.4 PART IV: CASE STUDY

4.4.1 VISUAL APPEARANCE

When samples were received from the Naples, New York test site, it was very easy to tell which came from which tank. The samples from the tank not receiving regeneration wastes were always much darker due to a higher suspended solids content. The clearer, or cleaner, of the two samples always proved to be from the tank that was receiving regeneration wastes. Upon opening the shipment box, it was immediately clear which of the two samples would have a higher concentration of suspended solids. This simple visual difference was very interesting considering the scope of this study.

4.4.2 SOLIDS TESTING

Each of the received samples were tested for solids concentration. As stated above, it was clear which had higher solids, but this test allowed a number to be put with the visual appearance. Very consistently, the tank receiving no regeneration wastes always had a higher suspended and volatile suspended solids concentration. The results for the average solids concentration over all received samples are shown below.

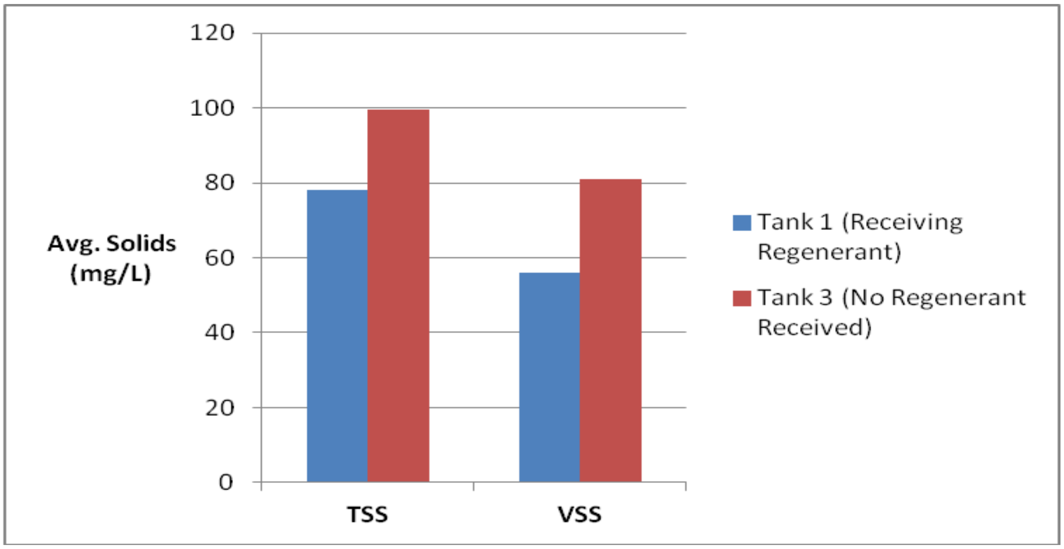

Figure 4-39. Average Solids Concentration in the Case Study Samples

4.4.3 CHEMICAL OXYGEN DEMAND (COD)

Since biochemical oxygen demand (BOD) needs to be tested within hours of sampling, these samples were preserved on-site, shipped to Virginia Tech and then tested for chemical oxygen demand (COD). This COD data served to provide a little more insight into the quality of the effluent from the case study tanks. As with the solids testing, the tank not receiving regeneration wastes yielded higher COD values. This trend was consistent over the entire run of testing these case study samples. The data for the average COD of samples received is shown below in Figure 4-38.

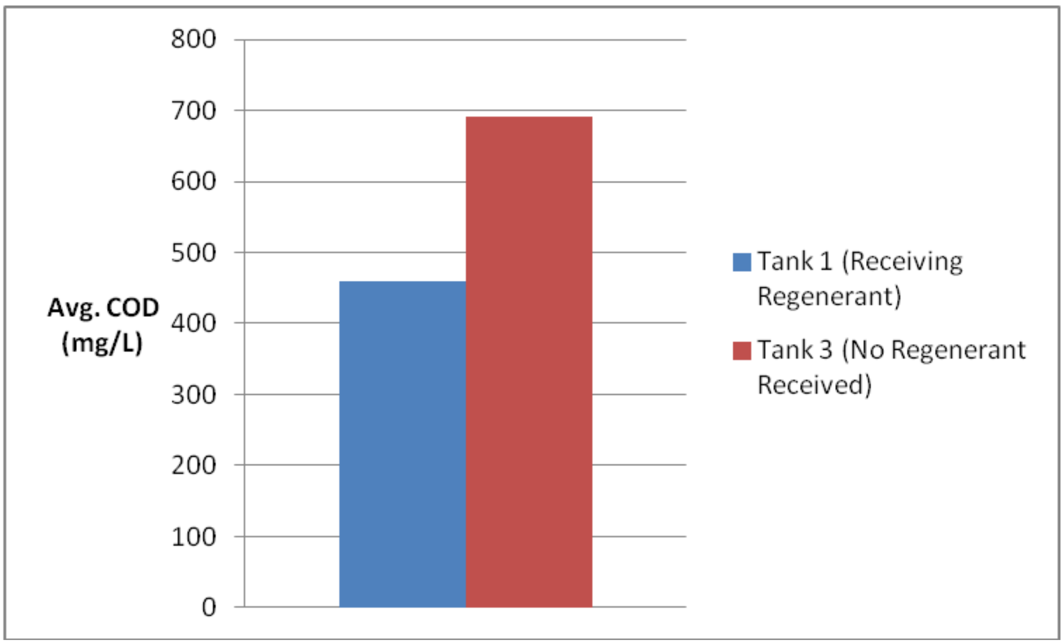

Figure 4-40. Average COD Concentration in Case Study Samples

4.5 RESULTS DISCUSSION

All results have been analyzed and compared to both the monovalent to divalent ratio (M/D) as well as the overall sodium content. Some tests, such as BOD, COD, and suspended solids showed results that suggested a pattern of deteriorating conditions with increasing sodium additions. That trend can be easily seen in some of the graphs noted above. The full set of TSS data for the fourth run also showed the interesting spikes that seemed to occur as the regeneration wastes were added. Even more interesting was that the spikes seemed to decrease in severity as the concentration of sodium in the regeneration waste became less. However, when considering an R^2 comparison, there were not many plots that could be considered evidence of a possible strong correlation (COD and M/D ratio in the 3rd and 4th runs being the exceptions). The trend is still visible in the raw data, though, and some R^2 plots did suggest a weak correlation. It could be possible that these analyses, or even the variation associated with the specific methods used (such as variation in the wastewater collected for use as influent), yield data that is somewhat variable and therefore can throw off hard statistical analysis of the exact values, such as correlation plots. The trends in most of the analyses on the fourth run are the most pronounced as well as the most interesting. This is most likely due to the increased sodium concentrations. During the first and second runs, sodium concentrations were comparatively much lower than in other runs, and few distinct differences were seen. In the third run, the "sodium overshot" in the regeneration waste was introduced and clear differences between analytical parameters of columns began to become apparent. For the fourth run, the overshots were increased further, and the trends became easy to see upon graphing the data. It seems that the expected benefit from the calcium and magnesium can be outweighed in situations with larger sodium overshots. In other words, it is apparent from the data that the most efficient home water softeners (such as DIR units) have an advantage over less efficient units as far as the effects the regeneration wastes have on septic tanks. Even more interesting, however, is that situations with more efficient water softening units also were shown to facilitate better quality effluent than situations where the regeneration wastes are diverted away from the septic tank. This means that sending regeneration wastes to the septic tank can actually be beneficial to effluent quality as long as the water softener is efficient in its timing of regeneration and use of sodium in the regeneration process. This shows an extension of earlier work: calcium and magnesium tend to aid in flocculation and settling while sodium is a detriment. These results make sense because the higher suspended solids give way to higher BOD's and COD's in the effluent of those columns. In other words, the trends are consistent over several related tests. The fourth run was the clearest in pointing this trend out and a follow up study is being conducted to duplicate the run and provide supporting data. One note to make on the COD data, however, is that all salts were added in their chloride form. This led to an abundance of chloride ions in the effluent, which is known to interfere with COD analysis. Although the samples were diluted to get the chloride concentration below an acceptable level, some of the COD values still seem excessively high. This is especially true in the third and fourth runs, where the salt additions were the greatest. It is important to note that the chloride levels could have played a role in this analysis, but the rest of the analyses seem to show good trends.

As for the grease study, there were no significant differences seen between different M/D ratios. It is possible that the salt content or M/D ratio of the tank has little effect on the flocculation of grease. However, it should also be stated that this method of testing was not the first attempt. Initially, grease was added to the columns with the daily influent, with a measurement expected to take place at the end of the run. The addition of grease through the influent pipe proved to be difficult and this practice was discontinued. While these data did not suggest any affects, it would be good to conduct a long term study in a column-like setup to ensure that salt concentration and M/D ratio have no effect on the grease flocculation.

The anaerobic digestion study produced noteworthy results. While the gas production was mostly consistent from each experimental level over the whole run (excluding the times when there was a leaking bag in use), the different gas concentrations varied between treatments. There was a trend on the first testing day that was not seen during the rest of the run. There was a stair-step pattern when looking at the data showing less methanethiol, dimethyl sulfide, and dimethyl disulfide in lower M/D ratios and then higher hydrogen sulfide concentrations in the same sample. This makes sense as the three other gasses are precursors to hydrogen sulfide. So, if there is more hydrogen sulfide, there should be less of the other three. As the M/D ratios grow, the hydrogen sulfide concentration lessens while the concentrations of the precursors grow. It could very well be that the salt present in these higher M/D ratio samples has inhibited the microorganisms responsible for converting these gasses, therefore leaving the gasses in their current state. This inhibitory action seemed to dissipate after the microbes adjusted to the new environment because this trend was no longer present at the time of the second concentration analysis. There was also no trend in the third analysis. This shows that given enough time, the microorganisms were able to adjust to the increased salt concentration and continue digesting the gasses.

The case study was also a great asset to this investigation. First of all, the simple visual differences between samples were astounding. Every time a new sample was received, the sample from the tank not receiving regeneration wastes was always much cloudier. This visual appearance was backed up by the actual numbers seen in both the suspended solids as well as the COD tests. Since this building operates with a very efficient DIR water softener, it lends credence to the column studies in the lab. It appears that if the softener operates efficiently, then the regeneration wastes can be an asset to the operation of the septic tank. Settling and flocculation tend to be helped the most, while no other detriments have been detected.

5. CONCLUSION

This investigation set out to determine the most appropriate course of action for dealing with regeneration wastes from water softeners. Through lab trials, as well as a case study, several conclusions have been made based on the results:

1. The addition of regeneration wastes with minimal sodium aids in the settling of solids and therefore helps to produce a better quality effluent.
2. The addition of regeneration wastes that contain large concentrations of excess sodium (e.g. inefficient water softeners) tends to be a detriment to solids settling and therefore produces a much lower quality effluent.
3. Diversion of regeneration wastes away from the septic tank allows for production of an effluent that is generally somewhere in the middle of the two cases listed above.
4. Addition of regeneration wastes does not affect the grease flocculation in a septic tank.
5. Addition of regeneration wastes may inhibit anaerobic microorganisms at first, but eventually they should adjust to normal operation. This shock may not happen in a system that has been operated a certain way for a long period of time.

6. FUTURE OF STUDY

This investigation helped to show what the addition of regeneration wastes to a septic tank does to the quality of the effluent, but there are still some parts of the study that could be expanded upon. Some recommendations for future study are listed below.

1. Perform further column studies to support the results seen in the final run. The final run showed the most telling results, so it would be beneficial to replicate this study to produce more support for the conclusions reached in this investigation. This is already underway at Virginia Tech using the same lab equipment and methods as in this study.
2. Perform more case studies on tanks that have been in operation for a long period of time. It is very hard to mimic a septic tank in the lab, so real world data can be a huge asset now that the lab work has laid the foundation.
3. Perform more intricate grease studies. This work may benefit from a more long term type of grease study, such as the columns in this experiment.

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