Quantifying fat, oil, and grease deposits formation kinetics in sewer collection systems

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Fat, oil and grease deposits in sewer systems are known as calcium based fatty acid salts that are responsible for a significant number of sanitary sewer overflows (SSOs) throughout the United States. Since 2007, clean water act (CWA) requires publicly owned treatment works (POTWs) to invest more than 15 billion dollars in new pipes and infrastructure to eliminate the overflows. However, little research has been performed to identify the potential key factors and quantify their effects that could lead to FOG deposit formation even in new pipes, such as types of fats used in restaurants, types of calcium sources, pH, temperature, and mixing conditions inside sewer systems. The objective of this study was to determine the kinetics of FOG deposits and exploring effects of the factors previously described. Laboratory scale saponification experiments were performed and kinetic data was collected under near-stoichiometric conditions. The results displayed a significant influence of pH and temperature on kinetics of calcium-based fatty acid salts since they influence the solubility of calcium sources in water. The kinetic data also suggested a fraction of fast soap formation either due to presence of some initial free fatty acid (FFA) in source fats and/or high intensity mixing condition of the constituents. The kinetic data was compared with two empirical models: a) saponification and b) crystallization. The results showed that both empirical models performed equally well. However, both models required modifications to the empirical constants based on changes to experimental conditions. Therefore, a mechanistic model was prepared that is expected to better elucidate the chemistry of the FOG deposit formation process. Future research includes investigation of more potential factors, such as use of detergent types in restaurants, presence of initial FFA and effect of microbial activities during the formation process.

Keywords: Fat, oil and grease (FOG), Sanitary sewer overflows (SSOs), saponification

INTRODUCTION

Fat, oil, and grease (FOG) deposits, which have been identified as calcium based fatty acid salts in sewer systems, are one of the major contributors to sanitary sewer overflows (SSOs) throughout the United States. The ASCE report card on America's infrastructure has continued to give a D rating to the nation's wastewater and stormwater conveyance systems. It was suggested that fixing or expanding the sewer collection pipes will address SSOs. Therefore, since 2007, the federal government has set a requirement to municipalities to spend 15 billion dollars on new pipes and wastewater infrastructure to reduce overflows that lead to raw sewage exposure affecting public health. While a significant repair or replacement of the sewer collection system is sorely needed, the fundamental understanding of factors that influence the FOG deposits formation in sewer systems is still unclear. This knowledge is needed to safeguard against the occurrence of FOG deposits in new or repaired pipes to achieve a sustainable

sewer collection system. The objective of this study was to identify and investigate potential source and environmental factors that may affect the formation mechanism of FOG deposits and their kinetics in sewer systems. The factors identified so far included the types of fats used in restaurants, types of calcium sources, pH, temperature, and mixing conditions inside sewer systems.

METHODOLOGY

Lab-scale experiments were performed in which calcium based fatty acid salts were prepared under alkali driven hydrolysis conditions. Experimental factors that were investigated include: 1) types of fats used in restaurants, i.e., unsaturated (canola) vs. saturated (beef tallow); 2) types of calcium sources in sewer system, background wastewater (calcium chloride) vs. biogenic concrete corrosion (calcium sulfate); and environmental conditions in sewer system, i.e., 3) pH (neutral, 10 and ≈14) and 4) temperature (room temperature, 22°C vs. warm temperature, 45°C). The extreme pH condition was investigated to understand the extent of alkali driven hydrolysis. The final salts were analyzed for fatty acid composition, mineral and metal analysis, and rheological properties. Kinetic samples were also collected and analyzed using a fingerprinting technique, known as Fourier transform infrared (FTIR) analysis. The average real lag time between sample collection and FTIR analysis was approximately two minutes. The baseline correction and peak determination of the spectral data from FTIR were performed using data analysis software, OriginPro 8.

RESULTS & DISCUSSION

The results of this study showed significant formation of calcium salts under alkali driven hydrolysis conditions as shown in Figure 1 & 2. Figure 1 & 2 displays the formation of saponified solids (i.e., calcium based soaps) with time with the changes in pH and temperature conditions respectively. Liquid canola oil with calcium chloride produced more saponified solids under high pH condition (Figure 1). Canola oil also produced more solids with calcium chloride with the increase in temperature (Figure 2). The results suggest that pH and temperature change solubility of calcium chloride affecting the amount of free calcium ions available for saponification. The kinetic data in Figure 1 & 2 also suggests that approximately 15-20% of the initial fat converts to saponified solid within two minutes of reactant mixing. This phenomenon of fast soap formation could be attributed to some initial free fatty acids present in source fats and/or high intensity instantaneous mixing (i.e., 460 rpm).

Figure 3 also displays the effects of different fats and calcium sources on colors and appearances of calcium based saponified solids under different pH conditions. Canola based solids made with calcium sulfate appeared granular and rough in texture compared to those with calcium chloride. The granular soap formation could be attributable to the solubility of the respective calcium sources under the prescribed environmental conditions. The observations here suggest that the visual characteristics, such as, color and texture of the lab based calcium fatty acid salts can be compared with fresh FOG deposit samples in sewers to provide a qualitative assessment on the possible calcium sources involved in the formation process. Previous studies (Keener et al., 2008; He et al., 2011) found palmitic, a saturated fatty acid, as the primary fatty acid present in FOG deposits. However, in the present study under alkali driven

hydrolysis, the fatty acid compositions of the final calcium fatty acid salt samples were similar to the fatty acid composition of the source fats introduced at the beginning of the saponification process (Figure 4). Beef tallow, which was studied only under warm temperature (45°C) conditions, also solidified above the solid calcium fatty acid salt matrix when cooled down to room temperature. Although a fraction of beef tallow and other similar solid fats may transport down to the sewer system beyond the effluent of the grease interceptor (GI), the present study suggests the fatty acid compositions in the fresh FOG deposits are primarily related to the source fat conditions. Fresh FOG deposits prepared by He et al. (2011) using GI effluents clearly showed that the largest fatty acid constituent in the GI effluent contains primarily palmitic, as shown in Figure 4. The fate of calcium based solids produced with other major unsaturated fats, i.e., oleic and linoleic, can be explained with continued biological hydrogenation in the layers of FOG deposits. While it's not known if any or all of these mechanisms are involved in producing a waste stream that predominantly contains saturated fatty acid, the results of this study clearly shows that FOG deposits created with pure oils or fats will have fatty acid contents similar to that pure fat or oil.

The kinetic data was compared with two empirical models to describe the FOG deposit formation process- a) saponification (Cotte et al., 2006), and b) crystallization model (Foubert et al., 2002). The results in Figure 5 showed that both empirical models performed well to some extent. The saponification model captured the initial rise well compared with the crystallization model that was able to better represent the kinetic data in later time periods. However, both models required modifications to the empirical constants based on changes to experimental conditions. A mechanistic model was subsequently developed and evaluated, as shown in Figure 5, to better elucidate the chemistry of the FOG deposit formation process. The model fits suggested that the mechanistic model tried to better capture the true nature of the experimental data, i.e., both the initial fast rise and the gradual change in later periods. The mechanistic model could also track changes in reactant concentrations (i.e., unreacted fat and calcium content).

CONCLUSIONS

Overall, this study provided evidence that source and environmental factors can play a significant role in FOG deposit makeup and its kinetics. General control of FOG concentrations in GI effluents may not be sufficient. Rather, selective removal of palmitic in pretreatment processes may also be necessary to reduce the FOG deposit formation in sewer systems. The results of the kinetic models can also be incorporated into large scale wastewater models to identify potential "FOG deposit accumulating hotspots" and therefore help guide collection system maintenance and the prevention of SSOs. Future research is also recommended that includes investigation of more potential factors, such as use of detergent types in restaurants, presence of initial FFA and effect of microbial activities during the formation process.

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References

Cotte, M., Checroun, E., Susini, J., Dumas, P., Tchoreloff, P., Besnard, M. (2006). Kinetics of oil saponification by lead salts in ancient preparations of pharmaceutical lead plasters and painting lead mediums.*Talanta, 70*(5), 1136-1142: 2006

Foubert, I., Vanrolleghem, P. A., Vanhoutte, B., & Dewettinck, K. (2002). Dynamic mathematical model of the crystallization kinetics of fats. *Food Research International, 35*(10), 945-956

He, X., Iasmin, M., Dean, L. O., Lappi, S. E., Ducoste, J. J., & de los Reyes III, F. L. (2011). Evidence for fat, oil, and grease (FOG) deposit formation mechanisms in sewer lines. *Environmental science & technology*, *45*(10), 4385-4391

He, X., de los Reyes III, F. L., Leming, M. L., Dean, L. O., Lappi, S. E., & Ducoste, J. J. (2013). Mechanisms of Fat, Oil and Grease (FOG) Deposit Formation in Sewer Lines. *Water Research*.

Keener, K.M., Ducoste, J.J., Holt, L.M. (2008). Properties influencing fat, oil, and grease deposit formation. *Water Environ. Res*. 80, 2241-2246

Oppenheimer, C. H. (1960). *Geochim. Cosmochim. Acta*, **19**, 244.

Rhead, M., Eglinton, G., Draffan, G., & England, P. (1971). Conversion of oleic acid to saturated fatty acids in severn estuary sediments. Nature, Volume 232, Issue 5309, pp. 327-330

Zobell, C. E., and Upham, H. C. (1944). Bull. Scripps Inst. Oceanog., 5, 239.

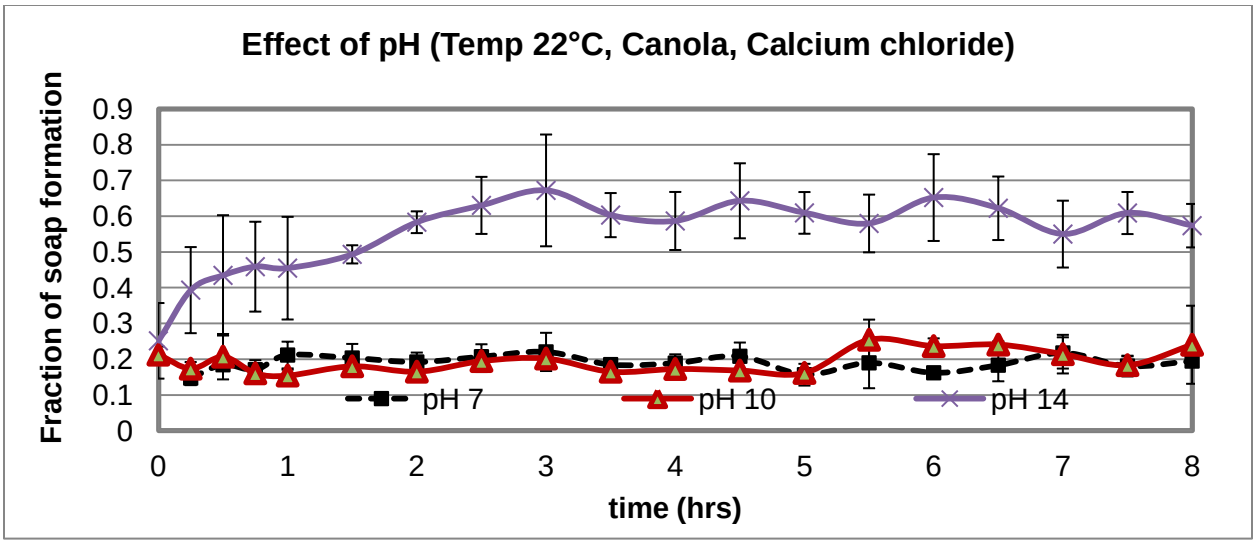

Figure 1 Effect of pH on calcium based fatty acid salt formation

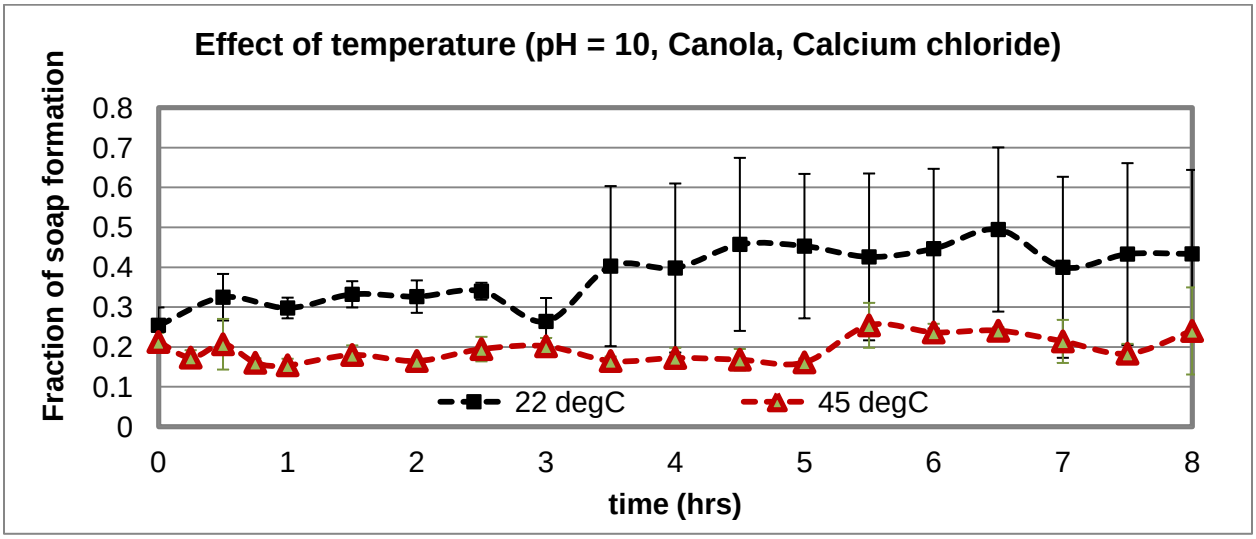

Figure 2 Effect of temperature on calcium based fatty acid salt formation

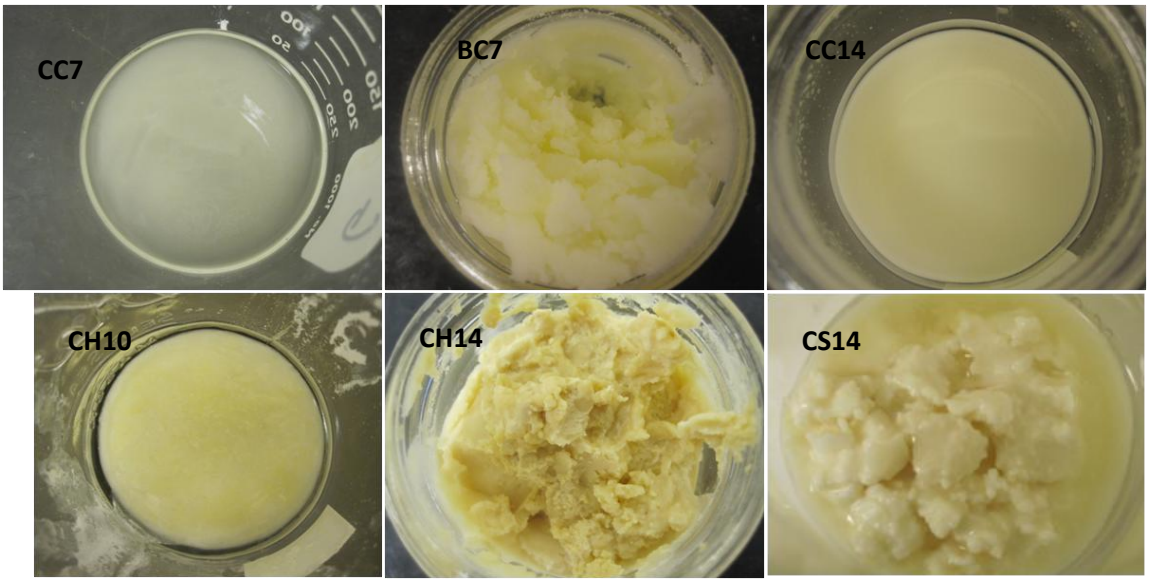

Figure 3 Calcium based fatty acid salts prepared in laboratory (*CC = Canola and calcium Chloride; BC = Beef tallow and calcium Chloride; similarly in the second letters, S = calcium Sulfate, and H = calcium Hydroxide; the numbers indicate pH values.*)

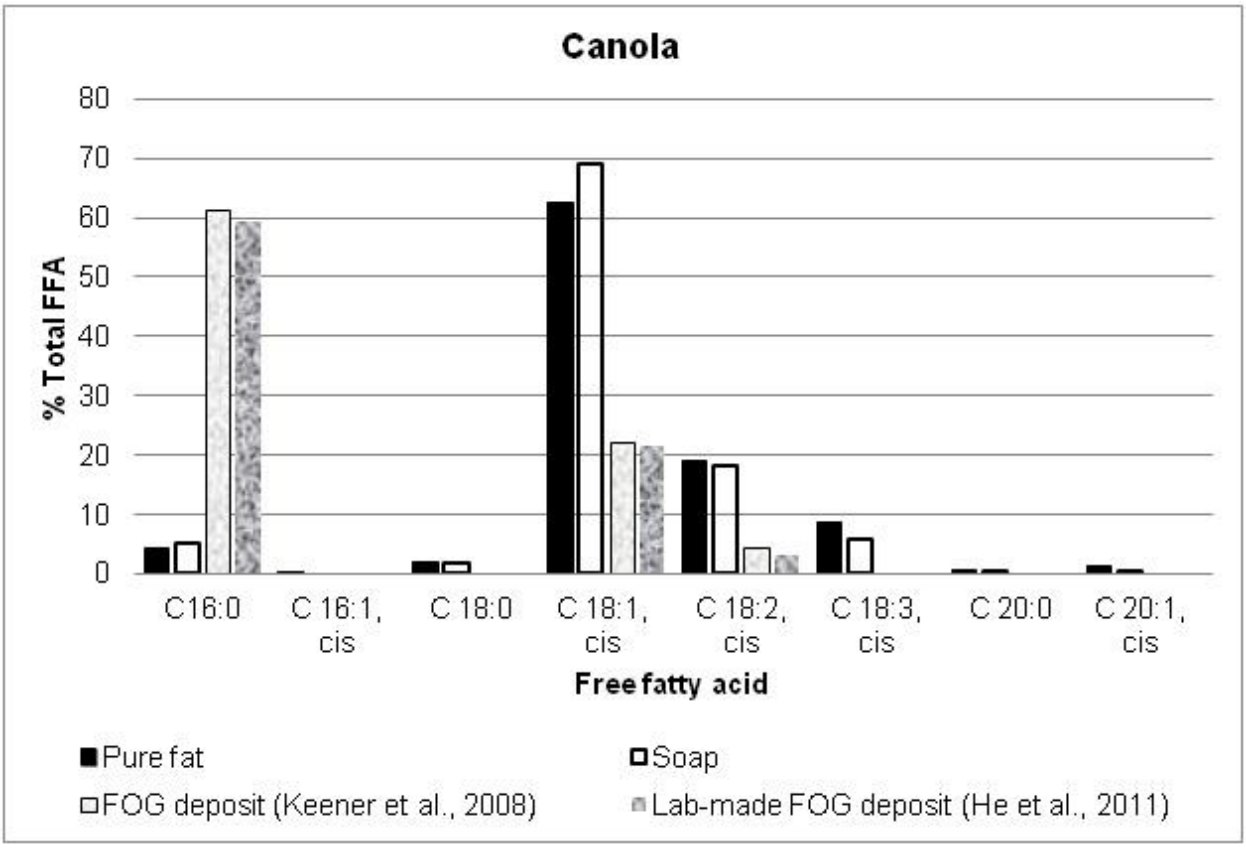

Figure 4 Fatty acid profiles of calcium based fatty acid salts (source fat: canola)

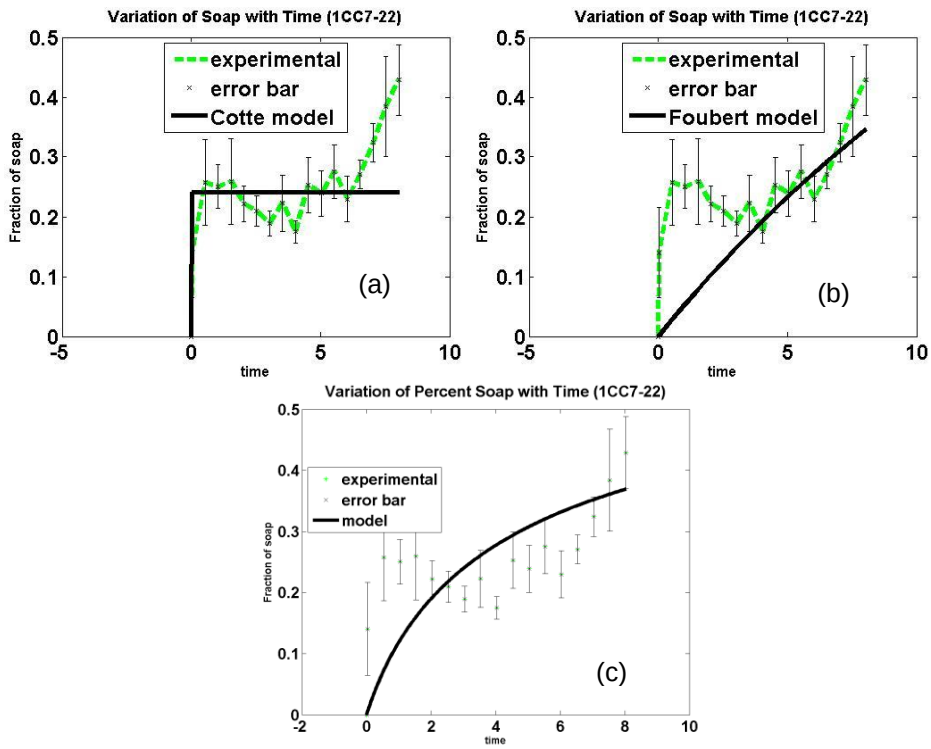

Figure 5 Performance of two empirical models: (a) saponification (Cotte et al., 2006) and (b) crystallization (Foubert et al., 2002), and (c) a mechanistic model to describe kinetics of FOG deposits made with canola and calcium chloride under pH 7 and room temperature