SIMULATING THE FORMATION OF FATS, OILS & GREASE (FOG) DEPOSITS IN A SEWER COLLECTION SYSTEM

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ABSTRACT

A large fraction (over 45%) of the sewer pipe blockages are due to the buildup of insoluble calcium salts of fatty acid. Research has shown that food service establishments (FSE) and high density dwellings release fat, oil, and grease (FOG) that react with the calcium present in the wastewater or released from the corrosion of concrete structures to form insoluble metallic salts through a process called saponification. If left unabated, the accumulation of these solids will lead to Sanitary Sewer Overflows (SSO) of raw sewage to the surrounding environment.

Pretreatment coordinators, responsible for the protection of the sewer collection system, routinely perform maintenance to clear pipes that may have accumulated solids or debris. Coordinators identify hotspots where there would be high risk of an SSO event, if no maintenance was performed. These regions need to be monitored carefully and maintenance performed frequently depending on the severity of the accumulation of solids such as FOG deposits to prevent such an event. While pretreatment coordinators may be aware of current maintenance requirements of an existing sewer system, the discharge wastewater quality may change due to the changing urban landscape (i.e., changes in the number and location of FSEs or high density dwellings). Yet, there is no tool that is available to help pretreatment coordinators anticipate how the sewer water quality may change due to the addition or removal of FSEs or high density dwellings and the consequent impact of FOG related solids formation in the sewer lines.

This research presents a computer model that simulates the sewer collection system transport and predicts the formation of FOG deposits based on the saponification reaction. The model is incorporated into CITY DRAIN 2.0.3, which is an open source software integrated within MATLAB/Simulink, to model the urban drainage system. The purpose of this study was to determine the critical hotspots for a given area using CITYDRAIN software to assist municipal pretreatment coordinators to plan future periodic maintenance of the sewer collection system due to dynamic changes in the urban landscape. Simulations as proposed in this study could potentially be performed for any sewer collection system if the GIS information is provided. Examples of two different sewer collection systems will be demonstrated using this numerical tool.

Keywords: FOG deposits, Sewer collection system, Modeling

INTRODUCTION

FOG deposits in sewer pipes have been shown to be insoluble metallic salts of fatty acids and may lead to SSOs that impose a risk to public health and the environment by releasing high concentrations of pathogens, nutrients, and solids (He et al., 2013). About fifty percent of SSOs are due to line blockages, where half of these blockages are caused by FOG deposits (EPA, 2004). According to EPA, about 3-10 billion gallons of untreated wastewater is discharged annually as a result of SSOs. Consequently, maintenance of the pipes and frequent cleaning activities become crucial to achieve a high level of wastewater conveyance by the sewer collection system.
Free fatty acids (FFA) are available in large amounts in waste restaurant oils and animal fats (Canacki, 2007) and can be released when wastewater from FSEs and high density communities is discharged into sewer system. FOG (Triglyceride) can undergo hydrolysis (Equation 1) either during the cooking process or by microbial activity. When free fatty acids and calcium come into contact, metallic saponified solids (Ca(FFA)₂ in Equation 2) are formed through saponification reaction (Keener et al., 2008; He et al., 2011, He et al., 2013). Calcium is either naturally present in wastewater or is released by Microbiologically Induced Concrete Corrosion” (MICC) (Gutiérrez-Padilla et al., 2010). These saponified solids display an adhesive character and can become securely bound to interior pipe walls (Keener et al., 2008). For details on proposed mechanisms of FOG deposit formation in sewer lines see He et al., 2013.

\[
\text{Triglyceride} + 3 \text{H}_2\text{O} \rightarrow 3 \text{FFA} + \text{Glycerol} \quad (1)
\]

\[
3 \text{Ca}^{2+} + 2 \text{FFA} + 6 \text{H}_2\text{O} \rightarrow 3 \text{Ca(FFA)}_2 + 2 \text{Glycerol} \quad (2)
\]

One of the pretreatment coordinator’s responsibilities is to inspect the sewer collection system for hotspots of accumulated solids where one type is saponified material (called FOG deposits hereafter). The absence of this routine maintenance would lead to a high risk of an SSO and the release of untreated wastewater to the surrounding environment. With the rapid change in urban landscape (i.e. change in the number or location of FSEs and high density dwellings), coordinators find it more difficult to anticipate the quality of wastewater that in turn changes the occurrence of these hotspots of limited wastewater conveyance.

Computer models of wastewater conveyance systems are usually constructed to determine the hydraulic capacity of the existing system under peak wet and weather flow conditions. Results from these models provide municipalities with potential limitations in pipe size capacity to achieve anticipated wastewater flows from future changes to the above rural or urban landscape. However, these models currently provide limited ability to track the transport of contaminants that undergo reaction processes that may limit the conveyance of these wastewater collection systems.

The purpose of this research is to develop a computer model that simulates the sewer collection system contaminant transport and predicts the formation of FOG deposits based on the saponification reaction. CITYDRAIN 2.0.3, which is an open source software integrated within MATLAB/Simulink, was used to model the urban drainage system. The goal of this study was to identify critical hotspots for a given area using CITYDRAIN software and provide municipal pretreatment coordinators a tool to plan future periodic maintenance of the sewer collection system due to dynamic changes in the urban landscape. Examples of two different sewer collection systems will be demonstrated using this numerical tool.

**METHODOLOGY**

A model of a sewer collection system was built using CITYDRAIN 2.0.3, which makes use of Muskingum method of flood routing (Achleitner et al., 2006). This model was further modified to include the FOG deposit reaction kinetics. The FOG deposit reaction model includes the FOG hydrolysis steps, the saponification reaction, and the rate of aggregation of saponified solids formed in the wastewater with those formed directly on the pipe wall. The rate of hydrolysis for the reaction described in Equation 1 is shown in Equation 5 where [Tri] is the concentration of Triglyceride. The saponification rate for the reaction described earlier (Equation 2) is shown in Equation 6. Finally, the rate of aggregation is described in Equations 7 where \(\gamma\) is the shear rate calculated as \((4.0/Q)\times P.R.h^2\), \(S_L\) is the concentration of the saponified solid in the liquid phase and \(S_W\) is the concentration of the saponified solid on the wall. \(K_{Tri}\), \(K_s\) and \(K_a\) are hydrolysis, saponification, and aggregation rate constants, respectively.

\[
r_{\text{FOGT}} = K_{Tri} \times [\text{Tri}] \quad (5)
\]

\[
r_{\text{saponification}} = K_s \times [\text{Ca}^{2+}] \times [\text{FFA}]^2 \quad (6)
\]
\[ r_{\text{AGG}} = k_a \times \gamma \times S_L \times S_W \]  

(7)

The modified CITYDRAIN model was used to simulate two different sewer collection systems. A basic sewer pipe model in the graphical interface of Simulink is shown in Figure 1.

![Figure 1. Basic model of a sewer pipe with the various components of CITYDRAIN integrated.](image)

The sewer collection system models were simulated for a time period of one week with a time step of 300 seconds. Two different sources were used as input for the model. The background wastewater contained only 50 mg/L of calcium and zero FOG in the form of Triglyceride while the wastewater from FSE contained 200 mg/L of Triglyceride and the same level of calcium. The flow rate used for the models was 0.0358 m³/sec (calculated from a scour velocity of 2.5 ft/sec) and 0.0041 m³/sec (Aziz et al, 2012) for the background and the FSE wastewater, respectively. A sensitivity analysis was performed on the model’s parameters in order to determine the changes in the hotspot location by varying the triglyceride hydrolysis rate constant \( k_{\text{Tri}} \), rate constant of FOG deposit aggregation to the pipe wall \( k_a \), and rate constant of FOG deposit formation through the saponification reaction \( k_s \).

RESULTS

A section of one of the model sewer collection system using CITYDRAIN is shown in Figure 2. The sewer collection system model was simulated for one week and the hotspots were determined. The hotspots in the given model were initially computed by determining the rate of change of FOG deposit accumulation at the wall. We assumed that the location in the sewer collection system where FOG deposits are accumulating at a high rate would be locations where pretreatment coordinators will be concerned about the rapid occlusion of the pipe and subsequent potential of an SSO.
Simulated hotspots were compared with the GIS and maintenance information that reported either the frequency of cleaning a segment of pipe with significant FOG deposit accumulation or SSO resulting from FOG deposit accumulation. The predicted locations of high FOG deposit formation (shown with blue boxes in Figure 3) were in reasonable spatial agreement with the reported data in the sewer collection system (shown with pink boxes in Figure 3).

The model was also able to predict additional hotspots, which were not reported in the maintenance records. We are actively working with the maintenance crew to determine the extent of FOG deposit accumulation in these additional model predicted hotspots. The prediction of these additional hotspots demonstrates that the model could be an asset for pretreatment coordinators in arranging their maintenance schedules to address all areas where there is a significant potential for FOG deposit accumulation. We are also exploring alternative approaches to assess the risk of FOG deposit accumulation using the model framework. The model’s reaction rate constants were determined by maximizing the agreement between reported high maintenance reported sites in the sewer collection system and the model’s predicted high rate of FOG deposit accumulation sites. A sensitivity analysis was performed to determine whether there were changes in the hotspot location due to changes in the rate constants $k_{Tr}$, $k_s$ and $k_a$. Preliminary results of the sensitivity analysis suggest a high degree of variation in the predicted hotspot with changes in $k_{Tr}$, $k_s$, and $k_a$. 

Figure 2: Section of the sewer collection system modeled in CITYDRAIN 2.0.3.
CONCLUSIONS

CITYDRAIN 2.0.3 was successful in predicting many of the hotspots for a given area based on the FOG deposit formation rate. However, many other sites that were reported as high maintenance regions were not predicted by the model. Possible reasons for the difference between model and actual maintenance reported sites in the sewer system is that the model does not currently include spatial variations in hydraulic characteristics, types of pipes, or age of pipes that may affect pipe surface characteristics (i.e., only straight sewer pipes are simulated). Further, there may be pipes in the sewer collection system that are deformed such as pipe sags. These additional characteristics may change the nature of accumulation and will not be properly simulated if not properly included in the model. However, as the urban landscape continues to change with the revitalization of major metropolitan cities, this analysis could be helpful to assess changes in the wastewater quality in the sewer system. These hotspot predictions can be performed for any sewer collection system if the necessary GIS data is given. Predictions from a sewer collection system model that includes FOG deposit formation kinetics will help assist pretreatment coordinators to plan periodic maintenance schedules to avert detrimental FOG deposit related SSOs. In the future, alternative methods to assess potential locations for hotspots will be conducted and a region of uncertainty in hotspots will be assessed using the parameter sensitivity analysis.

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