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Investigation of the control of the fat, oil and grease in sewer lines and their removal by surfactant treatment

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ABSTRACT

This study investigated different methods of controlling the fat, oil and grease (FOG) in sewer systems. A comprehensive control program was developed for the city of Mashhad (Iran) to maintain its sewer system and prevent blockages. The control program consisted of three parts: 1) fat, oil and grease source control, 2) sewer system modification, and 3) preventive maintenance. This program included guidelines for food service establishments, which are the major sources of (FOG). Food service establishments must implement better management practices to reduce (FOG) from entering the facility drain and install grease removal devices. As a part of preventive cleaning, the performance of several surfactants was evaluated as a cleaning agent. A 50:50 mixture (10 v. % in water) of two industrial surfactants, one containing monoethyl amine and sulfonated lauryl alcohol and one containing nonylphenol ethoxylate and potassium hydroxide, had the best performance and removed 80 % of the fat. Response Surface Methodology was used to determine the optimum conditions for the surfactant. The optimum conditions were a contact time of 36 h, shaking rate of 30 rpm and surfactant concentration of 12.5%. The second part of the program consisted of removing dead zones and increasing wastewater velocity in the sewer lines to enhance the hydraulic condition of the sewer system and decrease fat deposition. Finally, a detailed and well-defined control program could solve FOG problems in sewer systems.

1. Introduction

The presence of fat, oil and grease in wastewaters can cause extreme problems in municipal sewer networks. There are various sources of FOG waste including commercial sources like restaurants and catering kitchens, which are also known as food service establishments (FSEs). As well, domestic and industrial sources such as slaughterhouses and factories can introduce massive amounts of FOG to sewer networks. FOG related problems include line blockage and sewer overflow, interruption in pumping performance, reduction in oxygen transfer from air to water, and reduction of the sunlight penetration depth at wastewater treatment plants that decreases biological activity [1]. Most cities worldwide face FOG problems in their sewer systems. For example, 50% of the 25000 sewer blockages reported annually in Britain are due to FOG deposition [2,3]. Of the 10350-36000 annual sewer overflows in the USA, about 47% are reported to be FOG related [4]. In Dublin, southeast Australia and Scotland, 80%, 30% and 55% of the sewer blockages occur because of FOG deposition, respectively [5-7]. Therefore, employing a FOG deposition prevention strategy in addition to developing an efficient FOG removal technique is necessary. Mashhad is one of the biggest cities in Iran with a population of about 2.8 million. In fact, it is a pilgrimage site attracting more than 20 million people every year. It has

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been reported that more than 4510 blockages occur in the Mashhad sewer network yearly. About 1 million dollars are spent to maintain their sewer system including cleaning (1900 km of lines every year), inspection using CCTV (15% of the system every year), replacing broken lines (2.3 km every year), and emergency cleaning (more than 4510 emergency situations every year). This makes Mashhad an appropriate case study considering their FOG problem. The specifications of the Mashhad sewer system are listed in Table 1. In this study, the physical conditions of the Mashhad sewer system were investigated and a FOG control program was suggested based on these conditions. Moreover, as a part of their maintenance program, the susceptibility of several surfactants as a cleaning agent was examined. It will be discussed later in Section 2.4. Finally, the optimum conditions for the most appropriate surfactant system were determined using Response Surface Methodology (RSM).

Table 1. Specifications of Mashhad city sewer system

Feature	Description	Value
General	Main lines (>500 mm)	415 Km
	Laterals (<500 mm)	1800 Km
	Manholes	47000
Materials	Polyethylene	53.7%
	Concrete *	28.8%
	Armed concrete	16.3%
Age	<5 years	21.6%
	6< and <10 years	26.5%
	11< and <15 years	18.9%
	16< and <20 years	19.3%
	>20 years	13.6%

***** All concrete laterals are more than 13 years old.

An efficient FOG prevention strategy cannot be developed without understanding the FOG formation mechanisms. In fact, FOG deposition is usually formed through a saponification reaction followed by some physical processes. Fat, oil and grease, often from FSEs effluents especially in central regions of the city, undergo a saponification reaction in the presence of calcium or other metallic ions, free fatty acids and water [8]. These free fatty acids are introduced into the sewer system from sources such as fried foods [9].

The DLVO theory explains the forces between charged particles in a liquid media based on the Wan Der Waals attraction and electrostatic repellant forces [10]. First, the reaction between the FOG and metal hydroxides forms a solid product. This solid product sticks to the sewer line wall and creates a primary nucleus, which grows by the absorption of unreacted free fatty acids and the addition of calcium ions to form several layers of deposit [3,11,12]. This mechanism was substantiated by the multilayer and sandy structure observed in the samples taken from FOG depositions in the Mashhad sewer system [8]. Consequently, the composition of the fatty acids in the FOG deposit should be determined prior to commencing work on the remediation options. In this study, the FOG composition was analyzed through a gas chromatography method according to the ISIRI number 4091 standard [13].

The comparison between the composition of the FOG deposits and the oils used in FSEs showed that the content of saturated components in the FOG deposits was higher than the FSEs; this suggested that some unsaturated components were saturated due to chemical reactions. Also, calcium, magnesium and sodium were the most common metals found in these FOG deposits [8]. About 50% of the Mashhad sewer system is made of concrete. So, it can be concluded that these metals may be introduced into the sewer system because of concrete corrosion.

2. Developing a FOG prevention strategy

2.1. FOG source control

It appears that the first and most effective way to prevent FOG deposition is to stop FOG from entering the sewer system. Two methods have been suggested to achieve this end. The first method, called the FOG best management practice (BMP), includes six simple elements:

1- Collecting and rendering yellow grease

2- Scraping grease and food from plates and cookware before washing

3- Using drain screens

4- Wiping up grease spills before using water

5- Limiting garbage disposal use to non-greasy food materials

6- Employee training to perform the five mentioned elements.

The second method calls for installing grease removal devices (GRDs) such as grease traps and interceptors. These devices remove FOG from FSE's wastewater before it enters the sewer system. Grease removal devices, if appropriately designed and installed, have high efficiency in removing FOG.

To evaluate the condition of GRDs in the FSEs in Mashhad, 18 randomly selected restaurants and commercial kitchens were investigated. The investigation revealed that almost all of the GRDs had the same common problems:

1- High volume of GRD because of an inappropriate retention time considered for the GRD

2- Permanent baffles makes it harder to clean the GRD

3- Lack of an inlet basket that leads to large amounts of food, grains and trash entering the GRD

4- Long maintenance times that shut down facilities for long periods

These and other possible problems can be solved by using the standard design and installing procedures such as PDI G101 [14], ASME A112.14.3 [15] and ASME A112.14.4 [16]. These two methods should be legislated, and then executed in Mashhad. The code is called the *FOG Control Program.* Its principles are shown in Table 2.

Table 2. The main elements of FOG control program of Mashhad city

Section	Title	Description
1	Legal authority	- Identifies authority to implement the program
2	Characterizing FOG sources	-Describes a systematic procedure to characterize FOG sources
3	Regulatory requirements	-Identifies food service establishments -Determines variance from grease interceptor requirement -Determines waiver from GRD installation -Recovery of costs incurred for sewer line cleaning
4	Discharge prohibitions	-Discusses prohibited condition of facility discharge such as high temperature, using additives and food grinders
5	Discharge permit	-Explains the procedure to issue a discharge permit for FSEs discharging FOG
6	Best management practices	-Detailed requirements for best management practices
7	GRD requirements	-Determines requirements for GRD sizing, designing, installation and maintenance
8	FSE monitoring requirements	-Explains rules for FSE discharge monitoring
9	Record keeping requirements	-Specifies the information (i.e. manifests, receipts and invoices) that should be kept for a predetermined time to confirm FSE obedience

2.2. Sewer system modification

Another way to prevent FOG deposition is to promote the hydraulic conditions of sewer lines through the elimination of dead zones and increasing fluid velocity. Increasing the fluid velocity increases the lines self-flushing ability, which inhibits FOG and other sediments from accumulating and sticking to the interior walls as well as preventing deposition. The most important elements of sewer system promotion are well explained in references 17-19.

2.3. Preventive cleaning program

The appropriate execution of the *FOG Control Program* can greatly reduce FOG deposition, but various deposits still accumulate over time from existing unsolved defects in the sewer system and some FOG entering the system. In order to prevent deposit accumulation, which results in sewer blockage and overflow, sewer lines must be cleaned frequently. This is called *preventive cleaning*. The history and condition of the sewer system determine the frequency of the preventative cleaning. There are three different methods for sewer cleaning: mechanical, hydraulic and chemical. The mechanical method includes rodding and bucket machine cleaning while hydraulic cleaning includes ball, flushing, jet, scooter, kite, bag and polypigs. The third method uses chemical materials such as acids, bases, surfactants and microorganisms. The literature review showed that hydraulic cleaning is the most common method used for sewer cleaning. The preventive cleaning frequency is 1-6 months for hotspots and 3-5 years for non-critical sections of the sewer system [8]. A preventive cleaning plan calls for cleaning different sections of the sewer system with appropriate frequency, uses standard procedures for cleaning, and has an inspection plan. The inspection is usually performed using CCTV, and its frequency is about every 3 years [1]. Although rodding and flushing are being used in Mashhad to clean the sewer lines, chemical cleaning was also selected as an alternative to these methods. Chemical

cleaning is useful for lines with a small diameter or lines with inappropriate conditions, which are likely to break with mechanical or hydraulic methods. Chemical cleaning needs to be evaluated to determine its susceptibility and the efficiency. Materials such as alkaline, acids, surfactants and enzymes are used in chemical cleaning. The chemical composition is selected based on deposit characteristics (volume and composition), sewer characteristics (line material, wastewater flow rate and line diameter), safety considerations (flammability and toxicity), and downstream precautions (re-deposition at downstream and interruption in wastewater treatment). In this case, the suitable cleaning agents were selected via RSM experimental design.

3. Materials and methods

3.1. Materials

Three types of industrial surfactant solutions containing monoethyl amine (10% v/v), sulfonated lauryl alcohol (10% v/v), and nonyl phenol ethoxylate (10% v/v) (labeled solutions 1, 2 and 3, respectively) were purchased from local suppliers. The FOG removal efficiency of a 50/50 (v/v) mixture of solutions 2 and 3 were evaluated. In addition, the FOG removal efficiencies of three highly pure surfactants (Span 80, Tween 80 and sodium dodecyl sulfate (SDS)) from Merck KGaA (Darmstadt, Germany) were examined at different concentrations (10, 40, 70 and 100 Wt. %) in preliminary experiments. A sodium hydroxide solution (1 N) was employed to adjust the pH of the solutions when needed. The fat samples were provided from sediments taken from the Mashhad city sewer system and transported to a laboratory at a temperature of 4 ˚C. The composition of these samples was determined in our previous work [8] as Table 3.

Table 3. Properties of the fat samples used in experiments

Parameter	Sample No.	Sample No. 2
Humidity (Wt. %)	50.65	61.15
Melting Point	67	78
Solid volatile compounds (Organic compounds) (Wt. %)	44.7	38.38
Fat (Wt. %)	10.58	26.71

3.2. Investigating the performance of surfactants in FOG solubilization

The performance of various surfactant solutions on FOG removal was evaluated through a multi-step procedure. First, 15 g of the FOG sample (sample no. 1) were placed in each Erlenmeyer flask. The flasks were then weighed (initial weight) and sterilized for 30 min at 121 ˚C in an autoclave. The applied heat made the FOG sediments adhere to the bottom of the flask. After cooling the flasks, 20 ml of the desired surfactant solution with the specified concentration (Table 4) was added, and the pH was adjusted to 12. 30 flasks were prepared in this way including 29 surfactant treated samples and one blank sample. The performance of pure acetone and chloroform, as common chemical solvents, were also evaluated for comparison with the surfactant removal efficiencies. Then, 20 ml of these solvents was added to 15 gr of the fat sample, and the weight loss of the sample was reported after 60 min. The weight loss for acetone and chloroform were 1.83 and 0.26 %, respectively, which emboldened the functionality of the applied surfactant system. Consequently, a mixture of solutions 2 and 3 was selected for further investigation as the surfactant system with the higher performance. Since an increase in surfactant concentration of more than 10 v % has no significant effect on fat removal, a surfactant concentration of 10 v % was selected for the further experiments. After selecting the appropriate alkaline surfactant system, the effect of the most important operational parameters (surfactant concentration, contact time and agitation rate (rpm)) on fat dissolution (sample no. 2) was investigated using Response Surface Methodology (RSM). In fact, the contact time was important because the diffusion of the surfactant through the fat texture was a time-consuming process. The surfactant concentration could affect the diffusion process and was effective in dissolving more sediment through the emulsion formation at higher concentrations. The agitation rate was selected because of the shear rate produced by the stirrer that would help the fat solvation. RSM is a combination of convenient statistical and mathematical methods that analyze the effects of multiple independent variables on system response, with no need for a predetermined relation between the target function and variables [20]. In this methodology, the main effects and interactions of the variables are studied simultaneously, and statistical analysis determines the importance and optimizes the value of every variable. The Box-Behnken method was used to design the experiments. The Box-Behnken method is a three level design to fit response surfaces and is suitable for optimization [20]. The Box-Behnken experimental design is shown in Table 5. The Minitab software package (ver. 16.0) was used for the design of experiments and the results analysis.

Table 4. Weight loss of the fat samples for different surfactants

Surfactant Type	Concentration (v %)			
	10	40	70	100
Solution 1	1.57	6.65	13.58	10.1
Solution 2	5.52	1.58	10.06	8.25
Solution 3	-	-	-	-
Mixture of Solutions 2 and 3	10.68	9.61	9.21	9.38
Industrial SDS	7.54	4.79	4.45	4.21
Concentration	0.5 CMC	1 CMC	2 CMC	
Lab grade SDS	5.04	5.1	5.32	
Span 80	7.52	2.9	3.72	
Tween 80	-	6.07	6.8	

3.3. Results and discussion

The results for the fat removal from the Box-Behnken design are shown in Table 5. As can be seen, the alkaline surfactant system had an appropriate performance in fat removal. The analysis of variance (ANOVA) was used to determine the importance of each factor. The ANOVA results are presented in Table 6. The factors with P-value of less than 0.05 were important because the confidence level of analysis was selected to be 0.05.

The P-values of Table 6 show that all the main factors (shaking rate, contact time and surfactant concentration) as well as the interaction between the shaking rate and contact time are significant, and the other interactions can be eliminated. The F-value determines the impact of every factor on the response and a higher F-value means a greater effect on the response. So, the shaking rate, contact time and surfactant concentration are the most important factors. RSM also provides surface and counter plots, which are used to study the effect of every single factor. The surface and contour plots of the main factors are presented in Figure 1. It can be deduced from these plots that increasing main factors increases the fat removal percentage.

3.4. Optimum condition

Contact times higher than 30 h and shaking rates of about 120 to 160 rpm can provide the highest fat removal. The optimum condition (extreme point of response surface plots) was determined using Minitab software. The contact time of 36 h, shaking rate of 30 rpm and surfactant concentration of 12.5% resulted in a removal percentage of 80. This optimum condition is not the only one and RSM provides multiple optimum conditions that can be chosen according to operational problems in the sewer system. For example, the contact time of 36 h may not be appropriate because the sewer flow cannot be blocked for so long. Therefore, a lower contact time must be selected. The contact time of 6 h, surfactant concentration of 15 wt. % and a shaking rate of 180 rpm results in 73.5 % of fat removal. Although this value is lower than the former 80% value, the contact time of 6 h is more feasible than 36 h.

3.5. Experimental model

RSM provides an experimental model using results obtained for fat removal. This model, usually obtained from the linear regression method, can be used to extrapolate and optimize the results. Equation 1 shows the experimental model presented by the analysis of variance.

Response= -186 + 2.01042 (Shaking rate) + 10.35 (Surfactant concentration) + 3.74 (Contact time) – 0.00528 (Shaking rate)^2 – 0.43 (Surfactant concentration)^2 – 0.00694 (Contact time)^2 + 0.004167 (Shaking rate) (Surfactant concentration) – 0.01944 (Shaking rate) (Contact time) – 0.004167 (Surfactant concentration) (Contact time) (1)

The model does not exhibit lack-of-fit ($p > 0.05$). The lack-of-fit test is used to measure model failure to represent data in the experimental domain at points, which are not included in the regression. In addition, R^2 of the experimental model was calculated to be 0.99, which shows a good agreement with the experimental results.

Table 5. Experimental design based on Box-Behnken method and the results of the experiments

Run no.	Stirring Speed (rpm)	Surfactant concentration (%)	Contact time (hr.)	Fat removal (%)
1	120	5	12	38
2	180	10	12	73
3	120	10	24	75
4	120	15	36	79
5	60	10	36	61
6	60	15	24	33
7	120	15	12	60
8	120	10	24	72
9	60	5	24	14
10	180	10	36	70
11	180	15	24	75
12	180	5	24	51
13	60	10	12	8
14	120	5	36	63
15	120	10	24	72

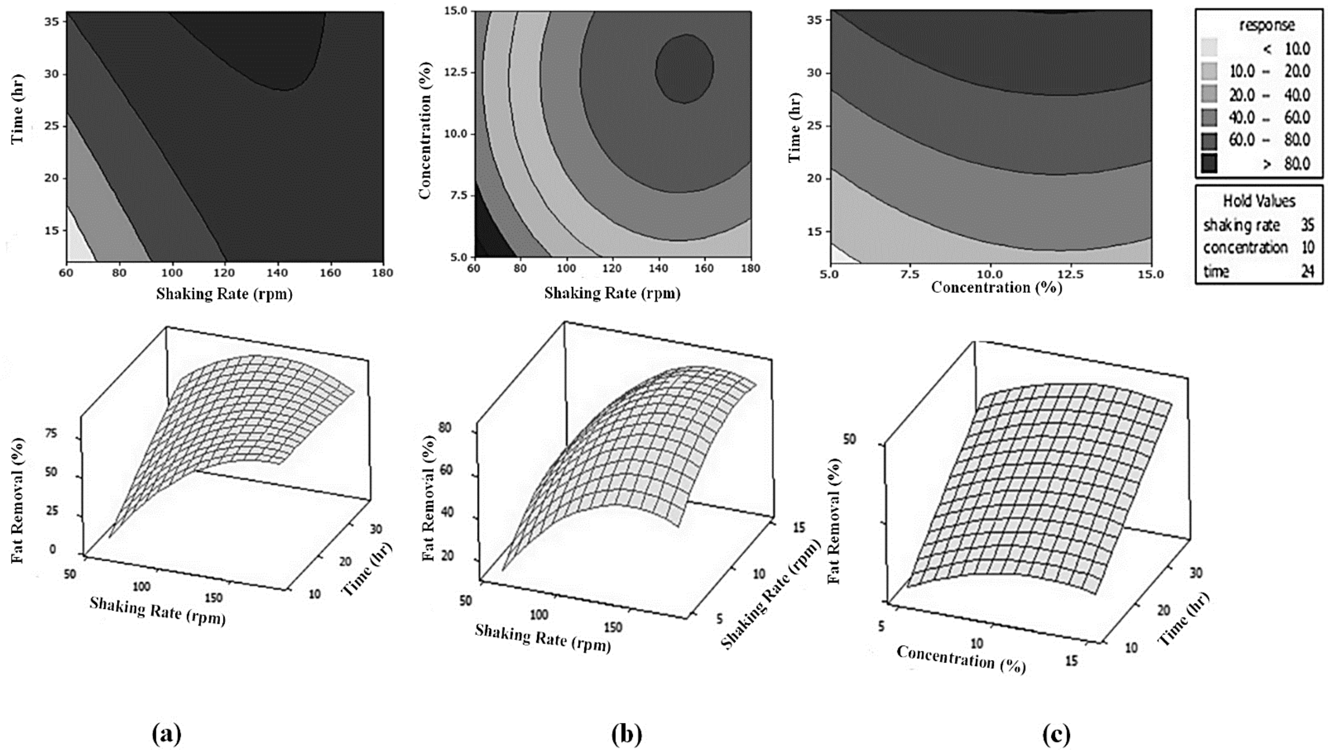

Fig. 1. Response Surface and contour plots for (a) time and shaking rate, (b) surfactant concentration and shaking rate, and (c) time and surfactant concentration

Table 6. ANOVA table of Box-Behnken design for fat removal experiments

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	7524.25	7524.25	836.04	451.91	0
Linear	3	5075.75	4098.98	1366.33	738.55	0
Shaking rate	1	2926.13	2315.13	2315.13	1251.42	0
Surfactant concentration	1	924.5	128.64	128.64	69.54	0
Contact time	1	1225.12	1655.2	1655.2	894.71	0
Quadratic	3	1658.1	1658.1	552.7	298.76	0
Shaking rate*Shaking rate	1	1231.13	1332.92	1332.92	720.5	0
Surfactant concentration* Surfactant concentration	1	423.11	426.69	426.69	230.64	0
Contact time*Contact time	1	3.69	3.69	3.69	2	0.217
Interaction	3	790.5	790.5	263.5	142.43	0
Shaking rate*Surfactant concentration	1	6.25	6.25	6.25	3.38	0.125
Shaking rate*Contact time	1	784	784	784	423.78	0
Surfactant concentration *Contact time	1	0.25	0.25	0.25	0.14	0.728
Residual Error	5	9.25	9.25	1.85		
Lack-of-Fit	3	3.25	3.25	1.08	0.36	0.792
Pure Error	2	6	6	3		
Total	14	7533.6				

4. Conclusions

This study discussed the different elements of an adequate FOG control program for the Mashhad city sewer system. The three main elements were source control, sewer system improvement and preventive maintenance. The source control consisted of the FOG best management practices and installation of grease removal devices. Sewer system improvement discussed dead zone elimination and increased fluid velocity in all parts of the system. The preventive cleaning was performed at an appropriate frequency. Several surfactants were evaluated in the cleaning process. A 50:50 mixture of two industrial surfactants (10 v. % in water) removed 80 % of the fat: one contained monoethyl amine and sulfonated lauryl alcohol and the other contained nonyl phenol ethoxylate and potassium hydroxide. The results gained from the Mashhad experiment showed that a detailed and well-defined control program could solve the FOG problem in sanitary sewer systems.

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