Advances in Environmental Biology, 8(3) Special 2014, Pages: 815-820

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/aeb.html

Mechanism of Fat, Oil and Grease (FOG) Deposit Formation in Sewer Systems.

[1]Iman A.F. Husain, [1]Ma'an Fahmi Alkhatib, [1]Mohamed Saedi Jammi, [2]Mohamed E.S. Mirghani, [1]Zaki Bin Zainudin, [3]Asif Hoda

[1]*Department of Biotechnology Engineering, International Islamic University Malaysia.*
[2]*International Institute for Halal Research and Training (INHART), Kulliyyah of Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia.*
[3]*Department of Mechanical Engineering, International Islamic University Malaysia.*

ARTICLE INFO

Article history:
Received 14 Feb 2014
Received in revised form 24 February 2014
Accepted 29 March 2014
Available online 14 April 2014

Key words:
FOG, Sewage, deposition, Saponification, hydrolysis.

ABSTRACT

Fat, oil, and grease (FOG) released into sewer systems results in a continuous build-up and subsequent blockage of sewer pipes. Currently, scientist, authorities and wastewater municipalitieshave a lack of comprehensive understanding of the mechanism of FOG deposit formation and the factors influencing the deposition. In this study, the mechanism of FOG deposit formation is investigated. FOG deposits and wastewater samples were collected from a sewer pipe and characterized in the laboratory to determine its physical and chemical properties. The results showed that the deposits mainly constitute of FFAs, FOG, metals and metallic soaps of FOG, while there is a high amount ofpalmitic (C16) and oleic (C18)free fatty acidsindicating the preference for hydrolysis reaction. The investigation of the site and the samples characterization justified the occurrence of the saponification reaction in the sewer pipes.

To Cite This Article: Iman A.F Husain, Ma'an Fahmi Alkhatib, Mohamed Saedi Jammi, Mohamed E.S. Mirghani, Zaki Bin Zainudin, Asif Hoda., Mechanism of Fat, Oil and Grease (FOG) Deposit Formation in Sewer Systems. ***Adv. Environ. Biol., 8(3),*** *815-820, 2014*

INTRODUCTION

The continuous increase in the population and the recent changes in the people life style and eating habits resulted in increasing the number of food facilities, hotels, restaurants and other food service establishments (FSEs) [1]. These changes have a direct impact on the environment especially the wastewater collection systems. One of the most burdening issues to wastewater municipalities is the release of fat, oil and grease (FOG) into sewer pipes. Within the sewage flow, FOG tends to solidify and form deposits on the interior surface of the pipes. The continuous deposition of FOG restricts thesewage flow and may cause a complete blockage of the pipe resulting in sanitary sewers overflows (SSOs). SSOs are considered hazardous to health and environment as they may cause insect and rat infestations, odor and contamination of the state water resources [2].

FOG includes animal fat, cooking oil, butter, cheese, sauces, and salad dressings. Some other sources of FOG are lubricating oil and grease, engine oil and palm oil mill effluent (POME) [3,4].

There are few recent researches that attempted to investigate the mechanism of FOG deposit formation. The researches were focusing on the effect of calcium carbonate ($CaCO_3$) on the FOG deposit formation in sewer pipelines [5,6]. The researchers concluded that the FOG deposition was mainly due to the saponification reaction that produces calcium soaps. Calcium was leaching from the concrete sewer pipes under the low pH conditions of wastewater [7]. The findings need to be further explored in order to reflect it on all situations of FOG formation especially where other types of pipes are used and less concentrations of calcium are found in the wastewater. Therefore, more researches are needed in order to develop an understanding of the formation of FOG particles and its deposition on the sewer pipes. In this paper, factors influencing the formation of FOG particles are investigated. Moreover, the mechanism by which the FOG particles form and depositto the sewer pipe is discussed.

Experimental:

Site Selection:

The sampling site was selected near to a fast food restaurant. The restaurant is well known for its fried food menu. The distance between the source and the identified manhole is 20-25 meters. Moreover, the Manhole was

Corresponding Author: Assoc. Prof. Dr. Maan Alkhatib, Department of Biotechnology Engineering, International Islamic University Malaysia.
Phone: 03-6196-4553, Fax: 03-6196-4442, E-mail: maan@iium.edu.my

partially blocked with FOG deposition with FOG particles floating on the surface of the flowing wastewater (Figure 1).

Fig. 1: FOG deposition at the Manhole.

Samples Collection:

Samples of FOG were collected from the deposited FOG in the manhole with accordance to Indah Water Konsortium (IWK) safety rules. The samples were keptin plastic containers with proper sealing.Moreover, samples of wastewater with FOG were collected in plastic gallons from the same sewer. All samples were stored at 4°C.

Physical Characterization:

pH:

The physical properties analysis includes pH, moisture content and density. To measure the pH, sample of FOG deposit was mixed with 1:1 ratio distilled water and stirred gently. The sample was let stand for 30 minutes. pH probe was calibrated to three points; 4, 7 and 9 using calibration buffers. The probe was dipped in the sample and the pH value was recorded. Similar method was used for the wastewater sample [8].

Moisture Content:

Pre-weighed samples of wastewater and FOG deposit were kept in the oven at 105 °C for overnight. The weight of samples after drying was recorder in order to calculate the moisture content. The moisture content is calculated using **Equation 1**.

$$\% \text{ Moisture} = \frac{\text{W1-W2}}{\text{W1}} \times 100\% \qquad \textbf{(Eq.1)}$$

Where: W_1: the weight before drying
W_2: the weight after drying

Density:

The density of the wastewater was measured using specific gravity bottle test. Equal volumes of distilled water and samples were weighed, and the weights were recorder. The specific gravity is calculated from **Equation 2**[9]. To calculate the density, the specific gravity of the sample is multiplied by the density of water (1000 Kg/m^3) [10].

$$SG_{4°C} = \frac{\text{weight of sample}}{\text{weight of equal volume of water at 4 °C}} \qquad \textbf{(Eq.2)}$$

Chemical Characterization:

Analysis for chemical properties was carried out following standard methods. The chemical properties analysis includestotal oil and grease, metal ions and fatty acid content.

Total oil and grease:

To measure the total concentration of FOG in the wastewater sample, partition-gravimetric method was used [11]. The sample was acidified with 1:1 HCl to pH 2. The sample was mixed vigorously with extracting solvent (n-Hexane) in a separatory funnel. After the layers are separated, the aqueous layer was drained away. The organic layer was drained through a filter paper and 10 g Na_2SO_4 and FOG was recovered using distillate recovery apparatus. The sample was cooled in the desiccator for 30 minutes and weighed.

Metal ions:

Metal ions analysis for Mg, Na, Al, Ca, Cu, Zn, K, P, S, Pb and As was done using inductivity coupled plasma (ICP)standard method at a commercial lab [12]. The equipment was calibrated before each analysis and the corresponding test kit was used for samples preparation and testing.

Free Fatty Acids (FFAs):

FOG was extracted using Soxhelt extractor with n-Hexane as an extraction solvent. The extracted FOG was mixed with KOH to prepare the fatty acids methyl esters (FAME). After centrifuging, the FAME was injected into GC/FID for FFAs analysis [13,14].

Investigation of Deposition Formation Mechanism:

To understand the factors that influence metallic soap production and the mechanism of FOG deposition, the food menus in the nearby restaurants were investigated for sources of FOG.Moreover, the possible chemical reactions and physical interactions of FOG are explored.

Results:

The FOG and waste water samples were characterized and the results are shown in **(Table 1)**.

Table 1: Characterization tests for FOG and Waste water samples.

Test	FOG deposit	Wastewater
pH	5.1	6.4
Moisture	68.1%	98.04%
Density	0.9996 g/ml	1.0012 g/ml
Calcium (Ca)	1.96 mg/l	25.42 mg/l
Sodium (Na)	1.71 mg/l	27.56 mg/l
Potassium (K)	0.77 mg/l	12.30 mg/l
Silica	0.81 mg/l	9.90 mg/l
Iron (Fe)	0.08 mg/l	3.58 mg/l
Magnesium (Mg)	0.93 mg/l	2.29 mg/l
Aluminum (Al)	0.20 mg/l	1.59 mg/l
Copper (Cu)	0.03 mg/l	0.05 mg/l
Zinc (Zn)	0.09 mg/l	0.33 mg/l
Sulphur	3.25 mg/l	7.35 mg/l
Lead (Pb)	N.D	0.03 mg/l
Arsenic (As)	N.D	0.016 mg/l
Phosphorus	2.69 mg/l	9.98 mg/l
Saturated fat	33.84 g/100g sample	0.05 g/100g
Unsaturated fat	30.42 g/100g sample	0.04g/100g
Oil & Grease	963 mg/l	919 mg/l
Hardness	N.D <1	80 mg/l

Figure 2: Shows the FOG sample after drying in the oven. The sample converted into liquefied oil and fat with minimum impurities.

Fig. 2: FOG deposit samples after drying in oven.

Discussion:

From Table 1, the low concentration of silica (0.81 mg/l) and high concentration of FOG (963 mg/l) in the deposit sample indicates that the deposit in the wastewater pipelines is mainly consisting of FOG deposits and have insignificant amount of other impurities. This result was also supported when the samples were put in the oven for drying to measure moisture content; the samples were observed to form a liquefied oil and fat with minimal impuritiesas shown in **(Figure 2)**.

The concentration of FOG in wastewater samples was 919 mg/l. this concentration is similar to the FOG concentrations found by Stoll and Gupta from Asian restaurants in Thailand which ranged from 730 mg/l to 1100 mg/l [15]. This high amount of FOG is a result of the items in the food menu which is served by the nearby fast-food restaurants. Based on the site investigation, the menu in these restaurants mainly consists of fried chicken, seafood and potato and salad dressing which contain high amount of FOG.

The pH test shows that the FOG samples are very acidic; this can be due to the presence of large amount of free fatty acids(FFA) which usually forms by the hydrolysis and oxidation reactions of oils during deep frying of food[16,17].These FFAare chemically active and will favour the saponification reaction in the presence of sodium hydroxide and potassium hydroxide which act as strong agents to form metallic soap [18,19].

To understand the way free fatty acids form during frying, it is very important to understand the role of sodium and potassium in the reactions. Sodium and potassium are naturally present in raw food, during deep frying; some sodium ions may be extracted by the FFA present in frying oil forming sodium oleate (*i.e.* sodium soaps). Sodiumoleate decreases the interfacial tension between the frying oil and the thin layer of water on the surface of the fried food migrating the polar lipids from the frying oil to the fried food. Moreover, sodium soapsstimulate the foaming of frying oil and thus accelerating its oxidation [20]. The oxidation reaction, which is promoted by heat, light and heavy metals, is a radical chain reaction that runs very fast under the frying conditions. First, the peroxy-, Alkoxy- and Alkyl- free radicals of the oil react with oxygen or RH **(Equation 2)**. Then, the reaction starts by an attack on the alkyl group of the oil followed by a chain reaction resulting in a hydroperoxide group (-OOH) in the chain **(Equation 3)**. The resultedhydroperoxides react further by combination of two radicals to form aldehydes, ketone and fatty acids (**Equation 4**) [21].This reactions during frying are the source of FFA in the used oil and thus in the FOG-containing wastewater.

$$R^{\cdot} + O{=}O \longrightarrow R\text{-}OO^{\cdot}$$
$$R\text{-}OO^{\cdot} + R\text{-}H \longrightarrow R\text{-}OOH + R^{\cdot}$$
$$R\text{-}O^{\cdot} + R\text{-}H \longrightarrow R\text{-}OH + R^{\cdot} \qquad \textbf{(Eq.2)}$$

$$R\text{-}OOH \longrightarrow R\text{-}O^{\cdot} + {}^{\cdot}OH$$
$$2\,R\text{-}OOH \longrightarrow R\text{-}O^{\cdot} + R\text{-}OO^{\cdot} + H_2O \qquad \textbf{(Eq.3)}$$

$$R^{\cdot} + R^{\cdot}$$
$$R^{\cdot} + R\text{-}O^{\cdot}$$
$$R^{\cdot} + R\text{-}OO^{\cdot}$$
$$R\text{-}O^{\cdot} + R\text{-}OO^{\cdot}$$
$$R\text{-}OO^{\cdot} + R\text{-}OO^{\cdot}$$
$$R\text{-}O^{\cdot} + R\text{-}O^{\cdot} \qquad \textbf{(Eq.4)}$$

The FFA reacts further with alkali (e.g. NaOH)to form metallic soap as shown in **(Equation 5)**.

$$R\text{-}COOH + NaOH \longrightarrow R\text{-}COONa + H_2O \qquad \textbf{(Eq.5)}$$

On the other hand, thetriacylglycerols (TAG) in FOG arealso saponifiable, *i.e.* hydrolyzed, in small parts to form metallic soap as well**(Equation 6)**.

$$C_3H_5(COOR)_3 + 3\,NaOH\ C_3H_5(OH)_3 \longrightarrow + 3\,NaOOCR \qquad \textbf{(Eq.6)}$$

The high amount of sodium (27.56 mg/l) contributes to the saponification reaction that produces hard soap. This explains why the FOG deposited samples are layers of white and hard material with a soft surface that is similar to any soap curds that form after a saponification reaction. The crude soap curds contain salt, alkali and glycerol as impurities [22].

The source of sodium present in the wastewater is the salt and other food ingredients that are usually used at the restaurants. Moreover, the commonly used detergents and sanitizers consist of high amount of sodium hydroxide (NaOH) which acts as a strong hydrolysis agent for FOG and thus, resulting in a saponification reaction of FOG.NaOH is a common alkaline catalyst for saponification reaction [23]. Also, 25.42 mg/l calcium was found in the wastewater samples and thus will contribute to the reaction as well.

Other researchers found that the water hardness affect the physical properties of FOG. They reported that an increase in water hardness was associated with increased Ca levels in FOG samples [6]. Another research reported calcium leaching from concrete pipes to be the main source of increased concentrations of Ca in the FOG deposit samples [7]. However, vitrified clay pipes (VCP) are used in Malaysian sewer lines thus; FOG deposition in Malaysia is not mainly due to the presence of calcium.

The presence of high amount of calcium and sodium indicates that the deposit is not only made of FOG but also metallic soaps that formed during the hydrolysis reaction (6).

Conclusion:

TheFOG deposits constitute of FFAs, TAGs and metallic soups of fatty acids. FFAs which are naturally present in small concentrations in cooking oils are also produced during the frying of food through oxidation reaction. Moreover, sodium, potassium and calcium ions are contributors to the formation of FOG deposit through the saponification reaction of FFAs and TAGs. The metal ions exist naturally in the wastewater and by the disposal of food leftovers in the washed dishes and cookware. Moreover, the commercial detergents and sanitizers used at the food preparation facilities contain high amount of NaOH and KOH which are known as hydrolyzing catalystsfor the saponification reaction.

ACKNOWLEDGMENTS

The researchers would like to thank Indah Water Consortium (IWK) for their kind cooperation and provision of samples.

REFERENCES

[1] He, X., M. Iasmin, L. Dean, S. Lappi, J. Ducoste and F. de los Reyes, III, 2011. Evidence for fat, oil and grease (FOG) deposit formation mechanisms in sewer lines. Environ. Sci. Technol., 45: 4385-4391.
[2] Aziz, T., 2010. Analysis of Grease Abatement Devices and the Measurement of Fat, Oil, and Grease in Food Service Establishment Waste Streams:PhD dissertation, North Carolina Univ., USA,http://www.lib.ncsu.edu/resolver/1840.16/4395.
[3] Garza, O.A., 2004. Food Service Establishment Wastewater Characterization and Management Practice Evaluation.Texas A&M.
[4] Indah Water Consortium, 2010. IWK sustainability report of 2010: http://indahwater.cntsb.com/pdf/csr-report2010.pdf.
[5] United States Environmental Protection Agency (EPA), 2004. Report to Congress: Impact and Control of CSOs and SSOs. www.epa.gov/npdes.(EPA 833-R-04-001).
[6] Williams, J.B., C. Clarkson, C. Mant, A. Drinkwater and E. May, 2012. Fat, Oil and Grease Deposits in Sewers: Characterization of Deposits and Formation Mechanisms.Water Res., 46: 6319-6328.
[7] He, X., de los, FL 3rd., M.L. Leming, L.O. Dean, S.E. Lappi and J.J. Ducoste, 2013. Mechanisms of fat, oil and grease (FOG) deposit formation in sewer lines.Water Res., 47(13): 4451-9.
[8] APHA 4500-H+ B., 1998. Standard Methods: Examination of Water and Wastewater (20th Edit). WEF, USA, 4: 86-4: 87.
[9] APHA 2710-F, 1998. Standard Methods: Examination of Water and Wastewater (20th Edit). WEF, USA, 2: 82-2: 83.
[10] Cengel, Y. and J. Cimbala, 2013. Fluid Mechanics: Fundamentals and Applications (3rd Edit). McGrow-Hill, USA, pp: 36-37.
[11] APHA 5520 B, 1998. Standard Methods: Examination of Water and Wastewater (20th Edit).WEF, USA, 5: 34-5:37.
[12] APHA 3120 B, 1998. Standard Methods: Examination of Water and Wastewater (20th Edit). WEF, USA, 3: 37-3:43.
[13] Akbari, M., R. Razavizadeh, G.H. Mohebbi and A. Barmak, 2012. Oil characteristics and fatty acid profile of seeds from three varieties of date palm (Phoenix dactylifera) cultivars in Bushehr-Iran. African Journal of Biotechnology, 11(57): 12088-12093.
[14] AOCS Ce 2-66., 1997. Official methods and recommended practices of the American oil chemists' society: Method Ce 2-66, GLC ranges of Fatty acid composition. AOCS Press, US.
[15] Stoll, U. and H. Gupta, 1997. Management Strategies for Oil and Grease Residues.J. Waste Manage. Res., 15: 23-32.
[16] Erickson, M., 2007. Deep Frying: Chemistry, Nutrition and Practical Applications. AOCS Press, US.
[17] Serjounie, A., C. Tan, H. Mirhosseini and Y. Man, 2010. Effect of Vegetable-Based Oil Blends on Physicochemical Properties of Oils during Deep-Fat Frying. Am. J. Food Technol., 5(5): 310-323.
[18] Marchetti, J.M., V.U. Miguel and A.F. Errazu, 2007. Heterogeneous Esterification of Oil with High Amount of Free Fatty Acids.J. Fuel., 86: 906-910.

[19] Turapan, S., C. Yotkamchornkun and K. Nuithitikul, 2010. Esterification of Free Fatty Acids in Crude Palm Oil with Sulfated Zirconia: Effect of Calcination Temperature: J. World Academy of Science, Engineering and Technology, 41: 520-524.
[20] Pkorny, J., 1999. Changes of Nutrients at Frying Temperatures. In Frying of food, eds., D. Boskouand I. Elmadfa: CRC Press, U.S., pp: 69-103.
[21] Bockisch, M., 1998. Fats and Oils Handbook. AOCS Press, US, pp: 100-102.
[22] Brown, W., 1998. Introduction to Organic and Biochemistry. Willard Grant Press, USA, pp: 155-156.
[23] Enweremadu, C. and M. Mbarawa, 2009. Technical aspects of production and analysis of biodiesel from used cooking oil-A review. Renewable Sustainable Energy Rev., 13: 2205-2224.