Problems, Control, and Treatment of Fat, Oil, and Grease (FOG): A Review

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Abstract: Presence of fat, oil, and grease (FOG) in wastewater is an ever-growing concern to municipalities and solid-waste facility operators. FOG enters the sewer system from restaurants, residences, and industrial food facilities. Its release into the sewer system results in a continuous build-up that causes eventual blockage of sewer pipes. Several researchers have investigated FOG deposition based on the local conditions of sewers and lifestyle. This paper attempts to review the physical and chemical characteristics of FOG, sources of FOG, and potential chemical and biological reactions of FOG. The effect of the aforementioned factors on the FOG-deposition mechanism is also discussed. Moreover, insight into the current control and treatment methods and potential reuse of FOG is highlighted. It is expected that this review would provide scientists and the concerned authorities a holistic view of the recent researches on FOG control, treatment, and reuse.

Key words: FOG, sewage, deposition, FFA, saponification, hydrolysis

1 Introduction

Fat, oil, and grease (FOG) is an ever-growing environmental concern. FOG is usually produced at food service establishments (FSE) or other food preparation facilities1. The by-products and wastes from these FSE include meat, sauces, gravy, dressings, deep-fried food, baked goods, cheeses, and butter. All these wastes are considered FOG and may lead to the FOG build-up in the sewer system when discharged directly into the facility’s plumbing system2. Other sources of FOG include discharge from industrial activities; for example, palm oil mill effluent (POME) and automobile workshop discharge. Recently, the eating habits of people have changed, with more people eating outside their homes, and thus the number of food outlets has continued to increase, resulting in increased blockage of a city’s sewer system because of FOG deposition3.

FOG blockage is a worldwide concern. For example, the American Environmental Agency (EPA) estimated that at least 10,350–36,000 sanitary sewer overflows (SSOs) occur per year in the USA, approximately 47% of which is related to FOG4. Moreover, up to 70% of the SSOs that occur in Malaysia are due to FOG. In 2010 only, the waste-water municipality in Malaysia, Indah Water Konsortium (IWK), received a total of 22,184 blockage enquiries5.

Continuous build-up of FOG decreases the capacity of the sewer system as the FOG solidifies and deposits on the interior walls of the sewer, causing blockage of pipes and hence restricting the wastewater flow (Fig. 1). Over time, sewers blocked by FOG will fail, leading to the overflow of sewage from manholes; this sewage may eventually make its way to state water sources as a contaminant. The blockages and sewer flooding may result in other environmental problems, both locally and beyond the premises.

Recently, extensive effort has been expended to investigate the possibility of treating and reusing FOG to reduce the amount disposed at landfills. However, understanding the chemical and physical properties of FOG and its deposition mechanism is essential for developing more environmentally and economically efficient methods of controlling, treating, and reusing FOG.
Definition of FOG

Fats, oils, and grease (FOG) are the by-products of cooking (also called brown grease). Typically, FOG includes matter such as food scraps, meat fats, lard, tallow, cooking oil, butter, margarine, sauces, gravy, dressings, deep-fried food, baked goods, cheeses, and butter. FOG can be solid or a viscous liquid depending on the saturation of the carbon chain. Oils and fats are a subsection of lipids that are composed of fatty acids, triacylglycerols, and lipid-soluble hydrocarbons that are minor but important components of FOG.

Chemical Composition of FOG

3.1 Free fatty acids (FFAs)

FFAs are carboxylic acids with long-chain hydrocarbon side groups. FFAs usually occur in the esterified form as the major components of lipids. There are over 1000 identified natural fatty acids; however, only around 20 of these are common in food sciences. Most common FFAs have a straight chain of 8–22 carbon atoms and frequently have one or more unsaturated centers (double bonds). Table 1 shows the most common fatty acids.

FFAs are very important constituents of FOG because of their chemical reactivity. Moreover, the FFA content of restaurant effluents can reach over 15%, which reduces the pH and serves as an indicator of the chemical activity of FOG.

3.2 Triacylglycerols

Fatty acids occur mainly as glycerol esters known as triacylglycerols (TAGs) (also called triglycerides). TAGs are nonpolar, water-insoluble substances, and are considered a class of abundant lipids. Glycerol contains three carbon atoms, each of which carries a hydroxyl group (HOCH₂CH(OH)CH₂OH). Depending on the number of hydroxyl groups that are acylated, the glycerol esters are named

Table 1 Most common Free Fatty Acids

<table>
<thead>
<tr>
<th>Name</th>
<th>Systematic name</th>
<th>Short-hand</th>
<th>Melting point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Butyric</td>
<td>Butanoic</td>
<td>4:0</td>
<td>-5.3</td>
</tr>
<tr>
<td>Caproic</td>
<td>Hexanoic</td>
<td>6:0</td>
<td>-3.2</td>
</tr>
<tr>
<td>Caprylic</td>
<td>Octanoic</td>
<td>8:0</td>
<td>16.2</td>
</tr>
<tr>
<td>Capric</td>
<td>Decanoic</td>
<td>10:0</td>
<td>31.6</td>
</tr>
<tr>
<td>Lauric</td>
<td>Dodecanoic</td>
<td>12:0</td>
<td>44.8</td>
</tr>
<tr>
<td>Myristic</td>
<td>Tetradecanoic</td>
<td>14:0</td>
<td>54.4</td>
</tr>
<tr>
<td>Palmitic</td>
<td>Hexadecanoic</td>
<td>16:0</td>
<td>62.9</td>
</tr>
<tr>
<td>Stearic</td>
<td>Octadecanoic</td>
<td>18:0</td>
<td>70.1</td>
</tr>
<tr>
<td>Oleic</td>
<td>Octadecenoic</td>
<td>18:1</td>
<td>16.2</td>
</tr>
<tr>
<td>Vaccenic</td>
<td>Octadecenoic</td>
<td>18:1</td>
<td>44.1</td>
</tr>
<tr>
<td>Linoleic</td>
<td>Octadecadienoic</td>
<td>18:2</td>
<td>-5</td>
</tr>
<tr>
<td>Linolenic</td>
<td>Octadecatrienoic</td>
<td>18:3</td>
<td>-11</td>
</tr>
<tr>
<td>Arachidonic</td>
<td>Eicosatetraenoic</td>
<td>20:4</td>
<td>-49</td>
</tr>
<tr>
<td>EPA</td>
<td>Eicosapentaenoic</td>
<td>20:5</td>
<td></td>
</tr>
<tr>
<td>DHA</td>
<td>Dodosahexaenoic</td>
<td>22:6</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 Sewer Pipe before (a) and after (b) deposition of FOG. Provided by IWK.
monoacylglycerols (MAG), diacylglycerols (DAG), and triacylglycerols (TAG). Fats and oils are complex mixtures of triacylglycerols, whose fatty acid composition varies on the basis of the organism of origin. Plant oils are generally richer in unsaturated fatty acid residues than animal fats, as indicated by the lower melting points of the oils. Thus, oils are typically liquids whereas animal fat is solid at room temperature\(^\text{11}\). 

### 3.3 Ester waxes

Wax comprises several types of medium- and long-chain compounds, including hydrocarbons (TCH\(_{n}\)), alcohols (RCH\(_2\)OH), aldehydes (RCHO), acids (RCOOH), and esters (RCOOR\(^\text{1}\)). Waxes are of both vegetable (e.g., carnauba and jojoba) and animal origin (e.g., beewax and woolwax)\(^\text{12}\).

### 3.4 Phospholipids

The amphiphilic nature of phospholipids imparts unique properties to them that make them important in foods, cosmetics, and pharmaceuticals. Although phospholipids are removed during oil refining, they are present in small quantities in vegetable oils and thus will appear in the FOG mixture\(^\text{13}\).

### 3.5 Sterols and sterol esters

Although sterols (e.g., cholesterol) are not lipids, they occur in many oils and fats and exhibit certain similar physical properties. Sterols can be esterified to long chain fatty acids via oxidation reactions. Most crude oils contain 0.1–2.2% of phytosterol, partly as free sterols and partly as sterols esterified with FFAs. The ratio of esterified to free sterols varies, where the free sterols (40–80%) are generally predominant\(^\text{14}\).

### 4 Physical properties of FOG

FOG may occur as liquid or solid and is characterized by a greasy texture. In its pure state, FOG is colorless, odorless, and tasteless. Moreover, FOG is insoluble in water but soluble in organic solvents such as hexane, ether, and chloroform\(^\text{15}\).

FOG has a density less than water (specific gravity <1) and thus, it floats on the water surface. However, FOG will form emulsions with aqueous media in the presence of soap or other emulsifying agents\(^\text{12–16}\). Generally, FOG has high viscosity that varies based on the fatty acid composition and presence of double bonds. The more double bonds present in the carbon chain, the lower the viscosity of FOG because of the more loosely packed structure\(^\text{16}\).

The presence of a large amount of FFAs in FOG, which are generally formed by the hydrolysis and oxidation reactions of oils during deep frying of food, results in a characteristically low pH of FOG\(^\text{17–20}\).

### 5 Sources of FOG in the Sewer System

FOG is usually produced at food service establishments, residences, and slaughterhouses. FOG components are introduced into the sewer system either by direct dumping into the sewer or by escape from grease traps (GTs) that are usually installed in restaurants. The GTs (interceptors) are designed to trap most of the FOG in the restaurant effluent and separate it from the sewage before reaching the sewer pipe\(^\text{21}\). However, the efficiency of the GT depends strongly on the frequency of its maintenance\(^\text{22}\). Moreover, if a dish washer or high-temperature water is used for dish washing, FOG may melt and emulsify within the wastewater phase and thus escape the GT. Upon subsequent flow into the sewer pipe, FOG may solidify and form particles that deposit on the surface of the pipe, thus obstructing the wastewater flow\(^\text{23–25}\).

Stoll and Gupta\(^\text{26}\) found that the concentration of FOG in wastewater from Asian restaurants in Thailand ranged from 730 to 1100 mg/L. This high quantity of FOG arises from fast-food restaurant effluent. The menu of these restaurants consists mainly of fried chicken, seafood, French fries, and salad dressing that contain a large amount of FOG.

### 6 Chemical and Biological Reactions Related to FOG

FFAs are chemically active and readily undergo saponification in the presence of sodium hydroxide and potassium hydroxide, which act as strong agents for generating metallic soap\(^\text{27}\).

To understand the mechanism by which FFAs 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 the frying oil to form sodium oleate (i.e., sodium soaps). Sodium oleate decreases the interfacial tension between the frying oil and the thin layer of water on the surface of the fried food, causing migration of the polar lipids from the frying oil to the fried food. Moreover, sodium soaps stimulate the foaming of frying oil and thus accelerate its oxidation\(^\text{24}\). The oxidation reaction, which is promoted by heat, light, and heavy metals, is a radical chain reaction that occurs rapidly under the frying conditions. First, the peroxy-, alkoxy-, and alkyl- free radicals of the oil react with oxygen or RH (Equation 1). The reaction is then initiated by attack on the alkyl group of the oil, followed by a chain reaction, resulting in a hydroperoxide group (−OOH) in the chain (Equation 2). The resulting hydroperoxides react further by the combination of two radicals to form aldehydes, ketones, and fatty acids (Equation 3)\(^\text{28}\). These reactions during frying generate the FFA found in used oils and thus in the FOG-containing wastewater.

\[\text{RCHO + O}_2 \rightarrow \text{ROO}^\cdot + \text{RO}^-\]
\[\text{ROO}^\cdot + \text{RH} \rightarrow \text{ROO}^\cdot + \text{H}_2\text{O} + \text{R}^-\]
\[\text{ROO}^\cdot + \text{R}^- \rightarrow \text{ROOR}\]
\[ R^+ + O = O \rightarrow R-O \]
\[ R-OOH + R^+ \rightarrow O-RO' + R' \quad (\text{Eq. 1}) \]
\[ R-OOH \rightarrow R-\overset{\text{)}{\text{OH}} + R' \]
\[ 2R-OOH \rightarrow R-O + R-OO' + H_2O \quad (\text{Eq. 2}) \]
\[ \text{R} + \text{H} \rightarrow \text{R} + \text{OH} \]
\[ \text{R} + \overset{\text{)}{\text{R-O}} \quad (\text{Eq. 3}) \]

The FFA reacts further with alkali (e.g., NaOH) to form metallic soap (Equation 4).
\[ R-COOH + \text{NaOH} \rightarrow R-COONa + H_2O \quad (\text{Eq. 4}) \]

On the other hand, small amounts of triacylglycerols (TAG) in FOG are also saponified, i.e., hydrolyzed, to form metallic soap (Equation 5).
\[ C_{n}H_{2n+1}(COOR)_{3} + 3\text{NaOH} \rightarrow C_{n}H_{2n}(OH)_{3} + 3\text{NaOOCR} \quad (\text{Eq. 5}) \]

Sodium contributes to the saponification of FOG to produce hard soap. Thus, the deposited FOG occurs as layers of whitish and hard material with a soft surface that is similar to the soap curds that form after a saponification reaction. The crude soap curds may also contain salt, alkali, and glycerol as impurities.

Sodium in the wastewater arises from the salt and other food ingredients that are usually used at restaurants. Moreover, the commonly used detergents and sanitizers contain a high amount of sodium hydroxide (NaOH) that acts as a strong hydrolysis agent for FOG, and thus, results in the saponification of FOG. NaOH is a common alkaline catalyst for the saponification reaction \(^{[26, 21]}\).

Researchers have found that the hardness of the water affects the physical properties of FOG. It is reported that an increase in the water hardness is associated with higher Ca levels in FOG samples \(^{[5]}\). Another study reported calcium leaching from concrete pipes to be the main source of increased concentrations of Ca in the FOG deposit samples \(^{[23]}\). However, based on the evaluations of vitrified clay pipes (VCP), which are used in some countries such as Malaysia, it was found that FOG deposition is not due primarily to the presence of calcium, but can be related to other minerals such as sodium and potassium. Moreover, the presence of high amounts of calcium and sodium in FOG deposits indicates that the deposit not only consist of FOG but also of metallic soaps formed during the hydrolysis reaction \(^{[5, 23, 24]}\). The aforementioned studies focused on the effect of calcium (CaCO\(_3\)) on the formation of FOG deposits in sewer pipelines. The researchers concluded that calcium was leached from the concrete sewer pipes under the low-pH conditions of wastewater. However, further research is required to understand the formation of FOG particles and its deposition on sewer pipes made of various materials.

7 Effects of FOG Deposition

FOG tends to stick to the surface of drain and sewer pipes causing clogging that restricts the flow of sewage and may lead to sanitary sewer overflows (SSOs). SSOs cause unpleasant odors and insect and rat infestation, and the sewage may make its way into water sources causing ground and surface water pollution \(^{[32]}\). They are very unpleasant and require quick action from the municipalities to clear the deposition to allay public concerns. Moreover, FOG deposition can cause corrosion of sewer lines under anaerobic conditions, thus reducing the lifetime of the pipe and demanding earlier repair and replacement of the pipe.

On the other hand, the biological treatment of wastewater with a high concentration of FOG suspended on the surface may be hindered by sticking of FOG to the pipes and clogging of the strainer and filters, thus affecting the treatment unit operations. At the last stage of the wastewater-treatment process, FOG is deposited in the sludge making it viscous and waxy, and thus reducing the sludge-dewatering efficiency \(^{[33]}\).

8 Methods to Control FOG Deposition

Currently, there is only one method to control FOG at the source of generation. This method involves installing a grease interceptor (GI) that separates the FOG from the restaurants’ sullage reducing, its concentration in the effluent \(^{[31]}\). Recent efforts have been made to enforce good management practices at restaurants and food service establishments to ensure the right disposal of residual FOG \(^{[30]}\). Moreover, certain companies have agreements with restaurants to collect used cooking oil and use it to produce biodiesel. As a solution to blockage of sewer pipes, wastewater municipalities utilize high-pressure water jets to clear FOG deposits from sewer pipes, whereas FOG in manholes is collected manually using a shovel and armored net. The collected FOG deposits are disposed as solid waste at landfills \(^{[32, 33]}\). This raises additional environmental concerns because the hydroconductivity of soil is highly reduced by FOG. Moreover, biological oxidation of high concentrations of FOG undesirably releases carbon dioxide and methane into the atmosphere \(^{[32]}\).

Revision of the sewer piping design is another alternative for the prevention of FOG deposition by adjusting the pipe gradient, diameter, roughness, replacing old and defected pipes, and improving the manhole design. These improve-
ments must be carefully performed to control the velocity of the sewage flow and ensure sufficient self-flushing capability to prevent FOG deposition\(^{30}\).

9 Treatment of FOG

Lemus and Lau reported a series of preliminary experiments for evaluating the biodegradability of organic wastes loaded with FOG by composting\(^{35}\). The lipid content was reduced by 70% over a processing period of 10 days. Moreover, the volatile solid content was reduced by 20%. The biological treatment of FOG-rich wastewater has also been investigated using a mixed bacterial culture isolated from a GT. Application of the mixed culture to the activated sludge resulted in >90% removal efficiency\(^{36}\). In another study, lipase-producing microorganisms were isolated from the bakery and palm-oil-industry wastewater. The biodegradation of FOG in the isolates was tested, and up to 87.7% FOG removal was achieved\(^{37}\).

10 Reuse of FOG

Hasuntree and others\(^{38-40}\) suggested the possibility of using FOG from the GI of restaurants as a biodiesel feedstock. However, there are two major challenges in the use of the restaurant trap: first, the methods of FOG collection from restaurants must be developed, and second, the issue of soap formation in the presence of alkaline catalysts because of the high content of FFA (>15%) in the FOG from restaurants, which hinders the conversion of FOG by transesterification, must be addressed. Hasuntree proposed a one-step acid-catalyzed esterification process using H\(_2\)SO\(_4\) as a catalyst. The use of H\(_2\)SO\(_4\) reduced the acid value of the FFA by up to 80%, whereas the highest methyl ester content obtained was 83.59% ± 1.51%. Zhu\(^{41}\) evaluated the feasibility of using FOG waste from the GT as a cosubstrate to improve biomethane production in the anaerobic digestion of municipal waste sludge from wastewater-treatment plants. Because of the high organic content (138 g/L) and methane potential (145 L\(_{\text{methane}}\)/L\(_{\text{FOG}}\)) of FOG from the GT, the process efficiency of the anaerobic digestion of municipal waste sludge could be significantly improved to up to 65% at FOG-loading rates of less than 4% (V\(_{\text{FOG}}\)/V\(_{\text{digester}}\)). The EPA suggested the recycling of FOG from GTs and the use of recycled FOG in rendering industries that produce animal food, cosmetics, soaps, and other products\(^{42}\). A successful case has been reported in one California wastewater-treatment plant where FOG was treated in an anaerobic digester unit to produce biogas that powers 80% of the wastewater-treatment plant\(^{43}\).

Conclusion

Few attempts have been made to understand the effects of the physical and chemical characteristics of FOG on the formation of FOG deposits. Thus, the exact mechanism by which FOG particles stick and deposit on the pipe surface is still ambiguous. Further studies are required in this field in order to deepen the understanding of the FOG-deposition mechanism and chemical reactions that occur, whether at the restaurants, in the GT, or along the sewer pipes. Moreover, evaluation of the deposition kinetics, and thus, the prediction of pipe blockage, is another field to explore. FOG is a nuisance not only to wastewater municipalities but also to operators of solid-waste facilities. Methods of treatment and economical use of FOG as a resource for other industries is a worthwhile pursuit, particularly in countries such as Malaysia and Indonesia that are known for their massive palm oil production and the consequent generation of high-FOG-containing effluents.

References