

Properties Influencing Fat, Oil, and Grease Deposit Formation

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ABSTRACT: Fat, oil, and grease (FOG) deposits are the reported cause of 50 to 75% of sanitary sewer overflows in the United States, resulting in 1.8×10^6 m³ (500 mil. gal) of raw wastewater released into the environment annually. The objective of this research was to characterize the chemical and physical properties of FOG deposits. Twenty-three cities from around the United States contributed FOG samples for the study. The FOG deposits showed a wide range in yield strength (4 to 34 kPa), porosity (10 to 24%), and moisture content (10 to 60%), suggesting uncontrolled formation processes. A majority of these deposits display hard, sandstonelike texture, with distinct layering effects, suggesting a discontinuous formation process. The results found that 84% of FOG deposits contained high concentrations of saturated fatty acids and calcium, suggesting preferential accumulation. *Water Environ. Res.*, **80**, 2241 (2008).

KEYWORDS: fat, sewer system, blockages, overflow.

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Introduction

Fat, oil, and grease (FOG) deposits are the primary cause of 40 to 50% of sewer overflows nationwide and the secondary cause of another 10 to 25% (Southerland, 2002; U.S. EPA, 2003). Statistics indicate that 138 000 sanitary sewer overflows (SSOs) occur every year, as a result of the pipe blockages from accumulations of hardened and insoluble FOG deposits (Southerland, 2002). On average, each of these spills releases 14 m³ (3700 gal) of raw wastewater into the environment (U.S. EPA, 2003), resulting in an estimated 1.8×10^6 m³ (500 mil. gal) of raw wastewater released per year. These overflows are considered unpermitted discharges to the waters of the nation and are interpreted by the U.S. Environmental Protection Agency (Washington, D.C.) (U.S. EPA) as violations of the Clean Water Act (1977). Thus, there is a need to understand FOG deposits, in hopes of preventing their occurrence.

Public and private utilities are charged with the responsibility of maintaining free-flowing sanitary sewer collection systems; however, limited knowledge is available on FOG deposits. Prevention strategies have been restricted to increased inspection frequency and cleaning to prevent SSOs. These approaches have met with limited success, as indicated by the above statistics. In addition, restaurant associations have begun asking local governments to adopt FOG effluent limits that are supported by scientific information, of which limited data are available. Evidence reported by sanitary sewer personnel suggests that FOG deposits form between 50 and 200 m

downstream from foodservice establishments, with a blockage frequency ranging from 30 days to 2 years.

The FOG deposits display an adhesive character and can become securely bound to interior pipe walls (Figure 1). In addition, a majority of FOG deposits also have a grainy, sandstone-like texture and high yield strength, at times requiring high-pressure (>13.8 MPa [2000 psi]) jet cleaning for removal (Holt, 2007). It is hypothesized that FOG deposits are metallic salts of fatty acids, resulting from chemical reactions between fats, oils, and grease; cleaners and sanitizers; and metal ions, such as calcium. Metallic salts of fatty acids, commonly called *soaps*, are sometimes insoluble in water. "Hard" soaps, which are insoluble in water, can be created from calcium, magnesium, and aluminum (Levitt, 1951; Martin, 1931; Mohr, 1979). It has been reported, in soap manufacturing, that calcium ions are preferentially selected over sodium ions, and these metallic soaps are sticky and become affixed to surfaces (Levitt, 1951). Calcium ions are naturally present in the wastewater of domestic and industrial sanitary wastewater.

In addition, it has been recently documented, in a study examining biological treatment of wastewater from restaurant kitchens using an immobilized fluidized reactor, that a white solid, identified as calcium di-stearate and di-palmitate, forms under high oil-loading rates (Matsui et al., 2005). This white solid was suggested to result from (1) the microorganisms' limited ability to reduce saturated fatty acids, and (2) the limited dispersion of saturated fatty acids in the bioreactor. It should also be noted that unsaturated fatty acids in wastewater are readily broken down by microorganisms via beta-oxidation (Matsui et al., 2005). If a similar condition occurs in United States sanitary sewer systems, one would expect to find FOG deposits containing high levels of saturated fats and calcium with lower concentrations of unsaturated fatty acids.

Thus, the objective of this study was to examine the physical properties and chemistry of FOG deposits and develop a hypothesis on formation mechanism(s). Samples have been received from 23 cities from around the United States. These results provide insight to the role that domestic wastewater, food waste, and industrial waste may play in causing FOG blockages.

Materials and Methods

The FOG samples were shipped by express in insulated, ice-packed shipping containers from participating cities to the Food Engineering Laboratory at North Carolina State University (Raleigh). Upon receipt, samples were placed in refrigeration (7°C) until testing. Testing consisted of measurement of physical properties, mineral and metal analysis, and fatty acid profiling. Because of technical difficulties, physical properties were only measured on the first 6 samples received. After testing of physical properties (samples 1 to 6), the remaining samples were delivered to

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Figure 1—FOG deposit in a pipe before cleaning.

Microbac Laboratories, Southern Testing Division (Wilson, North Carolina), for moisture content, mineral and metal analysis, total fat analysis, and fatty acid profiling. Samples 7 through 27 were shipped directly to Microbac Laboratories, where they were stored under refrigeration until testing. Sample weight ranged from 200 to 1000 g.

Laboratory Safety. All samples were treated as potential biohazards and shipped, stored, analyzed, and disposed of according to university procedures. All personnel were instructed in laboratory safety procedures. All testing equipment and contact surfaces were sanitized after use.

Physical Properties. Twelve cylindrical samples (1-cm diameter \times 1-cm height) were cored from each FOG sample. Water content, compressive strength, density, and porosity were measured based on methods of soil analysis. Water content was measured according to method 21-2.2 Gravimetry with Oven Drying (Gardner, 1986). Porosity was measured using the Gas Pycnometer Method 18-2.2 (Danielson and Southerland, 1986). Maximum compressive strength was measured using a TA-XT2 Texture Analyzer and Texture Expert 1.0 software with a 1-kg load cell (Texture Technologies, Scarsdale, New York). The sample was loaded between two parallel plates and compressed at a rate of 15 cm/min. Data were recorded at 100 samples/sec, with a stop trigger at 50% maximum strength.

Mineral and Metal Analysis. Mineral and metal analysis of FOG deposits was performed based on U.S. EPA method 200.7 (U.S. EPA, 2001). In brief, a 1.0-g dried, ground sample of FOG deposit was acidified using concentrated nitric acid. The sample was digested at 95°C for approximately 60 minutes. Hydrogen peroxide was then added, and the sample was heated for an additional 15 minutes. The sample was then delivered into an inductively coupled plasma-atomic emission spectrometer. The minerals and metal analyzed included aluminum, calcium, magnesium, sodium, copper, zinc, iron, potassium, phosphorus, and other less common metals. Mineral and metal analysis data of sample 7 are shown in Table 1.

Fat, Oil, and Grease (Total). The FOG content was measured based on U.S. EPA method 9071A (U.S. EPA, 1994). In brief, a 20-g sample of FOG deposit was acidified to pH 2.0 using hydrochloric acid solution. Then, $\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$ was added to chemically bind the water. After drying, the oil and grease was extracted with trichlorotrifluoroethane, using the Soxhlet apparatus (Brinkmann Instruments, Westbury, New York).

Fatty Acid Profile. Fatty acid profiling of FOG deposits was performed based on AOAC method 996.06 (AOAC, 1995). In brief, a 200-mg sample of homogenized FOG deposit was blended with

Table 1—Metal and minerals data obtained from FOG deposit sample 7.

Analyte	Result (mg/L)
Aluminum	170
Antimony	<5.0
Arsenic	<5.0
Barium	5.2
Beryllium	<0.10
Bismuth	<10
Boron	<5.0
Cadmium	<0.50
Calcium	9100
Chromium	0.76
Cobalt	<1.0
Copper	16
Gold	<1.0
Iron	270
Lead	<2.5
Lithium	<10
Magnesium	30
Manganese	2.7
Mercury	<10
Molybdenum	4.1
Nickel	<1.0
Phosphorus	130
Platinum	<10
Potassium	Not available
Selenium	<10
Silicon	93
Silver	<1.0
Sodium	72
Strontium	3.3
Sulfur	380
Thallium	<5.0
Tin	<10
Titanium	4.1
Vanadium	0.51
Zinc	18
Zirconium	<0.50

ethanol and a concentrated hydrochloric acid solution in a Mojonnier flask. This sample was gently agitated at 75°C for 40 minutes. A mixture of chloroform and diethyl ether was then added to the sample, and the sample was heated at 100°C for 45 minutes. The sample was then allowed to cool to room temperature (22°C). Hexane was then added, and the sample was allowed to separate into layers. The top layer contained the dissolved fatty acid methyl esters (FAME). This layer was collected and injected to the gas chromatography-flame ionization detector (GC-FID). The GC-FID analysis determines FAME composition, which can be converted to concentration and saturation levels of C4-C24 fatty acids.

Statistical Analyses. All experiments were performed in triplicate, unless otherwise indicated. Pearson Correlation and Proc GLM were performed using SAS version 6.12 (SAS, 1996), with a *P*-value <0.05 indicating statistical significance. Outliers were defined as data points farther than 3 standard deviations from the mean value.

Results and Discussion

Twenty-seven FOG deposit samples were received from 23 locations around the United States and analyzed for physical properties,

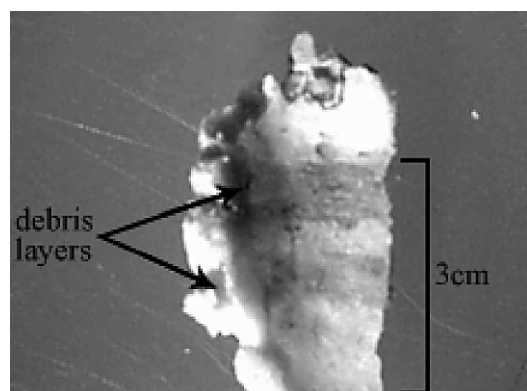


Figure 2—FOG deposit sample showing layering.

fatty acid composition, and metals. A majority of samples were received from the Southeast (63%), with minor contributions from the Northwest (22%), Southwest (11%), and Midwest (4%). No samples were received from the Northeast.

Of these 23 locations, 7 respondents provided sample collection information. These samples were collected downstream from food-service establishments, food-processing facilities, and residential sources, where significant cooking operations occurred (i.e., fast-food restaurants, full-service restaurants, nursing homes, a cafeteria, and grocery store with deli). Many listed multiple sources of FOG (i.e., 2 sushi bars, 3 fast-food restaurants, and 1 hotdog restaurant). Hydrojet cleaning was the reported method of choice for removing FOG deposits, with a cleaning frequency between 3 months and 2 years.

Figure 1 displays an occluded pipe containing FOG blockage before removal. The yellowish nodules are the leading surface of the deposit. As shown in Figure 1, the deposit preferentially accumulates at a specific position in the pipe cross-section, typically slightly above the low-flow water mark. This would support the hypothesis that a periodic, high-volume loading contributes to FOG accumulation. Figure 2 displays a close-up of a core taken from an FOG blockage. It distinctly shows layers of debris (sand, silt, etc.) interspersed with hardened FOG. A majority of samples exhibited this layering effect. These samples also displayed a sandstonelike structure, grainy and hard, with a distinct fracture plane upon failure. The thickness of deposit layers and debris layers varied between samples, but, in general, ranged between 0.25 and 0.50 cm. Based on the frequency of FOG removal, this suggests average FOG accumulation rates of 0.10 cm/d in the deposit. It is unknown whether the deposits grow uniformly. It is hypothesized that a periodic release of concentrated FOG results from either dishwashing or cleaning of the oil fryer. The debris layer is suspected to result from the cleaning and sanitizing of nonfood contact surfaces in the facility. Dirt and debris from floors, tables, and walls are rinsed into the sanitary sewer and accumulates at the FOG blockage site, possibly because of FOG surface charge, settling characteristics, and/or flow restrictions. Only a small portion of saturated FOG and dirt and debris discharged are accumulated, or FOG periodically sloughs off into wastewater. It should be noted that the sample displayed in Figure 2 was taken from a sanitary sewer and not a combined sewer. Thus, material in debris layer came from point sources and not a large rain event.

Physical properties for FOG samples 1 through 6 are shown in Table 2. Sample cores were collected perpendicular to debris layers

Table 2—Physical properties of FOG deposits (mean \pm standard deviation).

Sample	Porosity (%)	Moisture content (%)	Particle density (g/cm ³)	Yield strength (kPa)
1	11.26 \pm 0.21	10.12 \pm 0.38	0.99 \pm 0.09	4.50 \pm 0.38
2	14.42 \pm 0.30	60.74 \pm 8.43	1.14 \pm 0.04	29.43 \pm 8.43
3	16.54 \pm 0.27	42.51 \pm 6.69	1.23 \pm 0.09	34.25 \pm 22.39
4	7.11 \pm 0.21	49.98 \pm 6.39	1.04 \pm 0.06	29.35 \pm 6.39
5	23.50 \pm 0.29	32.32 \pm 12.78	1.21 \pm 0.03	24.2 \pm 12.78
6	10.73 \pm 0.47	41.19 \pm 5.07	1.10 \pm 0.05	16.13 \pm 5.07

when visually identified. The results reveal that gas-filled porosity was quite low for all samples, indicating limited open pores inside the FOG samples. Sample 1 was quite different than the other samples. It showed no layering effect, and its yield strength was quite low compared with other FOG samples. Sample 1 literally fell apart under test conditions, suggesting that it may have formed by a different process than the other samples. One possible hypothesis for the behavior of sample 1 is that it was formed from excess FOG accumulation, without chemical reactions. The remaining 5 samples showed similar layering and visual characteristics. Samples 2 through 6 displayed high moisture contents, low particle densities, and high strengths, suggesting that a porous, rigid structure developed during FOG formation, and, over time, water and debris accumulated in the voids. Based on these data, it was suspected that the FOG formation process for samples 2 to 6 resulted from a chemical reaction rather than FOG accumulation only.

Table 3 summarizes moisture content and fatty acid composition of FOG samples. The moisture content of samples ranged from approximately 6 to 86%. This wide range in moisture content suggests that moisture content may not be a significant factor in FOG blockage formation.

The lipid content within the FOG samples ranged from 0% to greater than 100%. Values greater than 100% resulted from large spatial variability in sample moisture content. Different subsamples of FOG were collected for determining moisture content and total FOG. The percentage of total FOG was then determined by subtracting the water content from the total sample weight. Thus, a large difference between subsample moisture contents could dramatically affect the calculated lipid percentage in FOG samples. This is further shown in Table 2, where the coefficients of variance for triplicate moisture content measurements taken from the same sample ranged between 4 and 40%.

When grouping data based on lipid content (>50%), it was observed that 84% (16 of 19 samples) of samples contained an average of 91% lipid content. Two of the remaining three samples contained 42% fat, with the remaining sample containing 0%. In examining the percentage of saturated fats within these data, the results displayed a range from 10 to 90%, with 67% having saturated fat content above 56%, with the primary saturated fatty acid being palmitic. These saturated fat contents are well above those found in common cooking oils and fats (Table 4), thus suggesting that the majority of FOG blockages results in high accumulations of saturated fatty acids. This result is consistent with existing research documenting formation of a white precipitate (calcium di-stearate and di-palmitate) in salad oil wastewater under high oil concentrations (Matsui et al., 2005). Conversely, these results also suggest that, for the majority of deposits, unsaturated and polyunsaturated

Table 3—Elemental fatty acid composition in FOG deposits.^a

Sample #	Moisture content (%)	Total fat ^b (%)	Saturated fat (%)	Primary saturated fat	Unsaturated fat (%)	Primary unsaturated fat	Polyunsaturated fat (%)	Primary polyunsaturated fat
1	10.12	N.R.	40.184	Palmitic	38.352	Oleic	18.711	N.R.
2	70.74	N.R.	87.074	Palmitic	8.326	Oleic	1.131	N.R.
3	52.51	N.R.	58.362	Palmitic	27.928	Oleic	8.317	N.R.
4	49.98	N.R.	69.973	Palmitic	21.261	Oleic	4.344	N.R.
5	32.32	N.R.	73.204	Palmitic	18.73	Oleic	4.206	N.R.
6	41.19	N.R.	80.423	Palmitic	14.581	Oleic	1.681	N.R.
7	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
8	44.8	68.12	69.7	Palmitic	N.R.	Oleic (cis)	N.R.	Linoleic (cis)
9	32.6	100.00	44.6	Palmitic	43.8	Oleic (cis)	8.94	Linoleic (trans)
10	58.8	97.57	87.8	Palmitic	9.1	Oleic (trans)	0.97	Linoleic (trans)
11	55.6	84.23	89.5	Palmitic	7.25	Oleic (cis)	0.51	Linoleic (cis)
12	42.2	74.22	56.9	Palmitic	26.2	Oleic (cis)	4.95	Linoleic (cis)
13	57.5	39.29	20.9	Stearic	8.95	Oleic (cis)	2.26	Linoleic (cis)
14	62.1	81.79	83.1	Palmitic	10.2	Oleic (cis)	1.12	Linoleic (cis)
15	61.1	120.31	87.6	Palmitic	10.23	Oleic (cis)	0.62	Linoleic (cis)
16	56.7	87.30	10.9	Palmitic	10.3	Oleic (trans)	0.64	Linoleic (trans)
17 ^c	16.7	94.48	15.2	Palmitic	70.4	Oleic (cis)	12.9	Linoleic (cis)
18	5.78	51.05	86.8	Palmitic	6.75	Oleic (trans)	0.61	Linoleic (cis)
19	64.3	112.04	77.10	Palmitic	14.30	Oleic (trans)	1.24	Linoleic (cis)
20	71.0	155.86	77.1	Palmitic	16.9	Oleic (trans)	1.76	Linoleic (trans)
21	58.9	51.34	78.8	Palmitic	17.1	Oleic (cis)	1.88	Linoleic (cis)
22	34.9	98.62	33.1	Palmitic	54.8	Oleic (cis)	6.48	Linoleic (cis)
23	71.7	93.99	67.1	Palmitic	15.1	Oleic (cis)	2.05	Linoleic (cis)
24	86.0	44.50	82.4	Palmitic	11.8	Oleic (cis)	1.7	Linolenic (gamma)
25	86.5	240.74 ^d	57.5	Palmitic	36.2	Oleic (trans)	2.21	Linoleic (cis)
26	71.3	N.R.	37.8	Palmitic	32.2	Oleic (cis)	28.2 ^c	Linoleic (cis)
27	36.4	0.0 ^d	N.R.	—	N.R.	—	N.R.	—
Mean	53.9	85.5	61.3		22.3		4.39	
Standard deviation	±21.0	±29.8	±26.5	—	±18.3	—	±6.82	—

^a N.R. = not reported.^b Total fat content calculated from sample moisture content and FOG measured in separate sample using U.S. EPA method 9071A (U.S. EPA, 1994).^c Sample came from location downstream from illegal dumping (food oil tanker rinse station).^d Value determined to be outlier. Data not included in average calculation.

fatty acids are not a major contributor to FOG blockages. The polyunsaturated fatty acids content averaged less than 5%, with a majority less than 2.5%. However, three samples had a polyunsaturated fatty acids content greater than 12%. It is suspected that

the polyunsaturated fatty acid content is dependent on the FOG source. The history of most FOG samples was unknown; however, for sample 17, it was reportedly taken from an FOG blockage located near an illegal vegetable tanker rinse station. Based on its fatty acid

Table 4—Fatty acid profiles of common cooking oils and animal fats (Stauffer, 1996).

Lipid type	Saturated fat (%)	Primary saturated fat	Unsaturated fat (%)	Primary unsaturated fat (%)	Polyunsaturated fat (%)	Primary polyunsaturated fat (%)
Cooking oils						
Canola	7.3	Palmitic	62.9	Oleic	30.5	Linoleic
Corn	13.6	Palmitic	25.6	Oleic	60.8	Linoleic
Olive	12.1	Palmitic	80.9	Oleic	7.0	Linoleic
Palm	49.4	Palmitic	39.5	Oleic	11.1	Linoleic
Peanut	19.4	Palmitic	48.5	Oleic	32.0	Linoleic
Soybean	15.4	Palmitic	23.3	Oleic	61.3	Linoleic
Animal fats						
Chicken fat	33	Palmitic	45.2	Oleic	21.4	Linoleic
Lard (pig)	41.8	Palmitic	47.9	Oleic	9.9	Linoleic
Tallow (beef)	47.9	Palmitic	47.4	Oleic	3.3	Linoleic

Table 5—Mineral and metal composition of FOG deposits.^a

Sample	Source location ^b	Calcium (mg/L [ppm])	Sodium (mg/L [ppm])	Magnesium (mg/L [ppm])	Aluminum (mg/L [ppm])	Silicon (mg/L [ppm])	Phosphorus (mg/L [ppm])	Sulfur (mg/L [ppm])	Iron (mg/L [ppm])	Lead (mg/L [ppm])	Water hardness (CaCO ₃) (mg eq)
1	SE	4290	41	31.1	186	67.6	107	237	142	N.R.	N.R.
2	SE	2620	314	98.2	673	87.2	205	56.2	678	N.R.	N.R.
3	SE	12 100	61.6	86.5	349	100	144	464	306	N.R.	N.R.
4	SE	1690	46.9	32.3	134	117	142	248	111	N.R.	N.R.
5	SE	461	30	13.2	142	42	86.2	467	106	N.R.	N.R.
6	SE	756	38.8	35.8	290	56.5	456	1750	1860	N.R.	N.R.
7	SE	9100	72	30	170	93	130	380	270	2.5	N.R.
8	SE	4140	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.	142
9	MW	2293	173	1016	406	55.4	107	62.25	536	2.21	143
10	SE	622	31.4	10.3	126	37.2	101	62.3	24	0.71	68
11	SE	2930	106	51.8	60.4	40.2	78.8	150	148	0.5	70
12	SW	5700	293	79	152	27.3	114	187	276	1.25	161
13	SE	3346	34.8	20.5	152	22.5	176	823	62.4	0.5	177
14	SW	6660	195	59	326	98.9	186	321	97.7	1.25	252
15	NW	10 700	137	42.8	77.8	13.3	58.7	165	52.2	0.5	86
16	SW	18 600	137	20.4	49.1	15.9	131	502	92.9	0.5	128
17 ^c	NW	35	56.7	9.23	17.9	12.5	25	68.5	21.1	1.14	N.R.
18	SE	2500	325	84	476	499	120	734	479	2.61	N.R.
19	SE	5410	122	57.8	58.7	55.1	209	432	112	0.57	N.R.
20	SE	1070	68	19.1	33.6	19.9	99.3	207	39.1	0.26	N.R.
21	SE	660	67.4	276	907	57.4	147	401	1110	3.04	N.R.
22	NW	2240	402	60.6	208	285	150	681	1080	1.83	N.R.
23	SE	2430	58.2	150	346	245	215	660	219	1.73	N.R.
24	SE	1250	147	231	515	103	381	755	1150	3.11	N.R.
25	NW	2000	44.9	32.6	162	139	125	660	42.4	1.29	N.R.
26	NW	2800	394	278	188	139	456	321	648	N.R.	N.R.
27	NW	198 000 ^d	181	4890 ^d	10 300 ^d	25.4	381	481	7980 ^d	2.64	N.R.
Mean		4255	139	117	257	101	172	447	387	1.37	136
SD		±4315	±119	±206	±214	±108	±109	±363	±471	±0.96	±58.5

^a N.R. = not reported.^b Sample location indicated as follows: SE = Southeast, MW = Midwest, NW = Northwest, and SW = Southwest.^c Sample came from location downstream from illegal dumping (food oil tanker rinse station).^d Sample data determined to be outlier (greater than 3 standard deviations from mean) in four categories, and sample data was removed from calculation of average.

profile, it is suspected that soybean or corn oil was being rinsed out and into the sanitary sewer, because its saturated fatty acid content was 15%, and the total unsaturated fatty acid content was 84%.

A majority of samples (24 out of 27) had fatty acid profiles with recoveries greater than 84%. The three exceptions were samples 13, 16, and 27. These samples are difficult to group or explain. Sample 27 contained 0% lipid and thus was a misidentified FOG sample, containing elevated mineral content (calcium, magnesium, aluminum, and iron). For samples 13 and 16, it was noted that less than 30% of the FOG was identified. It is hypothesized that the remaining 70% of unidentified lipid was either epoxy, oxidized, or polymerized free fatty acids, because these are not accurately detected in the performed fatty acid analyses. The mechanisms by which these FOG deposits form remain unknown; however, the physical properties and visual characteristics suggest that the majority of deposits (84%) are metallic salts of fatty acids formed by saponification. Saturated oil constituents are being preferentially selected and accumulated into a hardened mass with a porous structure. A strong oxidizing agent is required to initiate the saponification process. High pH (>10) alkaline detergents, degreasers, and sanitizers are commonly used in food-service establishments

and thus provide an available oxidizer to promote saponification. A secondary cause of FOG deposits may be oil accumulations without saponification, possibly from highly concentrated oil discharges resulting from illegal dumping or improper grease interceptor management. In minor cases, mineral deposits may be misidentified as FOG deposits.

Major minerals and metals from FOG deposits are summarized in Table 5. These analyses indicate that calcium is the primary metal present, with minor contributions of iron, sulfur, magnesium, and aluminum. In 85% (23 of 27 samples) of FOG deposits, calcium concentration was the highest-contributing metal or mineral and ranged from 0.01 to 19.8% of total solids. The FOG sample 27 contained the largest concentration of calcium (19.8%), magnesium (0.5%), aluminum (1%), and iron (0.8%). From Table 4, this sample also contained negligible lipids, suggesting that minor causes of FOG blockages are misidentified. The FOG sample 17 contained negligible levels of minerals and metals, suggesting that this FOG blockage, reportedly obtained from an illegal dumping location, resulted from a different formation process than the majority of samples. As previously hypothesized, this sample probably formed from lipid accumulation without significant chemical reactions.

There were no statistical relationships observed between water hardness and any minerals or metals measured. This suggests that the majority of FOG deposits do not depend on water hardness. Calcium levels measured are well above those represented by water hardness, suggesting that a preferential selection of calcium also occurs in the FOG formation process.

In summary, there appear to be three categories of FOG deposits. The primary category and majority (84%) of FOG deposits appear to be metallic salts of fatty acids. They exhibit high sample strength and very different fatty acid profiles than common cooking oils. These samples showed concentrations of saturated fatty acids and calcium well above background levels and distinct layering effects, suggesting an intermittent formation process. This layering effect would be consistent with the fluctuating flow profile seen in restaurant and industrial waste discharges. Some flows would contain the necessary “ingredients” to create a FOG layer, where other flows would contribute water and debris, filling the pores. A second category of FOG deposits results from the accumulation of lipids from waste discharges of highly concentrated lipids. These samples display oil profiles similar to cooking oils, without significant metals or minerals present. A third and minor category would be misidentified mineral deposits (elevated levels of calcium, aluminum, and iron) with no FOG present. These would be analogous to hard-water deposits found in potable water systems.

Conclusions

The moisture content of FOG samples ranged from 6 to 86%, suggesting that moisture content is not a primary factor in FOG deposits. A total of 16 of 19 FOG deposit samples (84%) contained greater than 50% lipid content, with the primary lipid being palmitic, a saturated fat. In addition, 85% of FOG deposit samples contained calcium as the primary metal or mineral present, with average concentrations of 4255 mg/L (4255 ppm). There was no correlation found between calcium concentration in FOG deposit samples and water hardness. The FOG deposits preferentially accumulate saturated fats and calcium, well above background levels, suggesting that a chemical process is responsible for their formation.

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