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Analysis of the characteristics of fat, oil, and grease (FOG) deposits in sewerage systems in the case of Korea

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ABSTRACT

Fat, oil, and grease (FOG) is the most common factor in sewer pipe blockage, and is the source of inundation and sanitary sewer overflows (SSOs). In the US and the UK, many inundation or SSO events occur each year, and a great deal of cost has been incurred to improve these situations. However in Korea, the database for sewer maintenance is still insufficient. In this study, FOG deposits collected in Korea were analyzed, and the characteristics of the FOG deposits were compared with the characteristics of the FOG deposits from places with different food cultures investigated in some of the major previous studies. Six FOG samples were collected from sewer mains and service laterals in the sewerage systems. The characteristics of the six samples were examined using FT-IR, Ca ion, and fatty acid composition analyses. The results of the FT-IR analysis indicated that the spectra defined in the previous studies of FOG were observed, and thus similarity to the samples of the previous studies was found. The proportions of the Ca ions included in the FOG of the six samples were 0.02–0.59%, and they are thought to be related with the maintenance of the discharging sources where the samples were collected. The results of the fatty acid composition analysis indicated that the proportions of total fat in the FOG ranged from 6 to 33%, and the proportion of total fat in the FOG decreased as the proportion of saturated fatty acid in the total fat increased. In some of the major studies performed previously in the US and the UK, saturated fatty acids accounted for a high proportion of the fatty acid compositions. However, the six FOG deposits analyzed in this study showed different compositions. It is thought that the fatty acid composition of FOG could vary with differences in the food culture, and the characteristics of FOG deposits could also vary. The data obtained from this study and future studies would be useful for the effective management of FOG deposits that are formed based on the food culture.

Keywords: FOG; Korea; Deposit; FT-IR; Fatty acid; Calcium

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1. Introduction

In foreign papers and journals from the US, the UK, etc. the fat, oil, and grease (FOG) in sewage that flows into sewers is collectively referred to as FOG [1–3]. In Korea, FOG is classified as “cohesion” or “waste oil adhesion” based on the rehabilitation decision criteria [4]. The definition and management of FOG has been more active in foreign countries than in Korea.

FOG in sewer pipes is a major problem that causes the sanitary sewer overflows (SSOs) of separate sewers and induces environmental and health hygiene damages [1]. In the UK, inundation occurs more than 25,000 times per year due to the blockage of sewer pipes [5]. As mentioned in the study by Arthur et al. [5], the causes of sewerage system inundation in the UK were classified by the sewerage system supply regulatory agencies (OFWAT and WICS) into two broad categories: hydraulic overload and other causes. The media tends to focus on the problem of hydraulic overload. However, for 84% of the sewerage systems in England and Wales that are known to cause inundation, the inundation occurred due to causes other than hydraulic overload, and more than 90% were due to blockage. Also, in the US, 48% of the 10,000 cases of SSOs occurring every year were due to the blockage of sewers and 47% were related to FOG, which reduces the cross-sectional area of the interior of sewers. In North Carolina, 15,000 cases of SSOs occurred every year, and $100,000 in costs has been incurred to resolve the blockage of pipes [6]. In Korea, the database for sewer maintenance is not yet systematically managed, and thus it is difficult to statistically estimate the cause of the problems.

Recently, various studies on the characteristics and mechanism of FOG, which affects sewer maintenance and environmental problems, have been performed in foreign countries. The results of an experiment using FOG deposit samples collected from 23 cities in the US indicated that the FOG deposits had cohesiveness and high yield strength, and the texture of the surface was similar to that of rough sandstone. Most of the collected samples (84%) contained more than 50% fat, which consisted of palmitic acid that was a major saturated fatty acid, and 85% of the FOG deposit samples contained calcium (4,255 mg/L on average), which was a major metal ion [2].

The focus of FOG problems is the formation of hardened solids as FOG is thrown into sinks and drains. However, the fact that the composition of fatty acid, which is the element forming FOG, varies depending on the oil and fat used for cooking needs also to be considered when evaluating FOG problems. All of the major studies have been performed previously in countries with a Western food culture. Therefore, it is thought that the results of the analysis of FOG characteristics in previous studies would not be universal.

In this study, the infrared spectrum (FT-IR) and fatty acid composition of FOG collected in Korea, which had a different food culture from those countries in which some of the major previous studies had been performed, were analyzed, and the results were compared with those found in some of the major previous studies.

2. Materials and methods

2.1. Sampling

To analyze the characteristics of FOG deposited on sewer pipes, three sewer mains and three service laterals, where FOG had been deposited, were selected. In the three sewer mains, FOG deposits were formed by the sewage discharged from mixed housing, a shopping center, and a commercial complex. In the case of the three service laterals, FOG deposits were formed by the sewage discharged from a super supermarket, a Chinese restaurant, and a pork restaurant. Each discharging source has many different food service establishments (FSEs). FSEs make wastewater that contains various types of oils or fat. For sample collection, a long rod was put into a manhole, and the deposit on the inner wall was scraped, which was then collected using a scoop net. The collected samples were stored in a cooler maintained at 5˚C, and were then sent to a specialized analysis center.

2.2. Analysis methods

To examine the characteristics of the FOG formed by the sewage discharged from the sewerage systems in Korea, the FT-IR, calcium proportion in FOG, and fatty acid composition were analyzed.

2.2.1. FT-IR (Fourier Transform Infra-Red Spectrophotometer)

For the six samples, a total of 32 scans were obtained using JASCO FT-IR 4100 in ATR measurement mode. The spectra were converted into absorbance units based on the negative log of the ratio of the spectrum of air and the spectrum of the sample. The data were obtained using a computerized processing program.

2.2.2. Calcium analysis

The proportion of calcium in the FOG was measured using an inductively coupled plasma spectrometer. For the pretreatment, mixed acids (hydrochloric acid, nitric acid, hydrogen peroxide, and hydrofluoric acid) were added to the samples, and they were decomposed at a high temperature. For the analytical instrument, iCAP 6300 SERIES (Thermo Scientific) was used.

2.2.3. Fatty acids profiles

The samples, which had gone through a pretreatment process using methyl ester, were analyzed through gas chromatography (GC) using 6890N GC-FID. Helium was used as the carrier gas at a flow rate of 1 ml/min. The temperature condition was first set at 120˚C for 7 min, and was raised to 180˚C by increasing 4˚C per minute. Then it was raised to 250˚C by increasing 5˚C per minute, and was maintained at 250˚C for 20 min. The fatty acid was calculated based on the internal standard ratio using a standard solution (SUPELCO^{TM} 37 Component FAME Mix).

3. Results and discussion

The FT-IR, calcium proportion in FOG, and fatty acid composition of the FOG deposits collected from the sewer mains carrying the sewage discharged from mixed housing (sample No. 1), shopping center (sample No. 2), commercial complex (sample No. 3), and the FOG deposits collected from the service laterals carrying the sewage discharged from the super supermarket (sample No. 4), Chinese restaurant (sample No. 5), and pork restaurant (sample No. 6) were analyzed. Also, the characteristics of the FOG from the sewerage systems in Korea were analyzed and compared with the results of the major studies reported previously in the US and the UK.

3.1. FT-IR of the FOG in Korea

Figs. 1 and 2 show the spectra of the six FOG samples collected from the sewer mains and the service laterals. All six spectra were similar to the baseline of the FOG collected from the sites reported in Reyes and Ducoste [7]. FOG deposits are formed by the saponification reaction between the fatty acid in oil or fat and the calcium in the interior of sewer pipes [7]. Poulenat et al. [8] identified four kinds of wavelength ranges that can contribute to the formation of calcium soaps [8]. These were region 1: 4,000–3,000 cm^{-1}; region 2: 1,800–1,350 cm^{-1}; region 3: 1,350–1,180 cm^{-1}, and an additional sideband near 720 cm^{-1}; region 4: near 670 cm^{-1}. The absorbance band in the range of 2,800–3,000 cm^{-1}, which represents the frequency of aliphatic chains, was observed in all the samples. This indicates that there was plenty of free fatty acid, which can react with calcium. If free fatty acid reacts with calcium and forms the hard metallic salt of fatty acids (soap), the stretching vibration of carboxylate group is not observed at 1,745 cm^{-1}, which is the absorbance band of triacylglycerol, and three kinds of characteristic absorbance bands of calcium soap are observed [9]. Among the three kinds of absorbance bands, the symmetric or asymmetric stretching vibrations, which occurred at 1,577 and 1,422 cm^{-1}, were similarly observed in samples No. 1 and No. 4. In the remaining four samples, after these two were excluded, an absorbance band was observed near 1,745 cm^{-1}. Reyes and Ducoste mentioned that the spectrum of fatty acids, such as palmitic acid and oleic acid, showed a strong absorbance band near 1,700 cm^{-1} [7]. It is thought that the fatty acid, which had been left after the reaction with calcium, was observed in the spectrum. Also, the shape of the spectrum absorbance band could change due to other materials included during the accumulation of FOG deposits. Among the six samples, No. 1 and No. 4 are thought to be FOG at the stage of forming saponification, and the rest are thought to be FOG that completed saponification. The FT-IR results of the six samples showed that the samples analyzed in this study were not different from the FOG deposits examined in the studies conducted previously in foreign countries.

3.2. Ca in the FOG samples

The proportion of Ca included in the same amount of FOG was examined. Keener et al. [2] stated that FOG is formed by the saponification reaction between the Ca ions in sewage and concrete, and the fatty acid produced by the hydrolysis of oil. They also mentioned that the important factors for the formation of FOG are concrete (pipe material), water, oil, fatty acid, and calcium ions [2].

The analysis of the proportion of Ca in the six FOG samples indicated that the range was 0.02–0.59%. The FOG collected from the service laterals (Nos. 4 and 6) excluding No. 5 had higher proportions of Ca in the FOG samples than the FOG collected from the sewer mains (Nos. 1–3). This is thought to be related with the maintenance of the sewer pipes summarized in Table 1. For the sewage discharging sources of Nos. 1, 2, 3, and 5, on which maintenance is performed

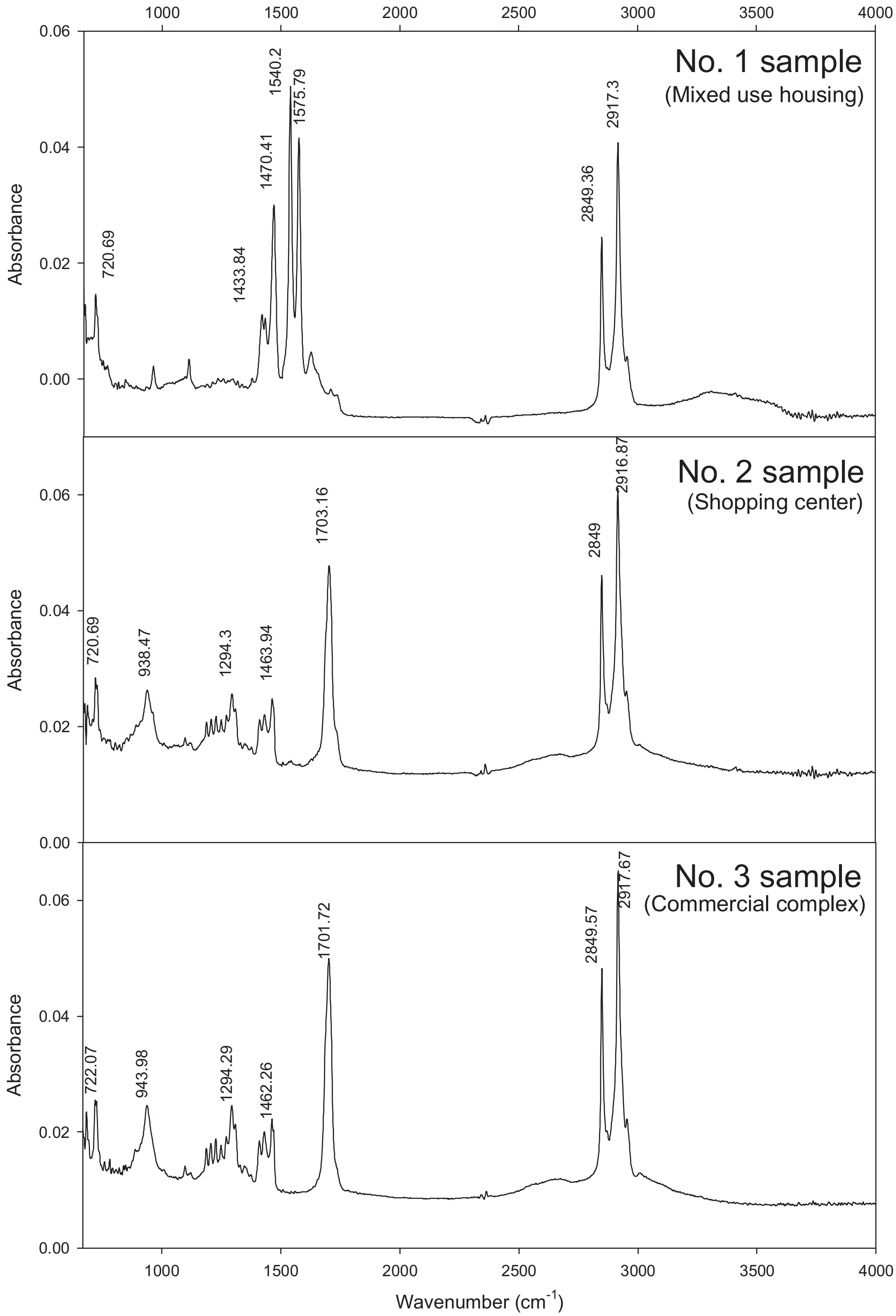

Fig. 1. Baseline infrared spectra of the FOG deposit samples (No. 1–3).

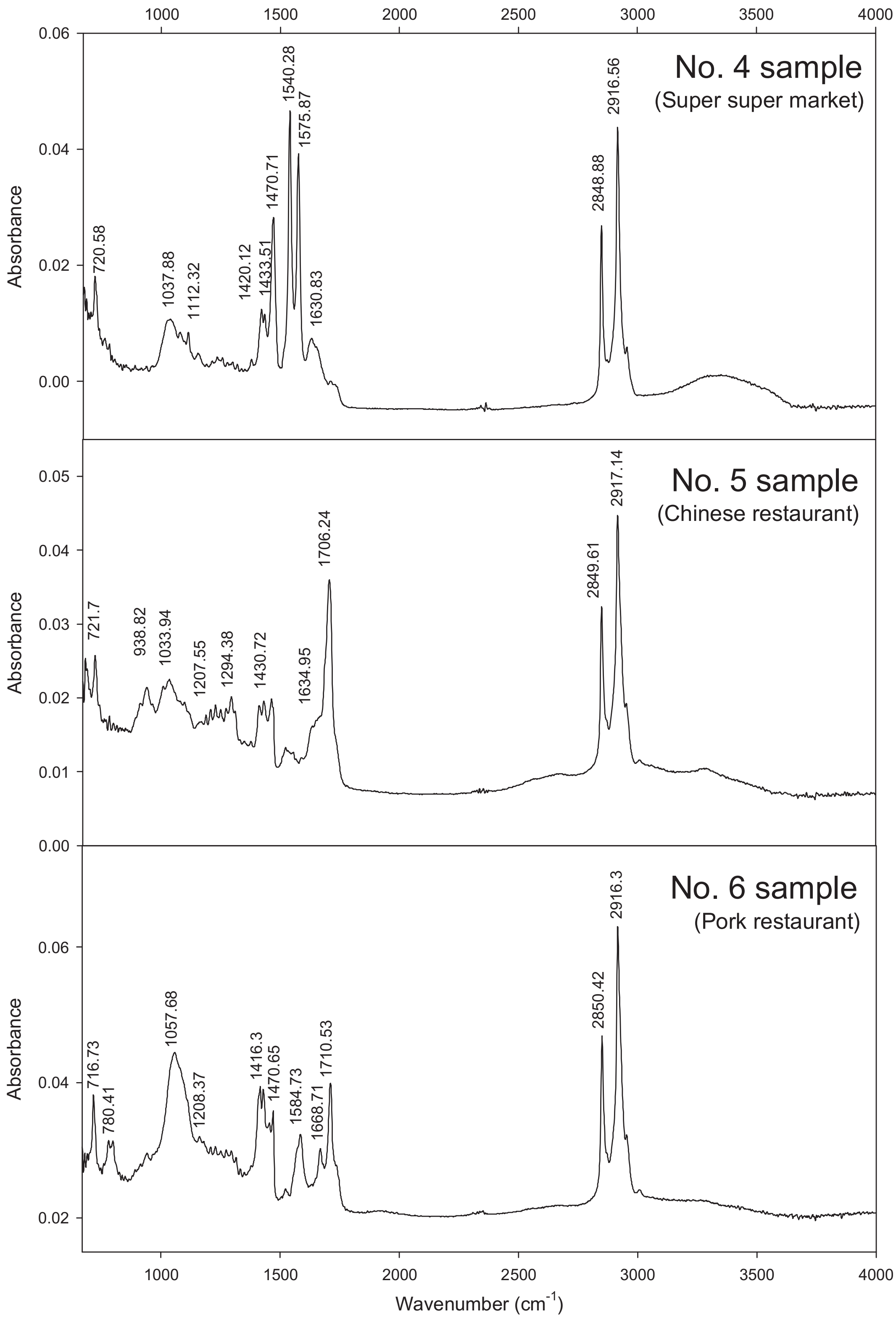

Fig. 2. Baseline infrared spectra of the FOG deposit samples (No. 4–6).

Table 1
Description of collected FOG samples in cooking

No.	Sampling point	Discharging source[a]	Type of the FSEs[b]	Cooking oil & fat	Maintenance of sanitary
1	Main sewer	MH	KR 4, JR 1, WR 1	Lard (pig), Soybean, Olive, etc.	Once a year
2	Main sewer	SC	KR 5, JR 2, WR 4	Lard (pig), Soybean, Olive, etc.	Once a year
3	Main sewer	CC	KR 3, JR 1, WR 2	Chicken fat, Soybean, etc.	Once a year
4	Service lateral	SSM	KR 1, JR 1, WR 1, CR 1	Chicken fat, Soybean, Olive, etc.	–[c]
5	Service lateral	CR	CR 1	Soybean	Once a year
6	Service lateral	PR	PR 1	Lard (pig)	–

[a]MH (Mixed housing), SC (Shopping center), CC (Commercial complex) SSM (Super supermarket), CR (Chinese restaurant), PR (Pork restaurant).

[b]FSEs (Food service establishments), KR (Korean restaurant), JR (Japanese restaurant), WR (Western restaurant), CR (Chinese restaurant), PR (Pork restaurant).

[c]The sampling point is not maintained periodically.

once a year, the periodic cleaning of the interior reduces the leaching of Ca ions from concrete pipes by preventing corrosion, and enables efficient flow without the stagnation of sewage. Therefore, this is thought to be related with the reduction of Ca ions in sewage (Fig. 3).

3.3. Composition of fatty acids

The analysis of the fatty acids indicated that the saturated, monounsaturated, and polyunsaturated fatty acids, which were distributed in the total fatty acid, showed diverse compositions in the six samples. The primary saturated fatty acids were palmitic acid and stearic acid, and the primary monounsaturated fatty acid and the primary polyunsaturated fatty acid were oleic acid and linoleic acid, respectively. The compositions of the primary fatty acids in this study were found to be consistent with those reported by Keener et al. [2] and He et al. [10] (Table 2). However, the proportions of saturated or unsaturated fatty acids in the total fatty acid were different from those reported in the previous studies. For samples No. 1 and No. 6 (MH and PR), the proportions of monounsaturated fatty acids were the highest at 36 and 37%, respectively. For samples No. 2 and No. 4 (SC and SSM), the proportions of saturated fatty acids were the highest at 54 and 96%, respectively. For samples No. 3 and No. 5 (CC and CR), the proportions of polyunsaturated fatty acids were the highest at 55 and 45%, respectively.

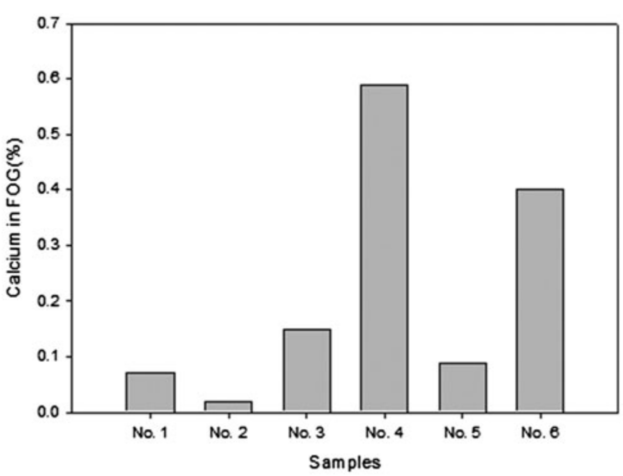

Fig. 3. Ratio of calcium in the FOG samples.

Samples Nos. 1–4 are the FOG deposits formed by the sewage discharged from a number of restaurants, while samples Nos. 5 and 6 are the FOG deposits formed by the sewage discharged from one restaurant. The fatty acid composition of No. 5 was similar to that of soybean cooking oil, and the fatty acid composition of No. 6 was similar to that of lard cooking fat [11] (Table 3). These results indicated that the FOG deposits formed on the sewerage systems in Korea had different fatty acid compositions from those in the US or the UK. Also, different FOG characteristics were observed depending on the oil and fat used for cooking due to the differences in food culture.

Palmitic acid, which was the primary saturated fatty acid, and oleic acid, which was the primary monounsaturated fatty acid, have different physical characteristics. Therefore, the physical properties of the FOG deposits could vary depending on the proportions of the fatty acid compositions. Each different solid, which is formed from palmitic acid or oleic acid, has different properties. Palmitic acid forms solids more quickly, but the solids formed from palmitic acid have lower viscosity and a smaller amount than the solids formed from oleic acid [11].

Table 2
Fatty acids composition of FOG deposits for comparison with major previous studies

Sample		Saturated fat of total fat (%)	Primary saturated fat	Monounsaturated fat of total fat(%)	Primary monounsaturated fat	Polyunsaturated fat of total fat(%)	Primary polyunsaturated fat
This study	No. 1	35	Palmitic	36	Oleic	25	Linoleic
	No. 2	54	Palmitic	38	Oleic	6	Linoleic
	No. 3	9	Stearic	30	Oleic	55	Linoleic
	No. 4	96	Palmitic	3	Oleic	1	Linoleic
	No. 5	17	Palmitic	27	Oleic	45	Linoleic
	No. 6	36	Palmitic	37	Oleic	26	Linoleic
[10]	R1[a]	78.8	Palmitic	9.8	Oleic	0.8	Linoleic
	R2[a]	57.5	Palmitic	9.0	Oleic	0.6	Linoleic
	R3[a]	70.6	Palmitic	14.0	Oleic	0.7	Linoleic
	Apartment	56.5	Palmitic	38.3	Oleic & Palmitoleic	1.0	Linoleic
	Shopping center 1	38.7	Palmitic	37.2	Oleic	15.3	Linoleic
	Shopping center 2	64.7	Palmitic	31.7	Palmitoleic	0.6	Linoleic
[2]	1[c]	40.2	Palmitic	38.4	Oleic	18.7	N.R.
	2	87.1	Palmitic	8.3	Oleic	1.1	N.R.
	3	58.4	Palmitic	27.9	Oleic	8.3	N.R.
	4	70.0	Palmitic	21.3	Oleic	4.3	N.R.
	5	73.2	Palmitic	18.7	Oleic	4.2	N.R.
	6	80.4	Palmitic	14.6	Oleic	1.7	N.R.
	7	N.R.[b]	N.R.	N.R.	N.R.	N.R.	N.R.
	8	69.7	Palmitic	N.R.	Oleic	N.R.	Linoleic
	9	44.6	Palmitic	43.8	Oleic	8.9	Linoleic
	10	87.8	Palmitic	9.1	Oleic	1.0	Linoleic
	11	89.5	Palmitic	7.3	Oleic	0.5	Linoleic
	12	56.9	Palmitic	26.2	Oleic	5.0	Linoleic
	13	20.9		9.0	Oleic	2.3	Linoleic
	14	83.1	Palmitic	10.2	Oleic	1.1	Linoleic
	15	87.6	Palmitic	10.2	Oleic	0.6	Linoleic
	16	10.9	Palmitic	10.3	Oleic	0.6	Linoleic
	17	15.2	Palmitic	70.4	Oleic	12.9	Linoleic
	18	86.8	Palmitic	6.8	Oleic	0.6	Linoleic
	19	77.1	Palmitic	14.3	Oleic	1.2	Linoleic
	20	77.1	Palmitic	16.9	Oleic	1.8	Linoleic
	21	78.8	Palmitic	17.1	Oleic	1.9	Linoleic
	22	33.1	Palmitic	54.8	Oleic	6.5	Linoleic
	23	67.1	Palmitic	15.1	Oleic	2.1	Linoleic
	24	82.4	Palmitic	11.8	Oleic	1.7	Linoleic
	25	57.5	Palmitic	36.2	Oleic	2.2	Linoleic
	26	37.8	Palmitic	32.2	Oleic	28.2	Linoleic
	27	N.R.	–	N.R.	–	N.R.	–

[a]R1, R2, and R3 had Ca^{+2} concentrations of 50, 400, and 750 mg/L, respectively, and were collected from steakhouse.
[b]N.R. = Not reported.
[c]FOG sample 1–27 were received from 23 locations around the US.

The analysis of the fatty acids in this study indicated that samples Nos. 2 and 4, which had high proportions of saturated fatty acids, had low proportions of total fat in the FOG (Fig. 4). This was consistent with the results of the analysis of the physical characteristics of palmitic acid and oleic acid

Table 3
Fatty acids profiles of common cooking oils and animal fat [11]

Lipid type	Saturated fat (%)	Primary saturated fat	Monounsaturated fat (%)	Primary Monounsaturated 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	33.0	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

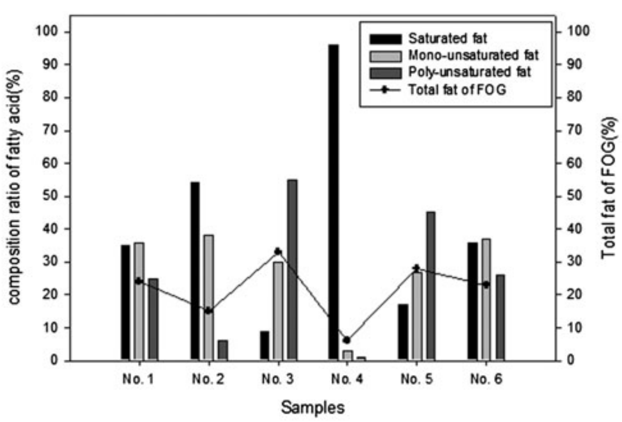

Fig. 4. Total fat comparison on composition ratio of fatty acid.

reported by He et al. [12]. Unsaturated fatty acid (e.g. oleic acid) forms more solids and has higher viscosity than saturated fatty acid. Therefore, the ease of sewer maintenance could vary depending on the properties of fatty acids.

4. Conclusions

In this study, FOG samples collected from sewer mains and service laterals in Korea were analyzed, and the characteristics of the FOG in Korea were investigated through comparison with the results of the previous studies from foreign countries. The FT-IR analysis indicated that the collected samples No. 1 and 4 were at the stage in which calcium soap is formed by the reaction between fatty acid and calcium. The remaining samples are thought to be the FOG that completed saponification. The proportion of Ca ions in the FOG samples was found to be related with the periodic sewer maintenance. Ca combines with fatty acid, and forms FOG deposits. Therefore, the formation of FOG deposits needs to be prevented by periodic cleaning before the blockage of pipes.

In addition, the characteristics of FOG deposits formed on the interior of sewers could vary depending on the oil and fat used for cooking due to the differences in the food culture. A high proportion of unsaturated fatty acid composition results in the formation of FOG deposits that are made of solid materials with high viscosity and in large amounts. This would make it difficult to clean the interior of sewer pipes.

In future studies, the physicochemical characteristics of FOG deposits, such as the correlation of penetration, melting point, and primary fatty acids (palmitic and oleic), need to be analyzed based on each restaurant in Korea. The data obtained from this study and future studies would be useful for the effective management of FOG deposits that are formed depending on food culture.

Acknowledgments

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