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The relationship between fat, oil and grease (FOG) deposits in building drainage systems and FOG disposal patterns

Eva Nieuwenhuis, Jeroen Langeveld and François Clemens

ABSTRACT

Fat, oil and grease (FOG) deposits are an important contributor to blockages in building drainage systems. Such blockages bring undesirable financial, health and environmental costs, and thereby burden society. It is unclear to what extent the behavior of inhabitants, and more precisely domestic FOG disposal, affects the occurrence of FOG blockages. For this study, samples of FOG blockages were collected from building drainage systems (kitchen drains and lateral house connections) and analyzed. The results showed that the deposits were calcium salts of fatty acids. Dissimilarities between the network locations demonstrate that, even at short distance, in-sewer transformation processes occur. Surveys were conducted to reveal information about FOG disposal patterns. Three households showed a clear link between the type of cooking oils used and the type of deposits collected.

Key words | building drainage systems, calcium, disposal patterns, fat, oil and grease (FOG) deposits, free fatty acids (FFAs), lateral house connections

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INTRODUCTION

The sewer system is an essential infrastructure in modern society, protecting our health and the environment. Sewer blockages are the dominant failure mechanism in sewer systems (Ashley *et al.* 2004; Arthur *et al.* 2009). Blockages decrease the available discharge capacity, thereby increasing the risks of flooding and the occurrence of sewer overflows that discharge (diluted) wastewater into open water bodies. In the United States, fat, oil and grease (FOG) deposits are reported to be the leading cause of sewer blockages: almost half of all blockages are related to FOG (EPA 2004). For the Netherlands, a statistical analysis of failure mechanisms in lateral house connections (horizontal drains that transport wastewater from domestic properties to municipal sewers) showed that more than one-third of all failure events were related to FOG deposits (Post *et al.* 2016).

FOG deposits have an adhesive character and become firmly attached to interior sewer pipe walls (Figure 1). For previous studies, FOG deposit samples were collected from different locations within the public sewer network; they showed that the deposits are calcium-based fatty acid salts resulting from a saponification process (Keener *et al.* 2008; He *et al.* 2011; Williams *et al.* 2012; Shin *et al.* 2015). Their

grainy, sandstone-like texture (Keener *et al.* 2008) requires intensive cleaning activities, such as hydraulic jetting, to remove them (Dirksen *et al.* 2012; Mattsson *et al.* 2014).

Until now, research has barely elaborated on the probable impact of domestic FOG disposal – they primarily focused on food service establishments (Keener *et al.* 2008; Williams *et al.* 2012; Dominic *et al.* 2013) and the fishing and meat industries (Cammarota & Freire 2006; Mattsson *et al.* 2014). Nevertheless, He *et al.* (2011) collected two FOG deposit samples from an apartment area, suggesting that residential users also contribute to the severity of FOG deposit problems. Additionally, a survey done among 127 Norwegian and Swedish sewer operators reported that 48 and 22% of the operators, respectively, experienced FOG-related problems in residential areas (Mattsson *et al.* 2014). Recently, Post *et al.* (2016) showed that FOG is the dominant failure mechanism in lateral house connections and that, compared with main sewers, lateral house connections are more prone to blockages. According to the European RecOil Project, which aims to foster used cooking oil recycling for biodiesel production, the domestic sector contributes to approximately half of the total amount of used cooking oils (EUBIA 2015).



Figure 1 | FOG deposits (source: Municipality of Arnhem).

They estimated that approximately 2.4 L of used cooking oil is improperly disposed per capita per year. Accordingly, a recent study by Wallace *et al.* (2017) mentioned the detrimental effects domestic FOG disposal can have. They emphasized the need for proper domestic FOG waste management.

Although all of these studies indicated the contribution of domestic FOG disposal to the accumulation of FOG in the sewer system, none of them further elaborated on the observed phenomenon. This research therefore aims to gain a better understanding of the occurrence of FOG deposits in building drainage systems by examining the deposits and their relationship with domestic FOG disposal patterns.

MATERIALS AND METHODS

Site selection and sample collection

Two service engineers of the drain and sewer cleaning company RRS (Riool Reinigings Service) collected FOG deposit samples from clogged building drainage systems in the area of Rotterdam between May and September 2016. A convenience sampling method was used: a sample was only collected if the service engineers were able to reach some clogging material.

Seven samples were collected from lateral house connections (Figure 2). If the FOG blockage was not close to the inspection opening (IO), high-pressure water jetting was used to clear the blockage. Backward-facing jets caused the detached FOG deposits to flow towards the IO. The other four samples were collected from kitchen

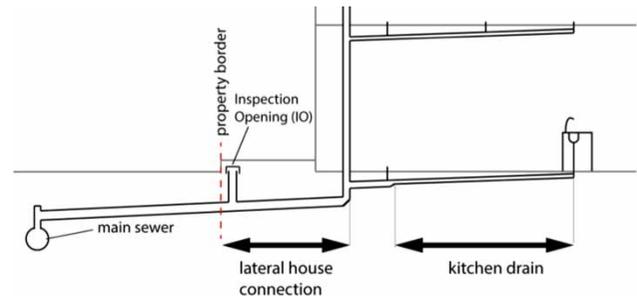


Figure 2 | Building drainage system showing the two sampling locations: lateral house connections and kitchen drains.

drains (the pipes that drain kitchen wastewater only and transport it to lateral house connections). The drains were cleared by mechanical drain rodding and the detached FOG deposits were collected using a wet vacuum cleaner.

The samples were stored in the ventilated sewer inspection car and at the end of the day refrigerated at 5 °C for further analysis within 7 days. For every sample, the service engineers were asked to provide information on each particular clogging (location and severity, for example), the manner of sampling and the structural conditions of the building drainage system. In addition, to address errors in, for example, the reported units, the data received from the laboratory was assessed using a plausibility check.

Analysis methods

Chemical and physical analysis

Chemical and physical tests were carried out by the AL-West laboratory (AL-West B.V., Deventer, The Netherlands). The kitchen drain samples were filtered (0.25 mm) prior to analysis. For all samples, dry matter and water content were analysed gravimetrically by drying and heating, according to a method equivalent to NEN-ISO11465 and conforming AS3000, AS3200 and NEN-EN 12880. The calcium concentration was determined with inductivity coupled plasma-mass spectrometry (NEN 6966) and after destruction with aqua regia (NEN 6961). The following free fatty acids (FFAs) were analysed by internal methods and conform to NEN 6671: hexanoic acid (C6:0), heptanoic acid (C7:0), octanoic acid (C8:0), nonanoic acid (C9:0), decanoic acid (C10), undecanoic acid (C11:0), undecylic acid (C11:1), dodecanoic acid (C12), tetradecanoic acid (C14:0), hexadecanoic acid (C16:0), octadecanoic acid (C18:0), octadecenoic acid (C18:1), octadecadienoic acid (C18:2), eicosanoic acid (C20:0), docosanoic acid (C22:0).

FTIR spectrometer analysis

Fourier transform infrared (FTIR) analysis was performed at the Chemical Engineering Laboratory at Delft University of Technology, using a Thermo Scientific Nicolet™ 6700 FTIR spectrometer. An attenuated total reflection crystal made of zinc selenide (ZnSe) was used to obtain infrared absorption spectra of the homogenized FOG samples. For every sample, separate analyses were performed on three sub-samples. Spectra were collected at the mid-infrared region (4,000–650 cm⁻¹) and a total of 64 scans were performed per run at a resolution of 4 cm⁻¹. For data processing Omnic software was used.

Survey

A survey (see Appendix A, available with the online version of this paper) was conducted by phone to collect information on the disposal of FOG (types of cooking oil), drainage of debris, laundry and dishwashing preferences and the observed sewer problems (time of residence and frequency of drainage problems).

RESULTS AND DISCUSSION

Sample collection

Table 1 provides an overview of the sample site characteristics. The pipes of the kitchen drains were 70 or 75 mm,

Table 1 | Sample site characteristics

Sample	Drain type	Diameter size (mm)	Sampling manner	Household size	Blockage interval (years)
1	K	75	MR + VC	2	3.3
2	K	70	MR + VC	5	10
3	K	75	MR + VC	2	2.5
4	K	75	MR + VC	1	5
5	L	110	IO	4	1
6	L	110	WJ + IO	3	1
7	L	110	WJ + IO	2	NR
8	L	125	WJ + IO	NR	NR
9	L	110	IO	1	1
10	L	125	MR + IO	NR	NR
11	L	110	WJ + IO	NR	NR

K, kitchen drain; L, lateral house connection; MR, mechanical rodding; VC, vacuum cleaner; WJ, water jetting; IO, inspection opening; NR, not reported. The blockage interval is the average time between FOG blockages, based on the last 10 years.

and the pipes of the lateral house connections were 110 or 125 mm in diameter. The pipes collected wastewater from a single household, except for samples 8 and 10; in these (private) pipes, wastewater from two to six households was collected.

Sample properties

Visual characteristics

The appearance of the FOG deposit suspensions collected from kitchen drains was very different to the appearance of FOG deposits collected from lateral house connections (Figure 3). In addition to clogging material, the kitchen drain samples also contained (dark) kitchen wastewater that could not pass the blockage. It is thought that the flexible rotating cable used for rodding had cut the larger deposits into smaller pieces. The FOG particles had a chalk-like, grainy appearance. By contrast, the deposits collected from lateral house connections predominantly had a soft, waxy consistency. They were round or bar-shaped with a length of up to 200 mm and fell apart when pressure was applied.

Physical characteristics

Table 2 shows an overview of characteristics of FOG deposits. The bulk density of the deposits collected both from kitchen drains and from lateral house connections was around 1.0 g/cm³. The relatively high moisture content for kitchen drains (75–90%) is thought to be attributable to the manner of sampling, as these samples also contained wastewater that could not pass the blockage.

Total fat content

For the kitchen drain samples, the extractable oil and fat content ranged from 9 to 22% (Table 2). For sample 1, no value was reported. The fat content of the lateral house connection samples ranged from 32 to 110%. Previous studies that analyzed FOG deposits from main sewers found comparable results (Keener et al. 2008; He et al. 2011; Williams et al. 2012; Shin et al. 2015). Values greater than 100% resulted from the method of analysis and sample inhomogeneity. The fat content equals the proportion of fat in solids and different subsamples were used for the moisture content analysis and the extractable oil analysis. Likewise, the use of different subsamples accounted for the higher

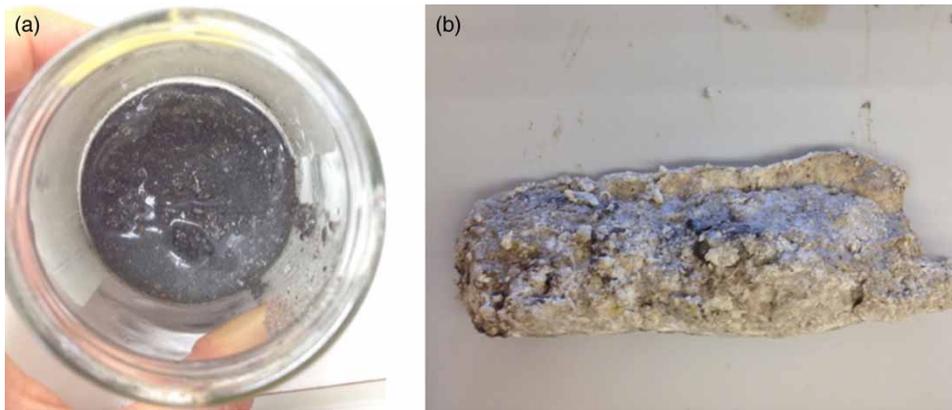


Figure 3 | FOG deposit samples collected from kitchen drains (left) and lateral house connections (right).

values for FFA identified than the total fat content measured (sample 11).

Calcium content

The calcium content of FOG deposits collected from kitchen drains and lateral house connections ranged from 2.74 to 14.9% and from 0.15 to 3.70%, respectively (Table 2). The higher calcium content of the kitchen drain deposits was consistent with their more chalk-like appearance. The calcium content of sample 1 (14.9%) was three to five times higher than the other samples from kitchen drains. As the total fat content was not reported for sample 1, this sample is not further discussed.

Table 2 | Characteristics of FOG deposits

Sample	Drain type	Bulk density (g/cm ³)	Moisture content (%)	Total fat content (%)	Calcium content (mg/kg DW)
1	K	NR	75.0	NR	149,000
2	K	1.1	82.1	15.0	32,400
3	K	1.0	84.6	22.0	54,200
4	K	1.0	90.2	9.2	27,400
5	L	1.0	54.4	110.0	9,400
6	L	1.0	52.5	88.0	1,500
7	L	0.99	77.1	66.0	37,000
8	L	1.0	60.4	56.0	17,800
9	L	NR	59.4	32.0	35,600
10	L	0.97	74.8	99.0	11,800
11	L	0.96	80.8	57.0	11,000

Total fat content is measured as the mass percentage of extractable fat in solids. NR, not reported.

Figure 4 displays the relationship between total fat and calcium content, and also contains observations of FOG deposits previously collected from separated public sewer deposits (Keener *et al.* 2008; He *et al.* 2011). The calcium levels measured in the deposits collected from PVC, PE and cast-iron pipes were relatively high. This was not expected, since several studies suggested (microbiologically induced) concrete corrosion as an important calcium source for FOG deposits (Dominic *et al.* 2013; He *et al.* 2013; Iasmin *et al.* 2014; Iasmin *et al.* 2016). Since building drainage systems do not contain concrete pipes, the calcium originates from drinking water, food waste and the human metabolism.

Also different environmental conditions, such as structural conditions, the drinking water composition or the pH levels of the wastewater, could have accounted for the differences. Iasmin *et al.* (2014) showed that pH levels affected the calcium content of FOG deposits. This is, however, considered beyond the scope of this article, since pH levels of wastewater discharged intermittently may fluctuate over time. Williams *et al.* (2012), who collected samples from

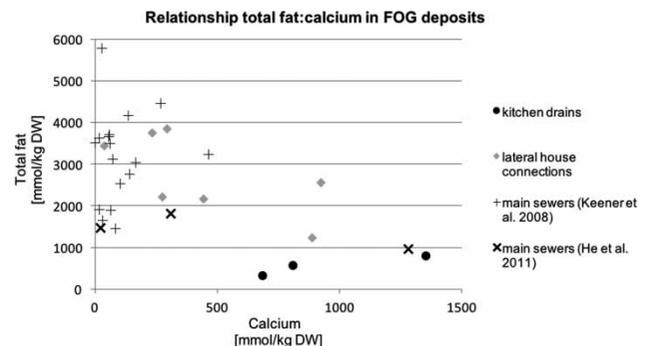


Figure 4 | Relationship between total fat and calcium content (in molecular weight, with the weighted average molecular weight of fatty acids in FOG).

main sewers in the UK, found a positive correlation between drinking water hardness and calcium levels in FOG deposits. Water hardness levels in Rotterdam and its surrounding area are around 150 mg/L CaCO₃ (Evides 2016). Since the hardness levels in the UK were higher overall, with values ranging from 140 to 300 mg/L CaCO₃ (Williams *et al.* 2012), one would expect, solely based on the water hardness levels, higher calcium levels in the UK study. Their calcium levels measured in the FOG deposits were, however, lower, and based on such data it can therefore not be concluded that drinking water hardness was the explanatory variable.

Total fat to calcium ratio

According to the reaction stoichiometry of saponification, the molar ratio FFA:calcium of calcium soaps should be 2:1. Figure 4 shows that this ratio was lower for the deposits collected from kitchen drains, and (overall) higher for the deposits collected from lateral house connections. This suggests that the FOG deposits also contained excess calcium, fatty acids and/or debris. Following the DLVO (Derjaguin, Landau, Verwey, and Overbeek) theory, counter-charged particles, e.g. positive calcium ions or slightly negative carboxylic chains of FFAs, could have been drawn into the FOG deposit matrix (He *et al.* 2011; He *et al.* 2013). The observation of fine deposits in the kitchen drain samples, the high levels of calcium and the large

fraction of the deposits that remained unidentified (Table 2) supports this hypothesis. The ratios of the lateral house connection samples were of the same order of magnitude as main sewer deposits from sanitary sewers (Keener *et al.* 2008; He *et al.* 2011).

Fatty acid composition

The recovery rates of fatty acid profiles ranged from a quarter to full recovery, and predominantly (>96%) contained long-chain fatty acids (C14–C18). Previous studies reported average recovery rates of around 90% (Keener *et al.* 2008; He *et al.* 2011). For all FOG deposits, palmitic acid (C16:0) was the most common saturated acid, and oleic acid (C18:1) and linoleic acid (C18:2) were the predominant monounsaturated and polyunsaturated acids present (Table 3). The kitchen drain samples showed a wide variety in their fatty acid profile: sample 2 predominantly contained saturated fat, while the samples 3 and 4 had a higher unsaturated fat content. Myristic acid (C14) was low for all kitchen drain samples. For the lateral house connection samples, palmitic acid predominated, as its proportion of total fat ranged from 32 to 67%. While previous studies reported average values of unsaturated fat content of more than 20% (Keener *et al.* 2008; He *et al.* 2011; Williams *et al.* 2012), six out of the seven lateral house connection samples had an unsaturated fat content lower than 4%. The proportion of myristic acid ranged from 3 to 14%.

Table 3 | Fatty acid characteristics of FOG deposits

Sample	Saturated fat		Monounsaturated fat		Polyunsaturated fat	
	Content [%]	Primary	Content [%]	Primary	Content [%]	Primary
1	NR	Palmitic	NR	Oleic	NR	Linoleic
2	38	Palmitic	4	Oleic	5	Linoleic
3	17	Palmitic	28	Oleic	17	Linoleic
4 ^a	44	Palmitic	37	Oleic	14	Linoleic
5 ^a	50 ^b	Palmitic	10 ^b	Oleic	21 ^b	Linoleic
6 ^a	64	Palmitic	1	Oleic	1	Linoleic
7	78	Palmitic	1	Oleic	1	Linoleic
8	64	Palmitic	0	Oleic	0	Linoleic
9	42	Palmitic	1	Oleic	0	Linoleic
10	47	Palmitic	1	Oleic	1	Linoleic
11	97 ^c	Palmitic	2 ^c	Oleic	2 ^c	Linoleic

Fatty acids are shown as their proportions of the total fat.

^aSamples for which the first laboratory reports contained errors in the reported FFAs. This was resolved by applying a second round of laboratory analyses.

^bFor sample 5, for which the total fat content measured was 110%, the fatty acid content was based on a total fat content of 100%.

^cFor sample 11, for which the FFA identified was greater than the total fat content measured, the fatty acid proportions were based on total FFA.

Samples 6, 8 and 10 had a relatively high myristic acid content (>8%) and also displayed other physical properties: they appeared to be more solid and were harder compared with other lateral house connection samples. However, sample 11, for which the myristic acid content was highest (14%), did not display such characteristics.

Relationship with cooking oils used

Figure 5 shows the fatty acid profiles of the FOG deposits and the cooking oils used by the households for which information about their FOG disposal was known. All deposits had fatty acid profiles with a higher saturated fat content and shorter aliphatic chains compared to the profiles of the cooking oils used. As myristic acid was also present in the deposits collected from lateral house connections, while common cooking oils hardly contain myristic acid, the results show that ageing and in-sewer transformations are relevant at the scale of building drainage systems. Williams *et al.* (2012)

also observed significantly different proportions of palmitic to oleic acid for different network locations and suggested this might be related to ageing. Keener *et al.* (2008) suggested that beta-oxidation might account for the in-sewer transformations. This is supported by several studies on anaerobic (treatment) processes that showed that during the treatment of oleic and linoleic wastewater, palmitic and myristic acids were the most important intermediate long-chain fatty acids produced (Lalman & Bagley 2000), and precipitates of calcium and palmitic acid were formed (Pereira *et al.* 2001; Matsui *et al.* 2005; Dereli 2015).

As the FOG deposits collected from lateral house connections 6 and 9 mainly contained saturated fats, no link between fatty acid profiles of these FOG deposits and disposal patterns could be identified. Only for samples 3, 4 and 5 was a relationship observed between the fatty acid profiles of the deposits and the cooking oils. For samples 4 and 5, the fatty acid composition of the cooking oils and the deposits were comparable.

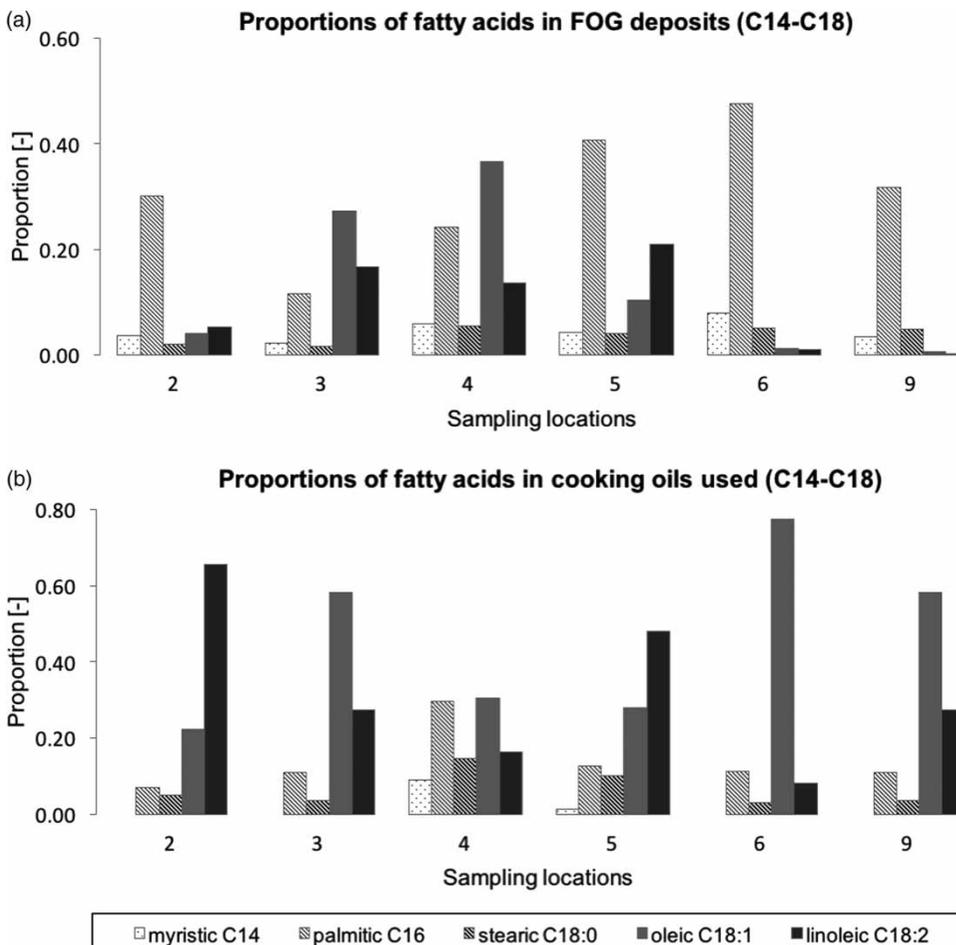


Figure 5 | Fatty acid profiles of FOG deposits and cooking oils used, reported as their proportions of total fat.

FTIR spectrometry

The FTIR spectra of the deposits were analyzed for the four characteristic infrared spectral band regions identified by Poulenat *et al.* (2003). Each region is attributable to a particular bond or functional group. For sample 2, no FTIR analysis was performed as there was no sample material left. The spectra of samples 7 and 9 showed negative absorption values. For these samples, it is thought that the crystal might not have been properly cleaned when the background spectra were collected. Despite their negative absorption values, relative absorption intensities displayed distinctive absorption bands and their wavenumbers were comparable to those of other lateral house connections; their values were therefore reported in this study.

Figure 6 shows the FTIR spectrum of sample 4 and displays the four characteristic regions. All spectra displayed absorption bands in the characteristic band regions, and hence it is thought that FOG deposits in building drainage systems are the result of saponification. Similar to previous studies (He *et al.* 2011; Shin *et al.* 2015), some differences in vibration bands (e.g. around 686 cm^{-1} instead of 665 cm^{-1}

and additional intensity absorption bands at around $1,700\text{ cm}^{-1}$) were observed compared with the characteristic bands (Poulenat *et al.* 2003). He *et al.* (2011) suggested that these differences could be attributed to other materials, such as FFAs, accumulating in the FOG deposits.

Additionally, in the spectra of lateral house connection deposits, interesting bands at around 938 cm^{-1} were observed. In the spectra of laboratory-based deposits (He *et al.* 2013) and pilot-scale system deposits (Dominic *et al.* 2013), these bands have been observed around 970 and 930 cm^{-1} and were thought to be attributed to glycerol. Such bands, however, have not previously been observed in the spectra of deposits collected from main sewers, and this suggests different formation processes in lateral house connections compared with both main sewers and kitchen drains. Differences in flow conditions may account for this: there are only pulses of water and flows have a shallow depth in building drainage systems. In between such pulses, deposits settle until the arrival of the next pulse of water (Ashley *et al.* 2004), allowing a lot of time for transformation processes to occur within the FOG deposits. In addition, Iasmin *et al.* (2014) found cooking fats that solidified above

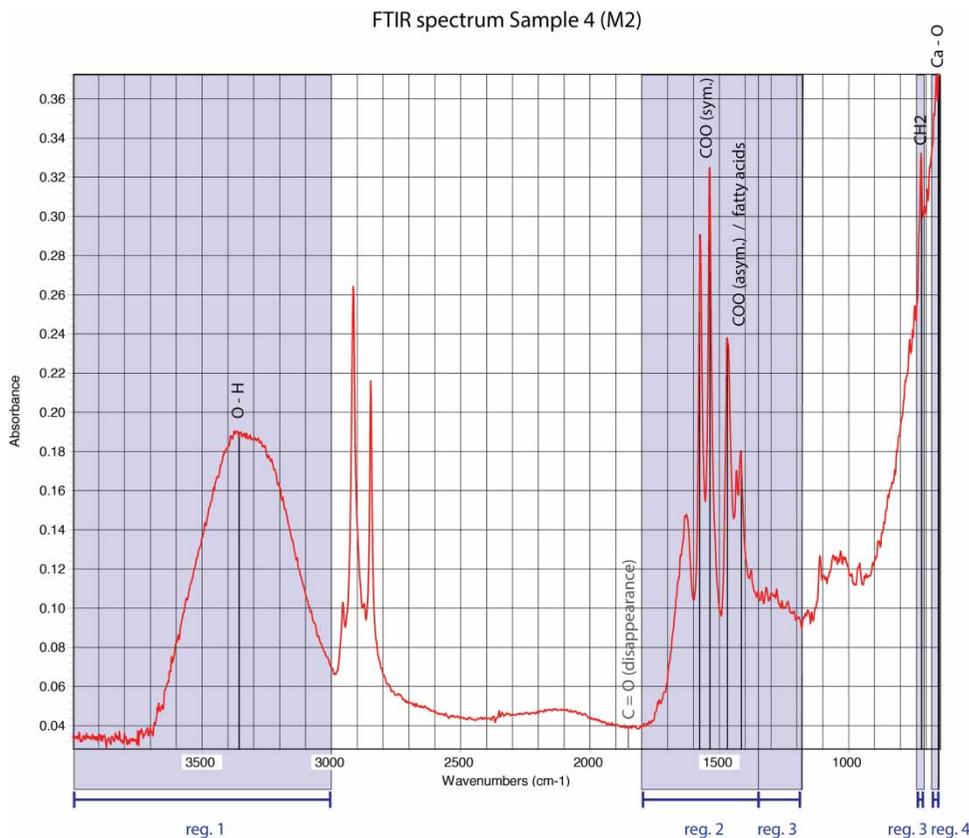


Figure 6 | FTIR spectrum of sample 4.

the solid soap matrix when they cooled down in sewer systems. After this solidification, oil hydrolysis can take place within the FOG deposits. As such, transformation processes in FOG deposits are associated with a range of relevant timescales, ranging from the highly variable intermittent discharges, fast cooling and, once captured in the deposits, potentially long solid retention times. Moreover, the service engineers indicated that most of the lateral house connections with FOG deposits were in a bad condition, confirming the findings of Dirksen *et al.* (2012) that local sewer conditions impact the FOG accumulation process. Further research is needed to examine the relevance of the influencing factors.

Data limitations

The service engineers only collected a sample when FOG was identified as the failure mechanism. Thus, FOG blockages with less typical FOG-appearance may have been excluded from the analysis. Additionally, samples were only collected when the deposits were close to the IOs or if they were jetted towards the IOs during clearing. Besides, for this study, only cooking oils and fats were considered, thereby neglecting possible other sources of oils and fats. Despite these limitations, the samples are thought to be representative of sites with severe FOG accumulation.

CONCLUSION

The outcomes of this study demonstrate that the FOG deposits collected from building drainage systems were, similar to FOG deposits from public sewers, metallic salts of fatty acids. They are the result of the saponification reaction between calcium and FFAs. Despite this similarity, the deposits collected from different locations within the sewer network (kitchen drains, lateral house connections and public sewers) display a great variation in their appearance and chemical composition. It is thought that in-sewer transformations occur or different formation mechanisms take place. Since building drainage systems are not made of concrete, this study demonstrates that concrete is not essential for the FOG deposit formation process in sewer systems. Furthermore, the FTIR analysis showed that glycerol accumulated in the lateral house connection deposits, suggesting that hydrolysis has taken place close to or within the FOG deposit matrix. This might be the result of intermittent flow patterns in building drainage systems. Three out of the 11 households showed a link between the cooking fats and oils used and the FOG deposits collected,

as their fatty acid profiles displayed similarities. For future research, an increase in the sample size is recommended (although organizing this is complicated) along with more precise information on disposal patterns; i.e. cooking and FOG disposal habits, and general wastewater characteristics. In addition, information on the condition of the building drainage systems should be collected.

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