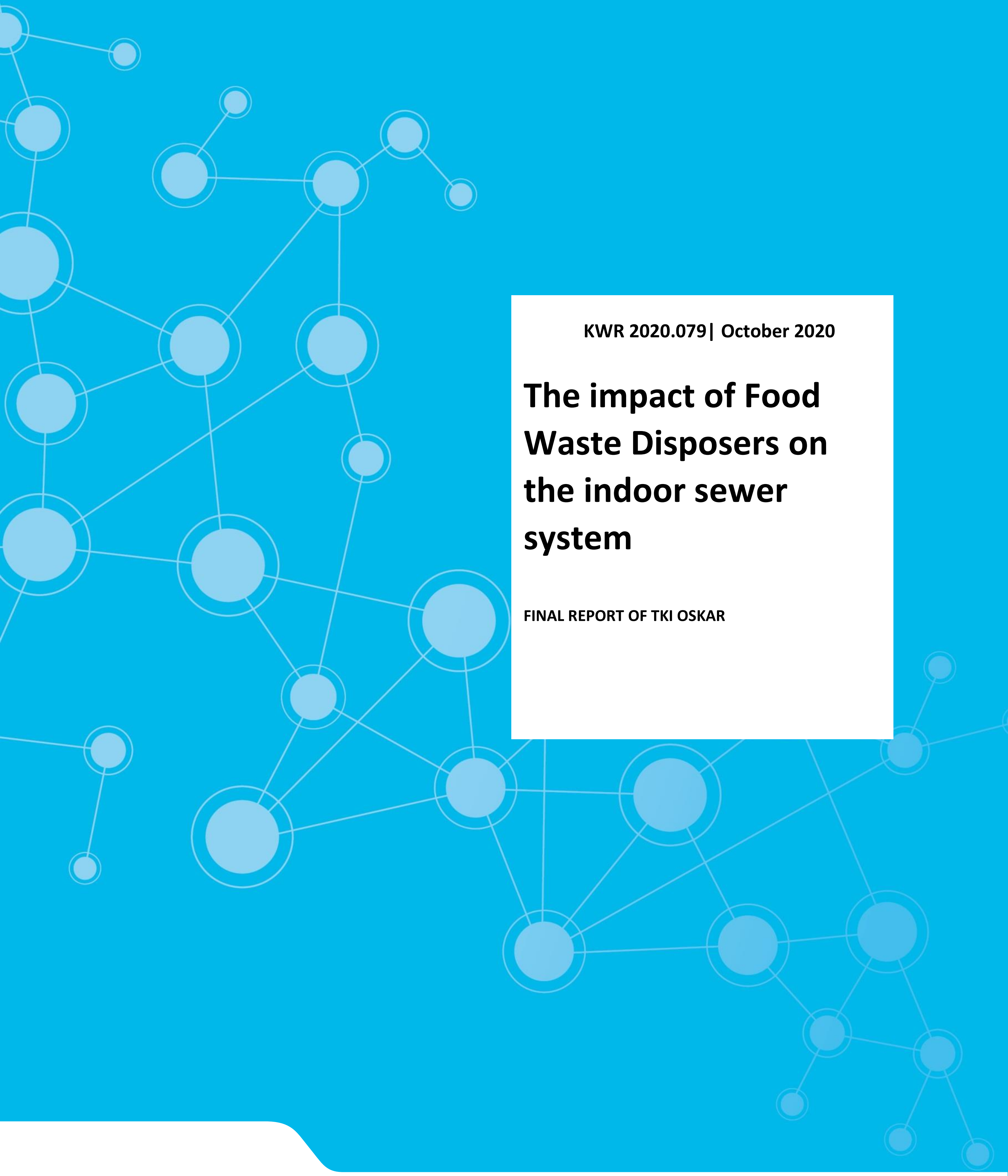

KWR 2020.079| October 2020

The impact of Food Waste Disposers on the indoor sewer system

FINAL REPORT OF TKI OSKAR

Bridging Science to Practice

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Report

The impact of Food Waste Disposers on the indoor sewer system

KWR 2020.079 | October 2020

Project number
402685

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Sent to
Project group

Keywords
Food waste, indoor sewer, grinder, transport, pipe

Year of publishing
2020

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Summary

The impact of the use of food waste disposers (FWD) on the municipal sewer system and in wastewater treatment plants has been studied worldwide. However, the effects on indoor sewer have remained overlooked with very few studies available. There is still very limited knowledge of practical experiences with food remnants in the Netherlands. This has resulted into that the application of FWDs is prohibited, based on the assumption that they will cause problems affecting the sewer system infrastructure. There are no practical strong research results that confirm or contradict the use of FWDs in the Netherlands, and especially, there is not any study focusing on the indoor sewer effects. This TKI study aimed to find out whether the use of a food waste disposer in high-rise buildings households has any negative effects on the indoor sewer. The experiments and analyses carried out involved looking at conventional indoor sewer configurations that have been installed following the applicable guidelines (NEN 3215+C1+A1), both at the horizontal and vertical sections. Key wastewater and indoor sewer parameters were evaluated when combined with a food waste disposer. Furthermore, time-series analysis to describe the transport of the wastewater was assessed. In this case, the behavior of the water and ground food inside the sewer pipe was assessed taking into account 17 different food-types.

Results showed that mainly the COD added by the ground food to the sewer is particulate and could be separated in the primary sedimentation process. An increase of 1.3% in water consumption in the total average water use in the Netherlands per person was estimated by using a FWD. It was found that the slope of the horizontal pipe has the greatest influence on the quantity of food remnants in the indoor sewer pipe. No accumulation of ground food waste was observed in the vertical pipe or the bottom horizontal pipe. In fact, the inclusion of the vertical pipe demonstrated to have a positive effect on the sedimentation of food waste in the sewer pipe, as it increases the velocity of arrival.

The time-series experiments demonstrated that for some food types there is consistency in the behavior of flow time series at the outlet point of measurement, while for other food types such as bones, lard (fat), and potato peels there is great variability in the results depending on the combined effect of the use of food grinder. In all cases reviewed the only case to pose the possibility of minor blockage is the combination of fat with the multiple-elbows configuration suggested in the NEN3215. Additionally, the experiments have demonstrated that a horizontal pipe slope of 1:50 guarantees the total flushing of food waste from the pipe. Given that this configuration can deviate from the typically installed configuration of 1:200, experiments were held for 2 food types (Eggs, and a food mix) with this particular slope (1:200) demonstrating that there was no blockage in both pipes.

Our laboratory experiments with horizontal and vertical pipes in the TKI OSKAR project showed that in principle, there is no obstacle for using FWDs, but in practice and long-term, it needs to be confirmed with a pilot study. Many Dutch local authorities are becoming increasingly interested in exploring a variety of ways to dispose of food waste in high-rise buildings. However, the guidance available to carry out a pilot study is currently limited. The purpose of conducting a pilot study is to examine the feasibility of an approach that is intended to be used on a larger-scale. Research directions and settings of pilot studies on food waste disposers are summarized, with emphasis on indoor sewer, which provides insight for subsequent pilot research carried out in the Netherlands by the TKI-OSKAR project partners.

Contents

1 Introduction

In the Netherlands organic waste is collected from the curb. However, in high-rise buildings, organic waste typically is not collected separately but combined with general waste. As circularity becomes more and more important for the Dutch municipalities, there is an interest in ways to also collect organic waste from high-rise buildings. A FWD, either on (via indoor and city sewer) or off (collected after indoor sewer) grid, is one way. The TKI-OSKAR study focused on the options for current systems. This report describes the technical aspect whereas van den Brand and van Aalderen (2020) describes the life cycle assessment and legal related issues of the application of FWD.

1.1 Background

In the current decade of sustainability and circular economy, considerable attention is being paid to recovering resources such as water, energy, and raw materials from municipal wastewater streams (Kehrein et al. 2020). This includes raw materials, such as phosphate, metals, and cellulose, and also energy carriers, such as biogas or ammonia. For all these raw materials and energy sources, the concentration of the municipal wastewater determines the recovery efficiency of downstream processes (Roest et al. 2017). One of the options in new or decentralized sanitation systems to facilitate resource recovery is by separating black water and greywater to avoid dilution, reducing the total water content and increasing the organics and nutrients concentration. The so-called "new water chain" strives food residues come together via food waste disposers (FWD) in the sewer together with black water. The resulted concentrated wastewater is then digested at the sewage treatment plant, producing biogas and obtaining a concentrated nutrients stream in the digestate. Separate collection of kitchen waste is particularly costly because of the transport. Therefore, combined transport with domestic toilet wastewater to increase biogas production can save costs and might have a more positive environmental impact (Maalouf and El-Fadel 2017).

The feasibility of FWDs application in many countries is still being debated due to the significant concerns over their impact on the wastewater treatment facilities (Zan et al. 2018). In the Netherlands discharging through a food waste disposer is currently forbidden according to the currently applicable "Environmental Management Activities Decree" which states that wastewater containing waste that has been cut by grinding equipment may not be discharged (see Article 3.131, paragraph 3, section 3.6.1). The reasons for this prohibition described in the law lies mainly in the prevention of blockages in the sewer or overloading the sewage treatment plants.
Previous studies have focused on the impact of the use of food waste disposers on the municipal sewer system (Battistoni et al. 2007a, Galil and Shpiner 2001, Koning 2002, Mattsson et al. 2014, Thota Radhakrishnan et al. 2018), and in wastewater treatment plants (Bolzonella et al. 2003b, Evans et al. 2010, Galil and Yaacov 2001b, Jeong et al. 2017, Moñino et al. 2017, Zan et al. 2018), among others. However, the effects on indoor sewers have remained underexposed with very few studies worldwide (Minami and Otsuka 2005, 2006) focused on the impact of ground food waste on the indoor sewer. Therefore, it is critical to investigate whether the commonly implemented indoor sewer systems can handle the removal of kitchen waste via a grinder and whether there are any negative effects such as blockages or deterioration of pipe materials.

1.2 Problem statement

There is still very limited knowledge of practical experiences with food remnants in the Netherlands. This has resulted into that the application of FWDs is prohibited, based on the assumption that they will cause problems affecting the sewer system infrastructure. It has been shown that several municipalities suffer from a low percentage of organic waste in high-rise buildings and also that the influent of municipal wastewater treatment plants is sometimes very diluted (Berg and Telkamp 2015). The application of FWDs might be beneficial to both of the latter issues. However, there are still no practical strong research results that confirm or contradict the use of FWDs in the Netherlands, and especially, there is not any study yet focusing on the indoor sewer effects.

1.3 Research questions

From the problem stated above the main question of this study is: What is the effect of applying a food waste disposer (FWD) on indoor sewer configurations from high-rise buildings?

To answer the main question, the following specific questions have been formulated:

a How does the wastewater characteristics change when a FWD is used with various food types?
  - What is the effect of adding ground organic kitchen waste to the wastewater in terms of water quality (COD, N, P, solids)?
  - What is the impact of a FWD on water use?

b What is the effect of a FWD and the configuration of indoor sewer on the transport of the wastewater?
  - Which parameters of the indoor sewer system, which has been installed according to the NEN 3215 standard (in high-rise buildings), affects the transport of the food remnants out of the system?
  - What is the effect of a prolonged interruption of use, for example, due to holidays, on the pipe system?
  - Is it possible to determine the effect of the vertical pipes in the downstream flow behavior?
  - Are the Dutch design standards for diameters (capacity) of indoor sewer pipes able to include the addition of food waste?

1.4 Objective

The objective of the research is to find out whether the use of a food waste disposer in high-rise buildings households has any negative effects on the indoor sewer. This involves looking at conventional indoor sewer configurations that have been installed in accordance with the applicable guidelines (NEN 3215+C1+A1), and any possible negative effect.

The outcome of this research will contribute to future pilot studies in high-rise buildings where the results are expected to encourage the parties involved to execute more practical research with or without necessary adjustments to the indoor sewer of the location to be tested. Even though the main emphasis of the study is on the technical aspects involved in transport through the indoor sewer system, also others aspects such life cycle assessment of applying FWDs and the legislative aspects that are needed to be knowledgeable of are also explored and reported in a separate report (van den Brand and van Aalderen 2020).

2 Materials and methods

2.1 Food waste disposer couple to indoor sewer – setup

All the experiments were carried out in an experimental setup built according to NEN3215 + C1 norm (2014), with the most extreme dimensions from the standard being used for the design. The most extreme values mean a reduced diameter for the siphon with 34 mm (40 mm outside diameter) connected to a food waste kitchen grinder or food waste disposer (FWD) (InSinkerator, Evolution Excel), the wall pipe, and the floor pipe with 44 mm inside pipe (50 mm outside diameter). A length of 1 meter of floor pipe was chosen based on the average installation height of a sink in the Netherlands which is 90 cm. A further 30 cm of the floor was calculated and the depth of the sink plus the FWD was subtracted (20 cm). In order to answer the research subquestion a, the collector pipe with a length of 5.0 m, a slope of 1:150, and without bends was connected to the floor pipe. A weighted collection bin was attached to the end of the pipe, from which samples are taken to determine their chemical characteristics. In addition, this scale was used to determine how much weight remains in the pipe per type of food as well as the cumulative weight in the outlet. This was carried out by synchronizing the scale (BR16, Baxtran) with the inflow time of water flushing. In that way, the total outflow time series was obtained. The time resolution was 4 Hz with a weight accuracy of up to 0.5 g. The difference between the input flow added to the food waste and the recovered ground food waste indicates the amount of food waste that is remaining in the pipe.
The schematic representation of the experimental setup is presented in Figure 1.

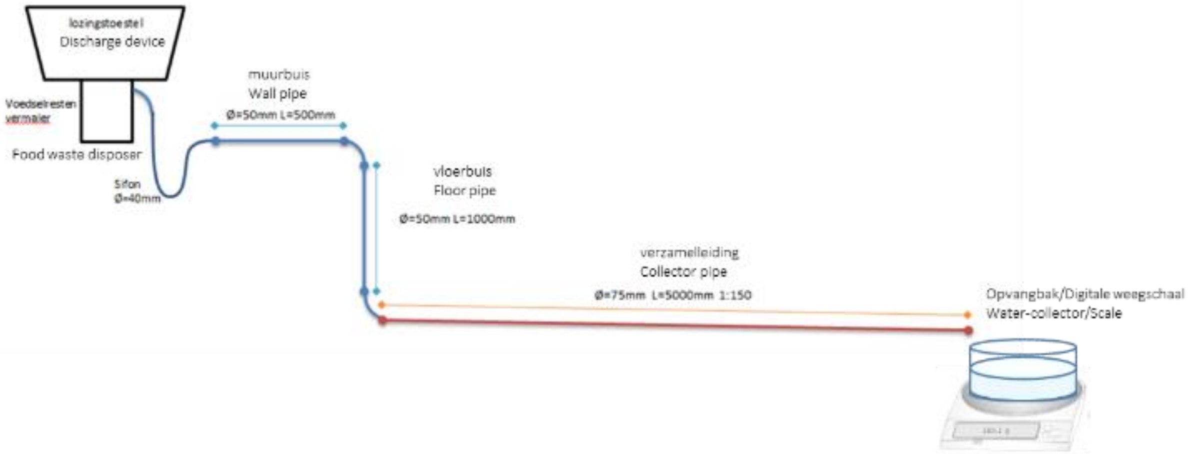


Figure 1. Schematic representation of the experimental setup.

2.2 Food waste characterization and selection

The wastewater flow and composition changes after being flushed through a food waste disposer was investigated with various food types and mixes of food. Seventeen types of food were selected on the basis of what the average Dutch person eats as presented in Table 1. Each of the experiments were carried out in triplicate, for a total of 51.

These food types (from Albert Heijn) were cooked and weighed in advance to about 250 g and then placed in the grinding chamber of the FWD (Insinkerator). This amount is based on figures from the Netherlands Environmental Assessment Agency, which states that 40 kg of solid food is thrown away per person per year, in combination with an average household size of 2.15 people per household in 2019 (CBS 2019). Three mixtures of food types (A, B, and C) containing vegetables, carbohydrates, meat/fish, and fat were also tested, thus giving a more realistic meal food waste. After the food was put into the FWD, the grinder was synchronized with the water flow for the rinsing to register the exact time between the start and the end of a rinse. A time-series analysis was made as input for further analyzes and modeling of the indoor sewer.

Table 1 Food waste type and mix of food waste

Food types		Mix food composition			
1. Carrot	8. Nuts	15. Mix A: 100 g rice	100 g broccoli	25 g fat/oil	25 g chicken
2. Broccoli	9. Potatoes	16. Mix B: 100 g potatoes	100 g carrots	25 g fat/oil	25 g chicken
3. Fruit (orange peels)	10. Pasta	17. Mix C: 100 g pasta	100 g spinach	25 g fat/oil	25 g fish
4. Rice	11. Potatoes peels				
5. Fish	12. Boiled Eggs				
6. Meat	13. Fat/Oil				
7. Bones	14. Coffee				

2.3 Wastewater characterization

The chemical oxygen demand (COD), ammonium nitrogen content (NH_4-N), phosphate (P-PO_4), total suspended solids (TSS), and dry-solids of the food waste were determined using *Hach Lange kits* and following the standard methods for the examination of water and wastewater(APHA 1998). After the food was ground and all the water went out of the pipe after flushing, a representative 60 ml sample was collected immediately to perform the chemical analysis (Figure 2). Visual observations on the position in the horizontal pipe where the residue remained in the pipe were performed.

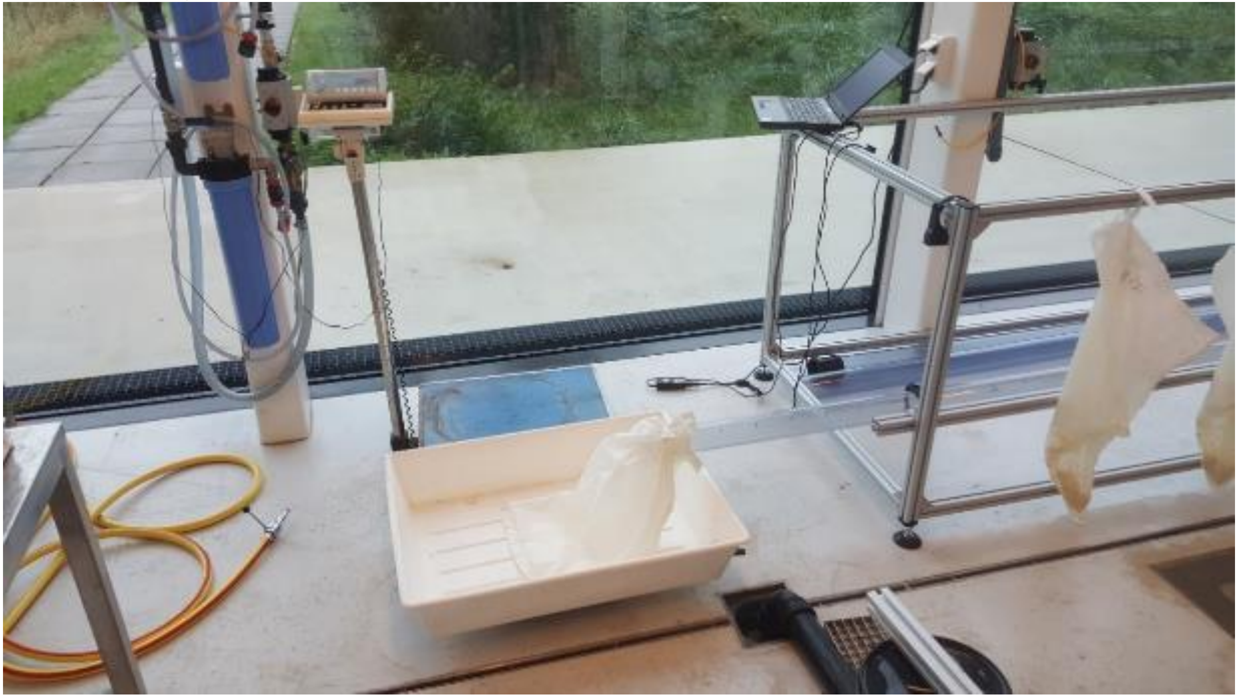


Figure 2. Collecting bag at the end of pipe, balance, and digital logger for weight time series. The balance is linked to a data logger that registers the weight variations at 4 Hz. The time is recorded simultaneously with the flushing at the grinder to guarantee the same start and end time.

2.4 Assessment of different indoor sewer configurations

Figure 3 describes the indoor sewer system sections of a household which is similar for high-rise buildings and houses. There is very little known of the possible impacts in the indoor sewer system when using a food waste grinder. The experiments focus on the horizontal pipes from the kitchen appliance which is the one with the smaller diameter and where more possible issues can arise. From the rest of the indoor sewer system, only a part of the soil stack pipe (vertical pipe) is considered (see section 5.3), and the underground manifold and the connection to the sewage are not taken into account. A larger diameter is used for these pipes and water regularly flows through it, which comes from other appliances such as toilets.

The main difference between regular sewers and high-rise sewers is the presence of a downpipe. The soil stack is a vertical pipe that runs from the top apartment to the collection pipe in the basement. This pipe is often made of PVC or metal and is primary or secondary ventilated. In primary ventilation, the vertical pipe runs up to the roof and can draw in the necessary air to keep the pressure in the pipe equal (Figure 4). Our experiments focus on the appliance pipe and the collecting pipe of the indoor sewer system. As shown in Figure 1, this consists of the discharge appliance, the siphon, the wall pipe, the floor pipe, and the collecting pipe.

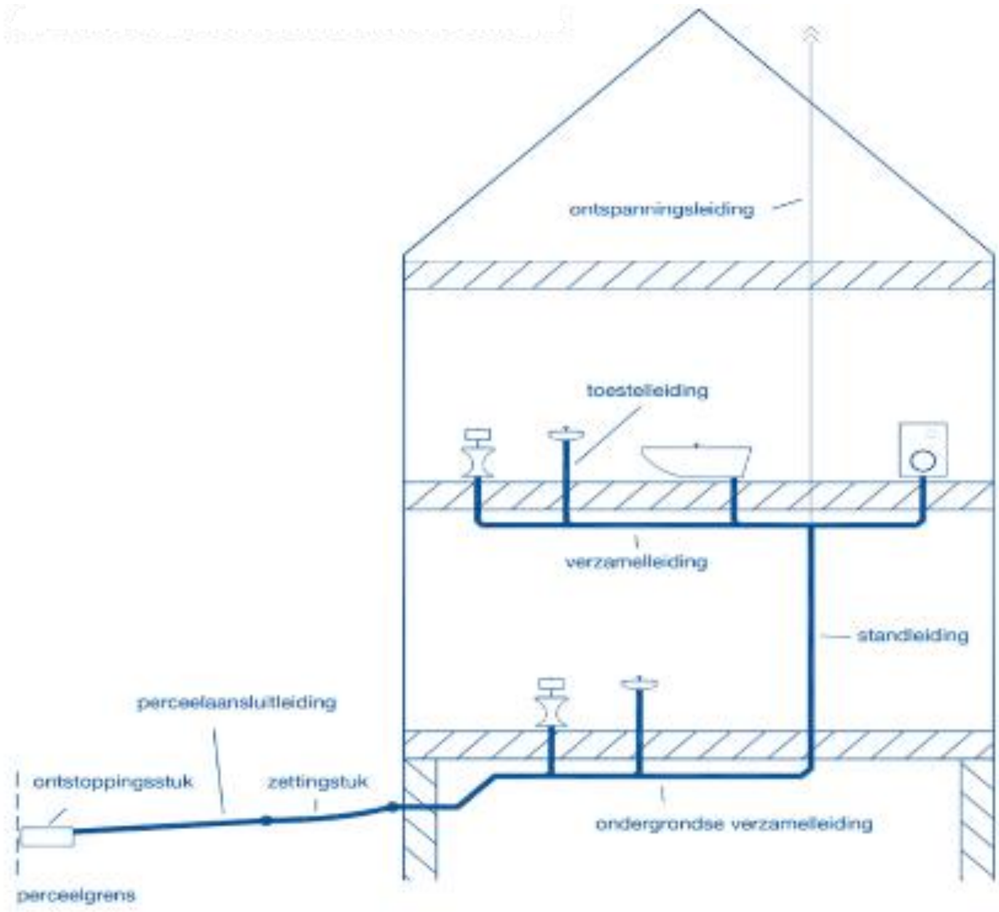


Figure 3 Components of the indoor sewer system (Wavin 2017)

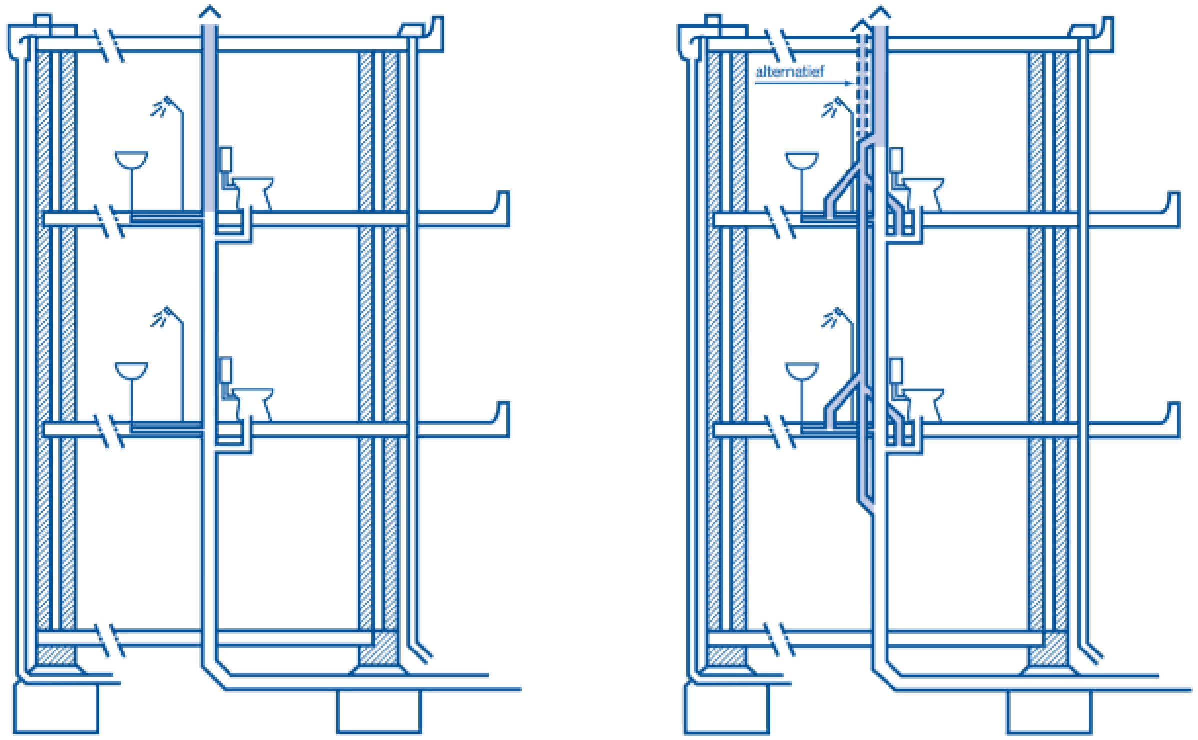


Figure 4 Primary ventilation (left) and secondary ventilation (right) of the indoor sewer. Secondary ventilation makes use of a separated pipe, which is connected to the manifolds of the apartments and maintained a balanced pressure in the system (Wavin 2017).

A fractional factorial design of experiments experimental was formulated by using Minitab (Minitab, 2018) to address the effect of adding ground organic kitchen waste on the transport of the wastewater in the most systematic way. A fractional factorial design consists of a carefully selected subset from the full factorial design providing a similar outcome while using only a fraction of effort and resources. Five continuous variables (Diameter, length, slope, flushing flow, and the number of bends) and one categorical variable (food type) with two levels were used for the design. Therefore, based on the results from section 2.2, two food types were selected (Boiled Eggs and mix C), and a minimum and maximum value had been selected based on the other variables for assessing different indoor sewer configurations. Subsequently, by applying the fractional factorial design, the number of experiments was reduced from 2300 experiments to 64, taking into account replicates to assure reproducibility. The matrix containing the fractional factorial design applied is shown in Appendix I. The effects of the critical parameters were evaluated (based on the NEN 3215+C1 norm), all of them with two-level values (Table 2). A statistical regression analysis was performed to come up with simple empirical models that describe to a certain extent the amount of food (eggs and mix C) that remained in the horizontal pipe. Furthermore, the impact of the most relevant sewer configuration variables was quantified.

Table 2 Possible values for the sewer pipe installation. Diameter, length, slope and number of bends of the collector pipe.

Variable	Units	Value 1	Value 2
Diameter	mm	63	75
Length	m	5.0	8.0
Slope/gradient	m/m	1:50	1:200
Number of Bends in the pipe	-	Hook and vertical (1 bend)	Hook and vertical modified (3 bends)
Food type	-	Eggs	Mix C
Water flow	L/s	0.1	0.3*

* With the characteristics of the current pipe (normally used in households), a maximum of 0.3 L/s could be achieved.

The installation presented in Figure 1, Figure 5 was rearranged to make use of different configurations (see Figure 7.). The pipe material was kept as PVC (transparent) to be able to verify the internal behavior within the pipe. In terms of the setup, the length, diameter, slope, and pipe fittings configuration were changed. The total number of lay-outs were 16 as presented in Table 2 (see Figure 8).
To guarantee an adjustable gradient/slope, the sewer pipeline was connected to the frame with plastic bracelets (see Figure 6.). Such bracelets can be adjusted for any pipe and guarantee compliance with the required values of Table 2.

The response of these experiments was based on the weight of the remaining food in the horizontal pipe (collector), which was quantified with a recovery flush (only the food remaining on the floor and collector pipe) of 10 liters (weighted) of water. This flush was done through an installed funnel (See Figure 6.C). The water was stored in the collection bin on top of the digital scale. The difference between the water and the weighted water with food remnants corresponds to the weight of the remaining food waste inside the pipe.

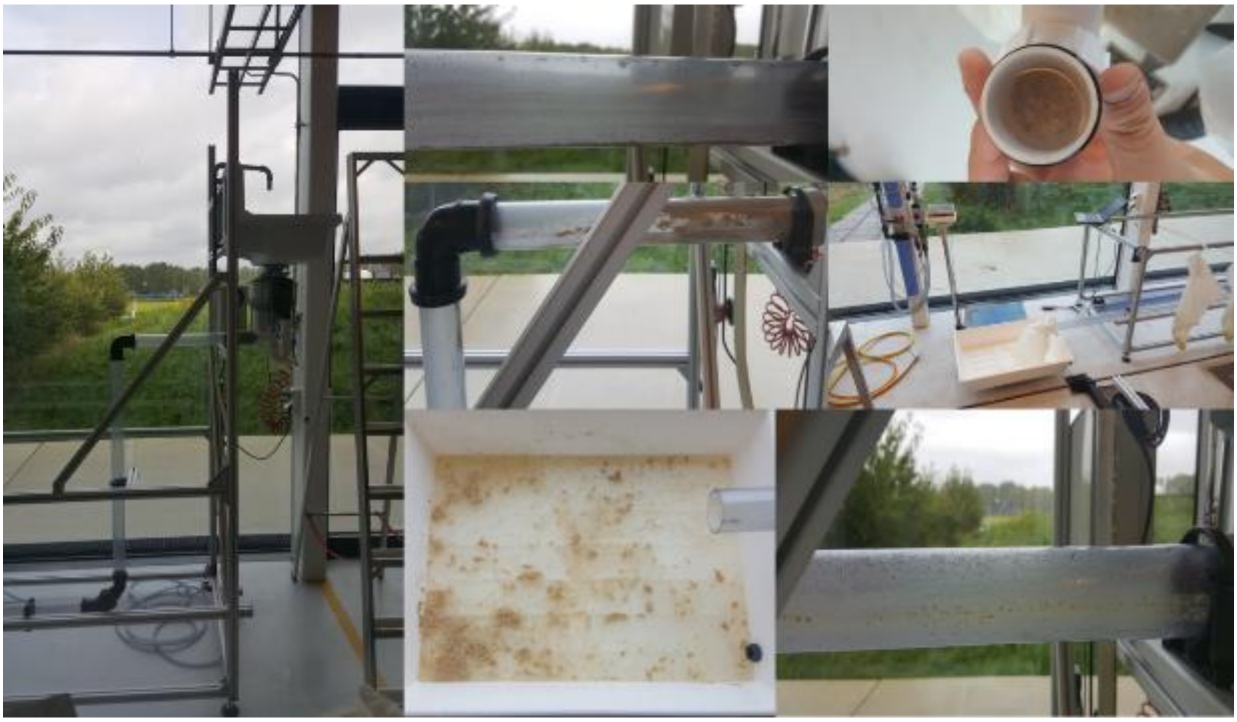


Figure 5. Experimental setup. A typical configuration of a kitchen sink and sewer water pipelines below the sink. The laboratory setup includes a collector at the end of the pipe and sample of residue, which may accumulate in the pipeline.

2.5 Three-weeks collector pipe waterlessness assessment (holiday event)

Food waste (Mix C) was ground in order to simulate the behavior of the indoor sewer during a summer holiday when residents are away from the household, and there are stagnant food remnants during a few weeks without flushing. This food waste was 10 times consecutively flushed through the grinder with a slope of 1:100. Afterward, a three-week waiting time was given to the indoor sewer pipe with the food waste in it. The collector pipe (5.0 m) was sealed airtight, packed in agricultural plastic (UV-protected), and was placed under a constant room temperature (18 °C).

Figure 6. Bracelet couplings on the sewer pipe, which guarantee the correct arrangement of pipe slope along. A. Detail of the bracelets can be set up to a different heights. B. Frontal view of the pipe with 5.0 m length, where a total of 8 bracelets have been placed. C. Indication of the place where the funnel was installed for the recovery flush.

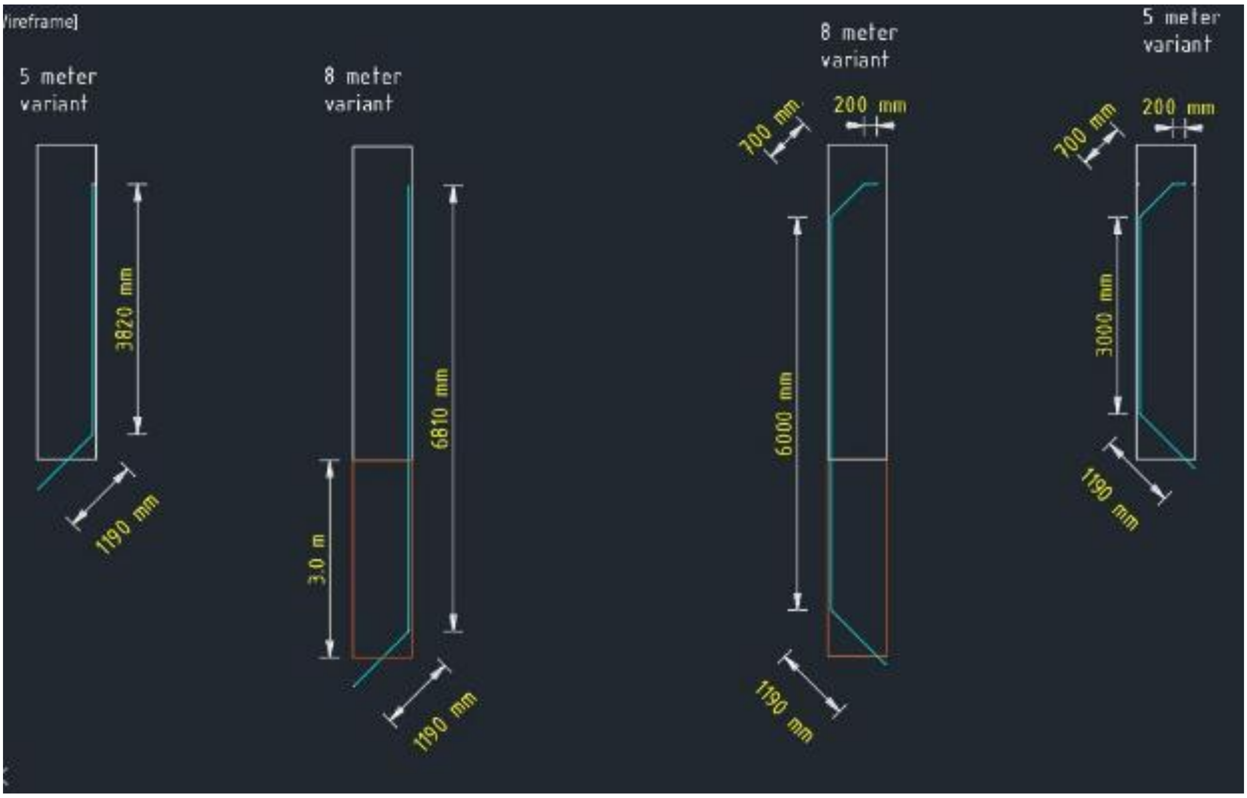


Figure 7. Pipe configurations chosen of lengths 5m and 8m, with 1 and 3 bends (after discussion with Will Scheffer, TVVL).


A.
B.
C.
D.

Figure 8 Different lay-out of the pipe configurations. A. 5 meter, 3 bends B. 5 meter, 1 bend C. 8 m, 3 bends D. 8 m , 1 bend

Subsequently, after the 3 weeks, the tube was placed back into the setup. Measurements of hydrogen sulfide (H_2S), oxygen (O_2), and methane CH_4 (by Low Explosion Level) were performed using a gas meter (Honeywell BW, Gas Microclip XL) before unsealing the pipe.

Food was ground and flushed to observe whether any disturbance in the transport of food remnants occurs in the pipe. A total of six rinses were carried out with water to look at the remaining material in the pipe and any signals of material attached to the pipe. Finally, a recovery flush was made to leave the tube completely clean. This was carried out by filling the sink, and by switching on the FWD once the sink plug is pulled out. As a result, the water was forcefully flushed through the set-up and thus took almost all the residuals out off the pipe.

2.6 Assessment of remained food-waste in the indoor sewer including the vertical pipe (stack)

Similarly as evaluated with only the horizontal pipe, an indoor-sewer configuration (5 m length, 75 mm diameter, without bends) was implemented with a two-fold objective. First to assess whether there are any food remnants in the vertical and horizontal pipe (after the vertical pipe), and second to evaluate the effect of the vertical pipe from the point of view of hydrodynamics as explained in chapter 5. In this case, the scale is placed at the end of the horizontal pipe (1.3 m) after the vertical pipe (stack) (see Figure 9). Such experiments were also carried out for the selected food types (Eggs, Mix C) but taking into account three different common horizontal pipe slopes (1:50, 1:100 and 1:200), and flow rates of 0.1 and 0.3 L/s. All experiments with slopes 1:50 and 1:100 were performed in triplicate, and with 1:200 in duplicates, for a total of 32 runs (see Table 3).

Figure 9 Indoor sewer configuration including 5 m horizontal collector pipe with 75 mm, vertical pipe (stack) of 2.4 m with diameter 75 mm, and horizontal bottom pipe of 1.3 m, 75 mm. Horizontal collector pipe Slope (1:50, 1:100, 1:200) and water flow rate (0.1 L/s, 0.3 L/s) varied according to the experiment carried out.

Table 3 Experiments carried out with the vertical pipe (stack)

Eggs		Mix C	
Flow	Slope	Flow	Slope
0,1	100	0,1	100
0,1	50	0,1	50
0,3	100	0,3	100
0,1	100	0,1	100
0,3	100	0,3	100
0,1	50	0,1	50
0,1	50	0,1	50
0,3	50	0,3	50
0,1	100	0,1	100
0,3	100	0,3	100
0,3	50	0,3	50
0,3	50	0,3	50
0,1	200	0,1	200
0,3	200	0,3	200
0,1	200	0,1	200
0,3	200	0,3	200

3 Results and discussion

3.1 Food wastewater characterization

In order to get insight in the composition of the wastewater produced by the food waste disposer a characterization was made based on the total suspended solids (TSS), total chemical oxygen demand (COD), dissolved COD, Phosphate and Nitrogen. These main parameters were chosen because discussions on the prohibition of the food waste disposers in the Netherlands has been around them (Koning 2002).

3.1.1 Total suspended solids

The TSS was calculated based on the dry weight (105 °C) of the filtered ground food wastewater. The concentration of TSS varied significantly depending on the food types and their apparent solubility after being ground. For example, a cooked potato turned into very small semi-solid particles whereas peanuts remained relatively in their solid shape. Other food types such as broccoli (7.3 gTSS·L^{-1}) and fruits (3.5 gTSS·L^{-1}) contained a high amount of water and flow through the FWD smoothly. The average TSS concentration found was about 24±24 gTSS·L^{-1} from all the 17 food types. The maximum and minimum were respectively peanuts (105.8 gTSS·L^{-1}) and fruit (3.5 gTSS·L^{-1}).

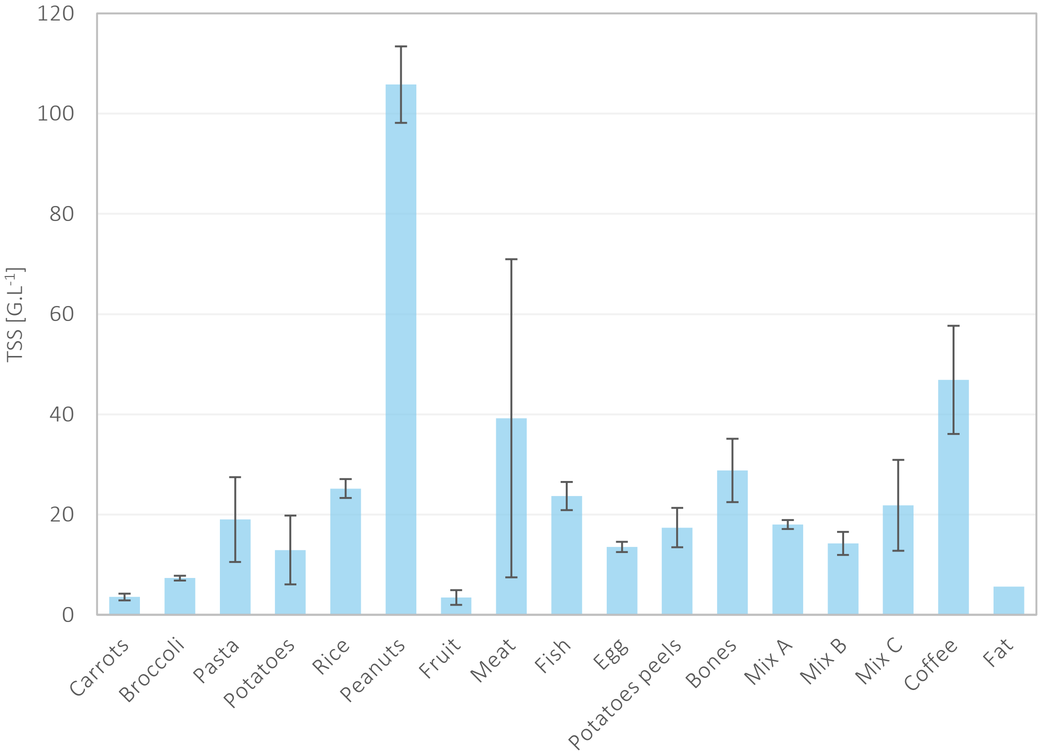


Figure 10 Total suspended solids in the wastewater of different ground food waste.

Berg et al. (2018) reported that a dilution in concentration can already occur in the indoor sewer when combining the ground food waste with water from dishwasher, shower, sink, or toilet. Their study reported a difference equivalent to 15.7 g TSS.person^{-1}.day^{-1} of suspended solids when comparing the wastewater with and without food waste disposer. When taking into account the average suspended solids found in our experiments, a value of about 11 g TSS.person^{-1}.day^{-1} was calculated due to the ground food waste.

3.1.2 Total and soluble chemical oxygen demand

The total COD concentration of the food types evaluated is shown in Figure 11. Food types such as nuts (106 gCOD.L^{-1}) and fat (103 gCOD.L^{-1}) exhibited a very high COD value of more than 100 gCOD.L^{-1}. The COD values of the other food types were between 10 and 30 gCOD.L^{-1}. Fish (41 gCOD.L^{-1}), which was fried in butter, and meat (51 gCOD.L^{-1}), which contains animal fats also presented a high COD value. In comparison with the other types of food, rice exhibited a large standard deviation with a value of 29 gCOD.L^{-1}± 13 gCOD.L^{-1} mainly due to the differences in particulate COD from the triplicate samples. The more homogeneous the sample and the smaller the particles, the more stable the measurement of COD.

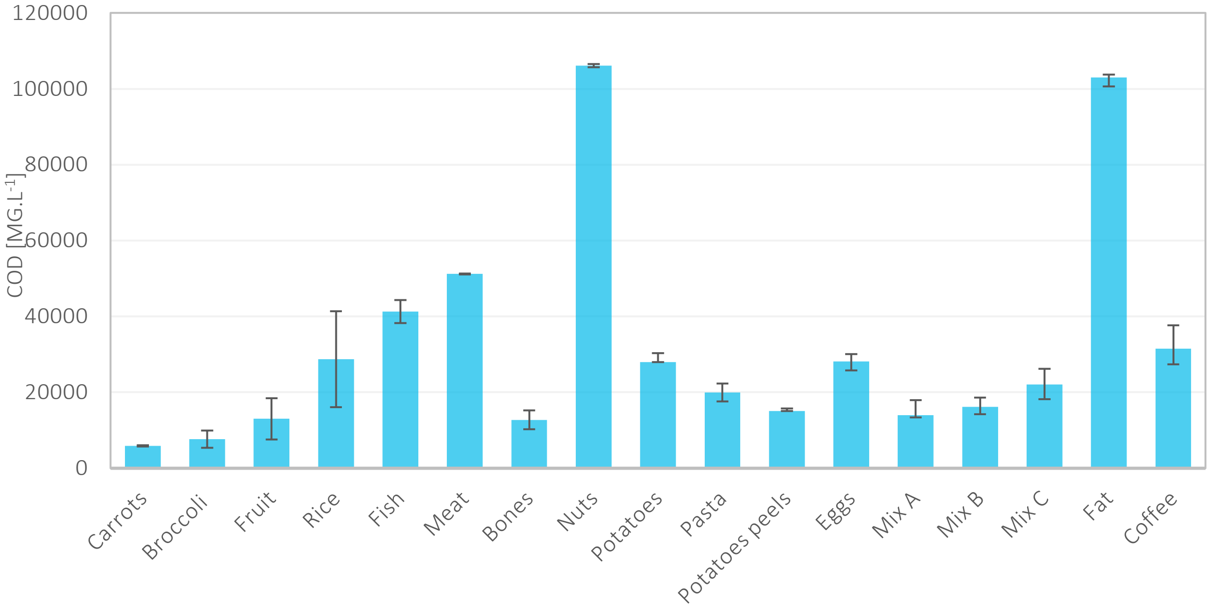


Figure 11 Total COD concentration in the wastewater of different ground food types.

It must be pointed out that the particulate fraction of the total COD can settle in the pretreatment or primary settling tanks of the wastewater treatment plant and sometimes already in the sand trap (Legge et al. 2018), becoming important to increase the carbon fraction of the primary sludge that is commonly further treated in an anaerobic digester at the municipal wastewater treatment plants. The dissolved COD could influence the performance of the aerobic biological treatment. In this case, meat has the highest dissolved COD value with 28560 mgCOD.L^{-1}, followed by fat (24150 mgCOD.L^{-1}) and peanuts (17050 mgCOD.L^{-1}). The lowest soluble COD is broccoli with a concentration of 2757 mgCOD.L^{-1} which is in accordance with the low total COD observed. Looking at the difference between the average total COD (32026 mgCOD.L^{-1}) and the average dissolved COD (10553 mgCOD.L^{-1}), it can be concluded that about 67% of the COD coming from ground food waste is particulate and can be removed during primary sedimentation of the wastewater treatment process. For the indoor sewer, the latter implies that the application of FWD could bring opportunities to valorize the total COD of ground food waste or only the 67% particulate in a different way than biogas/energy production.

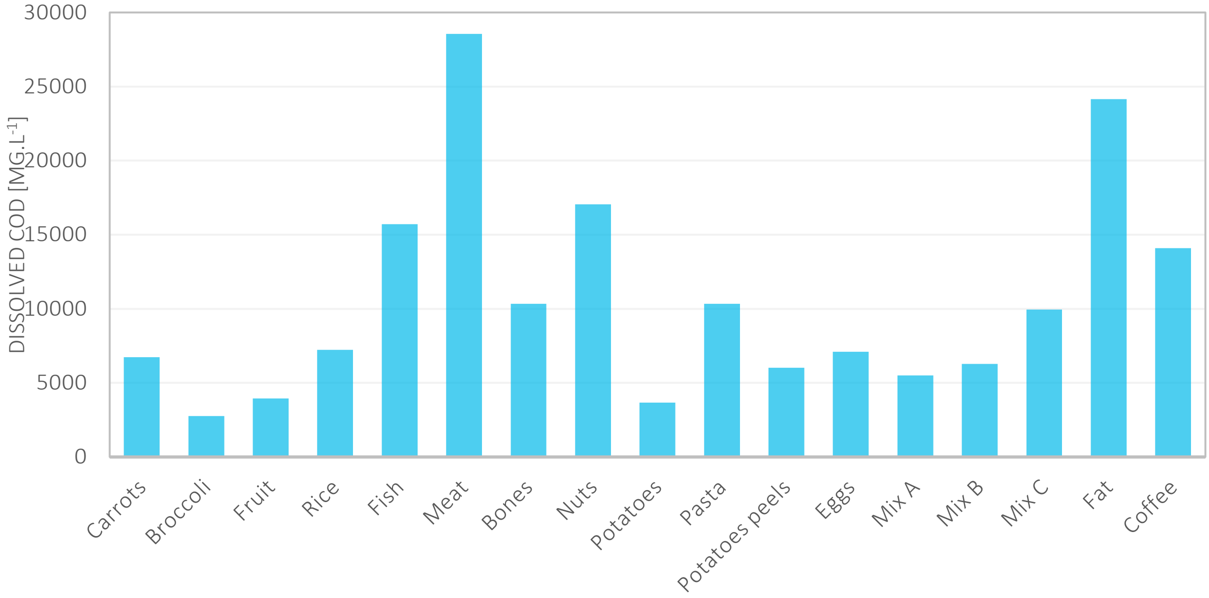


Figure 12 Dissolved COD concentration in the wastewater of ground food types

As expected, the observed COD values are very high compared to an average COD of 530 mgCOD.L^{-1} (CBS, 2019) in the influent of municipal wastewater treatment plants in the Netherlands. The food wastewater is very concentrated on a basis of 250 g food waste/household day since, in our study, only the usage of water by the food waste disposer is considered. However, further dilution with the use of other appliances such as toilet, shower, tap, washing machine, etc, is expected, besides the dilution by rainwater for combined sewage systems. This assumption is supported by De Koning (2002) and the practical tests by Tauw (Berg et al. 2018). De Koning calculated that with a penetration rate of about 5% of FWDs there will be an increase of only 2.9% of COD in the influent of the WWTP, whereas with a penetration degree of 10% there will be an increase of 5.9%. However, the COD that goes directly into the conventional aerobic biological treatment after settling, is only an extra load of about 1.8% at 10% of the FWDs penetration rate, which is negligible. On the other hand, the pilot study (32 apartments) conducted by Tauw at the Wageningen University campus showed that there is a 60% increase in the COD content when using a FWD compared to the situation without. The outcome of Tauw's research showed that most of the COD was particulate (72%) and only about 28% was dissolved COD, which is in agreement with the 33% dissolved COD found in our study.

3.1.3 Nutrients: Nitrogen and Phosphate

The total nitrogen that includes nitrate, nitrite, ammonium nitrogen, and organic nitrogen compounds was determined in the dissolved fraction of the wastewater. Figure 13 indicates that the total nitrogen concentration of three food types was substantially higher than for the rest of the food. Meat exhibited the highest total nitrogen value of 1816 mgTN.L^{-1}, followed by eggs with 932 mgTN.L^{-1} and bones with 532 mgTN.L^{-1}. The high value for the meat used could be attributed to preservatives such as nitrate and nitrites added. The concentration range of the other food types was between 50 and 200 mgTN.L^{-1}, with an average of 124 mgTN.L^{-1}.

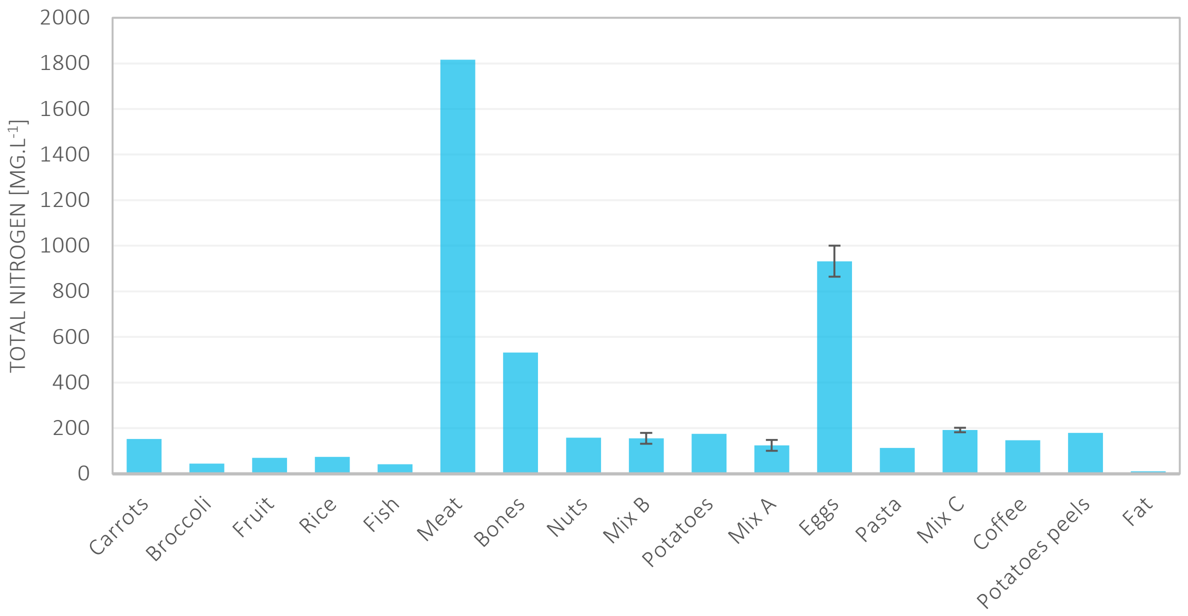


Figure 13 Total Nitrogen concentration in the wastewater of different ground food types

Figure 14 indicates an average total phosphate concentration of 22 mg P-PO4.L^{-1} in the food wastewater. Fish and broccoli had the highest and lowest concentration values of 69.2 mg P-PO4.L^{-1} and 1.1 mg P-PO4.L^{-1}, respectively. The different mixed food simulating a Dutch meal was in the range of 26-36 mg P-PO4.L^{-1}, with mix A having the largest standard deviation of ± 1.1 mg P-PO4.L^{-1}.

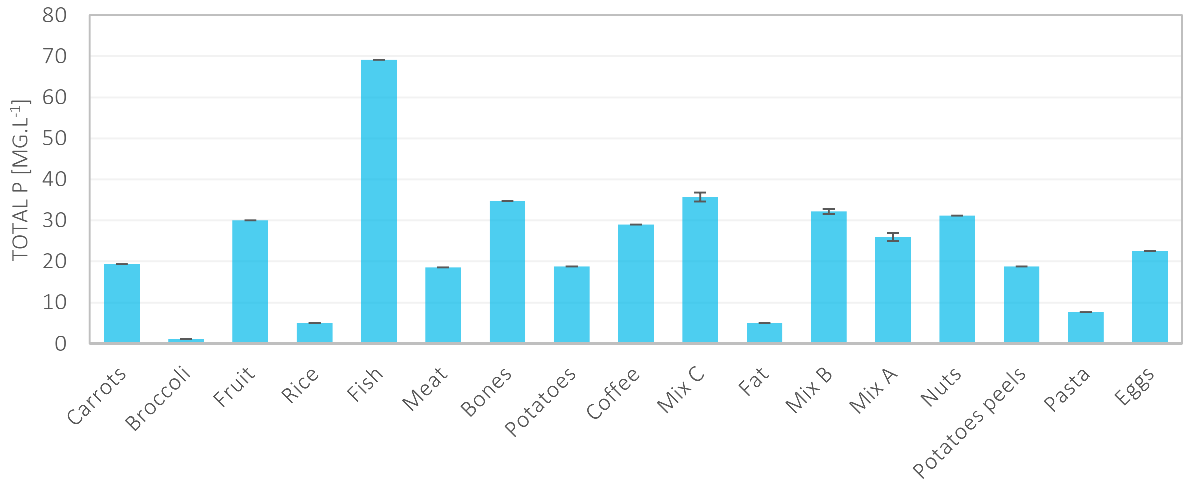


Figure 14 Total phosphate concentration in the wastewater of different ground food types

Based on Bolzonella et al (2003a), the additional loading per person due to FWD with a 100% penetration rate is about 1.5-14 gN/person d and 0.1-3.1 g P / person d. Looking at the dissolved Total N and total P, we measured 50-200 mg TN/L m with an average of 124 mg TN/L. In the case of TP, it was an average of 22 mg TP/L. Taking into account our discharge was 2.5 L, then we have, correspondingly on average: 310 mg TN and 55 mg TP. A total of 250 g of food discharge per household (2.19 people) per day was used, so that is 1.24 mg TN/ g ground food waste and 0.22 mg TP/ g ground food waste. This is equivalent to 0.14 g TN/ person d, and 0.025 g P/ person d, which is about 10 times lower than reported. It must be pointed out that we measured only the dissolved fraction right after the flushing, so it is not the total content of N and P in the ground food waste that could be dissolved.

The chemical characteristics of the wastewater flow are diverse, and the results showed a large difference between the dissolved and particulate COD concentrations. Most of the COD added by the food consists of particles that could settle and therefore might not have an impact on the aerobic biological treatment. Given the low influx of COD on WWTPs and the need sometimes for more COD available to carry out the nitrification/denitrification process, this is not necessarily a negative fact. The increase of nitrogen and phosphate values have a less positive effect on the conventional sewage treatment, but a higher COD/N ratio could improve the nitrification, even though extra energy will have to be used to remove the nutrients from the wastewater. On the other hand, also these concentrations will increase in the anaerobic digestion process, and more opportunities for resource recovery (biogas and nutrients) can be foreseen. According to STOWA, among other things, the food waste results in an increase in biogas production of 14% in the most conservative case (Berg et al. 2018), and based on other studies up to 50 - 70% in the most positive case (Davis et al. 2004).

3.2 Water consumption

The impact of the FWD on water consumption is important for the environmental benefits that are envisaged by applying the food waste disposer. Water consumption does increase when a food waste grinder is used. However, the increase accounts for only 1.3% per person over the entire year. The main uncertainty is that the user is responsible for the number of liters used to flush the food through the grinder. The experiments assume a minimum flow rate of 6 L / min, which is specified by the manufacturer. This can of course be more than estimated, but the flow will not easily exceed 18 L / min due to physical restrictions on the supply of water through a 15 mm pipe.

The results from the tests indicated that the water consumption of a FWD depends on the type of food. This is mainly due to the time it takes for food to be completely ground. For example, it was found that broccoli is ground very quickly and that the grinding chamber is empty within 25 seconds, with a rinsing flow rate of 0.1 L / s. On the other hand, bones need a grinding time of up to 120 seconds, with the same flush flow rate, which increases water consumption substantially compared to broccoli. A flushing flow rate of 0.1 L / s is the minimum flow rate at which the FWD can be used according to the manufacturer's manual (InSinkErator). The grinding time is also indicated by the manufacturer. However, this is indicated qualitatively, since the grinding time should be long enough until no grinding sound comes out of the FWD. Based on the experiment, the majority of food types took between 21 to 24 seconds to be completely ground on the basis of 250 g used (see Figure 15). Thereby, for practical reasons, this time has been extended to 25 seconds to guarantee that the FWD has enough time to grind, but does not consume unnecessary water during the grinding process. Despite the low flushing rate, this does not affect the grinding time, as the disc cannot rotate faster than it already does. A 35 s grinding time was observed with fruit (orange peels) for the peels to be completely ground.

Considering the minimum flow rate of 0.1 L / s and a grinding time of 25 seconds, almost all food types required 2.5 liters of water to grind and rinse the food completely. This means that an average household of 2.15 people (CBS 2019) would have a daily increase in water consumption of 2.5 L / 2.15 people = 1.16 liters of water per person per day, and 12 L/ 2.15 people = 5.7 liters per person per day in the worst case. It is important to mention that the worst case is not realistic (250 g bones are put into the FWD every day). If we consider the ratio of the use of the FWD concerning the average water consumption in the Netherlands, which is 107 liters per person per day Waternet (2019), this is only an increase of 1.3 % of the total water consumption on a daily basis of 250 gram ground food waste per household.

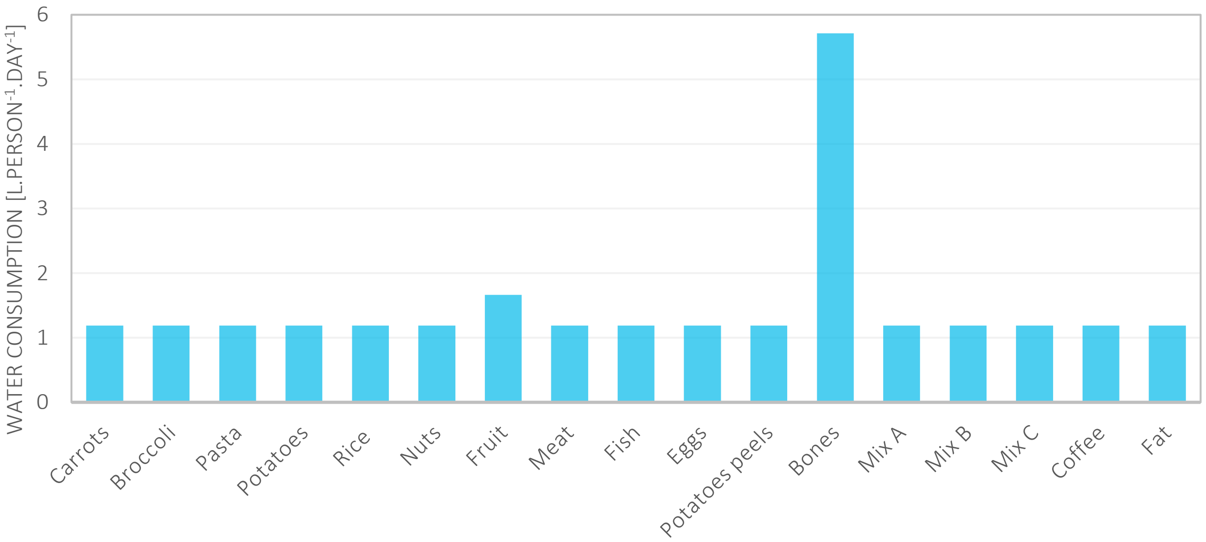


Figure 15 FWD water consumption to grind 250 g food waste per day in an average household of 2.15 people.

3.3 Effects of indoor sewerconfiguration on the transportation of wastewater

The influence of the various parameters of the indoor sewer configuration such as pipe diameter, slope, length, number of bends, and the type of food waste, and the water flow rate on the transportation of the wastewater was studied.

The chart of Figure 16 shows the standardized effects of the parameters (factors) on the residual ground food waste remaining in the collecting pipe (see data in Table 12, Appendix I). The slope of the collecting pipe (B), has the largest influence (65%) when taking into account all the effects of the experiments. An average of 16 grams of residual ground food remained at a slope of 1:50 compared to an average of 104 grams of residual waste at a slope of 1:200, which implies a difference of 88 grams of residual food waste in the pipe. This means that when the slope decreases (1:200), the weight of the residual food waste in the pipe increases. The combination of food and flushing flow rate (EF) factor had a 44% effect on the residual food waste. It must be pointed out that the effect of a factor, or combination of factors, only infers how large the impact could be on the response variable (ground food waste remaining in the pipe).

The results show that with a combination of a high flushing flow rate with eggs, an average of 66.7±59.2 grams remained in the horizontal pipe and with a combination of a low flushing flow rate with mix C, an average of 108.1±98.1 grams of residue remained in the pipe. The individual factors, food type, and flushing flow had less influence on the amount of residual ground food waste than the combination of both. Therefore, a higher flow does not necessarily result in less residue in the collection pipe. On the contrary with eggs, a low flow rate of 0.1 L/s yielded an average of 30.6±27.2 gr of residue instead of 66.7±59.2 gr at a flow rate of 0.3 L/s. However, the reason the eggs resulted in less residue at a rinse flow rate of 0.1 L / s is that eggshells are already settling in the siphon and wall tube, so they do not reach the collection pipe (Figure 17).

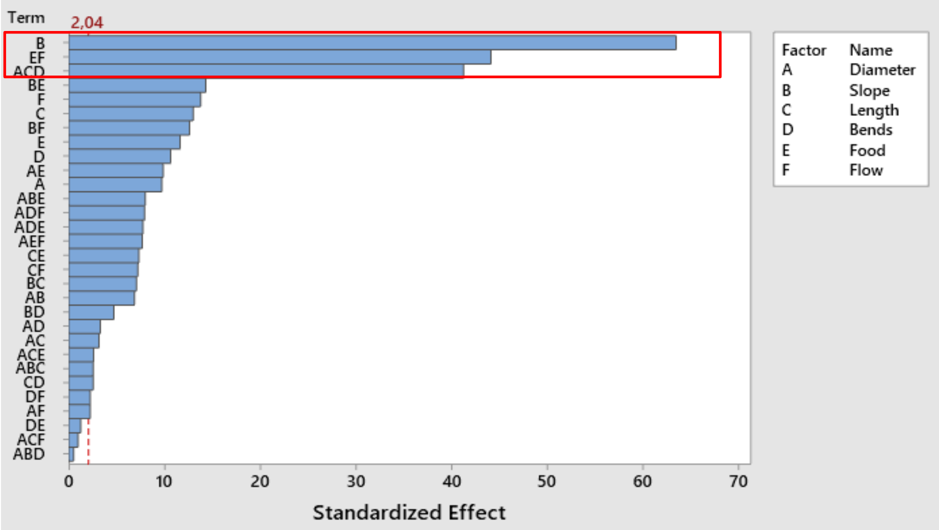


Figure 16 Effects of each parameter and their combinations with significance level α=0.05.

Figure 17 Residual egg shells in the wall pipe and siphon.

The combination of diameter, length, and the number of bends also has a significant influence of 42% on the residual food waste in the collection pipe. In the configuration of 5 meters, a diameter of 75 mm and 1 bend, an average of 15±7.2 gr of residual ground food waste in the horizontal pipe was left. The configuration with a length of 8 meters, a diameter of 63 mm, and 3 bends, an average of 91.7± 94.4 gr of residual food waste was found.

Regardless of the configuration layout of the indoor sewer, there was not a case where 0 gr of residual food waste remained in the pipe. The most favorable combination of parameters was a slope of 1:50, a length of 5 m, 1 bend, 75 mm diameter, mix C, and a flushing flow rate of 0.3 L/s. With this configuration, only 6 gr of ground food waste remained in the collection pipe. The least favorable configuration was a slope of 1:200, a length of 8 m, 3 bends, 63 mm diameter, mix C and a flushing flow of 0.1 L/s, resulting in 238 gr of ground food waste in the collection pipe (Figure 18).

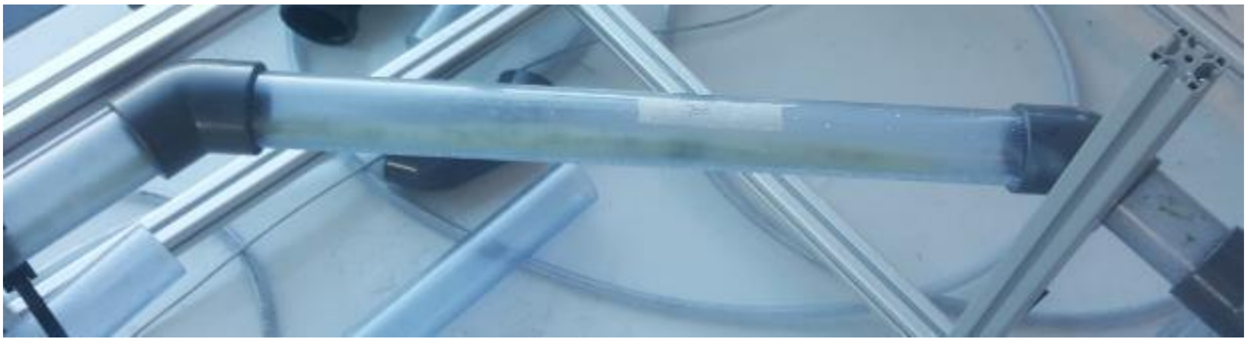


Figure 18 Residual ground food waste in the pipe in the least favourable configuration.

Besides, there are more factors and their combinations with less influence but still with a significant effect. These factors included: slope & food (16%), flow rate (15%), length (14%), number of bends (12%), diameter & food (11%) and diameter (11%). The factorial regression model (see Appendix II) taking into account all significant factors and combinations explained about 99.66% (R^2) of the experimental results. However, the regression and effects quantification is only an indication of the behavior of the response, since food is not a continuous variable, and therefore it is not possible to use this model for predictions.

However, by taking each of the types of food separately, simple multiple regression models can be used to explain the response based on the ground food waste that remained in the collection pipe, for either the Eggs or the Mix C, respectively. In both cases, the slope alone explained about 44 % (R^2-adj) of the response, confirming this is the main factor that influences the amount of ground food waste remaining in the pipe. The second most significant factor was the flow, and the third the combination factor of the slope and flow. In the case of Mix C, with these mentioned three factors, about 92.5% (R^2-adj) of the response of the experiments could be explained (Figure 19A). The model equation taking into account all the factors and their combinations explained 99.7% of the response:

$$\textit{Residual ground food waste in the pipe for Mix C [gr]} = -266.7+2.276*X1 + 1.0097*X2 +6.64*X3 + 44*X4 + 858*X5 – 0.516*X1*X4- 6.30*X1*X5 + 0.09306*X2*X3 + 0.0529*X2*X3 - 4.996*X2*X5 -1.312*X3*X4.$$

With X1: Diameter [65 – 75mm], X2: Slope [50 – 200], X3: Length [5 – 8m], X4: Bends [1 – 3], X5: Flow [0.1 – 0.3 L/s]

Correspondingly, Figure 19 B indicates that for the case of Mix C, the factors slope and flow contribute the most followed by a length, bends, and diameter with substantially less impact.

By only taking the slope, flow, and their combination, about 75.6% (R^2-adj) of the ground food waste residuals in the pipe could be explained for the case of eggs (Figure 20 A). The reason why the prediction of the eggs is less accurate compared to mix C could be that some eggs shells remained in the siphon, and therefore the total amount of eggshells remaining in the collection pipe could not be accurately quantified.

The model equation taking into account all the factors and their combinations explained 99.3% of the response:

$$\textit{Residual ground food waste in the pipe for Eggs [gr]} = 512 – 8.384*X1 + 1.731*X2 +21.05*X3 + 78.1*X4 - 614*X5 + 0.0229*X1*X2 + 0.448*X1*X3 + 1.286*X1*X4 +11.51*X1*X5 +0.0346*X2*X4 + 2.654*X2*X5 – 36.04*X3*X5 – 33.44*X4*X5$$

With X1: Diameter [65 - 75], X2: Slope [50 – 200], X3: Length [5 – 8], X4: Bends [1 – 3], X5: Flow [0.1 – 0.3]

Correspondingly, Figure 20 B suggested that for eggs, the factors diameter, and to a lesser extent the length and bends had a higher impact on the model compared to mix C, in which the slope and flow contributed the most to the model (see also Appendix III, main effects interactions).

The experiments carried out show that an indoor sewer system constructed following NEN 3215 + C1, could leave residual ground food waste in the collection pipe in some cases. The results show that with a slope of 1:50 the accumulation of residue is minimum when compared to a slope of 1:200, whereas in the 1:50 case it would be easily removed by a second rinse, not necessarily from FWD, but upstream kitchen tap or dishwasher discharge. Moreover, it is also important to consider that a minimum flow rate of 0.1 L/s, or higher, must be used when installing a food waste disposer. Cleaning advice, or rinsing regime depends on the intensity of use and the type of food that is ground in the FWD, as well as the frequency of use of other appliances or kitchen tap.

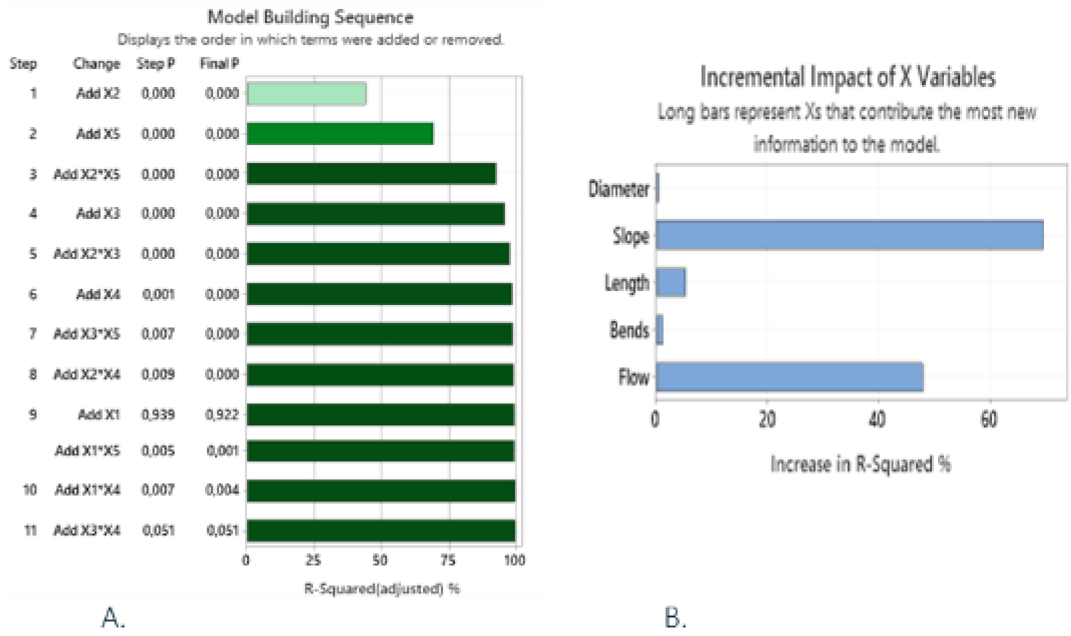


Figure 19 Regression model from the effects of different variables on indoor sewer with Mix C. X1: Diameter, X2: Slope, X3: Length, X4: Bends, X5: Flow. A. Model building sequence: addition of factors to the model to increase the explanation of the response. B. Contribution of factors to the model.

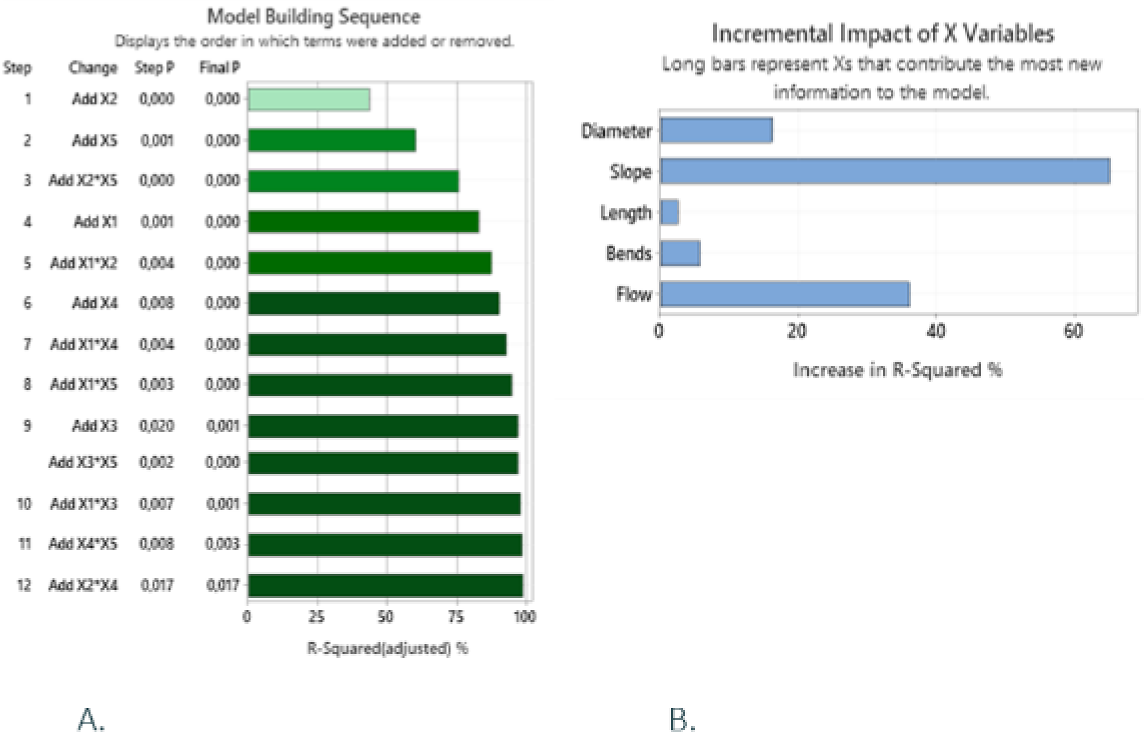


Figure 20 Regression model from the effects of different variables on indoor sewer with Eggs. X1: Diameter, X2: Slope, X3: Length, X4: Bends, X5: Flow. A. Model building sequence: addition of factors to the model to increase the explanation of the response. B. Contribution of factors to explain the proposed model.

The other variables, such as diameter, length, and the number of bends do not have a large adverse impact on the indoor sewer and, if installed following the NEN 3215, do not cause any problems when using a FWD. Accordingly, the results of the experiments do not indicate that adjustments need to be made to the NEN 3215 regarding the variables: diameter, length and bends when implementing FWDs. The only exception to this is flushing only fat (or FOG: fat, oil, and grease), which should be avoided because the experiments that were done for the wastewater characterization showed that the flushing of 250 gr of fat immediately obstructed the wall pipe as shown in Figure 21.

Figure 21 Wall pipe after grinding 250 gr of fat. A flow obstruction occurred.

3.4 Effect of a long interruption of the indoor sewer use (holiday event)

An experiment was conducted to investigate whether there is any effect of leaving the indoor sewer unused for an absence period of three weeks, simulating a holiday event, after using the FWD. In addition to the possible build-up of any gases, the state of the residues in the pipe after the period was examined as well as the impact of water rinses on removing residues from the pipe (van Riet 2019).

3.4.1 Gas build-up

Figure 22 indicates that the tube became slightly moldy and that the grease residual still looks relatively unaffected. The tube is otherwise intact and no traces of material deterioration were observed.

Figure 22 Mold and grease deposits on the collection tube after three weeks of absence.

After the visual inspection, a multi-gas meter was attached to the pipe to measure the build-up of potentially harmful gases such as H_2S, and CH_4 (measured by LEL). The measurements after three weeks showed that the gas content of the tube has an oxygen percentage of 10%, no H_2S (0%), and a lower explosion limit (LEL) of 25% (see Figure 23). The decrease in oxygen in the tube indicates that this has been converted into other gases, which are most likely CO_2, and other any anoxic conversion to methane. The increase in the LEL value indicates that there is some methane in the tube being produced. A 100% LEL means that there is enough flammable gas in the gas phase to cause an explosion, which in case of methane is produced the 100% will be reached at about 5% of CH_4. The value of LEL converted to concentration is about 12.500 ppm methane. After the 3 weeks, no hydrogen sulfide was detected. It must be pointed out that in reality the horizontal pipe would not be sealed, and the ventilation system through the vertical pipe might not allow an LEL of 25% to be reached.

Gas	***Measurements before:***
H_2S	*0 ppm*
LEL	*0 %*
O_2	*20.9 %*
	Measurements after 3 weeks:
H_2S	*0 ppm*
LEL	*25%*
O_2	*10.0%*

Figure 23 Gas measurements in the sealed horizontal pipe after 3 weeks.

3.4.2 Physical observations

In addition to the gas measurement and visual inspection, the tube was rinsed. This involved looking at the amount of ground food waste remnants the first rinse takes after 3 weeks and how many rinses with only water must be done to remove the majority of them. In Figure 24, a decreased in residuals and fat, oil, and grease deposits, mainly the larger particles, was observed by comparing the pipe before and after the first rinse.

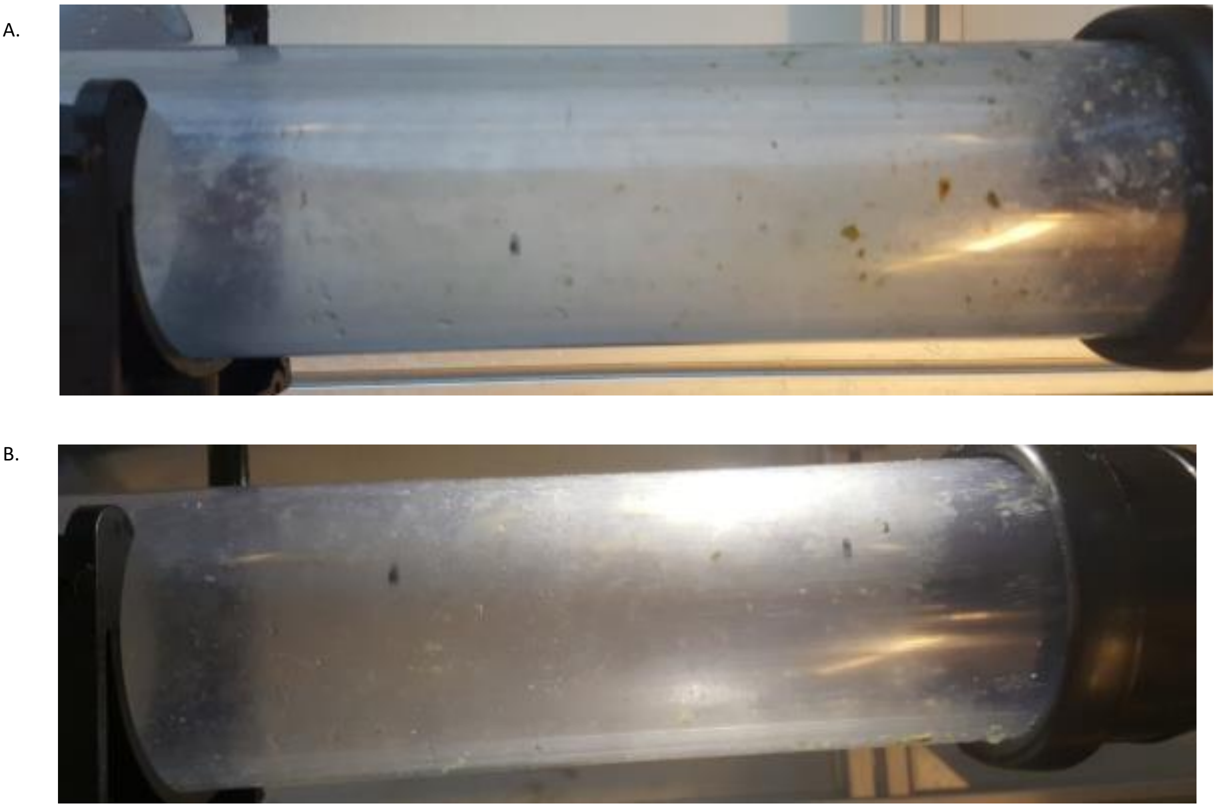


Figure 24 A. Collection pipe before the first rinse after 3 weeks. B. Collection pipe after 1st rinse.

This is also supported by the water turbidity in the outlet of the collection pipe after 1, 3, and 6 rinses. A of the residue left the pipe after six rinses (Figure 25).

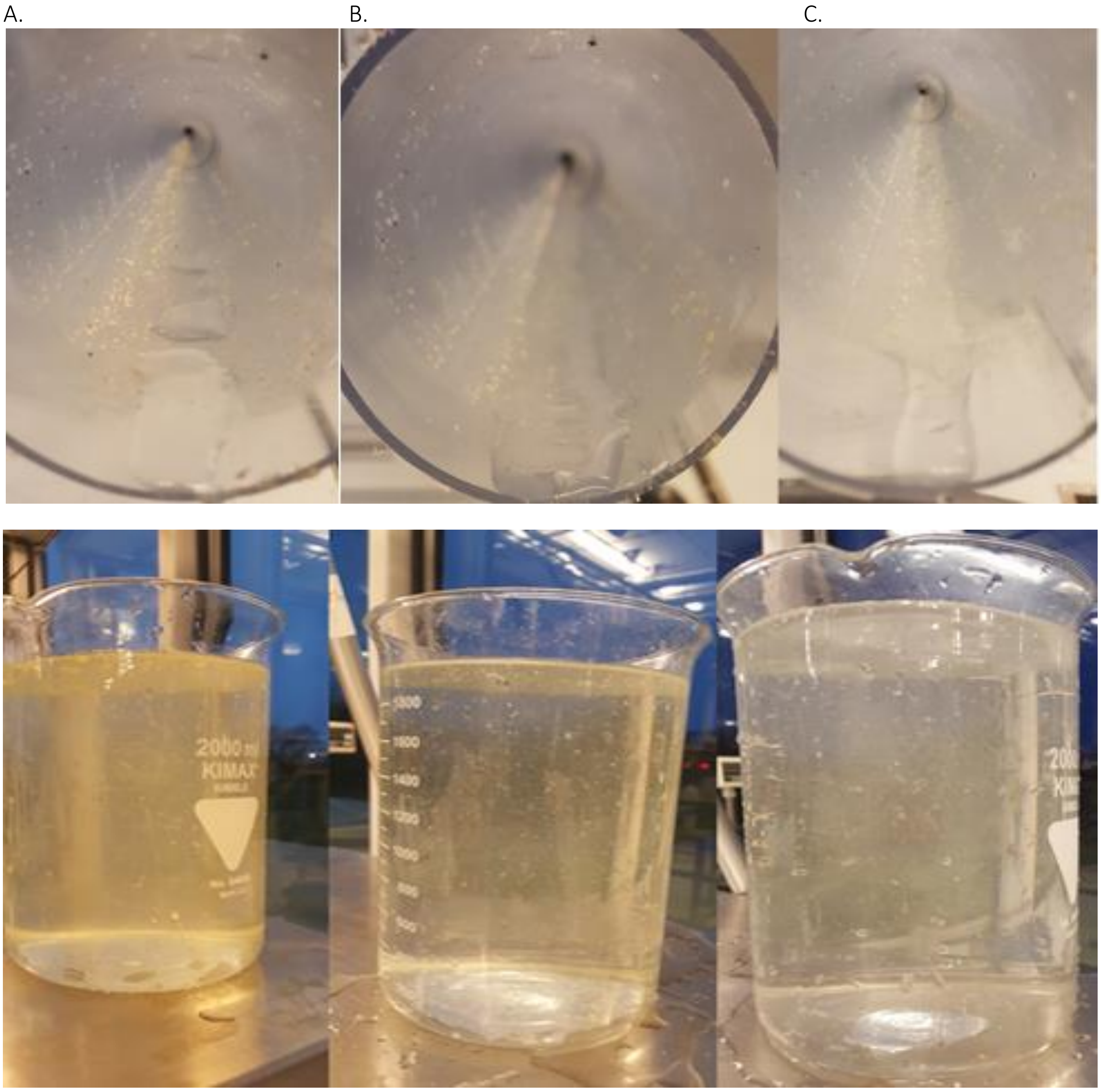


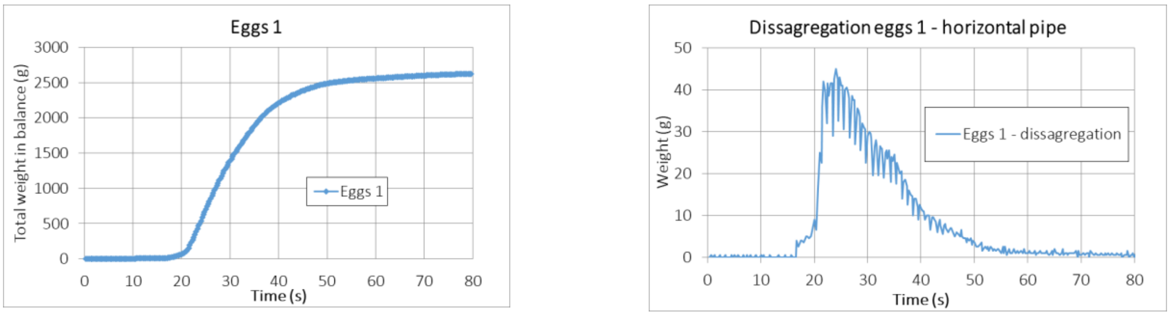
Figure 25 Collection and effluent water pipe after A. 1x rinse. B. 3x rinses. C. 6x rinses.

3.5 Time series analysis

After the experiments were held for the different food types, a series of analyses on the flow time series were performed. For a complete routing for inference of variation of flow within the pipe, both the input and output flow time series are required. In the pilot study, due to setup, only the latter is available. For each food type, a time series at the outlet of the horizontal pipe was obtained in each case. For most food types a replicate was performed to have validation of the shape and behavior of the original result. The first part of the experiments corresponds to the analysis of the influence of food type in the output time series for a horizontal pipe. This process is split into three different steps: (1) Disaggregation, (2) Filtering and variable extraction, and (3) understanding of flow behavior. In this case, the experiments were held for a pipe slope of 1:100 a diameter of pipe of 63mm. The pipe is horizontal of 5m and pipe fittings correspond to 1 bend. A flow rate of 0.1 l/s was used for this set of experiments.

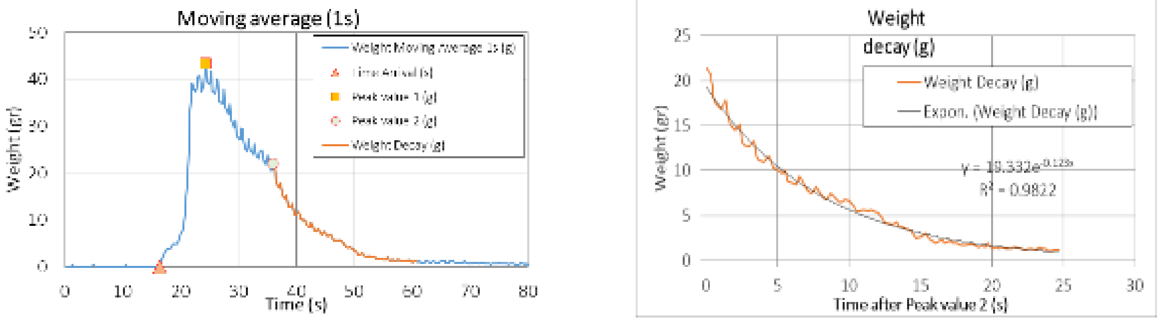
3.5.1 Step 1. Disaggregation

From the time series of the total weight in the balance (Figure 26A) a disaggregation is made to obtain the flow vs time, as presented in **Figure 26**B. In this case, Figure 26A-B corresponds to the time series at the outlet of the horizontal pipe.



(A)Total weight (water+food) measured in the balance at the outlet over time.

(B) Disaggregation to 4 Hz



(C) Filtered time series (at 1 Hz) showing the selected variables

(D) Estimation of the decay rate of the recession curve

Figure 26 Obtained time series for Eggs. Replicate No 1 for the horizontal pipe. (A) Total weight obtained in the balance, (B) disaggregated weight (flow), (C) filtered time series and obtained variables selected, and (D) obtained decay rate for this specific case.

3.5.2 Step 2 Filtering & variable extraction

In order to reduce the perturbations of the signal, the time series are filtered by using a moving average with a window of one second (1s). The resulting hydrograph is presented in Figure 26C and shows that there is a reduced number of fluctuations with respect to the time series in Figure 26B.

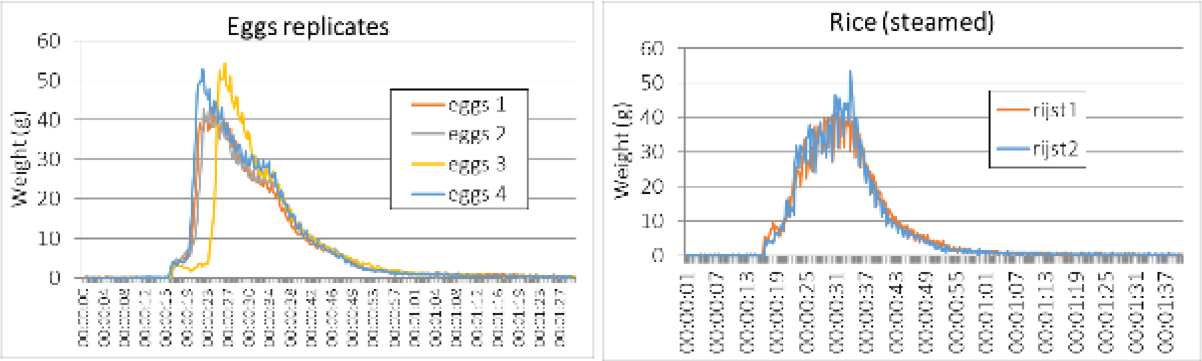
Subsequently, six different variables are manually obtained from each hydrograph:

1) Time of arrival (s) (triangle), helps to identify the first arrival of the flow after the grinder arriving at the outlet section of the horizontal pipe. Typically flow rate, slope, and pipe length determine the peak value, however, when the water is mixed with food waste additional time is expected to be measured.
2) Peak value 1 (g) (yellow square), for most food types, it is easy to identify the peak value of the time series.
3) Peak time 1 (s), corresponds to the time at which the peak value 1 occurs.
4) Peak value 2 (g) (white circle), for some time series, it is possible to identify a second peak value or the start of decay of the time series.
5) Peak time 2 (s), corresponds to the time at which the Peak value 2 occurs.
6) Decay rate (g/s) (portion of time series red also presented in Figure 26D), is used to characterize the exponential decay rate after peak time 2. For all food types, it has been considered that when the weight in the balance corresponds to 1% of the peak then the recession is complete. This variable is useful to understand the total time which it will take for the hydrograph to leave the pipe.

3.5.3 Step 3 – understanding of flow behavior

It is necessary to verify whether or not the behavior can be qualified as consistent between replica and experiments or whether more experiments need to be performed. To understand this, one would expect that for the same hydraulic conditions, the time series obtained should perform similarly. For each food type, a qualitative score is given if the time series show similar behavior.

Figure 27 shows the replicates for Eggs and Rice. In the case of Eggs, there is consistency in 3 out of 4 replicates of the same experiment, while for the case of Rice both flow hydrographs are almost identical in timing and magnitude.



(A) Four replicates of eggs experiments for the same hydraulic conditions. Not all replicates of the same experiment create the same hydrograph. Time series are filtered.

(B) Two replicates of rice experiments for the same hydraulic conditions. In this case, both replicates of the experiment show that there is consistency in the behavior of rice-water mixture outside of the food grinder.

Figure 27. Comparison of different replicates

A complete presentation of the obtained hydrographs for each food type is found in Appendix IV. From the qualitative evaluation of the replicates, it is possible to conclude that there is consistent behavior for: Carrots, Broccoli, Rice, Meat, Fish, Peanuts, Eggs, Coffee, Mix A, Mix B, and Mix C. On the other hand food types: Potato (cooked), Potato (peels), Fat (lard) do not show consistent behavior. There are variations of the food type rheology after grinding, and it is not possible to determine whether the time series differences lie in the rheology or the grinding process. For example, the potato peels and potato structure can be variable with the type of potato and the amount of material attached to the skin. One interesting case of output hydrograph is the case of bones. Two different experiments were run for different grinding times (80 s and 120 s). Although the characterization was made in the same way as for other food types (see *Table 4*), it is evident that within the process of grinding Bones several stages occur which are not easily depicted by a simple variable extraction as presented in the previous section. This will require further analysis in follow-up research.

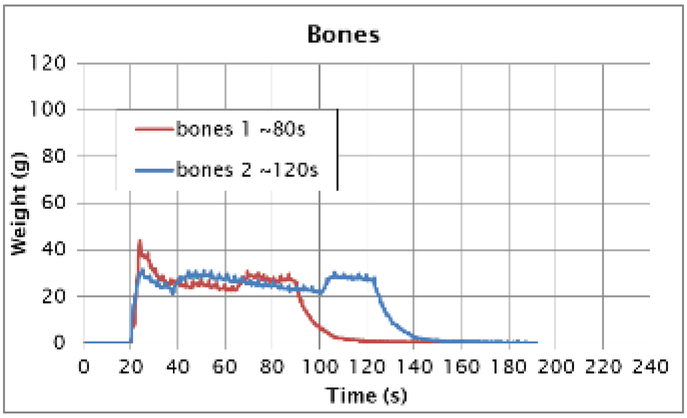


Figure 28. Outlet hydrograph of Bones after grinding. Showing a different type of behavior from other food types when the grinding time is increased.

The complete characterization of each output hydrograph of the horizontal sewer pipe is presented in *Table 4* for all food types. Moreover, a characterization of the time required for the arrival of peak 1 and peak 2 is presented. This information is useful to interpret how much time does water-food mix travel in the horizontal pipe.

Table 4 Characterization of hydrographs for each replicate of each food type for horizontal sewer pipes.

Food Type - Units	Time of arrival	Time to Peak 1	Peak weight 1	Time to Peak 2	Peak weight 2	Decay rate	Time Arrival - Peak 1	Time Arrival - Peak 2
	(s)	(s)	(g)	(s)	(g)	(g/s)	(s)	(s)
Carrots 1	16.0	30.5	98.3	-	-	-0.174	14.5	-
Carrots 2	16.0	30.0	96.1	-	-	-0.162	14.0	-
Broccoli 1	13.5	26.0	54.3	-	-	-0.102	12.5	-
Broccoli 2	13.5	23.5	71.1	-	-	-0.123	10.0	-
Pasta 1	18.0	26.7	21.3	34.5	36.9	-0.072	8.7	16.5
Pasta 2	21.0	23.3	17.0	35.7	35.8	-0.070	2.3	14.7
Potato 1	16.0	21.0	26.5	25.5	40.5	-0.123	5.0	9.5
Potato 2	17.5	27.7	33.5	35.3	50.2	-0.142	10.2	17.8
Rice 1	17.0	24.3	25.5	32.7	40.7	-0.108	7.3	15.7
Rice 2	17.0	24.3	29.5	35.0	46.1	-0.108	7.3	18.0
Meat 1	19.5	29.6	40.6	32.7	42.3	-0.110	10.1	13.2
Meat 2	21.3	30.3	41.9	36.7	35.3	-0.081	9.0	15.4
Fish 1	19.3	34.0	77.3	-	-	-0.120	14.7	-
Fish 2	20.0	34.3	79.1	-	-	-0.120	14.3	-
Peanuts 1	15.0	18.0	19.5	34.5	26.3	-0.095	3.0	19.5
Peanuts 2	17.3	20.3	23.8	31.0	34.6	-0.107	3.0	13.7
Fruit 1	18.3	32.7	58.3	65.5	25.3	-0.113	14.4	47.2
Fruit 2	17.5	25.3	43.4	63.5	27.1	-0.120	7.8	46.0
Potato (peels) 1	16.3	25.5	31.1	35.3	25.0	-0.104	9.2	19.0
Potato (peels) 2	18.5	23.5	49.0	33.0	30.8	-0.131	5.0	14.5
Fat (lard) 1	17.7	21	21.3	27.7	31.4	-0.081	3.3	10.0
Fat (lard) 2	23.5	29.7	25.0	35.3	37.1	-0.081	6.2	11.8
Bones 1 (80s)	20.3	24.0	44.1	89.0	26.3	-0.114	3.7	68.7
Bones 2 (120s)	19.5	25.0	31.8	122.7	26.6	-0.129	5.5	103.2
Coffee 1	17.3	23.7	13.6	34.5	39.0	-0.116	6.4	17.2
Coffee 2	18.0	23.7	19.0	31.0	44.0	-0.116	5.7	13.0
Mix A1	25.7	29.0	62.6	37.5	24.8	-0.112	3.3	11.8
Mix A2	24.5	27.5	61.8	35.3	33.8	-0.111	3.0	10.8
Mix B1	19.3	21.3	14.1	34.0	59.3	-0.117	2.0	14.7
Mix B2	18.3	20.0	3.3	32.5	72.1	-0.130	1.7	14.2
Duration test	15.0	29.0	185.0	32.0	229.0	-0.067	14.0	17.0
Water	17.7	20.3	17.8	35.7	34.8	-0.125	2.6	18.0

Concerning the time of arrival, there is not much variability for Carrots, Broccoli, Fruit, Rice, and Coffee. There is huge variability in this variable for Pasta and Fat.

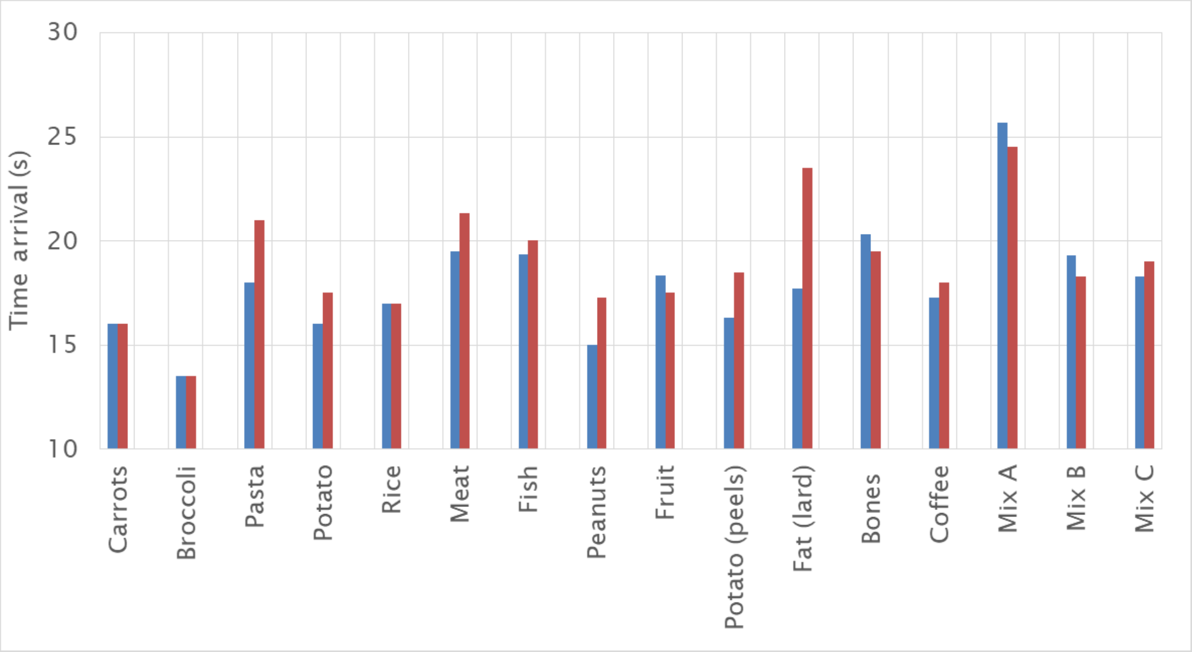


Figure 29. Time of arrival for each food type. Blue corresponds to the experiment, while red represents the replicate.

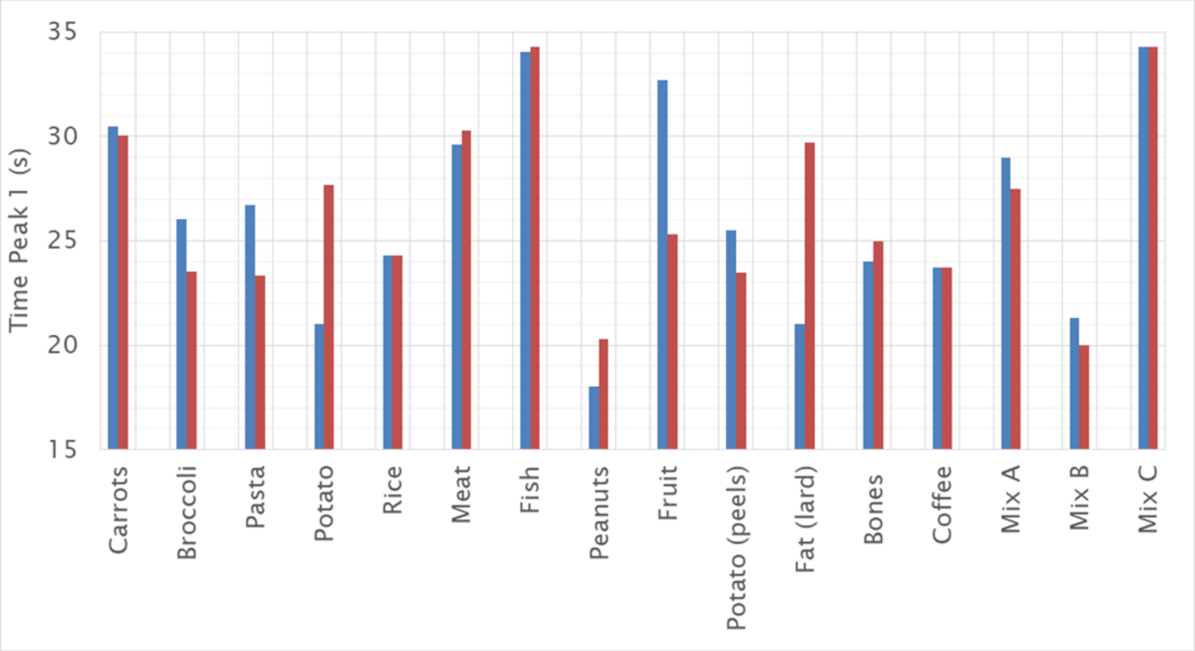
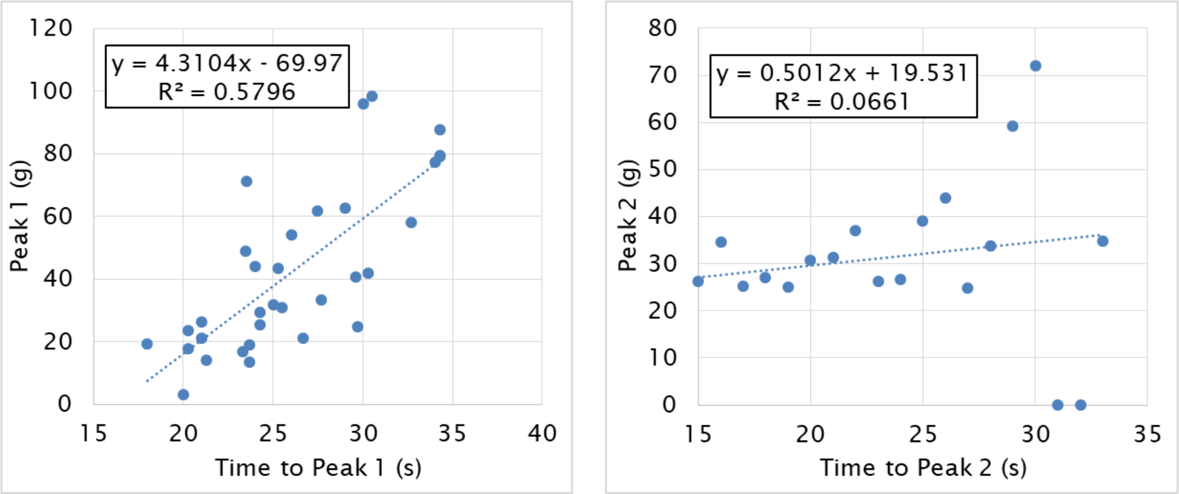


Figure 30. Time of Peak 1 for each food type. Blue corresponds to the experiment, while red represents the replicate.

In the case of tme to Peak 1, it is possible to see that there is a complete variability for different food types. The range of this time series variable is 18-36s. The food types with consistency between experiment and replicate are Carrots, Rice, Meat, Fish, Bones, Coffee, Mix A, Mix B and Mix C. There is more variability for Broccoli, Pasta, Potato, Peanuts. The largest variability was obtained for Fat (lard) of around 9s between experiment and replicate.

Given the times to peak and peak values, one may expect to obtain a correlation among these two variables for the first peak, however, this is not the case for the second peak as these variables may not exist for certain food types. In fact, for Peak 1 there is a correlation of 0.76. the higher the peak the longer the time to peak. This indicates that the time series becomes steep and the FWD accumulates the water-food for a couple of additional seconds for certain food types.



(a) Peak 1 (g) vs time to peak 1 (s). *Duration test not included

(b) Peak 2 (g) vs time to peak 2 (s). Some food types do not show a second peak.

Figure 31. Comparison of Peak variables for different food types.

3.5.4 Influence of vertical pipe on outlet hydrograph

The influence of the vertical pipe on the outlet hydrograph (a combination of vertical pipe and horizontal pipe) was investigated. For this, a new set of experiments was performed. The setup of this new configuration is presented in Figure 32.

In this way, it is possible to isolate the effect of the vertical pipe. However, the experiments were run only for Eggs and Mix C for both horizontal and vertical pipes. For this, a comparison was made for different flow rates while maintaining the horizontal pipe slope. The results are presented in Table 5.

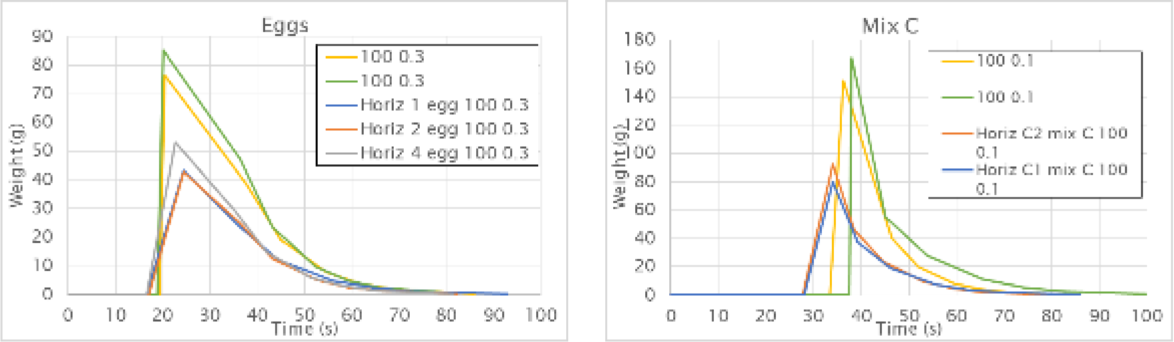
Once all the variables of each time series are obtained it is possible to parametrize the behavior of each food type. Given that the analysis was made for eggs and Mix C in both circumstances it is presented here a series of comparisons between the two experiments Figure 33.

3.5.5 Comparison of horizontal pipe and horizontal+vertical pipe outlet time series

For the same vertical pipe setup, the increase of flow rate has two effects on the time series variables, and it speeds up the time of arrival while at the same time the peak value becomes higher. For a simple comparison between the horizontal and the vertical pipe, it can be concluded that the vertical pipe adds up to six seconds on the arrival time. It is also discovered that the decay rate of the recession of the time series has an almost constant value for slopes of 1:50 and 1:100; however, for a lower slope 1:200, there is a reduction of the decay rate of at approximately 20% (see Table 5 and Appendix 6).

Figure 32 Indoor sewer configuration setup at KWR, including the vertical pipe.

The results of this experiment are performed in a controlled environment, while there is the need to perform measurements in a real system (building) to be able to verify the results obtained.



(a) Results of parametrized curves of Eggs for similar slope 1:100 and flowrate 0.3 L/s for horizontal pipe and horizontal+vertical pipe.

(b) Results of parametrized curves for Mix C for similar slope 1:100 and flowrate 0.3 L/s for horizontal pipe and horizontal+vertical pipe.

Figure 33. Comparison of horizontal and horizontal+vertical pipe outlet flow time series.

There are two main conclusions which are obtained for both food types:

1) The addition of the vertical pipe makes the outlet time series more step and delays the arrival approximately 6 s for eggs and ~10s for Mix C.
2) The recession process does not change once the vertical pipe is installed, although the analysis is made for two different flow rates, one for each food type.

One aspect to point out is that the total water balance (area under the time series) is not the same, this indicates that the total amount of water flushed in each experiment was not the same, and more experiments to validate the obtained results obtained should be performed in follow-up research.

Table 5. Results of vertical pipe experiments for the six variables selected for each time series. Only Eggs and Mix C have been used for both experiments.

Nr. experiment	Food Material	Pipe slope (1:x)	Flow rate(m/s)	Time Arrival (s)	Peak value 1 (g)	Peak Time 1 (s)	Peak value 2 (g)	Peak Time 2 (s)	Decay rate (g/s)	Time between peak 1 AND arrival time	Time between peak 2 AND arrival time	Time of tail* to 0.01g (s)	Total Travel time (s)
V1	egg	50	0.1	23.4	37.8	26.9	23.0	40.9	-0.102	3.5	17.5	75.9	93.4
V2	egg	50	0.1	23.9	44.5	27.3	31.8	37.3	-0.104	3.5	13.5	77.5	91.0
V3	egg	50	0.1	23.7	40.0	32.3	31.0	36.9	-0.100	8.7	13.2	80.4	93.6
V4	egg	50	0.3	17.9	66.8	23.7	56.0	37.3	-0.114	5.8	19.5	75.7	95.2
V5	egg	50	0.3	18.0	71.7	31.4	60.3	37.4	-0.110	13.3	19.3	79.1	98.4
V6	egg	50	0.3	17.0	74.7	22.7	56.3	36.3	-0.108	5.7	19.3	80.0	99.3
V13	egg	100	0.1	22.9	46.0	25.9	23.5	39.7	-0.094	3.0	16.8	82.6	99.4
V14	egg	100	0.1	25.7	40.8	32.7	31.5	38.7	-0.097	7.0	13.0	83.0	96.0
V15	egg	100	0.1	22.4	48.5	27.7	21.8	40.9	-0.099	5.3	18.5	77.7	96.2
V16	egg	100	0.3	19.4	76.5	20.4	38.3	37.9	-0.096	1.0	18.5	85.9	104.5
V17	egg	100	0.3	18.9	85.3	20.0	47.2	36.4	-0.101	1.2	17.5	83.8	101.2
V18	egg	100	0.3	19.4	109.7	24.9	51.0	36.4	-0.099	5.5	17.0	86.2	103.2
H Eggs 1	*egg*	*100*	*0.3*	*16.5*	*43.3*	*24.3*	*24.0*	*36.0*	*-0.081*	*7.8*	*19.5*	*96.1*	*115.6*
H Eggs 2	*egg*	*100*	*0.3*	*17.0*	*42.7*	*24.4*	*24.8*	*36.4*	*-0.100*	*7.3*	*19.3*	*78.2*	*97.5*
H Eggs 3	*egg*	*100*	*0.3*	*16.5*	*54.3*	*26.5*	*27.0*	*35.4*	*-0.094*	*10.0*	*18.8*	*84.1*	*102.9*
H Eggs 4	*egg*	*100*	*0.3*	*16.5*	*53.0*	*22.7*	*29.5*	*35.0*	*-0.099*	*6.2*	*18.5*	*80.7*	*99.2*
V24	egg	200	0.1	28.3	44.0	37.7	26.8	43.4	-0.077	9.4	15.0	102.5	117.5
V25	egg	200	0.3	20.4	69.4	28.4	28.6	39.9	-0.083	8.0	19.5	95.9	115.4
V7	mix C	50	0.1	33.7	123.5	35.4	100.5	37.0	-0.108	1.7	3.3	85.3	88.7
V8	mix C	50	0.1	34.7	136.0	36.7	92.7	37.7	-0.107	2.0	3.0	85.4	88.4
V9	mix C	50	0.1	33.4	128.0	35.4	76.2	36.4	-0.099	2.0	3.0	90.3	93.3
V10	mix C	50	0.3	20.2	147.3	21.2	66.0	36.2	-0.120	1.0	16.0	73.3	89.3
V11	mix C	50	0.3	19.2	112.8	21.5	32.8	38.5	-0.108	2.3	19.3	75.0	94.3
v12	mix C	50	0.3	22.0	140.7	22.9	54.7	37.7	-0.115	0.8	15.7	74.8	90.5
V19	mix C	100	0.1	37.5	167.3	38.0	55.2	45.2	-0.079	0.5	7.7	109.1	116.7
V20	mix C	100	0.1	33.4	151.5	36.4	39.8	46.4	-0.122	3.0	13.0	67.9	80.9
H Mix C1	*mix C*	*100*	*0.1*	*28.0*	*80.0*	*34.0*	*37.5*	*39.3*	*-0.143*	*6.0*	*11.3*	*83.1*	*94.4*
H Mix C2	*mix C*	*100*	*0.1*	*27.7*	*92.5*	*34.0*	*46.5*	*38.5*	*-0.134*	*6.4*	*10.8*	*76.1*	*86.9*

Nr. experiment	Food Material	Pipe slope (1:x)	Flow rate(m/s)	Time Arrival (s)	Peak value 1 (g)	Peak Time 1 (s)	Peak value 2 (g)	Peak Time 2 (s)	Decay rate (g/s)	Time between peak 1 AND arrival time	Time between peak 2 AND arrival time	Time of tail* to 0.01g (s)	Total Travel time (s)
V21	mix C	100	0.3	22.7	156.8	24.4	43.5	39.4	-0.106	1.7	16.7	79.0	95.7
V22	mix C	100	0.3	19.7	129.5	22.4	52.0	39.9	-0.109	2.7	20.2	78.5	98.7
V23	mix C	100	0.3	20.7	134.2	24.7	63.3	39.4	-0.105	4.0	18.7	83.4	102.0
V26	mix C	200	0.1	39.7	61.8	43.4	42.5	47.4	-0.070	3.7	7.7	119.4	127.0
V27	mix C	200	0.1	34.9	92.0	38.4	41.0	43.4	-0.065	3.5	8.5	128.0	136.5
V28	mix C	200	0.3	23.7	105.0	26.4	66.7	40.4	-0.078	2.7	16.7	112.9	129.5
V29	mix C	200	0.3	24.4	142.3	25.7	88.5	36.4	-0.096	1.3	12.0	94.7	106.7

* it is estimated with the exponential decay rate reaching 0.01g

4 Pilot research insight

The purpose of this chapter is to summarize research directions and research results of pilot studies on food waste disposers, with emphasis on indoor sewer, which provides insight for subsequent pilot research carried out in the Netherlands by the TKI-OSKAR project partners.

4.1 Background

The production of municipal solid waste (MSW) in Europe is estimated to be some 500 kg per capita per year in Western Countries and some 350 kg per capita per year in Central and Eastern Countries (EEA, 2005), as an average, about 30% of this material is organic waste. Over the past few decades, European countries have implemented several different food waste collection systems for later biological treatment (ACR+,2005). In the Netherlands, about 66.6 kg per capita per year is reported as food waste, from which only about 16% is collected as organic waste (Berg & Telkamp, 2015). Recently it was stated that in the large cities (Amsterdam, Haarlem, Maastricht, Rotterdam) the percentage of organic waste in the residual waste is between 29-34%, and in the regions, is around 26% (Steenhuisen, 2020).

Various alternatives for collecting food waste have been introduced. These include roadside collection and recycling, centralized incineration, home-concentrated composting, etc. (De Koning and van der Graaf,1996). Among those, kitchen grinder installation at the household is one of the options to manage food waste. By using a kitchen grinder, the requirement for transporting and using separate bins can be avoided (Saraiva Schott et al., 2016). After grinding food waste in households, ground food wastewater enters sewage treatment plants through sewers and is treated together with urban sewage (Moñino, et al., 2016). The use of food waste disposers (FWDs) is not a usual practice in Europe, but they are common in other parts of the world, such as North America, Japan, and Australia (Guven et al.,2018).

Recommendations on the use of FWDs as a waste management option differ widely, and there is widespread uncertainty regarding their potential benefits and impacts to wastewater treatment works among the studies. This is mainly because different area-specific characteristics such as water resources, household practices, the condition and infrastructure of the sewer system, and different wastewater treatment processes can affect the viability of FWDs as a waste management option. These characteristics are important factors that are encouraged to evaluate before the adoption of FWDs as a wide-scale waste management option (Lacovidou et al., 2012).

The purpose of conducting a pilot study is to examine the feasibility of an approach that is intended to be used on a larger-scale study. Different countries have different national conditions, regulations, and people's different eating habits that may have an impact on the application and benefits of FWDs. Local authorities in the Netherlands are becoming increasingly interested in exploring a variety of ways to dispose food waste from their residents, mostly related to high-rise buildings. However, the guidance available to them for carrying out studies is currently limited. Therefore, a pilot test of a food waste disposer is necessary for Dutch municipalities to guarantee the success of the implementation in the Netherlands.

4.2 Pilot research objectives

The research objectives of previous FWD pilot studies were focused on the following four aspects:
1 Impact of FWD on users' behavior and water/energy consumption.
2 Impact of FWDs on wastewater treatment plants (WWTPs).
3 Impact of FWDs on transportation in the sewer system.

4 Impact of installing FWDs on the indoor sewer

By describing the research directions of previous pilot studies, insight on the research scope and limitations are obtained, which provide guidance on future research choices for a pilot study with a focus on indoor sewer, which is the focus of this study.

4.2.1 Research-oriented to water consumption and user's behavior

The user's attitude towards FWDs ultimately determines the purchase behavior, and the market's final penetration rate. The user's attitude depends partly on whether the government supports FWDs' usage. The different countries' governments and regions have different opinions on FWDs; thus, they have proposed different measures to encourage or restrict the use of FWDs. In a UK survey on food waste disposers (LGA,2016), in total, 66 % of households with FWDs surveyed completed the questionnaires. 89% of respondents said that they found the FWD easy and convenient to use; meanwhile, 83% of respondents agreed that using the FWD meant that their bin did not smell. The greatest concern with FWD was its water usage, with 56% of respondents agreeing that they worried how much water they use. There was little concern about FWD causing the drain to smell, with 11% of respondents believing this to be an issue. 39% of respondents agreed with both the statements that using FWD means having to clean the sink more often. In the Netherlands, research efforts to understand people's waste separation behavior showed that by instructing people about 20% improvement of organic waste separation improved (Vang HHW, 2020). The latest inferred that educating people on the use of FWDs is essential.

In 2008, in the UK, 5% of households had FWDs (MTP, 2008), an installation rate considered to be the highest amongst the EU member states (EPA, 2008). FWDs use is controlled in European countries, being banned in Austria, Belgium, The Netherlands, Luxembourg, and regulated locally by municipalities in other countries (Carey et al., 2013). The highest installation rate is found in the USA, where 50% of households have FWDs, whereas, in Canada, Australia, and New Zealand, the installation rate of FWDs is about 10%, 12%, and 30% of households, respectively (EPA, 2008). The electrical energy consumed by FWDs will depend on the model, type, frequency, and duration of FWD use (MTP, 2008). It has been difficult to evaluate the actual volume of water consumed by these FWDs. This is because water consumption depends on different household practices (Diggelman and Ham, 2003). The amount of ground food waste generated per capita per day, the frequency of use of the unit, and the duration of the grinding are some of the factors that can cause significant variations in water consumption rates.

Based on the average per capita water consumption, which in the Netherlands is about 107 L per day (Waternet, 2019), it can be suggested that the additional water consumption of 1.19 (our study) – 4 L/per capita per day (average) (see Table 6) due to the use of FWDs would be insignificant. However, in countries or areas where the risk of water scarcity is high, either due to the low availability or high demand, even low increases in water consumption might be crucial, especially with long-term and large-scale use of FWDs.

Table 6 FWD water consumption rates. (Martin, 2015).

Reference	FWD Water Consumption Rate (L/person/day)
Clauson-Kaas, 2011	3-6
CECED, 2003	3-4.5
Kegebein, 2001	3-4.5
Cooperative Research Centre, 2000	2.95
Shpiner, 1997	1.01
de Koning, 1996	4.5
Terpstra, 1995	4.48
Waste Management Research Unit, 1994	4
Average	3.99

The annual electricity consumption is about 2 – 3kWh/household year, assuming an electricity use of FWDs motor (0.5–0.75 hp) of about 350–500W if usage averages 2.4 times per day for 16 s per use (Evans et al. 2010). Assuming an FWD is used for 30 seconds per person daily with a power draw of 1000 W, the estimated power consumption for FWDs is about 0.008 kWh/capita/day (Leverenz and Tchobanoglous, 2013).

4.2.2 Research-oriented to the impact of food waste disposers on the wastewater treatment plants

Most of the research focuses on the impact of installing FWDs on sewage treatment. The main discussion point is biogas production from anaerobic digestion. In the context of recycled energy, more biogas production means that more energy can be recovered from food waste. In addition, the uses of FWD increases the COD concentration in the wastewater and hence the C/N and C/P ratios. The food waste might help the municipal wastewater plant to conduct the biological nitrogen and phosphorus removal procedures more efficiently, and for example can help in the situation of low-carbon, high-nitrogen, and high-phosphorus wastewaters. Several authors suggested that the increases in the organic content of wastewater can be beneficial for wastewater treatment processes, as it can improve the biological nutrient removal and hence reduce the cost of chemicals used to remove nutrients from the wastewater (Thomsen et al., 2018; Maragkaki et al., 2018; Battistoni et al., 2007). Although the increase in TSS, BOD, and COD concentrations by adding ground food in the wastewater has been reported, additional loadings to the WWTP would not cause any significant modifications in wastewater treatment. However, the extra organic load may increase the operational cost of the wastewater treatment process, where the additional aeration and nutrient removal are the main contributions (Zan et al., 2018; Battistoni et al., 2007; Bolzonella et al., 2003; Marashlian and El-Fadel, 2005). Please refer to the Literature review report “Discharging organic kitchen waste via food waste disposers into the sewer system” KWR 2020.078 (Muñoz Sierra, J.D., 2020).

4.2.3 Research-oriented to the impact of food waste disposers on transportation in the sewer system

At present, the two main reasons why FWD may increase the risk of pipeline clogging, are the sedimentation of the large particles, and some fat, oil, and grease (FOG) may stick to the sewer wall. A few studies reported possible suspended solids deposition in the sewerage system (Bolzonella et al., 2003; Galil and Shpiner, 2001). Bolzonella et al. (2003) demonstrated that the different fractions of organic wastes disposed in the sewer, the size of the ground particles, and their settling velocities are important parameters of solids susceptibility to settlement and explained based on measurements that some deposition could be expected in the sewer (Bolzonella et al., 2003). At the same time, researchers are also concerned based on measurements about whether FWDs installation will affect the production of more biofilms or harmful gases in the pipeline, which may increase the corrosion of the drainage system (Zan et al., 2019; Zan et al., 2020).

4.2.4 Research-oriented to the impact of food waste disposers on the indoor sewer system

Only a few studies have been done in the last twenty years on the impact of installing FWDs on the indoor sewer with a focus on high-rise buildings (Minami and Otsuka (2005), (2006)). Compared with traditional clean water drainage, the main component of food waste drainage is a mixed flow composed of kitchen waste, drainage, and air. The researchers pointed out that food waste might accumulate at the bottom of the vertical pipe (Minami and Otsuka (2005). Based on observations, the instantaneous positive pressure wave that occurs when the wastewater strikes the bottom of the vertical pipe may lead to exceed the drainage capacity standard and cause the siphon under the FWD to break. Moreover, the additional drainage load of the ground food waste might result in changes in the ventilation flow of the pipeline, in the pipeline pressure, and changes in the water level, parameters that are significantly important for the indoor sewer system performance, and therefore also for the performance evaluation and design when considering adding the FWDs. The focus of the pilot studies was on these parameters changes and exploring the flow characteristics of the drain and how the instantaneous positive pressure wave affects the entire system. Also, the worst hydraulic conditions of transport of the ground food waste, avoiding food sedimentation were explored (see section 4.4).

4.3 Pilot study design boundary

In order to design a pilot study, different settings such as duration, the number of households, type of monitoring implemented were summarized from previous experiences:

4.3.1 Duration of the pilot study

Among all papers and reports of FWDs surveyed, ten were analyzed further to set the scope for a pilot study. Four of them were executed in a period less than one year long (Thomas, 2011; LGA,2016; SOHGRPIPD, 2013; Lin et al.,2019), two were between one and two years (Battistoni et al., 2007; NYC Department, 1997), two were between 2-5 years (InSinkErator, 2015; Japan National Institution, 2005) and, the final three were carried out over more than five years (Mattsson et al., 2014; Evans et al.,2010; Malmo,2000) (see Figure 34). Battistoni et al. (2007) stated that the criteria for determining the pilot to run for twelve months are the benefit of sufficient monitoring that provides a better understanding of the impact on the environment, systems conditions. However, it is indisputable that the pilot trial duration will depend on the cost of monitoring and evaluation.

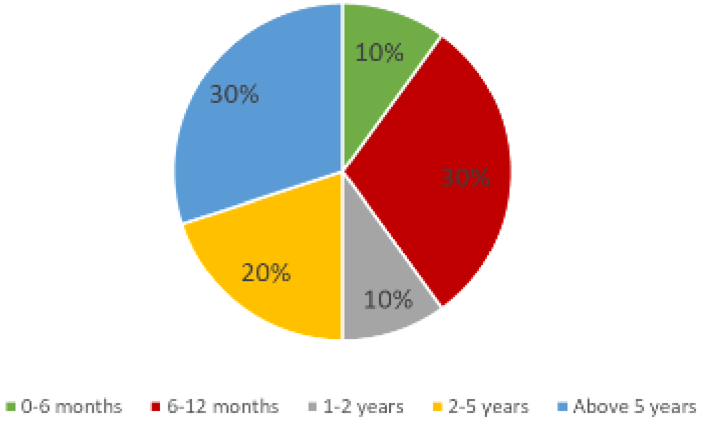


Figure 34 The percentage of the pilot study lasting time

The need to look at the long-term impact of food waste disposers installation in pilot studies, from one to more than ten years, is because pipeline blockages may be the result of long-term accumulation (Arthur et al. 2008).

The short-term pilot studies need certain representativeness and periodicity. The method of comparing before and after the application of FWDs was also applied (Battistoni et al. 2007). The data sampled in the early stage is mainly used for control, which is more beneficial for data analysis. For example, one of the recent studies was carried out for 275 days: 96 before and 179 days after the installation of the FWDs (LGA 2016).

4.3.2 Number of households

We determined the number of apartments involved in the research of pilot studies (SOHGRPIPNA, 2013; LGA 2016; Mattsson et al., 2014; InSinkErator, 2015; Japan National Institute, 2005), and based on the FWDs market penetration rate and population density as an indication (Lacovidou et al., 2012). Some penetration rates of different studies were 36.5% (Japan National Institution, 2005), 50% (Nilsson et al. 1990), and 67% (Battistoni et al. 2007); respectively. All the possible market penetration scenarios reviewed in the literature within 25 and 50% are more due to the fact that after 60 years of marketing FWDs in the US (which is considered the oldest market worldwide) a maximum penetration rate of 50% has been observed (Galil and Yaacov 2001).

From an experimental standpoint, most representative experimentation probably concerns the city of New York. This study looked at three different communities which were in the range of 70-400 households (NYC Department, 1997).

Meanwhile, a maximum of 1,228 households participated in a study in the community from high-rise buildings in Shanghai, China (SOHGRPIPNA, 2013).

LGA (2016) inferred that a pilot of fewer than 50 households would have a high level of uncertainty and that more than 500 households would produce flagging results.

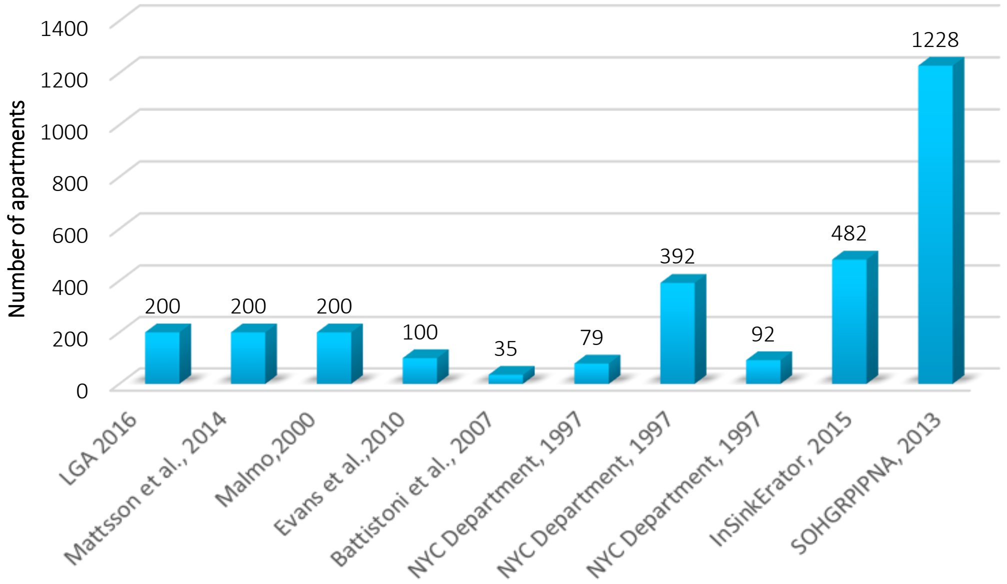


Figure 35 Number of apartments involved in different FWDs implementation pilot studies.

In the Netherlands, the number of households evaluated in the pilot studies in different cities has been:

- Sneek, with about 200 households with FWDs
- Wageningen, 32 apartments with FWDs
- Apeldoorn, 100 households with FWDs (project proposed)

4.3.3 Collection methods and sampling parameters

At present, there are two main methods to collect FWDs discharge, off-grid, and on-grid. Off-grid collects the ground food waste in a tank, normally a septic tank, and the supernatant is discharged regularly, while the settling material is recycled (Lin et al., 2019). On-grid discharges the wastewater from FWDs through the existing sewage system (Battistoni et al., 2007). At present, most of the pilot studies are based on on-grid applications.

For changes in water quality, the location of the sampling is very important. An inspection site in the sewer outside the high-rise building is convenient to avoid measurement interferences (SOHGRPIPNA, 2013).

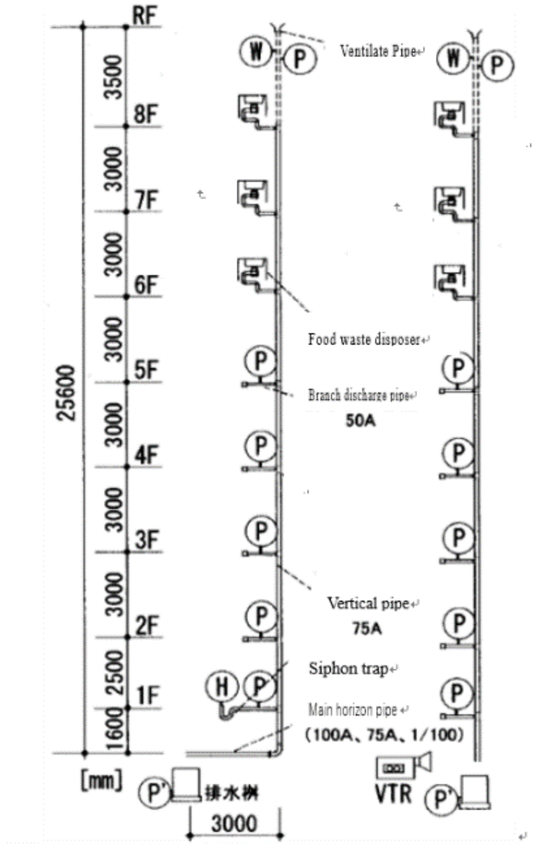
The following parameters are normally characterized: total Nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), suspended solids after one-hour settling, biochemical oxygen demand (BOD), chemical oxygen demand (COD), FOG; and settled solids after 30 minutes. Depending on the aim, parameters such as flow rate or water consumption, velocity, frequency of discharges, are key to be monitored in key locations of the sewer pipelines. The monitoring plan needs to be organized for sampling on the same day every month, the same hours of sampling during the day (LGA 2016).

4.4 Pilot studies outcomes with a focus on Indoor Sewer

Minami and Otsuka (2005), (2006) evaluated the FWDs indoor sewer system in Japanese high-rise buildings. Both studies were carried out at the Kanto Gakuin University in a building with 9 floors, 23.6 meters high in total. The water flow rate was set up at 4, 6, and 8 L/min by using a digital flow meter. The grinding was carried out for 40 seconds from start to finish. Clean water was provided for 5 seconds before and after the grinding, and the FWD continued to operate for 30 seconds, i.e. 2.7 L, 4 L, and 5.3 L per use. 250g, 500g, and 750g of food waste were used for the evaluation (see Table 7). For simulating the real condition, researchers discharge ground food waste from 3 floors at the same time (floors 2+3+4, 4+5+6, 6+7+8) and compared it with the situation of single discharge (see Figure 36).

When the clean water flows from the highest three floors (8, 7, and 6) was 8 L/min, the ventilation flow was 9.9 L/s (Minami and Otsuka (2005). However, when ground food waste was drained, under the same conditions, the ventilation flow rate was 20.5 L/s, which is about twice compared to clean water drainage.

Under normal clear water discharge conditions, the maximum ventilation flow value will increase with the height of the floor. But when the water flow rate is at a low level, the maximum ventilation flow tends to increase. It can be inferred that the lower the water flow rate is, the easier the wastewater and food waste separated in the pipe, and by flowing down draws in more air. Therefore, in the design, compared with the clean water drainage, the load of the vertical stack pipe becomes critical and must be taken into account to avoid creating positive pressure in the system. If the water flows impact into ground food waste accumulated near the elbow of the vertical pipe, an instantaneous positive pressure wave is generated and may break the siphon or seal of the sinks.



○,W	Anemograph (Ventilation flow)
○,P	Pipe inner pressure
○,H	Water level in trap
○,P'	Discharge Value

Figure 36 Pilot study experimental scheme.

Table 7. Experimental parameters evaluated in Minami and Otsuka (2005) (2006).

Parameter	Value
Particle size after grinding	1mm & 0.5mm
The diameter of the Branch drainage pipe	50mm
The diameter of the Vertical pipe	75mm
Main horizon pipe	75mm/100mm
Water flow rate	4, 6 and 8 L/min
FWDs working time	40s (5 seconds before and after the operation, and the food waste disposer lasting time is 30 seconds)
Amount of food waste	250g and 500g & 100, 250, 750 g

Minami and Otsuka, (2006) found that when 3 apartments (8+7+6 floors) drained at the same time with a water flow rate of 8L/min and 250g of food waste was put in, only a small amount of eggshells left the bottom of the pipe intermittently. When the water supply flow rate was 8L/min, and the drainage came from floors 6+5+4, 4+3+2, the ground food waste was completely transported in the pipeline. Under 4l/min, and three floors discharge at the same time, ground food waste was scattered in the horizontal pipe. Therefore, even if the water flow was under 4 L/min, as long as the water is drained from three places at the same time, food waste will not be accumulated in the pipes. However, when there was a discharge only from one floor, the risk of stagnation increased with a lower flow rate and on the lower floors. The worst situation occurred on the second floor and 4L/min.

Minami and Otsuka (2006) also investigated the transport performance in the main drainage horizontal pipe and the force required to transport the ground food waste. By studying the changes in water flow, food waste input, and floor height, and understanding the impact of these variables on the flow rate and transportation performance, they proposed suitable values for indoor sewer pipes design. To test the minimum force to move the food disposer forward, the researchers set two points in the main horizontal pipe with a distance from the vertical pipe of 600mm and 2600mm, respectively. The study established a model equation to analyze the stress of the food waste deposited on the bottom of the vertical pipe when it is impacted by the water flow discharge.

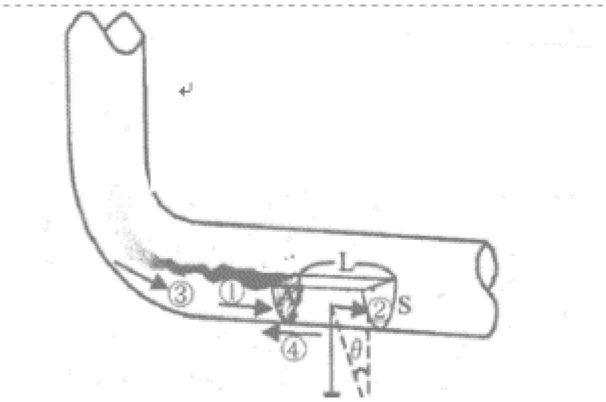


Figure 37. The force diagram of the food waste impacted by the liquid at the bottom of the vertical pipe

$$F_c = \rho g h_g A + mg \sin\theta + f_p$$

F_c: the force required to push food waste.

$\rho g h_g A$: the hydrostatic pressure remaining on the food waste.

$mg\sin\theta$: the horizontal component of gravity produced by the sediment.

f_p is the force generated when the water hits the food waste. However, it was omitted because it is difficult to quantitatively measure the corresponding force.

If the design is required under harsh conditions in terms of transportation performance, a force of 0.92N with 250g, 1.61N with 500g, and 2.74N with 750g is required, which makes food waste flow away smoothly. The water depth and the force are linearly distributed. For example, in the case of a pipe with a diameter of 100 mm and about 250 grams of food waste, by increasing the drainage water level to about 52 mm (water depth ratio is 0.52), food waste can start flowing forward. The recommended value of the flow velocity in the horizontal drainage pipe was 0.6 m/s. Based on this recommended value, food waste can be transported smoothly.

4.5 Pilot study recommendations

The impact of FWDs on the indoor sewer in high-rise buildings has been barely studied. Studies looking at transportation in sewers assumed clogging could occur, but it has not been shown yet. Our laboratory experiments with horizontal and vertical pipes in the TKI OSKAR project showed that in principle, there is no obstacle for using FWDs, but in practice and long-term, this needs to be confirmed. More pilot studies are required to support new designs, results of experiments, and models. A more in-depth understanding of how multiple discharges may affect the pressure of the pipeline and the ventilation system in the indoor sewer is required. Furthermore, when studying the impact of installing FWDs on indoor sewer pipes, the experimental results of a single apartment, and several apartments from different floors together will differ, especially when the discharge from the food waste disposer is combined with discharge from other appliances.

Based on the aforementioned pilot research insight, we have formulated the following recommendations:

1. The duration of the pilot study must be at least two years.
2. A study with at least 200 apartments with FWDs installed in all of them is needed, assuring users are fully instructed on the proper use of the device.
3. Measurements should take place at the lowest point in the shaft and just outside the building.
4. The study should not start with new/clean pipes but with used pipes.
5. Monitoring of the following parameters is required: COD, TSS, TN, TP, FOG, velocity, water consumed/discharged. Inspection of unwanted objects getting out of the indoor sewer is also recommended. Monitoring must be regularly and well-defined periodicity (same days and hours of the month).
6. Monitor the water and energy use of FWDs, and compared data to LCA results.

5 Practical design of indoor-sewer pipes for a typical Dutch building

5.1 Typical Layout

For a practical analysis of the dimensioning of the pipes for a typical building in the Netherlands, a *portiekflat* was selected as presented in Figure 38. Five floors and 40 apartments, plus a ground floor with storage and common areas.

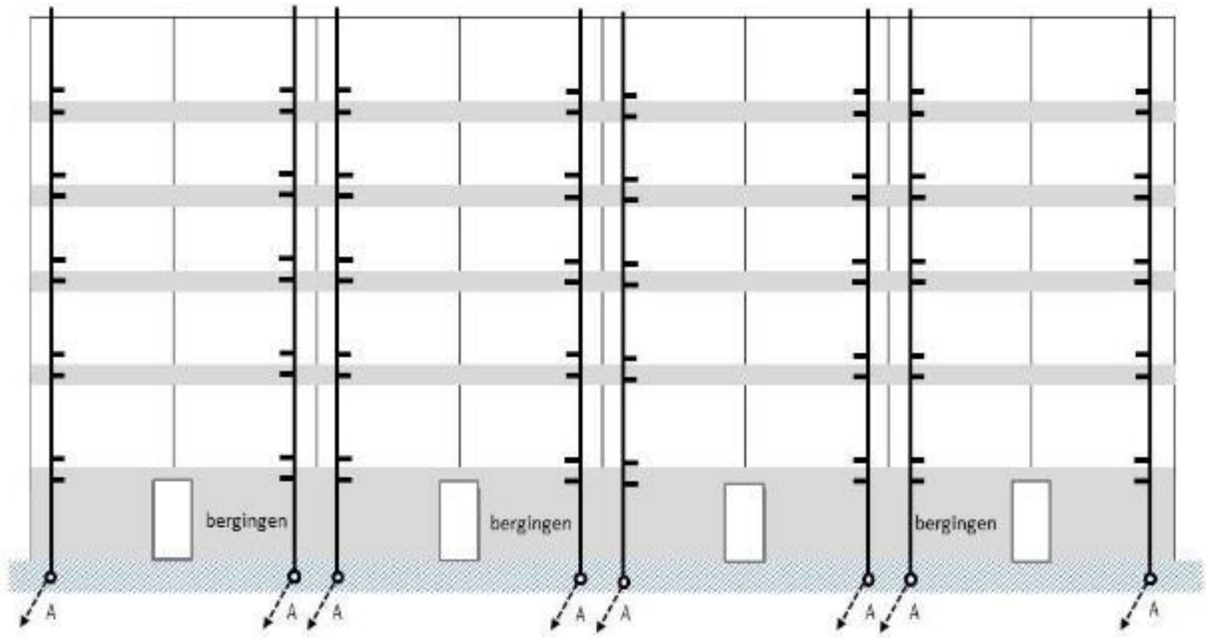
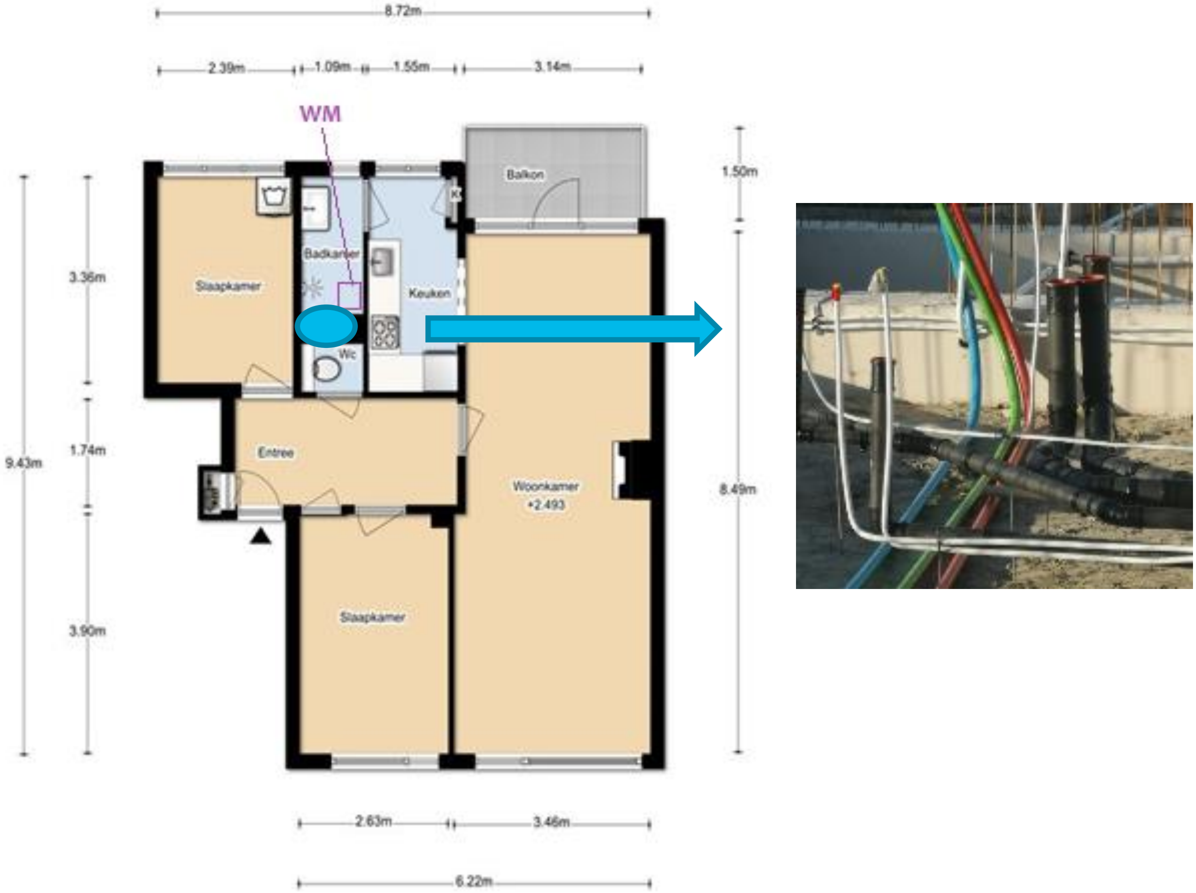


Figure 38. Typical portiekflat building vertical stacks layout (Provided by Will Scheffer, TVVL Expertgroep Sanitaire Technieken). Five floors and 40 apartments, plus a ground floor. Vertical pipelines are marked as A, meaning a total of eight vertical pipe stacks.

In order to select a configuration of the pipe system, a typical apartment needs to be chosen in terms of the number of appliances. The typical setup of appliances in an apartment household is presented in Figure 39 where the location of the vertical pipe collector is presented. All apartments in the building have been designed with the same floor plan, although this is just an exercise of quantification of the dimensioning of pipes for a typical building. Typically a Dutch apartment contains a bathroom, kitchen, and sometimes a separate toilet. A difference with other countries is that there is no sink located in any bedroom in a typical Dutch apartment. To save space the kitchen and bathroom are generally located close to the vertical pipe. In addition, no bathtub or Jacuzzi are considered or outside taps to sprinkle outside the garden. In most portiekflats such appliances are not part of the typical household. There are two different configurations of horizontal pipes inside the apartment presented in

Figure 40. The first configuration considers only a horizontal pipe for the kitchen grinder (off-grid), while the second configuration considers the combination of kitchen and bathroom effluent. Regarding the vertical pipes, the configuration of the stacks is the same.

In addition, three different pipe design methodologies were considered taking into account Dutch (NL), British (UK), and a Chinese (CN) method. In general, the Chinese method deviates just in some parameters from the United Kingdom method.



(A) Typical layout and distribution of appliances inside an apartment. Blue oval shows the location of the vertical pipes.

(B) Typical location of vertical pipes stacks on the ground floor of a multistorey building. The black pipe corresponds to the sewer pipe.

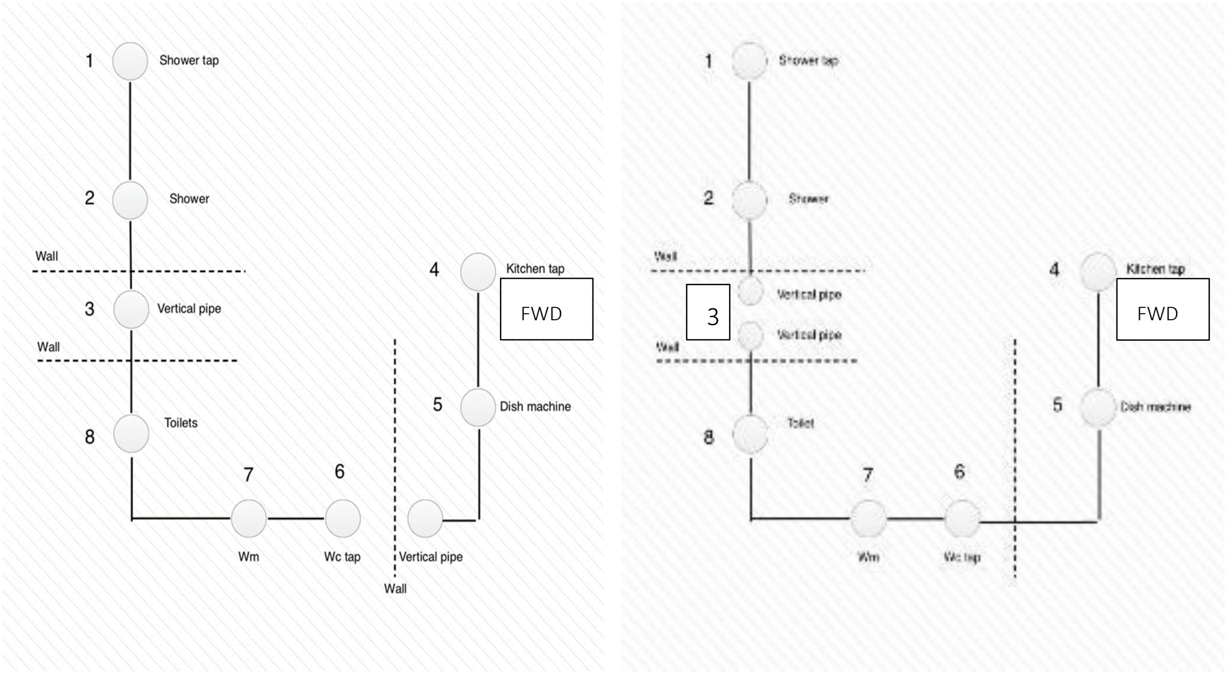
Figure 39. Typical layout of an apartment in the Netherlands. This can vary from building to building; however, the configuration of pipelines is representative of the distribution in multistorey buildings

All methods require the use of different parameters to indicate the expected capacity to be conveyed by each branch (independent of the configuration, as presented in

Figure 40. The most relevant being the required flow capacity. For this, a set of consumption patterns was developed using SIMDEUM®. This tool allows for the synthetic generation of stochastic patterns based on demographics and typical consumption of the various appliances in a Dutch household. It has been broadly used in the Netherlands and abroad and has demonstrated a good adjustment to real consumptions for both drinking water(Blokker et al. 2017, Blokker et al. 2011), smart metering (Steffelbauer et al. 2020) and sewer water(Bailey et al. 2019, Bailey et al. 2020).

The location of devices, the number of devices per apartment, and the patterns considered in each case are presented in Table 8. In some cases, for example, the shower, both cold and hot water patterns are considered. The same is true for the case of the kitchen tap where both cold and hot water are available. The FWD is assumed to be attached to the kitchen tap. For each device, a set of 365 daily patterns was generated. Each pattern corresponds to daily consumption (24 hr) of an average family (2.1-2.2 inhabitants/household) with a time resolution of 10 s. The patterns include both weekdays and weekend patterns; however, for the design of the sewer pipes it is considered the maximum simultaneous flow in a specific branch, as presented in

Figure 40, as this is the maximum required flow for such pipe. For the vertical pipe, the calculations are made taking into account the maximum flow for a household. In early trials no superposition of flows was observed, this means that in general there are basically simultaneous flushes of apartments located in a vertical stack are seldom to occur, the flow of the vertical pipe will correspond to the flow of an individual household.



(A) only kitchen (off-grid) (B)Kitchen + WC (combined sewer)

Figure 40. Representation of pipelines to be taken into account for the pipe sewer design. A) taking into account separated pipes for kitchen, B) combined sewer system, including kitchen and bathroom appliances.

Table 8 Patterns of water consumption considered for each apartment for pipe sizing calculation.

Location	Device	Water Consumption Patterns
Bathroom	Shower	Shower_COLD, Shower_HOT
	Tap water	Brtap_COLD,. Brtap_HOT
	WC	WC_COLD_#1,. WC_COLD_#2,. WC_tap_COLD
Kitchen	Tap water (including FWD)	Ktap_COLD,. Ktap_HOT
	Dishwasher	Dw_COLD
Other	Washing Machine	Wm_COLD

5.2 Horizontal pipes dimensioning

Based on the patterns, the maximum flow is obtained for each configuration of Figure 40. Three methods of calculation were used: NL with maximum simultaneous flow rate, Chinese method, and UK method. The three methods of calculation used to obtain very similar pipe dimensioning for both configurations, as presented in Table

9. All pipes have been designed for a slope of 0.02 m/m or (1:50). The only discernible difference is the pipe size for the branch 4—5, which corresponds to the one connected to the kitchen tap or to the food grinder itself. However, it is of notice that the three methodologies over-dimension based on different factors, for that reason the pipe of branch 5—6 is able to convey both the water of the kitchen tap and the water from the dishwasher (depending on the configuration of Figure 40, either to the vertical pipe or to the branch 6—7). This means in general that

Table 9. Dimensioning of horizontal pipes for a typical apartment with a slope of 1:50.

Branch	Design flow rate (NL)	pipe size	Design flow rate (CN)	pipe size	Design flow rate (UK)	pipe size
-	(L/s)	(mm)	(L/s)	(mm)	(L/s)	(mm)
1--2	0.354	50	0.277	50	0.354	50
2--3	0.612	75	0.885	75	0.791	75
4--5	0.433	*50*	0.855	75	0.707	75
5--6	0.612	75	0.960	75	1.000	75
6--7	0.707	75	0.982	75	1.061	75
7--8	1.000	75	1.393	75	1.369	75
8--3	1.225	75	1.483	75	1.620	75

After a round of concertation with the project partners, one of the aspects to be considered was that the typical Dutch building considers a pipe slope of 5mm/m or 1:200. This indicates that the pipe diameter should be estimated using the NEN 3215. After using the slope proposed by TVVL partners (Table 10), vs the slope used in the first stages of research, it shows that there is not a large difference with the obtained diameters for both pipe slopes.

Table 10. Comparison of pipe dimensioning of horizontal pipes for two different slopes.

Branch	Pipe size (1:50)	Pipe size (1:200)
-	(mm)	(mm)
1--2	50	50
2--3	75	75
4--5	*50*	75
5--6	75	75
6--7	75	75
7--8	75	75
8--3	75	*90*

5.3 Vertical pipe dimensioning

As for the vertical pipe, the dimensioning was made, taking into account the same three methods. In this case, the vertical pipe size takes into account the flow of the current floor plus the previous ones. Notice that the total flow rates are not corresponding to the sum of all the flows of the horizontal pipes. This is due to the fact that taking into account the simultaneity of flows in the pipe (which is very uncommon), the design flow rates do not represent the total flow. The corresponding pipe sizes are presented in Table 11. For both Dutch (NL) and Chinese (CN) method, the vertical pipe sizes are similar, while for the case of the British (UK) method, there is a large diameter, although this pipe diameter corresponds to the next available diameter in different catalogs obtained from commercial pipe vendors. In general, the three methods are consistent in delivering a similar pipe size. It should be noted that this dimensioning of the vertical pipe also depends on the type of ventilation used, the type of pipe fitting from horizontal to vertical pipe, while these are not considered within this study.

Table 11 Dimensioning of vertical sewer pipes.

Method	Dutch NL	Chinese CN	British UK
Design flow rate (L/s)	3.06	2.35	4.03
Pipe size (mm)	110	110	125

6 Conclusions

In a typical Dutch high-rise building situation, the only potential issue found is within the apartment with a slope to faint (1:50 recommended). Pipe length, the number of bends of the indoor sewer configuration, and the exact flow of flushing are less important. A three weeks stagnant period is no problem either. The vertical pipes are beneficial only in preventing blockage. The different type of food is not an issue for the indoor sewer, neither their combination. No 100% fat in 250 g of food should be discharged, otherwise, no problem was identified in the short-term.

Therefore, there is no obstacle for using FWDs from the indoor sewer perspective, but in practice and long-term, this needs further confirmation in a pilot study. A more in-depth understanding of how multiple discharges may affect the pressure of the pipeline and the ventilation system in the indoor sewer is required, as well as the discharge from the food waste disposer combined with discharge from other appliances. A pilot study with a duration of at least two years, 200 apartments, with well-defined periodicity and regular monitoring of parameters such as COD, TSS, TN, TP, FOG, velocity, water consumed/discharged, as well as water and energy use of FWDs.

Based on the results, the following specific conclusions were drawn:

- The COD value of the ground food wastewater from seventeen different types of food varied significantly, however, a high percentage (67%) of the added COD is particulate and could be separated in the primary sedimentation process. The total nitrogen and phosphate concentrations of the wastewater flow from the FWD were on average 30 mg/L and 124 mg/L, respectively.

- Water consumption increased with the majority of food types by 1.16 L/p.d when using a FWD. This amounts to an increase of 1.3% in the total average water use in the Netherlands per person of about 107 liters per day.

- The slope of the horizontal pipe has the greatest influence on the amount of food remnants in the indoor sewer pipe followed by the flow. Applying a slope of 1:50 greatly reduces or even counteracts the negative consequences of other variables such as the number of bends or length. The residue that remains at a slope of 1:50 is removed with another flush and does not accumulate in the pipe.

- The layout with the variables: 63mm, 1:200, 8 meters long, 3 bends, and 0.1 L/ s flushing flow was the most detrimental layout with about 238 grams of ground food remnants in the collection pipe after one flush. The layout with the variables: 63mm, 1:50, 5 meters long, 1 bend, and 0.3 L/s flushing flow was the most beneficial. Only 6 grams of ground food remnants remained in the collection horizontal pipe after one flush.

- No accumulation of ground food waste was observed in the vertical pipe or the bottom horizontal pipe.

- Flushing only completely saturated fat (i.e., 250 g), regardless of the layout or installation of a food waste disposer, may lead to issues of blockage or accumulation.

- In case a food waste disposer is installed in the sink, the current standards for indoor sewer in the NEN (3215+C1+A1:2018) should be followed with the explicit requirement of a minimum slope of 1:50 in the collection horizontal pipe.

- To change the specific text in the NEN (3215+C1+A1:2018) article 4.1.6 “Het gebruik van voedselrestenvermalers is niet toegestaan”, pilots (practical testing) shall be executed to validate that with the installation requirements in NEN 3215 (including the minimum slope of 1:50 in the collection horizontal pipe) the ground food waste will be transported in the sewage systems without causing any problems.

- A long interruption in the use of a food waste disposer, for example, due to holidays, does not lead to negative effects on the functioning of the internal sewer system and the remnants are easily taken along by subsequent flushes. In addition, there was no production of H_2S but methane production was observed after this period while the pipe was sealed (without ventilation).

- Our laboratory experiments with horizontal and vertical pipes in the TKI OSKAR project showed that in principle, there is no obstacle for using FWDs, but in practice and long-term, it needs to be confirmed with a pilot study. Until this is done the consequences from the results presented in this report are not fully clear and should be dealt with caution.

The use of FWDs, either via indoor and city sewer (on-grid) or collected after indoor sewer (off-grid) are ways to collect organic waste from high-rise buildings as circularity becomes more important for the Dutch municipalities. The current ban on the use of food grinders originates in the Dutch waste policy. This also includes food waste being collected separately as organic waste in most Dutch municipalities. The introduction of food grinders is considered to put an additional burden on the sewage system, both in terms of the potential blockage of the sewage pipes and higher emissions at the WWTP. Nonetheless, the local circumstances of the organic waste collection can differ substantially at the national level. Not all municipalities collect organic waste on a household level and also the collection of organic waste is challenging in high-rise buildings. The use of food grinders seems to be most promising for households in these conditions. Based on the current legislation some exclusions appear to be possible as municipalities have the authority to provide alternative ways of waste collection in designated areas. In the case they would promote the use of food grinders this would include the separate treatment of the wastewater outside of the WWTP (off-grid). Within the current legislation, the treatment of waste from the food grinder in the WWTP (on-grid) is considered undesirable by the national government and is therefore discouraged.

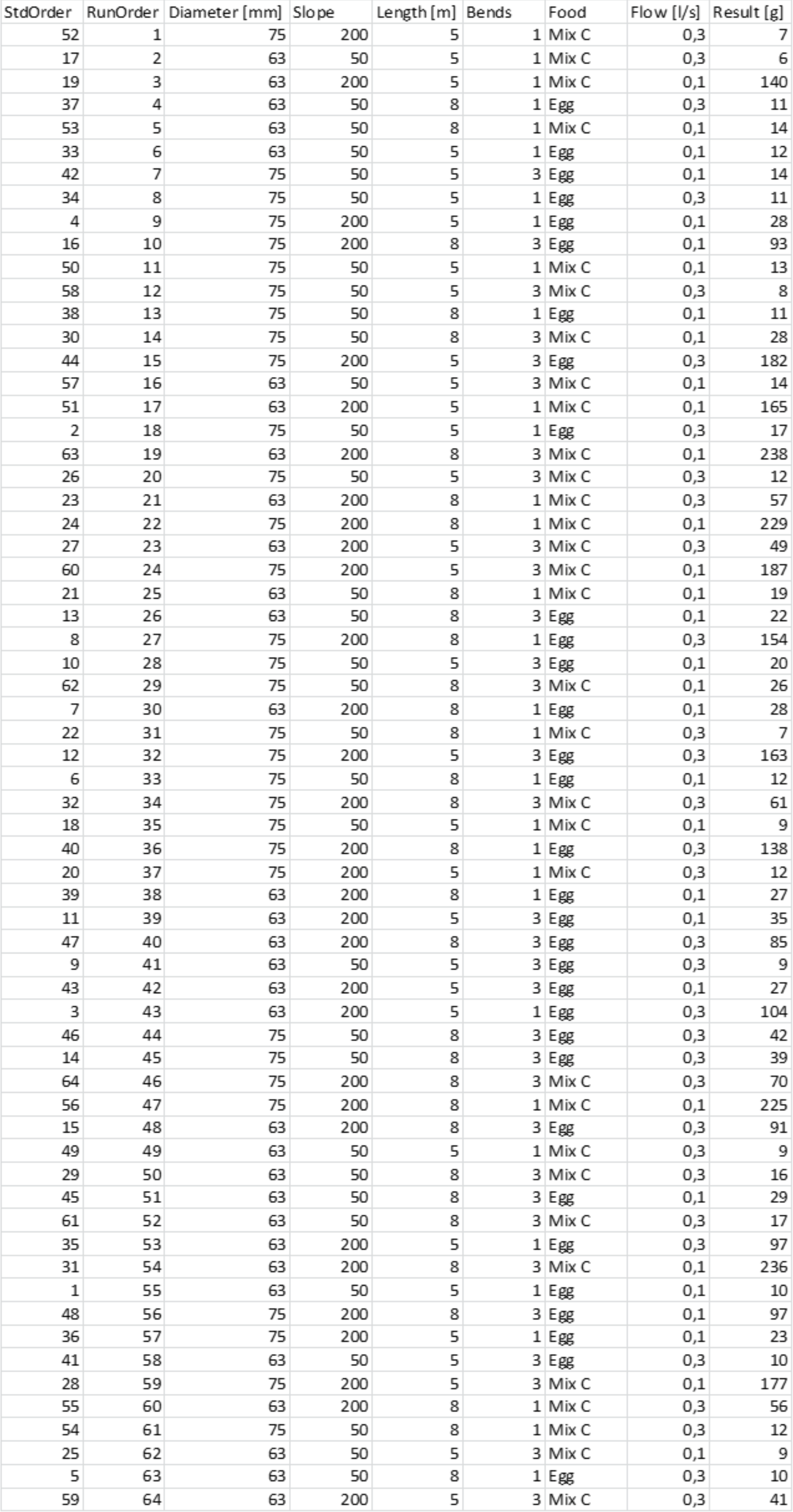
LCA results confirmed the conclusion from STOWA that the removal of organic kitchen waste via kitchen and garden waste collection has a lower impact than via the sewer system with an updated life cycle inventory, albeit to a lesser extent. The parameter sensitivity analysis shows four important key points. Firstly, the greening of the energy form mainly has a favorable effect on the scenario with discharge via the sewer system. Secondly, reducing water consumption per kg of ground food lowers the environmental impact. Thirdly, it appears that in the scenario with discharge via the sewer system, the impact of the grinder is very large, it appears to be worthwhile (~ 20%) if several households (4) dispose of their kitchen waste via the same grinder. The advice is, therefore, optimizing the use of the FWD and focus primarily on the options for having several households disposed of via one grinder, or extend the lifetime of the grinder. The disposal of food waste is mainly considered in high-rise buildings, where food waste is mainly disposed of via residual waste. In this model, the removal of food residues via the sewer system scores significantly better than the removal via residual waste.

In the Netherlands, research efforts to understand people’s waste separation behavior showed that by instructing people the organic waste separation improved by 20%. The latter, together with the different water consumption reported by using FWDs, inferred that educating people on the proper use of FWDs is essential before implementation. Furthermore, in the municipal sewer, quantifying the impact due to implementation of FWDs with water conservation technologies and various penetration rates on wastewater quality parameters and transport carried out by TKI project New Urban Water Transport Systems (NUWTS), suggested that traditional/contemporary city sewer system in the Netherlands does not comply in transporting flow with ground food waste.

We recommend FWDs as a viable option to improve the waste collection of the organic kitchen waste concerning the indoor sewer.

I Experimental fractional design

Table 12. Experimental fractional design. Total of combinations for the 64 experiments carried out and the response.



StdOrder	RunOrder	Diameter [mm]	Slope	Length [m]	Bends	Food	Flow [l/s]	Result [g]
52	1	75	200	5	1	Mix C	0,3	7
17	2	63	50	5	1	Mix C	0,3	6
19	3	63	200	5	1	Mix C	0,1	140
37	4	63	50	8	1	Egg	0,3	11
53	5	63	50	8	1	Mix C	0,1	14
33	6	63	50	5	1	Egg	0,1	12
42	7	75	50	5	3	Egg	0,1	14
34	8	75	50	5	1	Egg	0,3	11
4	9	75	200	5	1	Egg	0,1	28
16	10	75	200	8	3	Egg	0,1	93
50	11	75	50	5	1	Mix C	0,1	13
58	12	75	50	5	3	Mix C	0,3	8
38	13	75	50	8	1	Egg	0,1	11
30	14	75	50	8	3	Mix C	0,1	28
44	15	75	200	5	3	Egg	0,3	182
57	16	63	50	5	3	Mix C	0,1	14
51	17	63	200	5	1	Mix C	0,1	165
2	18	75	50	5	1	Egg	0,3	17
63	19	63	200	8	3	Mix C	0,1	238
26	20	75	50	5	3	Mix C	0,3	12
23	21	63	200	8	1	Mix C	0,3	57
24	22	75	200	8	1	Mix C	0,1	229
27	23	63	200	5	3	Mix C	0,3	49
60	24	75	200	5	3	Mix C	0,1	187
21	25	63	50	8	1	Mix C	0,1	19
13	26	63	50	8	3	Egg	0,1	22
8	27	75	200	8	1	Egg	0,3	154
10	28	75	50	5	3	Egg	0,1	20
62	29	75	50	8	3	Mix C	0,1	26
7	30	63	200	8	1	Egg	0,1	28
22	31	75	50	8	1	Mix C	0,3	7
12	32	75	200	5	3	Egg	0,3	163
6	33	75	50	8	1	Egg	0,1	12
32	34	75	200	8	3	Mix C	0,3	61
18	35	75	50	5	1	Mix C	0,1	9
40	36	75	200	8	1	Egg	0,3	138
20	37	75	200	5	1	Mix C	0,3	12
39	38	63	200	8	1	Egg	0,1	27
11	39	63	200	5	3	Egg	0,1	35
47	40	63	200	8	3	Egg	0,3	85
9	41	63	50	5	3	Egg	0,3	9
43	42	63	200	5	3	Egg	0,1	27
3	43	63	200	5	1	Egg	0,3	104
46	44	75	50	8	3	Egg	0,3	42
14	45	75	50	8	3	Egg	0,3	39
64	46	75	200	8	3	Mix C	0,3	70
56	47	75	200	8	1	Mix C	0,1	225
15	48	63	200	8	3	Egg	0,3	91
49	49	63	50	5	1	Mix C	0,3	9
29	50	63	50	8	3	Mix C	0,3	16
45	51	63	50	8	3	Egg	0,1	29
61	52	63	50	8	3	Mix C	0,3	17
35	53	63	200	5	1	Egg	0,3	97
31	54	63	200	8	3	Mix C	0,1	236
1	55	63	50	5	1	Egg	0,1	10
48	56	75	200	8	3	Egg	0,1	97
36	57	75	200	5	1	Egg	0,1	23
41	58	63	50	5	3	Egg	0,3	10
28	59	75	200	5	3	Mix C	0,1	177
55	60	63	200	8	1	Mix C	0,3	56
54	61	75	50	8	1	Mix C	0,3	12
25	62	63	50	5	3	Mix C	0,1	9
5	63	63	50	8	1	Egg	0,3	10
59	64	63	200	5	3	Mix C	0,3	41

II Fractional Design model including food type (Minitab 2018)

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5,56496	99,66%	99,33%	98,64%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	31	289969	9354	302,04	0,000
Linear	6	146402	24400	787,90	0,000
Diameter	1	2943	2943	95,03	0,000
Slope	1	124609	124609	4023,70	0,000
Length	1	5256	5256	169,73	0,000
Bends	1	3511	3511	113,36	0,000
Food	1	4193	4193	135,38	0,000
Flow	1	5891	5891	190,21	0,000
2-Way Interactions	15	82805	5520	178,26	0,000
Diameter*Slope	1	1463	1463	47,24	0,000
Diameter*Length	1	315	315	10,17	0,003
Diameter*Bends	1	342	342	11,05	0,002
Diameter*Food	1	3025	3025	97,68	0,000
Diameter*Flow	1	156	156	5,05	0,032
Slope*Length	1	1560	1560	50,38	0,000
Slope*Bends	1	689	689	22,25	0,000
Slope*Food	1	6360	6360	205,37	0,000
Slope*Flow	1	4935	4935	159,36	0,000
Length*Bends	1	203	203	6,56	0,015
Length*Food	1	1661	1661	53,62	0,000
Length*Flow	1	1620	1620	52,31	0,000
Bends*Food	1	49	49	1,58	0,218
Bends*Flow	1	156	156	5,05	0,032
Food*Flow	1	60270	60270	1946,16	0,000
3-Way Interactions	10	60761	6076	196,20	0,000
Diameter*Slope*Length	1	203	203	6,56	0,015
Diameter*Slope*Bends	1	9	9	0,29	0,594
Diameter*Slope*Food	1	1980	1980	63,94	0,000
Diameter*Slope*Flow	1	2	2	0,07	0,789
Diameter*Length*Bends	1	52670	52670	1700,75	0,000
Diameter*Length*Food	1	210	210	6,79	0,014
Diameter*Length*Flow	1	30	30	0,98	0,330
Diameter*Bends*Food	1	1871	1871	60,40	0,000
Diameter*Bends*Flow	1	1958	1958	63,23	0,000
Diameter*Food*Flow	1	1828	1828	59,01	0,000
Error	32	991	31		
Total	63	290960			

Regression Equation in Uncoded Units

result = 2615 - 39,00 Diameter + 0,896 Slope - 419,9 Length - 1354,1 Bends - 311,3 Food
+ 523 Flow - 0,00765 Diameter*Slope + 6,192 Diameter*Length + 19,794 Diameter*Bends
+ 4,675 Diameter*Food - 6,24 Diameter*Flow - 0,1382 Slope*Length - 0,014 Slope*Bends
+ 0,986 Slope*Food - 0,272 Slope*Flow + 218,75 Length*Bends + 17,29 Length*Food
- 26,5 Length*Flow + 61,30 Bends*Food - 200,5 Bends*Flow + 94,7 Food*Flow
+ 0,00264 Diameter*Slope*Length + 0,00083 Diameter*Slope*Bends
- 0,01236 Diameter*Slope*Food - 0,00128 Diameter*Slope*Flow
- 3,1875 Diameter*Length*Bends - 0,2014 Diameter*Length*Food
+ 0,235 Diameter*Length*Flow - 0,901 Diameter*Bends*Food + 2,837 Diameter*Bends*Flow
- 2,740 Diameter*Food*Flow

III Effects plots

Main effects Plots and interaction of effects for Mix C (Minitab 2018)

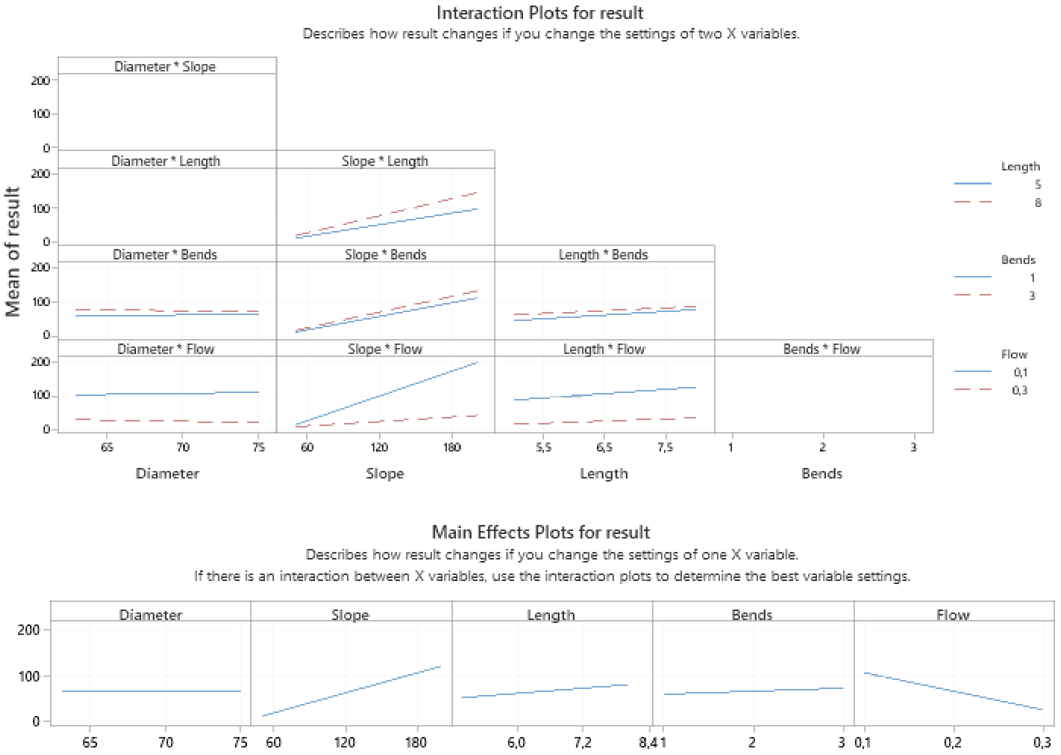


Figure 41 Main effects Plots and interaction of effects for Mix C

Main effects Plots and interaction of effects for Eggs

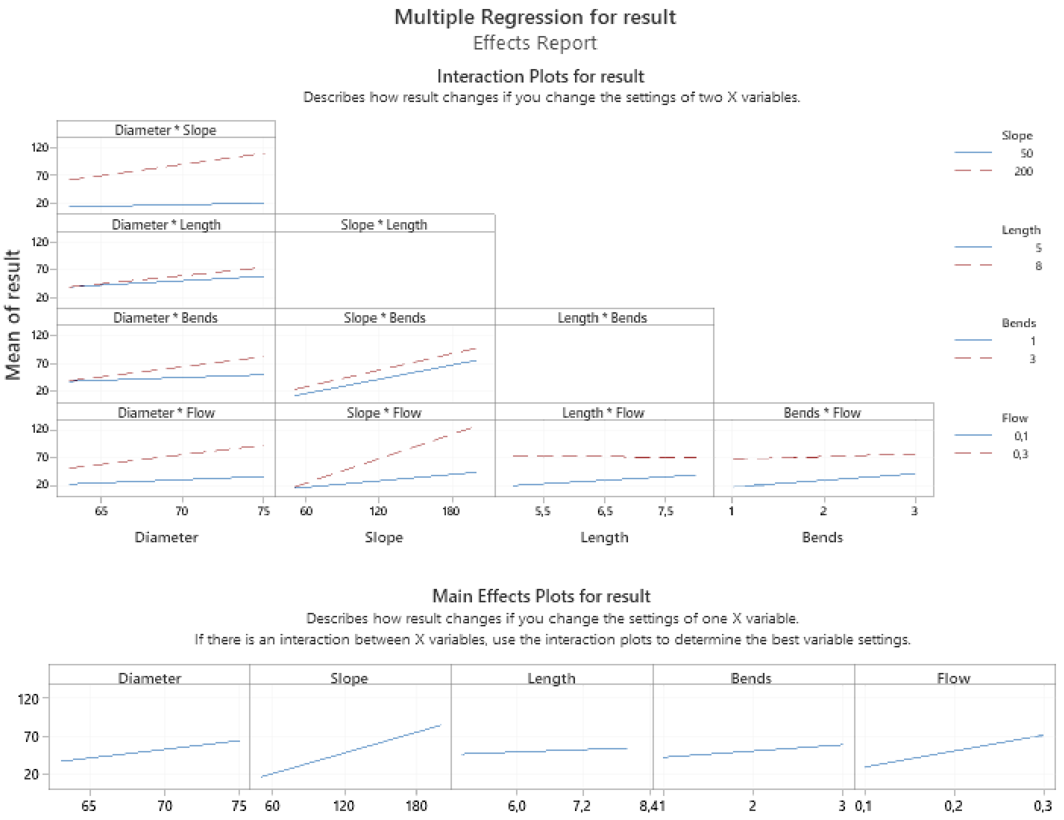


Figure 42 Main effects Plots and interaction of effects for Eggs

IV Outlet hydrographs

Outlet hydrographs of horizontal sewer pipe for different food types – Part 1

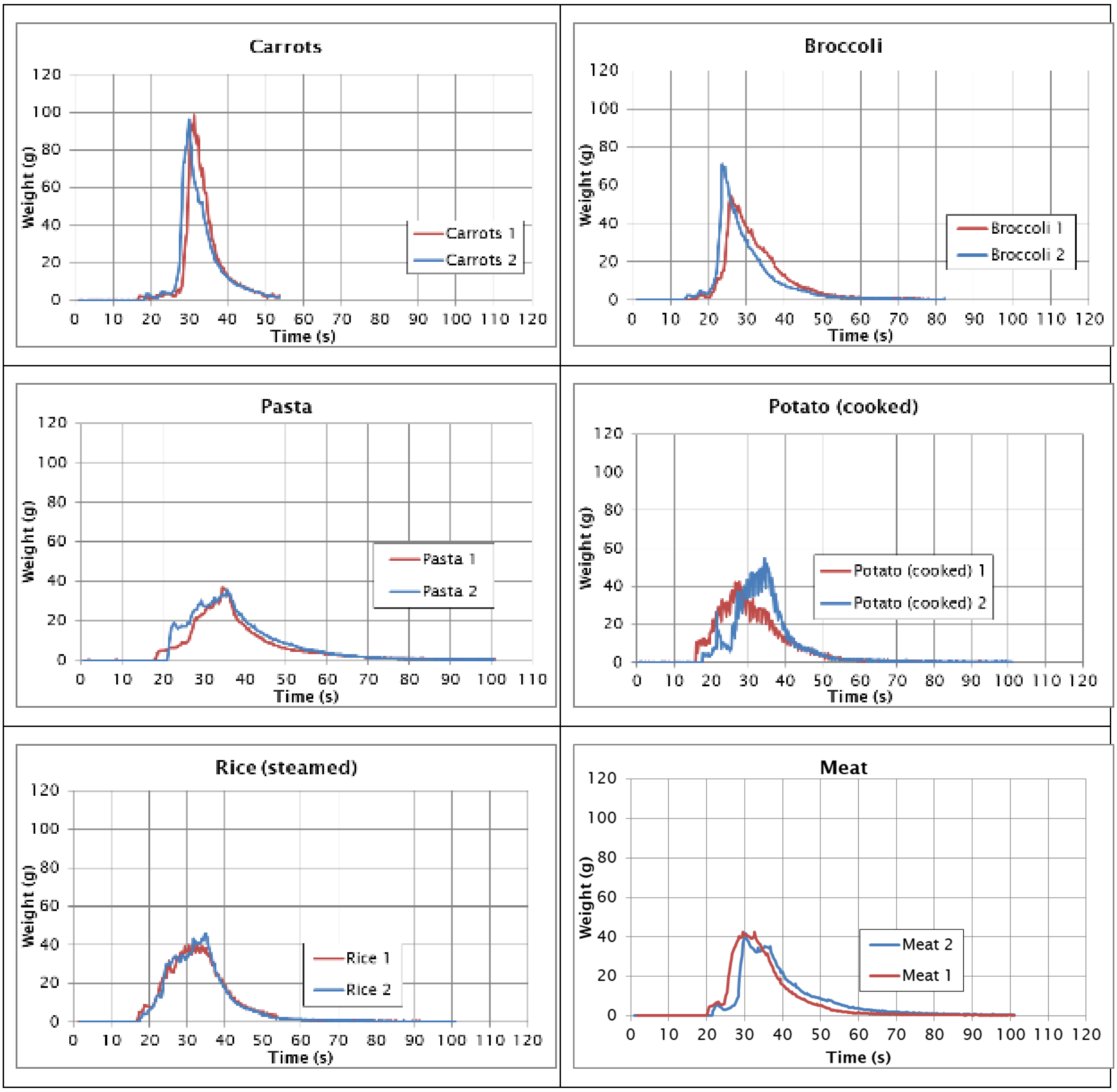


Figure 43 Outlet hydrographs of horizontal sewer pipe for different food types – I

Outlet hydrographs of horizontal sewer pipe for different food types – Part 2

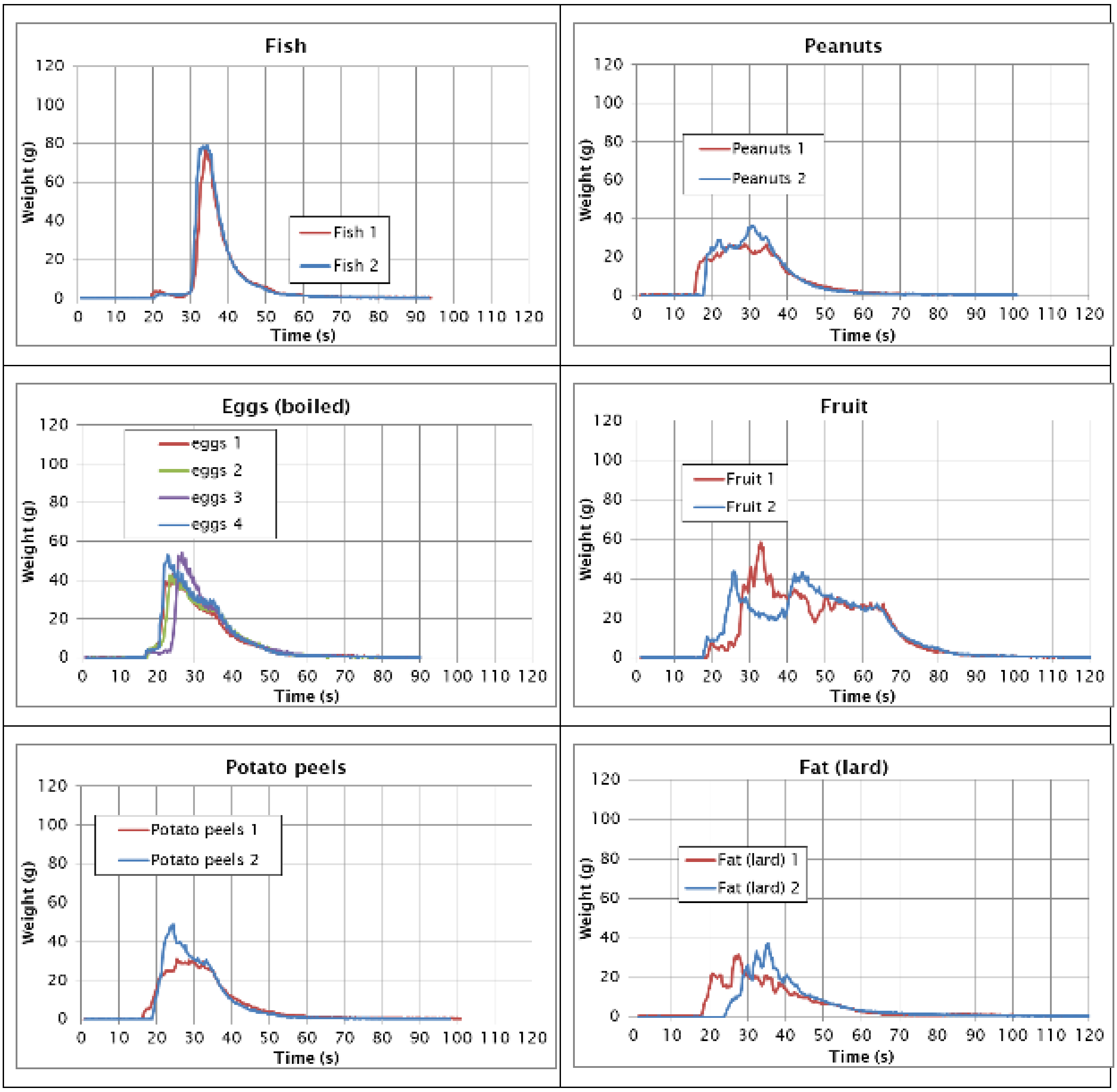


Figure 44 Outlet hydrographs of horizontal sewer pipe for different food types – II

Outlet hydrographs of horizontal sewer pipe for different food types – Part 3

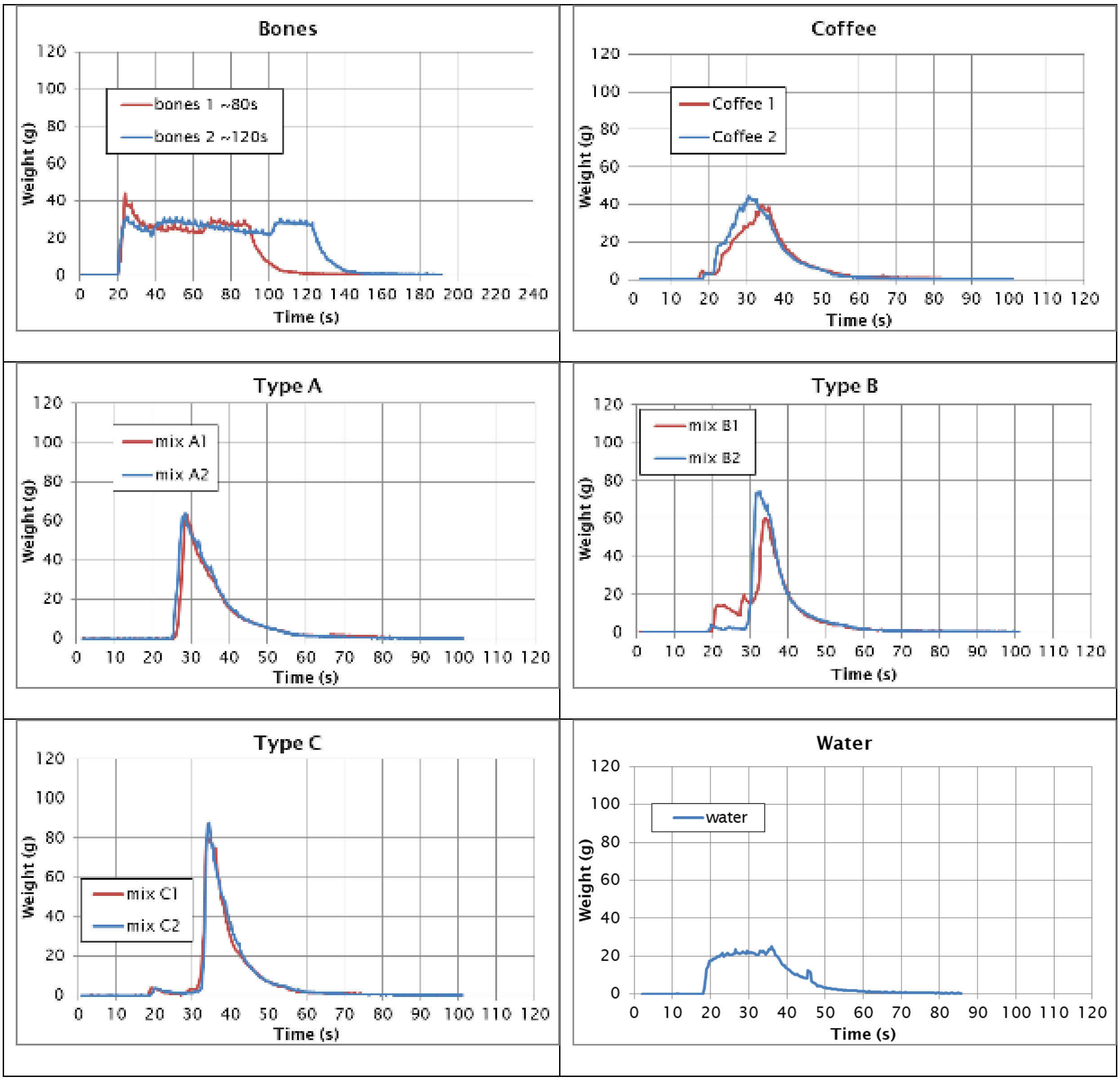


Figure 45 Outlet hydrographs of horizontal sewer pipe for different food types – III

Outlet hydrographs comparison for eggs and Mix C for horizontal pipe and horizontal+vertical pipe setups.

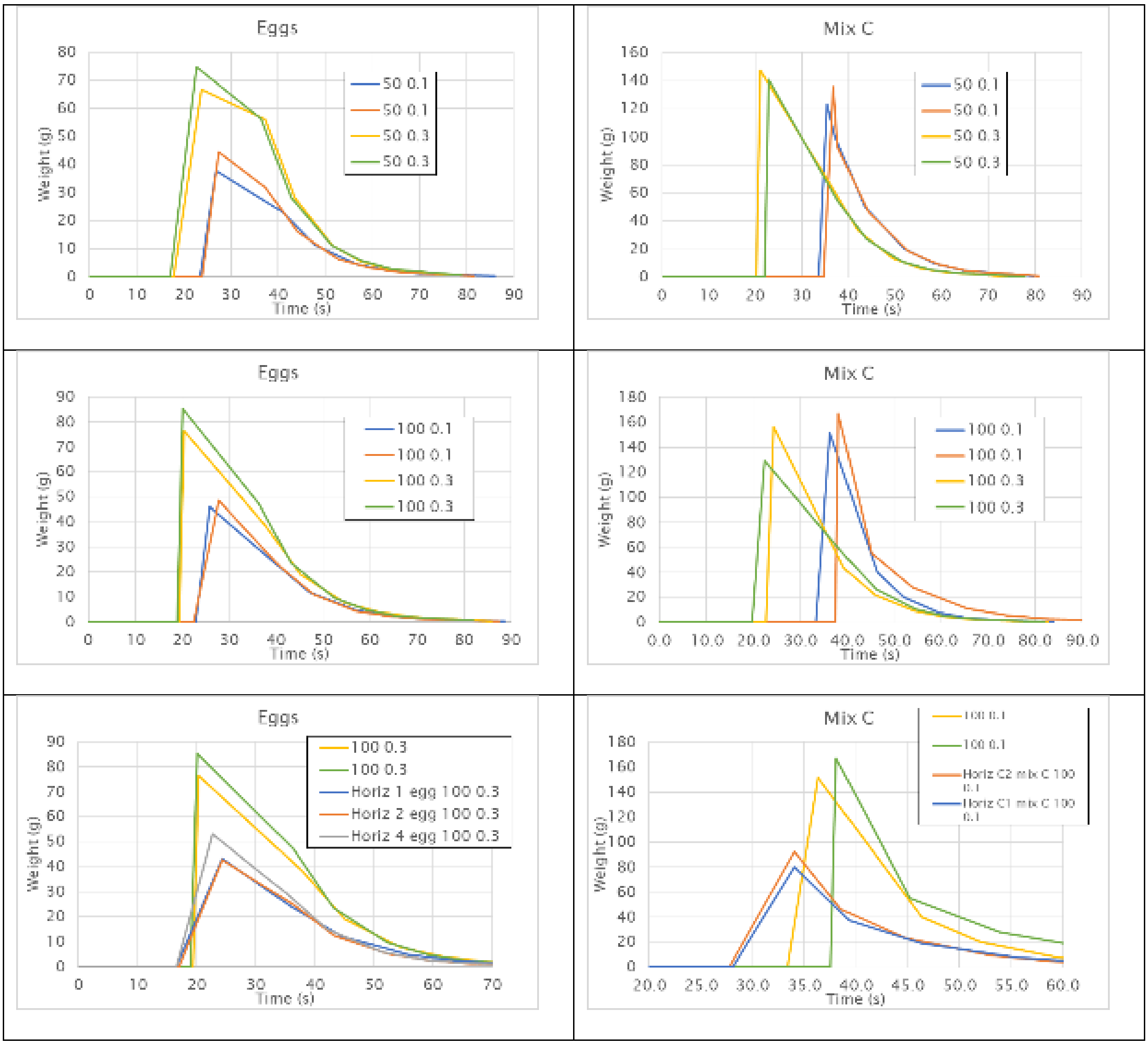


Figure 46 Outlet hydrographs comparison for eggs and Mix C for horizontal pipe and horizontal+vertical pipe setups.

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