공학석사학위논문

조절수형 변기의 배수 시스템의 막힘 사능성

# Clogging Potential of Low-Flush Toilet Drain System

2017 년 8 월

서울대학교 대학원

건설환경학부

**Muhamed Abubakr M. Shuaeb**

# Clogging Potential of Low-Flush Toilet Drain System

조절수형 변기의 배수 시스템의 막힘 가능성

지도교수 한 무 영

이 논문을 공학석사학위논문으로 제출함

**2017 년 8 월**


서울대학교 대학원

건설환경공학부

**MUHAMED ABUBAKR M. SHUAEB**


MUHAMED ABUBAKR M. SHUAEB의 석사학위논문을 인준함

**2017 년 8 월**

위 원 장 최 용 주 (인)

부위원장 한 무 영 (인)

위 원 최 정 권 (인)

**Master of Science Degree in Civil and Environmental Engineering**

# Clogging Potential of Low-Flush Toilet Drain System

By:

**Muhamed Abubakr M. Shuaeb**

Advisor:

Professor Mooyoung Han

A dissertation submitted in partial fulfillment of the requirements for the degree

**Master of Science**

Department of Civil and Environmental Engineering

The graduate school

**Seoul National University**

August 2017

## Abstract

# Clogging Potential of Low-Flush Toilet Drain System in Residential and Office Buildings



Muhamed Abubakr M. Shuaeb

Department of Civil and Environmental Engineering

The graduate school

Seoul National University



Water scarcity is a global issue. In residential buildings, water closet appliances share the biggest portion of water consumption. Therefore, they are targeted for improvements to consume less water while keeping acceptable performance. Low-flush toilets (6/3LPF) consume a significantly smaller amount of water compared to their predecessors (13LPF). However, lower water flows pose challenges like unreliable waste transportation and frequent clogging in old drainage systems. Furthermore, it is not economic to upgrade an entire drainage system to adapt to the new generation of toilets. In addition, recently there was rapid increase in the use of toilet friendly sanitary products. Their impact on the drainage system, especially with reduced flushing of volume is still a research subject.

This study was divided into two parts. In the first parts the clogging potential was defined for two toilet models and the effect of the related hydraulic parameters was evaluated. After, the minimum flushing condition to carry the waste samples without clogging was calculated and the clogging charts were created. In the second part, the hydraulic characteristics were defined for two toilet models. Next, the clogging potential was calculated for selected toilet paper product as representative of flushable sanitary products. Moreover, the relation between the toilet hydraulic characteristics and the clogging potential for the toilet paper products were investigated. Finally, in both study parts it was shown how the results can be used in real practice and how it can help in reducing water consumption while maintaining proper waste drainage.

The study in the first part showed flushing volume to have the greatest impact on clogging potential followed by pipe diameter and finally slope. Using the clogging charts it was shown by example how to calculate the minimum flushing conditions in cases where there is slope limitation, or flushing amount. In the second part of the study the clogging potential for the toilet papers also was influenced by the flushing volume more than slope. Furthermore, the flow profile was chosen to represent toilet characteristics and further simplified into two values namely C.g. and $Q_{max}$. The analysis

showed that toilet model with more peaked and short period flushing waves have lower clogging potential than toilets with flatter flushing waves.

***Keywords***: clogging potential; clogging charts; low-flush toilet; toilet branch drain; toilet drain transportation

**Student number:** 2015-23306

# Table of content

## List of figures

# List of Tables

# Chapter 1 Introduction

## 1. Introduction

Water scarcity is a global issue. The majority of world population is suffering from the lack of access to clean drinking water. The situation of water is heading to declining even more in the near future. The studies made by the United Nations shows that in 2025 more than 1.9 billion people will live under absolute water scarcity condition, while more than 65% of world population is expected to be under water stressed condition (UN2015). This situation is not focused in certain continent or region; rather it is spread through the whole word.

The reasons for such problem are related to several factors, Climate change, and world population increase and over/misuse of water. Among these reasons, the latter one is within the scope of the research done in this dissertation thesis. Our concept of using water has changed dramatically in the past 50 years (WWF2013). 50 years ago the use of water efficient apparatus in houses and office facilities was not the norm. In-house apparatus here can be anything from the shower, laundry to water closets. However, with the implementation of water policy use by local and governmental authorities the use of water efficient apparatus started to increase.

In residential buildings, toilet shares the biggest amount of water consumption. Water closets consume over than 50% of the daily uses inside residential buildings. For this reason, it was targeted to consume less by policy makers. In 1992 as a country-wide plan to promote sustainability and energy efficiency the environmental protection agency (EPA) in the USA has issued an act that includes sections restricting toilet manufacturers from producing water closets that consume more than 6 liters per flush (LPF) (Energy Policy Act 1992).This act was based on the ASME/ANSI requirements for water closets operational performance (ASME 2008). Nowadays, there are standards that require toilet products to go through several tests to assure their eligibility to provide full extraction of waste and proper odor seal while consuming less than 6 LPF. Figure 1, shows that in Scandinavia toilets have undergone through more water reductions policies when compared with other parts of the world, where toilets that consume as low as 3 LPF was implemented much earlier than other countries (Jack 2000). The Australian standards also specify that the maximum flushing volume of water closets should not exceed 5.5 LPF and 6/3LPF for dual flushing toilets (WELS Regulator 2007).

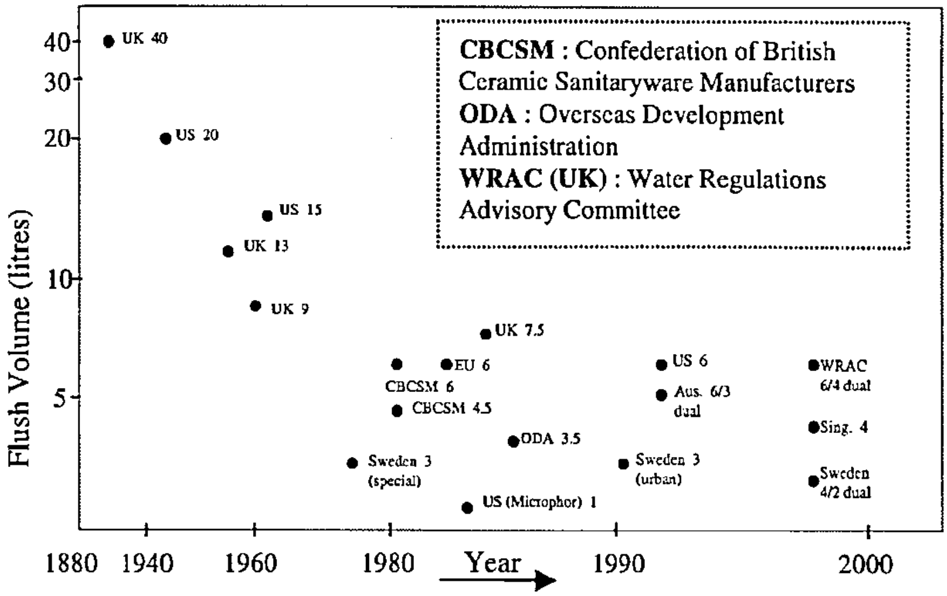



Figure 1 Trends in flushing water reduction at different locations of the world

On the other hand, the reduction of flushing water has caused problems in the toilet and inside the house drainage pipes. The reductions in flushing water lead to inadequate flushing and the need for the second flush. Having the need to flush two times do not reduce the water consumption, in fact sometimes it increases it. Furthermore, the reduced amount of water in the toilet drain has reduced the ability to transport waste which leads to clogging and raised the cost of maintenance. These issues specially occur in old drain pipes as they were designed to receive a higher amount of water. Also, the portions of waste to water have increased leading to what it is called nowadays by dry drains. These issues raised complain by end users and city officials and gave a bad reputation to low flush toilets. Currently, even certified toilet products by standards such as the mentioned above show a lack of performance and cause problems to the end users.

The challenge in evaluating toilets is that it is affected by usage habits. Usage habits differ from country to another as well as the products that are introduced to the drainage system. This makes it hard to set a global standard that can work for different parts of the world. Also, the plumbing codes differ from country to a country have an effect on the accuracy of a certain standard in evaluating products from other countries. For example the ASME/ANSI standards evaluate the toilet ability to flush waste through the drains using the system shown in figure 2. Polypropylene ball is used as a testing media to mimic human feces and the system is set to a fixed assembly. The transportation ability is measured based on the average distance that the testing media travel through the drain pipe. In real situations, the human feces are flexible and deform under the flushing wave while the polypropylene does not. Moreover, the waste composition found in house drainage is different as other products get mixed with human feces such as toilet papers, feminine hygiene, and seat covers. Etc. Finally, the drainage assembly might be different, according to the plumbing codes slope can range from 1 to 2% and pipe diameter can range from 64mm to 150mm (IPC2012). This makes the evaluation result inaccurate because it does not reflect the flushing scenarios found in real life.

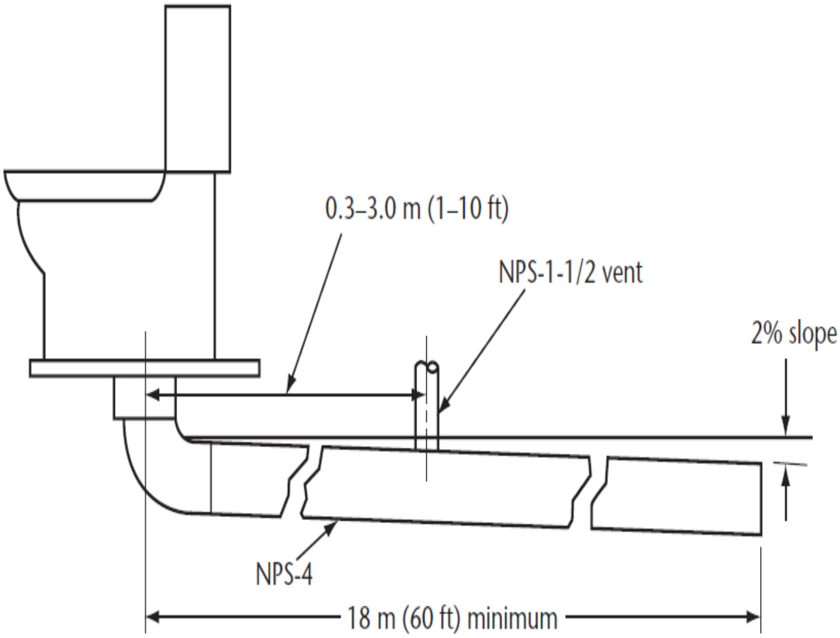



Figure 2 testing system for transportation characteristics of toilet appliances

## 2. Clogging potential for toilets

Clogging in the toilet drain system can be divided into two parts. One occurs at the toilet apparatus itself and it is governed by the flushing mechanism, the toilet shape and the amount of water. And the other happens at the toilet drain or at the following drains in the house. The latter is governed by the flushing wave of the toilet and the assembly of the drainage system. Although the two parts are important as a research topic, clogging in the drain pipe consume larger cost and it is not easy to detect by the end user and usually, the condition of clogging is sever when it is detected.

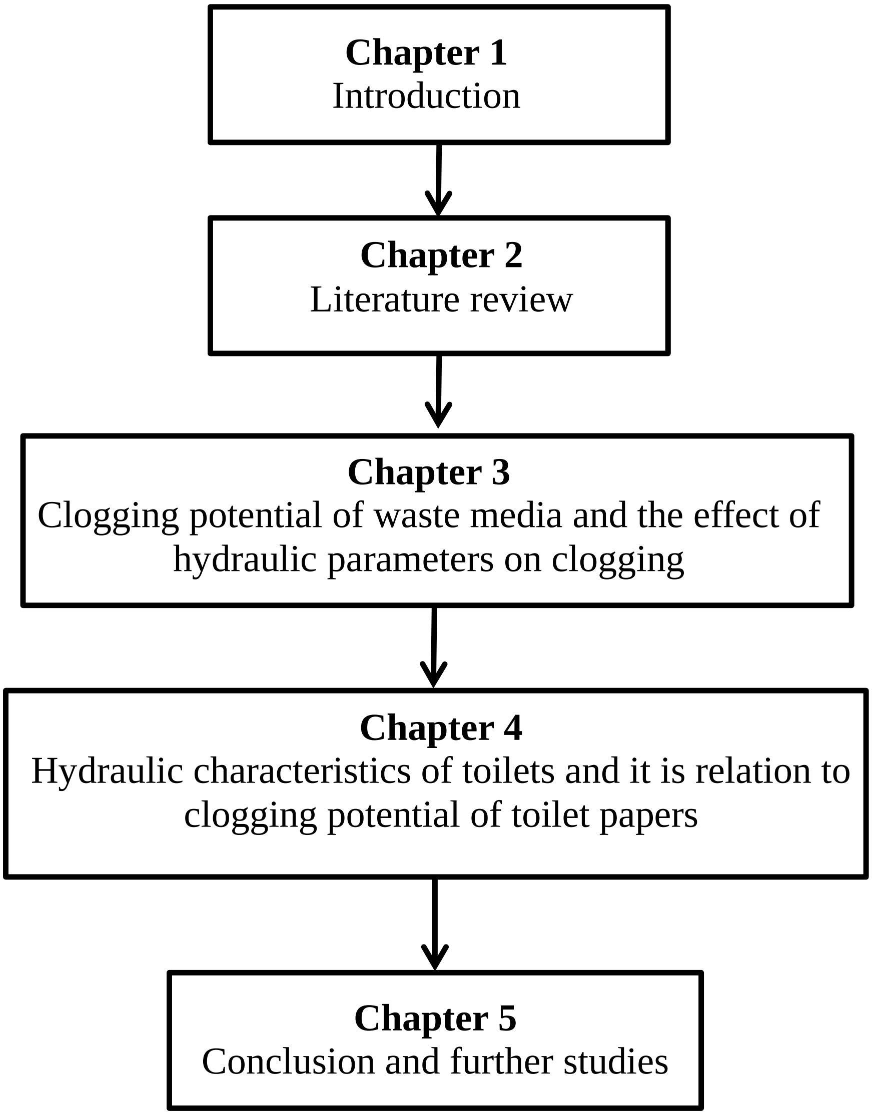
The majority of testing standards relay on distance as a measurement of waste transportation ability. However, clogging occur at a short distance in real flushing conditions. Also, they use fixed assemblies to mimic the toilet drainage system and the testing media usually does not give comprehensive representation for the waste composition and characteristics found in the real situation.

(Swaffiled 2009) suggested that the distance between the toilet appliance and the first flow-joining junction is likely to suffer from deposition and clogging problems if it is not well designed. Also from previous practical experience, it was found that this distance would fall around or below 5m. In toilet evaluation laboratories toilets would be able to flush up to distances beyond the critical distance mentioned earlier. However, when such toilets used in the real house some of them still suffer from clogging in their drain pipes. This can be related to various factors of which flushing of inappropriate waste, miss-installed drain system, and damaged drain or not enough water was supplied to the toilet itself. In real drain systems clogging might still occur even if the above problems did not exist. It is necessary to have criteria that address clogging rather than transportation of waste.

# 3. Research objectives

This study aims to determine the clogging potential in the toilet drain branch and investigate the effect of the hydraulic parameters in the system on the clogging potential. Moreover using the result of the experiment to develop clogging potential charts for the toilet drainage branch, under several working conditions that are common in real-life flushing scenarios. In addition, the clogging potential is investigated for the flushable consumer products that are witnessing increased use in recent years. Finally, to demonstrate the role of clogging potential charts in reducing the clogging potential in real-world toilet systems by using them as a supplementary guidance for the design.

## 4. Dissertation structure



# 5. Reference

*"Water Scarcity. International Decade for Action 'Water for Life' 2005–2015". un.org. Retrieved 20 October 2013.*

"Water Scarcity. Threats". WWF. 2013. Retrieved 20 October 2013.

Energy Policy Act of 1992, 1992. Public Law 102486: 102nd Congress. Washington, D.C: US Government Printing Office.

Canadian Standard Association ASME A112.19,2 – 2008/ CSA B45.1-08, "Ceramic plumbing fixtures", American Society of Mechanical Engineers, N.Y.C., NY,2008

Jack, L.B., 2000. Overview of investigations addressing the issue of low water use sanitary appliances and associated drainage network design. Building Service Engineering Research Technology, 21 (2), 139-144.

Water Efficiency Labelling and Standards (WELS) Regulator, 2007.

*Water Rating Home* [online]. Available from: http://search.waterrating.com.au [Accessed March 2017].

International code of plumbing a member of the international code family, international code council 2012

Swaffield J.A., 2009. Dry drains: myth, reality or impediment to water conservation. *CIB-W62 International Symposium*, 7-9 September 2009 Gelsenkirchen: Fachhochschule Gelsenkirchen, University of Applied Sciences, 301-313.

# Chapter 2 Literature review on the factors that govern clogging in toilet drain branches

## 1. Introduction

One of the early studies made on the subject of solid transportation in-house drainage was conducted by the national bureau of standards in 1960. The studies found that flow in house drainage is an example of free surface unsteady flow in partially filled pipes. The flow is governed by the appliance discharge wave and it is attenuation through the pipe. Furthermore, the wave attenuation level is controlled by the physical parameters of the drainage system such as diameter, slope, inner roughness, and the usage habits of designated appliance and discharge profile of the appliance (Wyly 1964).

The development of computer-based simulation software’s has made it simpler to solve flow problems such as the ones found in house drains. The use of computer simulation has resulted in solid movement prediction models. Furthermore, these models have been validated using laboratory and large-scale field tests. However, with the development of low flush appliances, the change of usage habits and the new waste types that are been introduced to house drains, these models are becoming irrelevant and need more development to cope up with the change of drainage practice (Wyly

1964). In addition, the physical modules used for calculation validation are becoming not representative with time, as the majority of tests were conducted on a singular toilet drain systems and with testing materials that does not represent the real properties of waste found in drain systems today.

Finally, the different usage habits, drainage systems, and guidelines make the study of clogging problem in-house drainage complex. For example, studies conducted in Norway suggested that toilet drain pipes with a diameter of 64mm improved the waste transportation and compensated the reduced flow from the new low flush toilets. On the other hand, the international plumbing code and a wide group of researcher’s l the use of pipes equal or larger than 75mm. From the hydraulic point of view reducing the pipe diameter would increase the flow velocity and compensate the reduction in water volume. However, drains with small diameter might increase the possibility of clogging. Small diameter would increase friction between the solids and the inner surface of the pipe especially when large or non-deformable solids being a washout (Littilewood & buttler 2003).

## 2. Quantifying clogging

The majority of research conducted use waste transport distance to measure the ability of toilets to flush waste and to study the factors that cause clogging in the drain pipes. This method is direct and does reflect the performance for different toilet flushing mechanisms. However, practical use and clogging reports cases have shown that clogging can occur in really short distances from the discharge point of the appliance. The process of clogging in drain pipes are influenced by more parameters such as the mass and the characteristic of the waste, the shape and the profile of the discharge wave. GAULEY and KOELLER investigated the clogging in-house drainage by evaluating the transportation distance of several waste masses and combinations when flushing through different slopes and pipe sizes that are usually found in real life. They also included a toilet with different flushing mechanisms that are found in the market. The study showed positive results for different flushing mechanisms, as the transport distance varied between 6 to 24m and there was no sign of clogging. Moreover, the authors concluded that the reduction of flushing water amount is not the reason of clogging and clogging is related to flushing of inappropriate objects, damage/ miss-installation of the drainage system or build-up of grease and grit in the drain pipe. In this study, the waste simulants combination were not reflecting real world usage habits, which makes the findings idealistic and a bit far from the conditions found in the real world  (Gauley& Koeller 2005).

# 3. Testing materials

Having a representative material that reflects the properties of waste found in toilet drain is quite challenging. The properties that affect the waste transportation are flexibility, compressibility, deformability and its surface roughness and how it interacts with the pipe inner surface. Some laboratories use sponges as a representative for human feces because they are practical and can be reused. However, compared to actual feces they lack flexibility and they are not as deformable under the discharge waves. Other researchers and standards use plastic balls with round shape, yet like the sponges, they are still not quite representative of the human feces[]. The most promising testing media so far are the ones used by the maximum performance test (MaP) testing institution. Their testing materials possess more realistic properties and similar to actual facial.  The institution uses soybean paste to extrude sausages with predetermined length and diameter to mimic the actual waste (Gauley & Koeller 2009). Also, some portions of rice are added to control moist and give similar consistency see Figure 3.

Figure 3 soybean sausage extruded according to MaP guidelines to be used as human faces simulants

The usage habits, either by region or type of facility such as residential and office buildings make the use of the mentioned testing media, not representative. Standards and institutions still investigating such topic to have detailed information about the unknown factors related to usage habits. Finally, the testing materials reproducible properties are necessary for statistical reliability and confidence in the test results. The materials physical properties must be durable for different discharge flow, chemistry, and pH level (Galowin 2001).

# 4. Testing system

The majority of standards and research conducted uses single toilet mounted to customized rig as it is shown in Figure 4. The reason for this approach is to reflect the real situation that toilets would operate. First, the drop height of the 90$^{o}$ elbow varies from 20 to 90cm. In research the use of standard 20cm drop height is common, however, a study made by GAULEY and KOELLER showed that there is none or minor effect of drop height on waste transport distance. Second, Toilet drain size is found to be either 75 or 100mm in common residential houses, however in Scandinavia toilet drain of 64mm proved to improve waste transport. The comparison of the pipe size is made to investigate if smaller diameter pipes improve waste carry. McDougall and Swaffield have conducted a research on three drain sizes 75,100 and 150mm. Their research results showed that 75mm pipe size had the longest transport distance for a singular water filled cylinder. The waste sample was exposed to a single toilet discharge wave. Many researchers conducted their experiment utilizing only single toilet as it is considered as the most critical part of the house drainage. However, in a real situation, the waste solids can be exposed to combined flows discharged from other appliances. Third, the length of the pipe drain varies as there are no limitations and usually there is no justification for choosing a certain length even by researchers. However, Swaffield 2009 has reported based on practical experience that the majority of house drainage pipes from the toilet to the first connection where a flow confluence is less than 5m see Figure 5. This zone is considered to be the most critical among the house drainage network in regard of clogging as the waste is only influenced by the toilet discharge wave and there is no influence from other appliances.

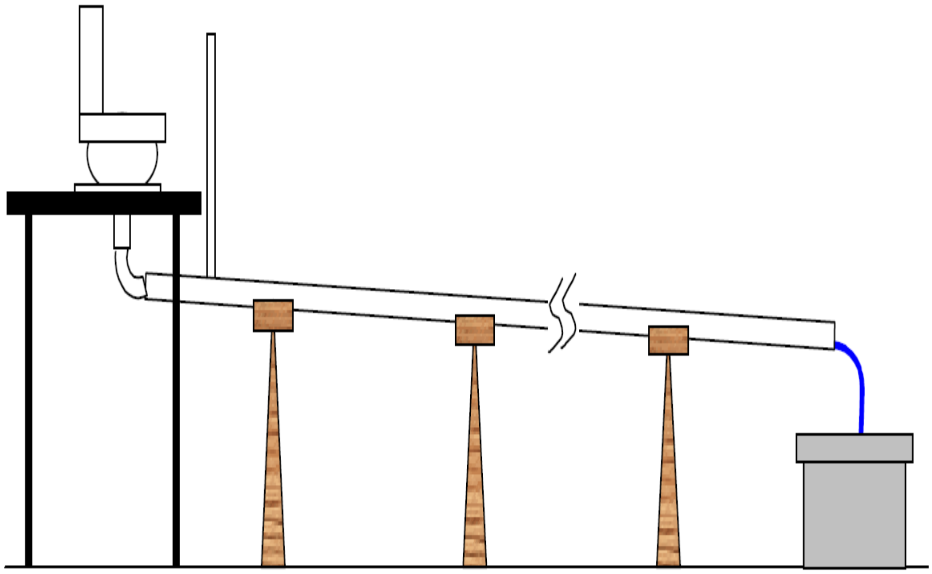


Figure 4 regular toilet drain testing system used by several researchers and standards

Finally, GAULEY and KOELLER have conducted an investigation about the effect of venting on waste transportation. Their study showed that there is no effect, as they blocked the venting while flushing their test samples through the drain pipe and the transportation distance was similar to when the venting pipes were open.

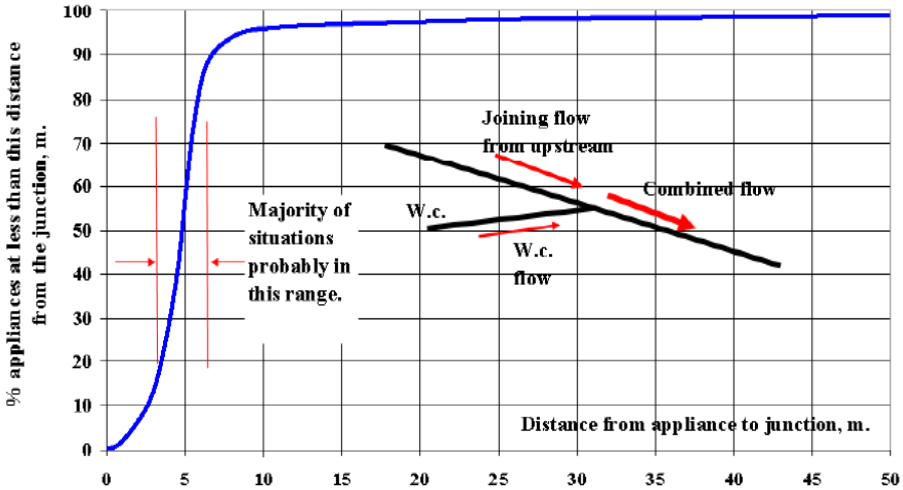



Figure 5 Likely distribution of drain length from toilet discharge point to the first joining flow junction in UK

# 5. Toilet bowl shape and flushing mechanism effect on clogging

The shape of the bowl plays a great role influencing the shape of the hydraulic characteristics of the toilet, in addition to the flushing mechanism. The bowl of the toilet needs to be smooth, clear from edges and follow the pattern of the water when it rushes down through the rim. Usually, bowls with bad design have sharp edges and the water pattern is interrupted while flowing from the tank into the bowl. The effect of such parameters on the hydraulic characteristics of the toilet and its influence on clogging is still a subject of study. Furthermore, flushing mechanism affects the hydraulic characteristic of the toilet, for example, pressure assisted toilets to have longer transport distance when compared to gravity fed toilets using the same or different flushing volume. Despite these findings, the reason behind such results still needs to be addressed [Gauely & Koeller 2009].

The shape and type of siphon influence the hydraulic characteristic of toilets. Figure 6 shows the conventional type of toilets, which use fixed siphons. Fixed siphon types use siphon action to initiate the suction force in the siphon pipe to flush all of the waste. This mechanism is effective as there is an odor seal made by the water in the toilet bowl while the strong siphon action will make sure to discharge all of the waste from the bowl and replace the water. However, the drawback is that to provide a water seal the siphon pipe needs to be designed in a complex way which makes the movement of the waste hard and usually result in clogging. In addition, initiating the siphon action requires strong flush pressure and this can be provided either by a large amount of flushing water or by assisting the flush with an external pressure, which is not quite sustainable as both consume high energy.

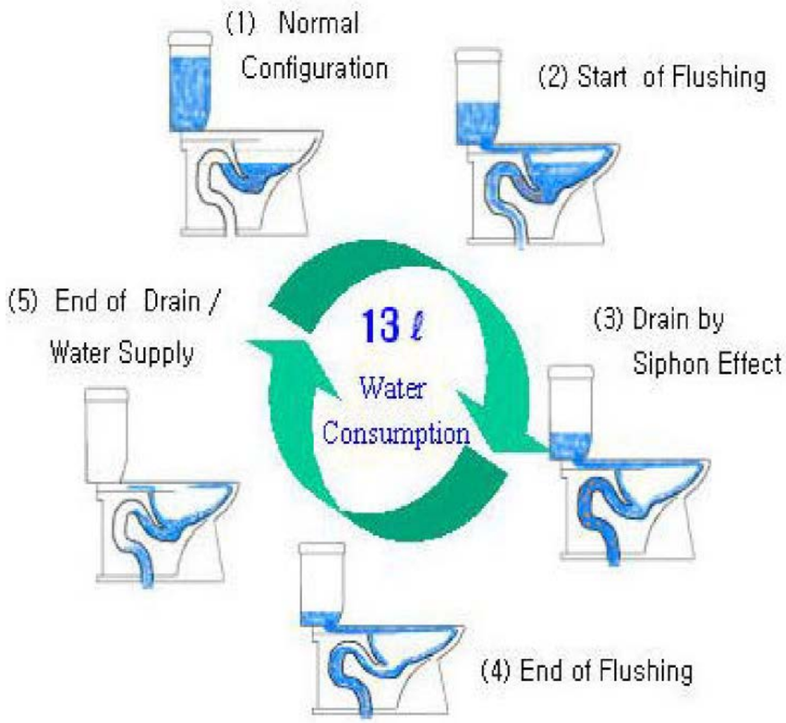



Figure 6 Operating Method of Conventional Toilet Bowls

To tackle such challenges some toilet manufacturers started using spring siphons for their toilets see Figure 7. This spring does not use siphon action to release the waste into the drain pipe, rather when the weight of the water flushed mixed with the waste is higher than the spring resistance to keep the pipe vertical, the spring expands and waste is released into the toilet drain. This mechanism is more mechanical than hydraulic and from this comes it is a disadvantage as springs are exposed to fatigue after a number of uses and rusting. Still, it is a promising approach and provides a solution to water conservation with fewer drawbacks when compared to fixed siphon pipes (Lee &Lee 1996).

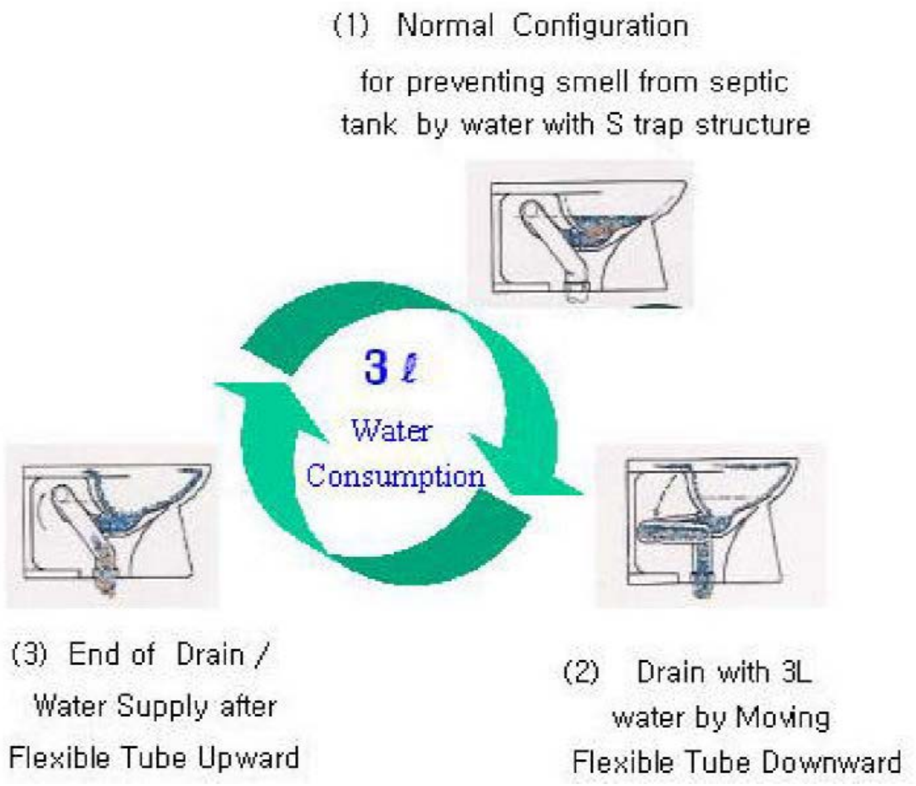



Figure 7 Operating Method of New Water-Saving Toilet Bowls

# 6. Reference

Wyly R S Investigation of the hydraulics of horizontal drains in plumbing systems Monograph 86 (Washington DC: National Bureau of Standards) (December 1964)

Littlewood K. Buttler D., Movement mechanisms of gross solids in intermittent flow, Water Science and Technology Vol 47 No 4 pp 45–50 © IWA Publishing 2003

Gauley, W., and Koeller J., 2005. Evaluation of Low-Flush-Volume Toilet Technologies to Carry Waste in Drainlines. A Canada Mortgage and Housing Corporation Project

Gauley, W., and Koeller J., 2009. *Maximum performance testing of popular toilet models* [online]. 15th edition, Available from: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/products/MaP/MaP_15/Map-15th-edition-Full-Rpt-2009-10-20.pdf [Accessed March 2017].

Galowin, Lawrence S., NIST, United States. Standard deviation acceptance criteria for water closet waste extraction tests.Proceedings of the 27th International Symposium on Water Supply and Drainage for Buildings, September 2001, Portoroz, Slovenia

McDougall, J.A., and Wakelin, R.H.M., 2007. The influence of flush volume and branch drain cross-section on deformable solid transport in attenuating flows. *Building Service Engineering Research and Technology,* 28 (1), 7-22.

McDougall, J.A., and Swaffield J.A., 2007. Transport of deformable solids within building drainage networks. *Building Research and Information,* 35 (2), 220-232.

McDougall, J.A., and Swaffield, J.A., 2000. Simulation of building drainage system operation under water conservation design criteria. *Building Services Engineering Research and Technology,* 21 (1), 41-51.

Swaffield J.A., 2009. Dry drains: myth, reality or impediment to water conservation. *CIB-W62 International Symposium,* 7-9 September 2009 Gelsenkirchen: Fachhochschule Gelsenkirchen, University of Applied Sciences, 301-313.

Lee H.S. Lee K.W. 1996. Practical Case Study of Resolving the Physical Contradiction in TRIZ; Super Water-Saving Toilet System Using Flexible Tube. KID Inc. (Korea Item Development Inc. www.innokid.com). Dept. of Mechanical Design, Korea Polytechnic University (www.kpu.ac.kr)

# Chapter 3 Clogging potential of waste media and the effect of hydraulic parameters on clogging

## 1. Introduction

In response to the water shortage of our time and its impacts on climate, water conservation has become a design parameter in new building codes, because, in residential and office buildings, water closets account for the largest portion of water consumption among the devices used daily (Swaffield 2009, Hashemi and Han 2017). Moreover, toilets needed to be improved to consume less water. Consequently, several governmental agencies have used local standards to apply restrictions on toilet manufacturers in the design of water closets, to reduce water consumption and improve water use efficiency (Han and Hashemi 2017).

In 1992, as a country-wide plan to promote sustainability and energy efficiency in the USA, the Environmental Protection Agency (EPA) issued regulations that included sections restricting toilet manufacturers from producing water closets that consume more than 6 L per flush (LPF) (Energy Policy Act 1992). This act was based on the ASME/ANSI requirements for water closet hydraulic performance (ASME 1995). Nowadays, there are standards that require toilet products to go through several tests to assure their eligibility to provide full extraction of waste and a proper odor seal while consuming less than 6 LPF. In Scandinavia, toilets have undergone more water reduction policies. There, some toilets that consume as low as 3 LPF were deployed much earlier than in other countries (Jack 2000). The Australian standards also specify that the maximum flushing volume of water closets should not exceed 5.5 LPF (WELS Regulator 2007).

The two main goals for the developing low-flush toilets (LFTs) are low water consumption and better flushing performance (Schlunke *et al.* 2008). However, these goals are not effectively satisfied yet. Many toilets are capable of doing the full extraction of waste but are not able to carry the solids beyond the point of joining the flow. Furthermore, reduction of flushing volume has a greater effect on older sewage systems because they were designed to receive a larger amount of water. Because upgrading all existing drainage connections to adapt to the toilets being developed now is not economical, research is required to make LFT's work acceptable with existing drainage systems. Currently, several certified LFT's are receiving negative feedback from end users, including complaints about weak flushing performance and frequent clogging in their drainage systems (Schlunke *et al.* 2008).

## Previous research review and methodology

Thanks to previous research efforts, the movement of waste through toilet branch drains is fairly well understood (McDougall and Swaffield 2000, McDougall and Wakelin 2007, McDougall and Swaffield 2007). In addition, one previous study applied the ANSI testing method on a multi-floor house drainage module. The study concluded that combined flows from other appliances such as the kitchen sink, contribute to waste transportation and discussing the toilet drain branch as an isolated system is a conservative practice (Shigefuji *et al.* 1999). According to these studies, the main parameter that was used to evaluate the performance was the distance the waste in the test pipes would be transported. While the distance criterion is a valid criterion to evaluate flushing performance, it is not useful to investigate clogging events inside a toilet drainage system.

One aim of this study was to determine the clogging potential in a toilet drainage branch and investigate the effect of related hydraulic parameters on the clogging potential. An additional aim was to develop clogging charts for the toilet drainage branch, under several working conditions. The final aim was to demonstrate the role of clogging charts in reducing the clogging potential in real-world toilet systems by informing their design.

# 2. Material and methods

## Apparatus and experimental set-up

In the system shown in Figure 8, the toilet model was mounted on a customized rig using a flange-to-floor fitting. Then the toilet was linked to a PVC branch drain (size 75 and 100 mm). The pipe was linked to the toilet using a 90° PVC elbow with a drop height of 20 cm. The pipe was hung using adjustable steel rods attached to a leveled hanger. The rods were spaced at equal distances to reduce sag of the pipe and to distribute the weight of the pipe uniformly between the rods. A narrow cut was made in the pipes to facilitate monitoring of the waste simulants. The cut was tightly covered with transparent thin PVC sheets to maintain the original pipe section and to prevent air from escaping. A vent pipe was linked to each pipe 1 m from the toilet discharge point. The diameter of the vent pipe was the same as the branch drain size. Finally, the previous study suggested that in practice, the distance from the toilet appliance to the first joining flow point is less than 5 m (Swaffield 2009). Based on this, the pipe length was fixed at 5 m.

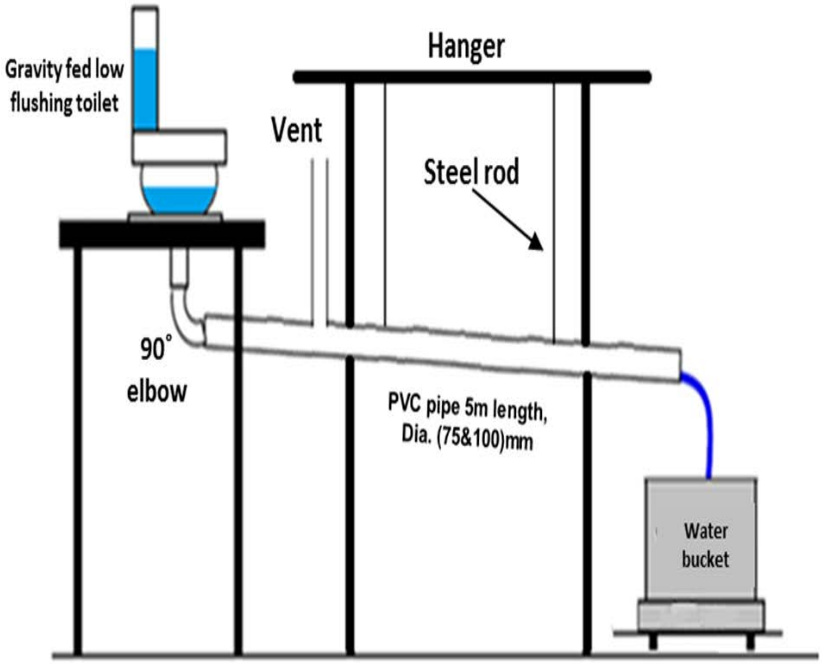



Figure 8 Experimental setup and apparatus.

## Waste simulant properties and toilet specifications

The maximum performance (MaP) guidelines were followed to make waste samples to represent fecal waste (Gauley and Koeller 2009). The samples extruded were 2.8 cm in diameter, with the length of (90 ± 5) cm and weight of (50±5) g. The waste sample was combined with one sheet of feminine hygiene product (FHP). The FHP was manufactured by Yuhan-Kimberly (Republic of Korea) with a length of 24 cm and an average width of 1.25 cm. The combination of the waste sample and the feminine hygiene product will be referred to as the waste simulant from now on. Toilets tested included a YMF-001 model with a fixed siphon and 4.5 L flushing volume and a YMB-

001 model with a moving spring siphon and 6 L flushing volume. The toilets were manufactured by YM Tech, (Republic of Korea). Both toilet models are certified by the Korea Environmental Industry and Technology Institute as a sustainable green product (KEITI 2017).

## Testing procedure

Before the experiment began, both modules were checked for any leakage or misalignment. It was assured that the toilets were level with the rig platform and that there was no leakage from the floor flange fitting. The elbow connection was checked for leakage and to ensure if it was properly linking the toilet with the drain. Finally, the pipe was checked for any sag.

The testing started by laying the pipe at the slope selected for testing. The toilet tank was filled with a targeted amount of water for the clogging investigation. Next, the waste simulants were dumped into the bowl using a dumping guide to simulate real defecation conditions. The waste simulant was flushed through the pipe and its movement monitored through the narrow transparent cut. Several waste simulants were flushed using the same procedure until clogging occurred. In this study, when the flushed waste stimulant did not show movement after more than four consecutive flushes, the pipe was considered clogged. In case the flushed waste simulants ejected from the pipe before four consecutive flushes, or there was no sign of stoppage after each flush, the mass of the waste simulant sample was increased by 50 g, and the test was repeated at the higher weight. When the flushing volume was changed to a higher amount, the starting mass of the waste stimulant was made the same as the mass that caused clogging in the previous test. In Figure 9, the testing procedure is simplified in the form of an algorithm.

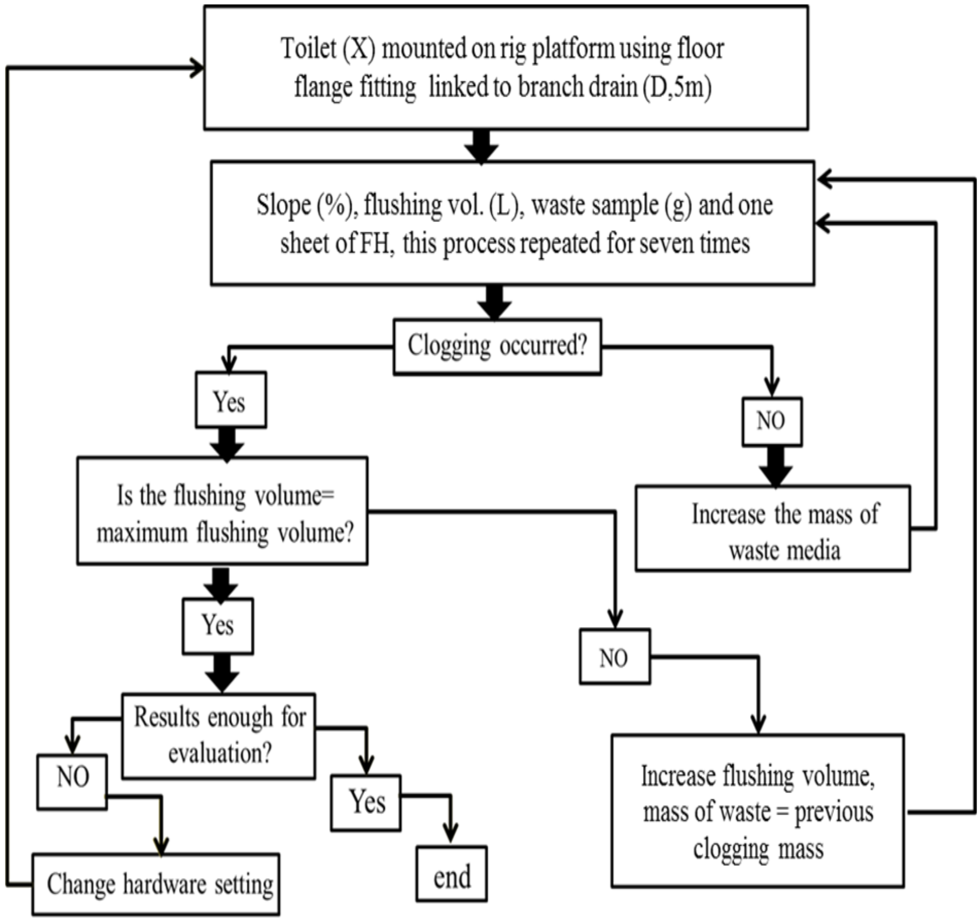



Figure 9 Summary of the experimental procedure.

## Experimental plan and parameter setting

Table 1 shows the flushing conditions chosen for testing the toilet branch drain. In this study, 28 hydraulic compositions were prepared to investigate the effect of operation items on the clogging potential and to calculate the minimum flushing volume required to flush the waste properly. For each flushing composition, seven samples were flushed to validate the results. Accordingly, 182 samples were flushed during testing, without taking into account the unsuccessful tests.

Three parameters were included and their influence was quantified in relation to the clogging mass. These parameters were: flushing volume, pipe diameter, and slope. For the purpose of comparison, and to study the effect of these parameters, one standard criterion combination was selected for each toilet module. For the YMF-001, the standard criterion was 3.5 L flushing volume, 75 mm pipe diameter, and 1% slope. For the YMB-001, the standard criterion was 3.7 L flushing volume, 75 mm diameter, and 1% slope.

Table 1Experimental design.

| | | Toilet Type | | Diameter (mm) | | Slope% | | |
|---|---|---|---|---|---|---|---|---|
| | | YMF-001 | YMB-001 | 75 | 100 | 0.5 | 1 | 2 |
| Flush Volume (L) | 3.2 | | | | | | | |
| | 3.5 | F | | F/B | | | | F/B |
| | 3.7 | | B | | | | | |
| | 4 | | | | | | | |
| | 4.5 | | | | | | | |

F: standard criterion for YMF-001
B: standard criterion for YMB-001

# 3. Results and discussion

## Testing results and parameter effect

Figure 10 A to D shows the results of 28 tests of combinations. The symbol  refers to the mass of waste stimulants that caused clogging when flushed in a certain combination. It should be mentioned that testing of the YMB-001 toilet was only to supplement the data gathered from testing the YMF-001 toilet module. For this reason, the testing combinations used for YMB-001 toilet were significantly fewer than the ones used to test the YMF-001 toilet module. To evaluate the effect of each parameter on clogging potential one at a time, six combinations were compared to the standard criterion of the YMF-001 and four were compared to the standard criterion of the YMB-001.

Accordingly, the difference between the clogging mass of the standard criterion and the other combinations were converted to a quantitative mass index. The mass index was used to measure the effect of each parameter on clogging potential.

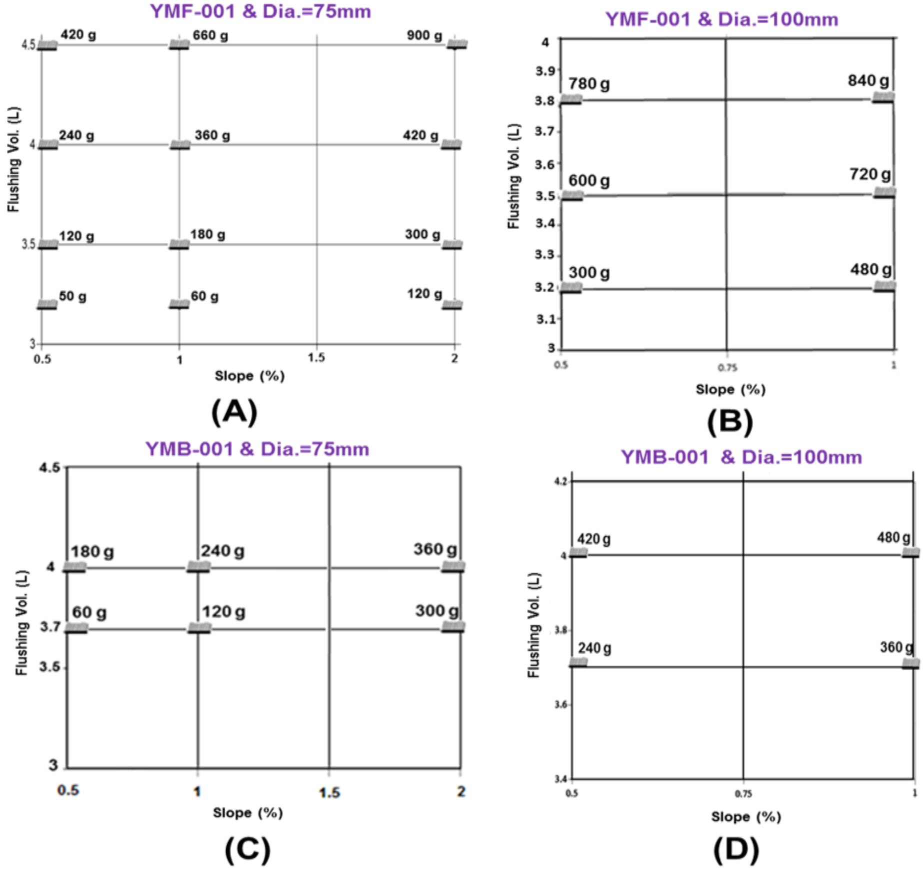
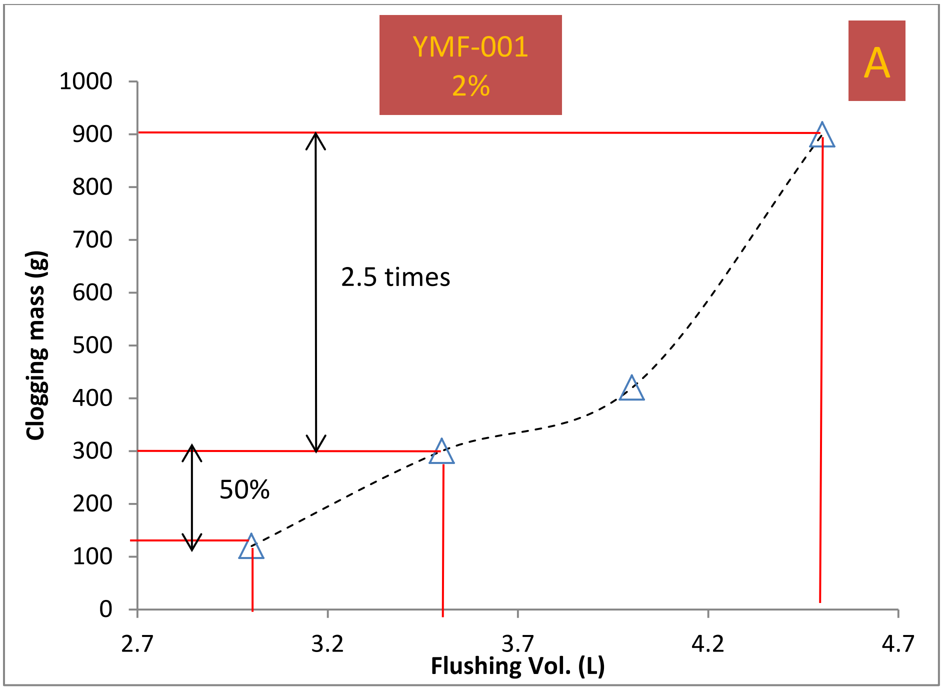
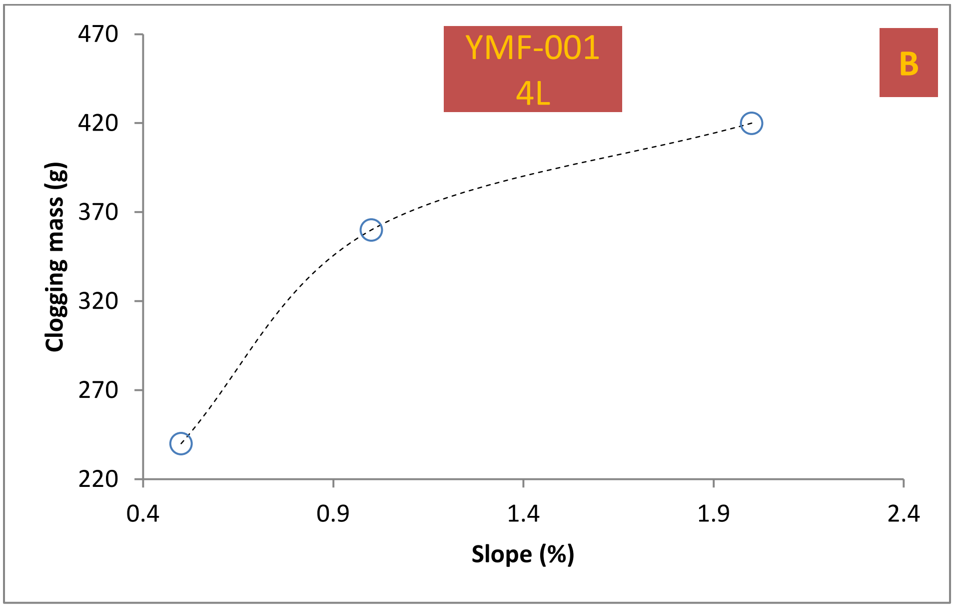



Figure 10 Test results (A) and (B) for toilet module YMF-001 with branch size 75 and 100 mm, respectively; and (C) and (D) for toilet module YMB-001 with branch size 75 and 100 mm, respectively.

Figure 11 A to C presents the effect of the flushing parameters as a function of the clogging mass. It should be noted that flushing vol. effect on clogging for YMB-001 was not included because of the limited results, were a trend cannot be drawn. However, for slope the comparison shows similar trends for both toilets tested. The flushing volume had the strongest influence on clogging potential for toilet YMF-001. Thus, a small change in flushing volume changed the clogging potential radically. With the YMF-001, a one-liter increase in flushing volume reduced the clogging potential by more than 2.5 times; while a 0.3 L decrease in flushing volume increased the clogging potential by 50%. The pipe diameter came second in its influence on the clogging potential. The test results showed that the 75 mm branch drain clogged with lower mass than the 100 mm drain size when both were operating under the same flushing conditions. With the YMB-001, the 100 mm branch drain was able to carry 2-times the mass possible with the 75 mm pipe, without any signs of clogging. The author believes that such findings have a relation to the characteristics of the waste composition used in the study. The slope had the least influence on clogging potential. With the YMB-001, a slope increase of 1% decreased the clogging potential by almost 1.5 times, while a 0.5% reduction in slope increased the clogging potential by 50%.


YMF-001
2%
A
1000
900
800
700
600
500
400
300
200
100
0
Clogging mass (g)
2.5 times
50%
2.7
3.2
3.7
4.2
4.7
Flushing Vol. (L)


YMF-001
4L
B
470
420
370
320
270
220
Clogging mass (g)
0.4
0.9
1.4
1.9
2.4
Slope (%)

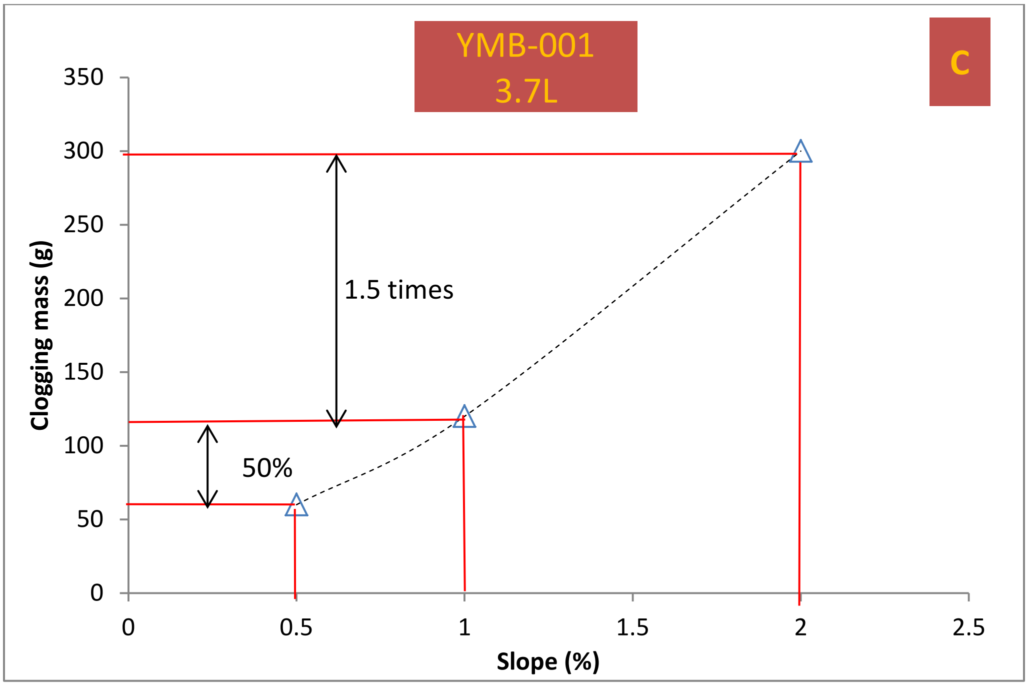



Figure 11 (A) effect of Flusing vol. on clogging potential for YMF-001 slope is fixed at 2%. (B) Effect of slope on clogging potential flushing vol. is fixed at 4L. (C) effect of slope on clogging potential for toilet YMB-001 flushing volume is fixed at 4L

The slope was considered to have a minor effect on clogging potential because even with a slope of 2% (high in typical toilet drainage design), the clogging potential did not decrease as it did with other parameters. Finally, the flushing volume was targeted for limitation because it could not increase over a certain limit. Increasing the branch pipe size was the most suitable option to decrease clogging potential because it is not limited by ceiling space as a slope would be, or by water saving policies that limit the flushing volume.

During visual observation, the feminine hygiene sheets were shown to have a great impact on waste transport. The contact between the inner surface of the pipe and the sheets resulted in significant friction force. Furthermore, the force of the waves of flushes was dissipated by the FH sheets, which protected the waste samples from breaking into smaller pieces. This contributed to increased clogging potential. It was noticed that 100 mm pipe was better at transporting the FH sheets.

## Clogging potential charts

Figure 12 A to D show the clogging potential charts for the toilet modules YMF-001 and YMB-001. The Modified Shepard method was used to interpolate the results of the investigation on the two toilet modules. These interpolated data were then used to plot the clogging potential charts for the toilet modules under common working conditions. The interpolation calculation and the chart plotting were done using Surfer version 13.6.618 (Golden Software, 2016). Furthermore, to check the reliability of the interpolation method, extra validation tests were conducted. The test results showed that the interpolated data were accurate and within the expected range.

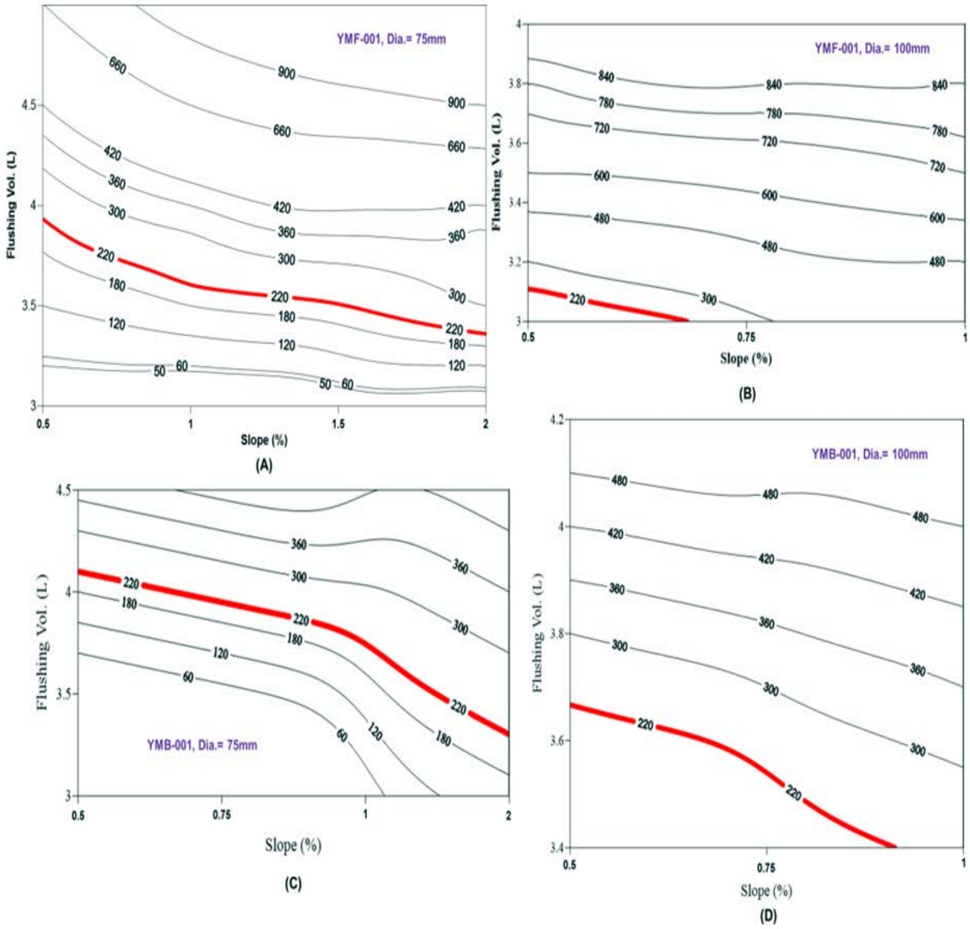



Figure 12 Clogging potential chart for several flushing conditions (A) and (B) for toilet module YMF-001 with branch size 75 and 100 mm, respectively; and (C) and (D) for toilet module YMB-001 with branch size 75 and 100 mm, respectively.

The clogging charts under various flushing conditions show that the YMF-001 toilet model has significantly better flushing performance than the YMB-001 toilet model. The author believes that the reason behind this performance difference is related to the syphon design for each toilet. Both toilets were designed to consume a lower amount of water and to work with flushing volumes that were not very different. However, the YMB-001 has a mechanical spring syphon by which it initiates the syphon action in response to the weight collected at the syphon tube. Even though this design consumes only a small amount of water, the clogging potential charts show that it has poor flushing performance. This is because it clogs under lower mass when compared to the YMF-001 model.

The results from previous studies indicate that the average weight of human faeces ranges from 140 to a maximum of 220 g (per sitting) (Rendtorff and Kashgarian 1967). The maximum value of 220 g was highlighted red in the clogging potential charts as a reference to critical working conditions. The values of flushing volume and slope above the highlighted red line are preferred because they are able to flush a heavier mass of waste. However, it is should be mentioned that the feminine hygiene sheets strongly influence the clogging potential and the results are conservative for normal flushing loads. Finally, with this approach, it is possible to mitigate clogging events for toilet drain branches.

## Clogging potential in practice

Figure 13 is produced based on the clogging potential chart for YMF-001, and the branch drain size of 75 mm. The charts show the minimum flushing values for a known or limited parameter. Figure 13 A shows the minimum values of flushing volume and the maximum mass of waste stimulants that can be flushed when the slope is limited to1%. When the slope is 1%, 300 g of waste stimulant requires at least 3.9 L of flushing volume to be flushed properly through the branch drain.  Similarly, Figure 13 B represents the minimum slope values that are needed to flush the waste simulants properly, when the flushing volume is limited to 4L. A 1% slope, in this case, is capable of flushing no more than 360 g of waste simulants. Finally, if it is possible to estimate the maximum load to be flushed in a toilet drainage system, Figure 13 C represents the minimum values of slope and flushing volume to flush 300 g of waste simulant.

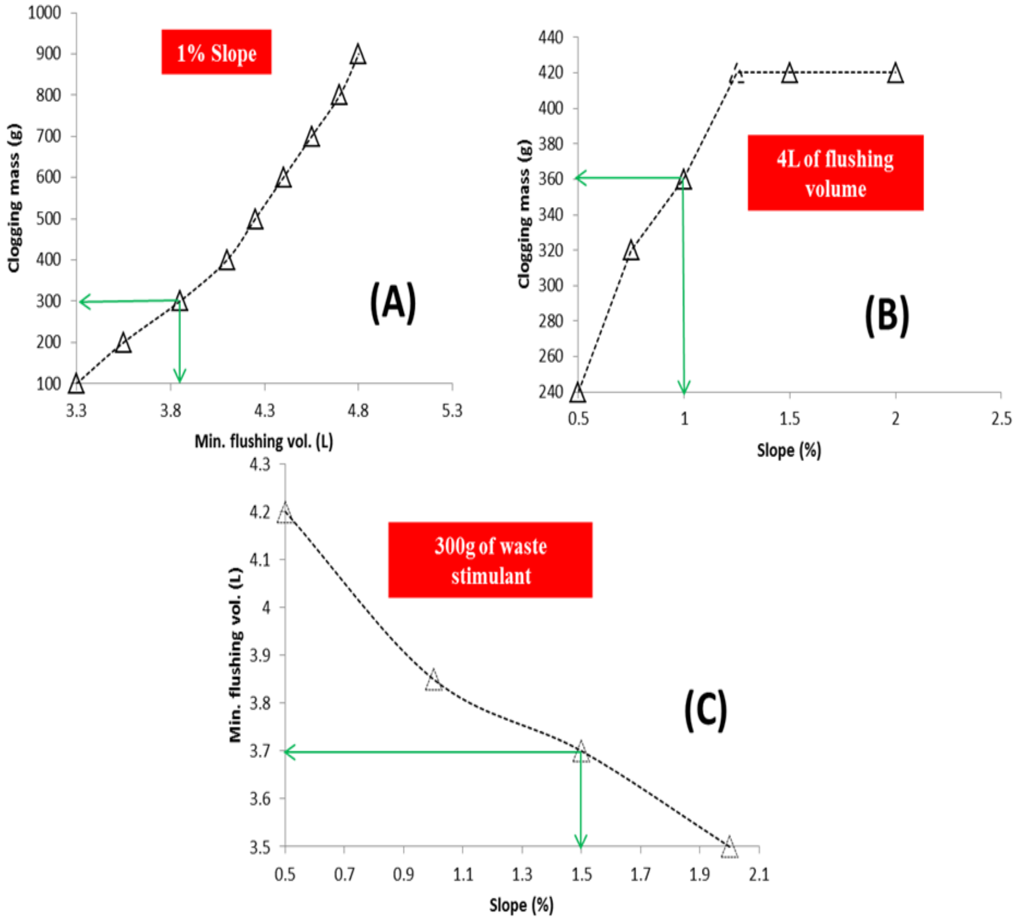



Figure 13 Minimum flushing properties for fixed (A) Slope value, (B) Flushing volume, and (C) Waste load.

In a real-world toilet drainage system, the slope of the branch drain might be limited because of the ceiling space. Not providing the minimum slope increases the clogging potential. However, with the aid of clogging potential charts, the minimum flushing volume for a certain slope value can be estimated, thus mitigating the clogging events in the branch drain. In addition, the flushing volume supplied to the toilet might not be enough for proper waste transportation. Knowing the flushing volume value and using the clogging potential chart for the toilet module under consideration, the minimum slope value can be estimated and clogging can be avoided. In addition, it is possible to estimate the maximum load of waste in a certain situation for residential and office buildings. Using the clogging chart in such case makes it possible to estimate the minimum flushing volume and slope as it was shown in Fig 6 C. In summary, these practices have potential to enhance toilet drainage design and improve overly conservative assumptions.

# 4. Conclusions

In this article, factors affecting the clogging potential inside a toilet branch drain were investigated. Two toilet modules were tested to model real-world toilet drainage conditions. Twenty-eight test combinations were prepared to cover the common work conditions in toilet drainage systems. For each testing combination, around seven waste simulants were flushed and their movement was monitored. The criterion used to measure the effect of each hydraulic parameter on the clogging potential was the mass of the waste simulant. The results of the investigation were used to interpolate the clogging potential chart. Finally, the clogging potential charts showed the working limitations of the two toilet modules under different flushing conditions.

The results of the tests were analysed to investigate the effect of the hydraulic parameters on clogging. Among the three parameters examined, flushing volume had the most influence on clogging potential. Next was pipe size: 100 mm had better performance than the 75 mm pipe. Furthermore, slope showed less influence than the other parameters with relative index less than 0.5. Finally, during visual observation, the existence of feminine hygiene products in the waste had a significant impact on increasing the clogging potential.

Finally, it was shown how the clogging potential charts can support the design of new toilet drainage systems or adjust existing systems to reduce clogging events and enhance their transport performance. Slope or flushing volume limitations that are suspected to lead to clogging could be avoided using the values obtained from the clogging charts. This approach has potential to support better house drainage design and reduce conservative assumptions.

# 5. References


Energy Policy Act of 1992, 1992. *Public Law 102486: 102nd Congress.* Washington, D.C: US Government Printing Office.

Gauley, W., and Koeller J., 2009. *Maximum performance testing of popular toilet models* [online]. 15th edition, Available from: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_C enter/Library/products/MaP/MaP_15/Map-15th-edition-Full-Rpt-2009-10-20.pdf [Accessed March 2017].

Han, M., and Hashemi, S., 2017. Sanitation Revolution: From Waste to Resource. *Desalination and Water Treatment*, In Press.

Hashemi, S., and Han, M., 2017. Effect of Nitrosomonas europaea Bio-Seed Addition on the Fate of Carbon and Nitrogen Compounds in Human Feces. *Waste and Biomass Valorization,* In Press. doi: 10.1007/s12649-017-9857-5

Jack, L.B., 2000. Overview of investigations addressing the issue of low water use sanitary appliances and associated drainage network design. *Building Service Engineering Research Technology*, 21 (2), 139-144.

Korea Environmental Industry and Technology (KEITI) (2017). *Institute Eco Label Certification* [online]. Available from: http://www.keiti.re.kr/home/index.do [Accessed March 2017].

McDougall, J.A., and Wakelin, R.H.M., 2007. The influence of flush volume and branch drain cross-section on deformable solid transport in attenuating flows. *Building Service Engineering Research and Technology*, 28 (1), 7-22.

McDougall, J.A., and Swaffield J.A., 2007. Transport of deformable solids within building drainage networks. *Building Research and Information*, 35 (2), 220-232.

McDougall, J.A., and Swaffield, J.A., 2000. Simulation of building drainage system operation under water conservation design criteria. *Building Services Engineering Research and Technology*, 21 (1), 41-51.

Rendtorff, R.C., and Kashgarian, M., 1967. Stool patterns of healthy adult males. *Diseases of the Colon & Rectum*, 10 (3), 222-228. doi:10.1007/BF02617184

Schlunke, A., Lewis, J., and Fane, S., 2008. *Analysis of Australian opportunities for more water-efficient toilets.* Sydney: Institute for Sustainable Futures, Department of the Environment, Heritage, Water and the Arts.

Shigefuji, H., Tsukada, R., Otsuka, M., and Shimoda, K., 1999. Basic study on transport performance test of waste solids in drainage piping for lower flush water closets. *CIB-W62 Annual Meeting,* 21-23 September 1999 Rotterdam: in-house publishing.

Surfer (Version 13.6.618) [Computer software]. Colorado: Golden Software.

Swaffield J.A., 2009. Dry drains: myth, reality or impediment to water conservation. *CIB-W62 International Symposium,* 7-9 September 2009 Gelsenkirchen: Fachhochschule Gelsenkirchen, University of Applied Sciences, 301-313.

The American Society of Mechanical Engineers, 1995. *Hydraulic Requirements for Water closets and Urinals.* New York: American Society of Mechanical Engineers.

Water Efficiency Labelling and Standards (WELS) Regulator, 2007. *Water Rating Home* [online]. Available from: http://search.waterrating.com.au [Accessed March 2017].

# Chapter 4 Hydraulic characteristics of toilets and it is relation to clogging potential of toilet papers

## 1. Introduction

There is increasing the need for water conservation throughout the world due to climate change, water scarcity and increased the population. Knowing that most of the water consumed in residential and office buildings are from toilet flushing, has led to switch to high-efficiency toilets (HET) which consume less than 6LPF. The use of High-efficiency toilets came as a response to regulations made by developed countries to reduce water consumption. For example, the Australian standards mandate toilet manufacturers to produce toilets with a maximum flushing volume of 5.5 liters. Also, in 1999 the UK issued the new water supply (water fitting) regulation that mandates the reduction of water closet flushing volume to 6 liters. These reductions in flushing water from water closets have led to poor waste transportation and repeated clogging issues inside buildings drainage networks. One of the clear reasons is that the existing drainage pipes are not able to cope up with the water reduction, as they were designed based on a much larger amount of flushing water (UK water regulation 1999). Moreover, the use of high-efficiency toilets has raised other challenges as inefficient waste extraction which leads to seconds flushes and consumes almost the same amount of water in conventional toilets and in some cases evens more (WELS).

The proper design of toilet appliance or drain system depends on it is ability to transport feces and other sanitary products to the main sewer pipeline outside of the facility property or beyond the point of joining flow. The reduced amount of flushing volume and the growing use of flushable sanitary products have increased the probability of improper waste transport and clogging the drain system. To resolve such issue starting from 1980 the association of sanitary protection manufacturer has developed a testing method to ensure that the discharge flow from the water closet is enough to transport such products until the first point of joining flow, where the risk of deposition and causing blockage is low (Howarth et al., 1980). The test requires the sanitary product to pass through the water closet and 10 m in the drain pipe of 100mm size and slope of 1.3%. the test is repeated 100 times to provide reliability and the product needs to pass through at least 94 times out of the 100 to be counted as a flushable product.

Manufacturers claiming that their products are flushable and have no harm on the drainage system often prove the opposite. This is because the condition that is used during testing the products does not reflect the conditions found in the real world or because of the misuse by end users.

This lead to the necessity to create guidelines that can identify the flushability of such nonwoven sanitary products. INDA in the US and EDANA in Europe are agencies that have been conducting research and studies since 2006 to create direct means to differentiate between products that can be flushed through the drainage systems and the ones that do not. INDA and EDANA require the product to clear through the toilet and drainage properly, pass through the waste line and be compatible with the wastewater treatment system. Finally, the products need to be fully digested to sludge before leaving the wastewater treatment plant. In Figure 14 the process the agencies follow to determine the suitability of a product to be labeled as flushable is illustrated (EDANA, 2006).

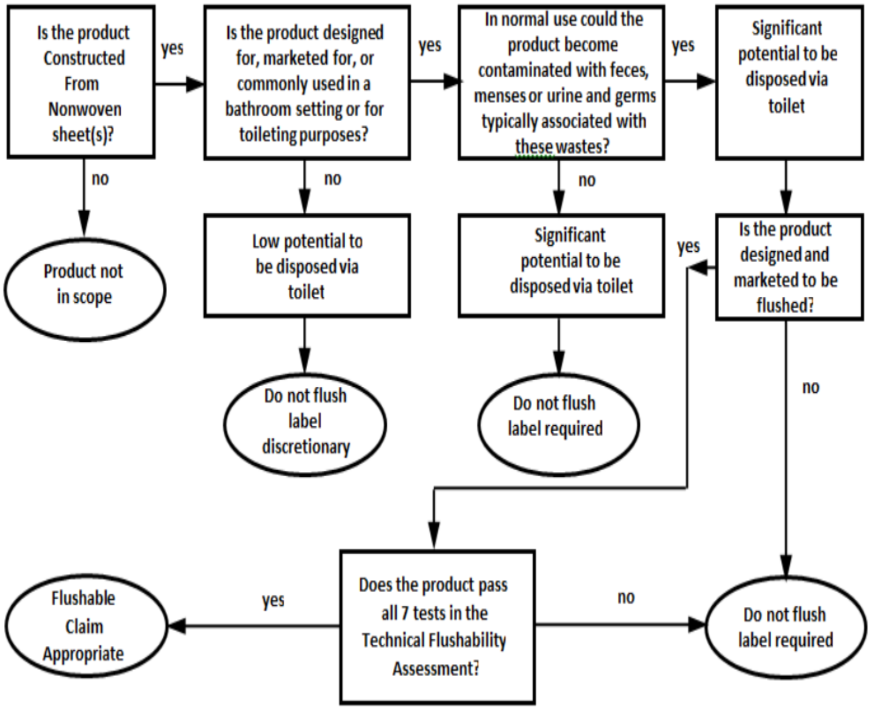



Figure 14 the decision-making process for determining whether a product is within the scope of this Flushability Assessment and the labeling requirements specified by the INDA/EDANA Code of Practice.

The work conducted by INDA and ENDA (2006) is comprehensive and covers all of the phases that the sanitary products run through in the drainage system. However, their method is quite complex and there are only two labs in the world to conduct such work due to the large cost. This fact makes it hard to be done in other labs or by manufacturers. Moreover, the products tested in these agencies are used in the region of North America and Europe; there is no consideration for products from other regions. This requires a more cost effective and simpler approach to study the effect of nonwoven products on clogging inside toilet drainage system.

Figure 15 shows the three main factors that cause clogging in toilet drainage system. First, the flushing of inappropriate waste through toilet drains. Second, toilets with poor design will result in efficient waste extraction and will probably get clogged at it is bowl or siphon tube. Finally, if the drain system is not installed properly providing the minimum slope and diameter clogging will be unavoidable result. Among the three factors mentioned, toilet drainage system is the most challenging as the end user cannot detect when it is system is clogged and maintenance are usually expensive and require skilled labors.

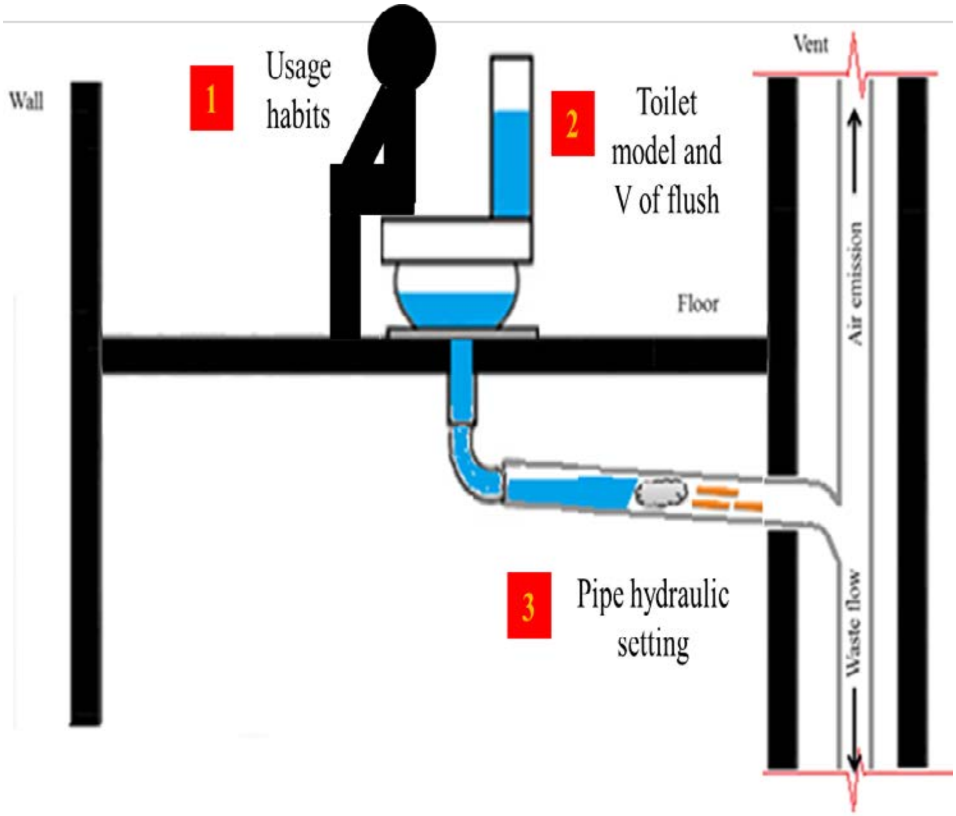



Figure 15 parameters that control the function of the toilet drainage system

## Previous research review and methodology

Studies made by Littlewood and Butler on the movement of gross solids under toilet discharge wave shows that there is a limiting transport distance. This limiting distance depends on the pipe diameter, flush condition, and solid combination. The study also showed that adding toilet papers to the waste combination actually increases the transport distance due to their ability to create dam behind the solids. Finally, the study shows the clogging due to gross solids is not impossible; however, it is not only a function of reduced flushing (Littlewood & Butler 2003). Kardagli et al. (2012)

developed a model to predict the breakdown of sanitary products that is flushed in toilets. The model is only a lab scale and it is not supported by field study. However, their study shows that products with water-soluble content are harder to disintegrate because they break up to smaller solids faster than products with low or no water-soluble content. The previous us literature provides valuable information about the behavior of flushable consumer products through the drainage system. Yet, the effect of such products on clogging potential inside house drainage systems is still not addressed. The purpose of this study is to determine the wither toilet papers cause clogging in toilet drains and to what extent they're affecting the waste transportation. Also, to determine the minimum inputs that need to be provided to prevent or mitigate clogging the drainage system.

This research aims to calculate the hydraulic characteristics (H.C.) for the toilets under consideration. Furthermore, to define the clogging potential (C.P.) of toilet papers when flushed through the toilet drain system under different flushing scenarios that reflect real-world situation. Finally, to examine and investigate the relationship between the hydraulic characteristics and clogging potential and use them as mean to evaluate toilet performance and address the clogging issue.

# 2. Materials and methods

## Apparatus and experimental set-up

The experimental setting that was used in this study is similar to the one used in the previous chapter. The toilet under examination was mounted on an elevated rig and linked to a 75mm PVC pipe using a 20cm drop height $90^c$ elbow. The pipe was hanged using steel rods that are attached to a fixed horizontal beam. A longitudinal cut was made through the upper part of the pipe to help to monitor the movement of waste samples and it was covered with thin transparent sheets. Finally, the pipe was vented with an equal diameter pipe at 1 m from the toilet discharge points.

## Waste simulant properties and toilet specifications

The toilet paper that was used in this study was a premium product with 4 layers. It was chosen to represent an extreme case as premium products have a greater potential to cause clogging with their lower disintegration and higher absorption rate. The weight of one wet sheet was recorded to be 8 8 ±0.5g. The MaP testing agency guideline was used make the artificial fecal samples. The samples were made by extruding soybean paste into 2.8cm diameter and 90 ±5 length sausages and it will be referred to as Soybean sausage (S.S.) (Gauley and Koeller 2009). in the later parts of this article. The weight of each waste media sample was maintained at 50 ±

5g. Two spring siphon gravity toilets were used for this study.YMf-002 with a design flushing volume of 4.5Liters, an outlet diameter of 70mm, and assisted with a vacuum flushing valve. YMB-001 designed to flush with 6 liters and outlet diameters of 75mm. both toilets have bowl average width is 28cm, and closet dimensions (15X38X53)cm. The toilets were manufactured by YM Tech, (Republic of Korea). Both toilet models are certified by the Korea Environmental Industry and Technology Institute as a sustainable green product (KEITI 2017).

## Measuring the hydraulic characteristics of toilet

Figure 16 shows the system that was used to measure the flow profile. EK 600i balance was used to measure the mass of water collected at 1 m from the toilet discharge point. The balance is able to measure the mass increment added per 0.1 second. Using equation 1 and 2 the average flow rate for each time step was calculated.

$V = \frac{M}{\rho}$ = volume increment in ($cm^3$) (1)

Where

M= mass increment in (g)

$\rho$= density of water was assumed to be 1g/ $cm^3$

$Q = \frac{V}{0.1}$ = flow rate ($cm^3$/sec.) (2)

Where

V= water volume increment in ($cm^3$)

0.1 is the time interval for each balance reading in (seconds)

To insure measurement reliability readings were considered when the water tank was stable. Also, for each flushing condition the measurement was repeated three times and there average was calculated. Only water was flushed through the pipe and flushing conditions was the same as the ones selected to calculate the clogging potential.

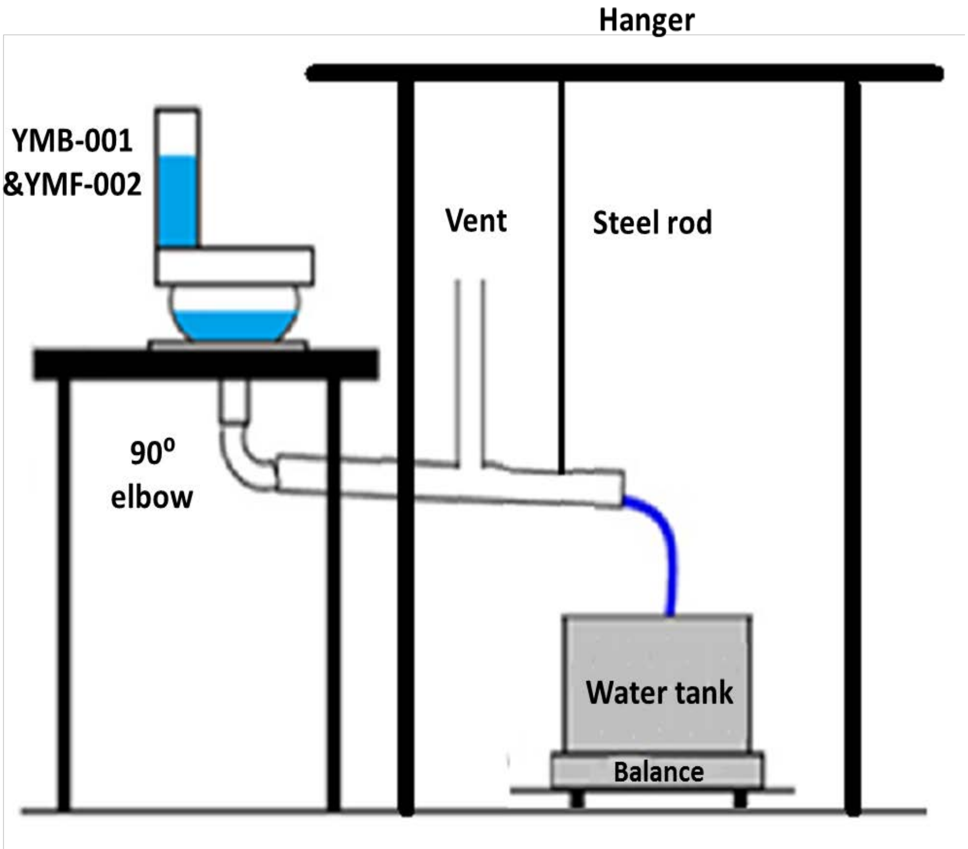



Figure 16 Flow rate monitoring system after flushing

The flow profiles that was measured using the circuit were simplified to two representative values the center of gravity of the flow profile in the x-axis which referred to as (C.g.) and the peak value of the flow rate referred to as $Q_{max}$. These two values were used to represent the shape of the flow profile and the intensity of the discharge wave. Intense flush waves would have small C.g. and large $Q_{max}$ value. C.g. was calculated using Autodesk software and by considering only the effective part of the flow profile as shown in Figure 17. The reason behind this is that the tail part of the flow profile does not contribute to the waste movement, as the waste would be already deposited after the effective part of the flow profile pass beyond it.

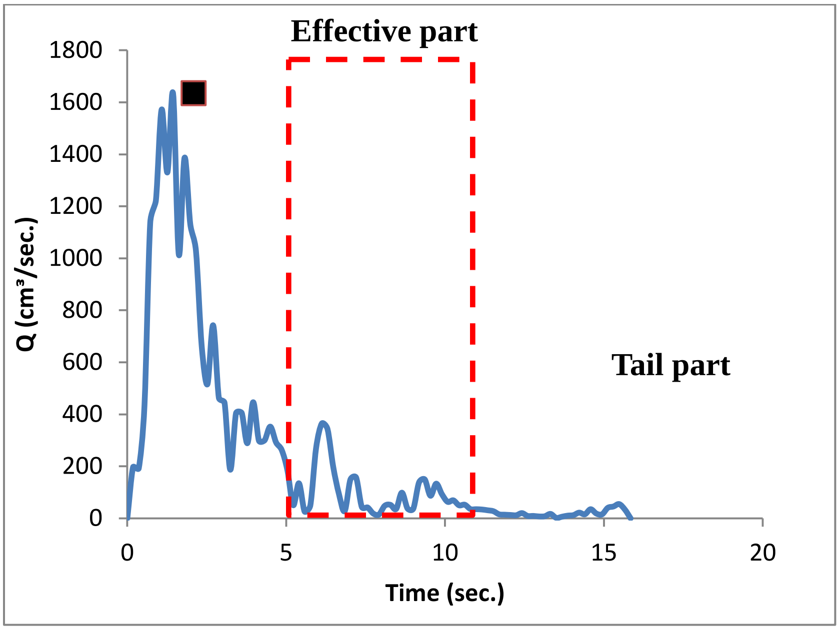



Figure 17 sample of flow rate profile calculations

## Testing procedure

The testing procedure used in this study follows the steps described in the last chapter. The pipe was first laid to a certain slope and the toilet tank was filled with a fixed amount of water. Later, the waste simulants were dumped in the toilet bowl and flushed to investigate the maximum mass that a certain flushing condition can carry without clogging. The waste media weight was fixed to 200g± 10g to represent human feces and mixed with the toilet papers. Several samples are flushed while monitoring theirs inside the drain. If there were no movement of the samples after four consecutive flushes the mass of the waste simulants are considered the clogging mass. On the hand, if the waste simulants pass through and out of the drain or there were no apparent clogging after more than four consecutive flushes, the drain is cleared and mass of the toilet paper is added by 8g (one sheet) and the same procedure is repeated again.

## Experiment plan and design

Table 2 shows the conditions investigated in this study. Nine flushing conditions were chosen to represent the real world situation. Slope values of 0, 0.5 and 1% and for each slope value three flushing volumes were investigated 3.7, 4 and 4 liters. 0% slope was chosen for comparison and to evaluate the performance of the toilets when there is an absence of slope. Furthermore, to investigate the movement of the waste in the toilet drains in cases the drainage were designed no properly or not following the plumbing code guidelines.

Table 2 Expirment design to investigate the effect of flushing volume and slope on the clogging potenital of toilet papers

| | | Toilet Type | | Diameter (mm) | Slope% | | |
|---|---|---|---|---|---|---|---|
| | | YMB-001 | YMF-002 | 75 | 0 | 0.5 | 1 |
| Flush Volume (L) | 3.7 | | | | | | |
| | 4 | | | | | | |
| | 4.5 | | | | | | |

## 3. Results discussion

### The effect of flushing volume and slope on C.g. and $Q_{max}$for YMB-001

Figure 18 shows the effect of slope and flushing volume on the center of gravity of the flow profile for YMB-001. The flushing volume increased from 3.7L to 4L has decreased the C.g. value by an average of 0.5 seconds. However, the increase in flushing volume from 4L to 4.3L did not have the same significant effect on C.g., were the values for both flushing volumes were almost the same. Furthermore, the same trend was found under different slopes from 0 to 1%.This leads to the conclusion that for YMB-001 increasing the flushing volumes higher than 4L has no significant effect on C.g. on the other hand slope and C.g. showed to have a proportional relation. The increase of slope has reduced the C.g. values significantly under different flushing volumes. Also, YMB-001 showed to have more sensitivity to slope than flushing volume, as 0.5% increase in slope has reduced the C.g. by an average of 1.4 seconds compared to 0.5 seconds of 0.3L increase in the flushing volume.

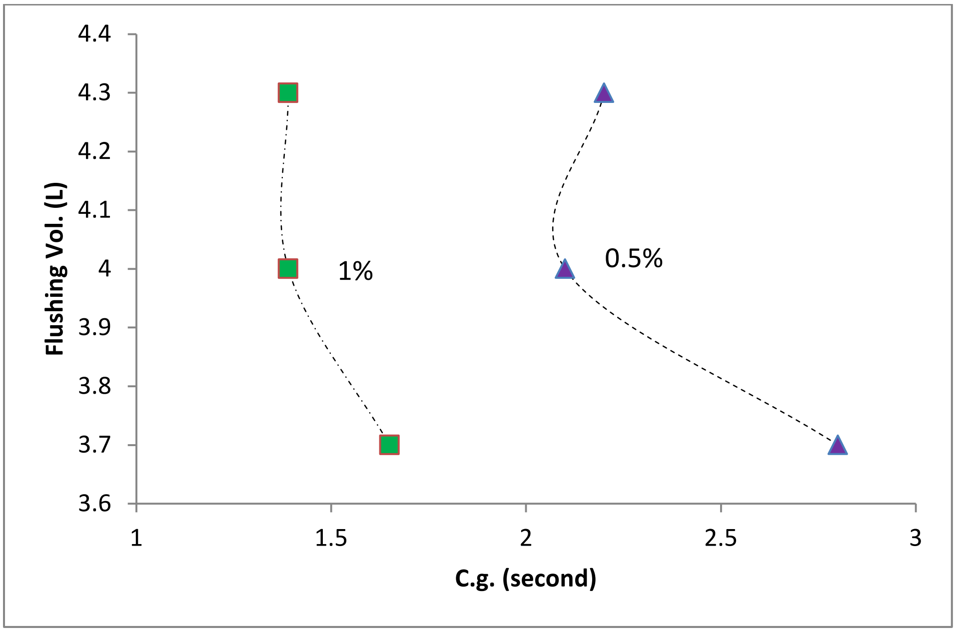



Figure 18 The effect of slope and flushing vol. on C.g. value for YMB-001

Figure 19 shows the effect of the flushing volume and slope on the maximum flow rate $Q_{max}$. The increase of flushing volume by 0.3L from 3.7L to 4L has increased the maximum flow rate dramatically. However, there was no significant increase the maximum flow rate value for flushing volume higher than 4L. This shows that YMB-001 produces the highest maximum flow rate and the shortest C.g. under a flushing volume of around

4L. Slope increase resulted in increasing the maximum flow rate to double under flushing volume of 4L or higher.

The previous discussion leads to the conclusion that YMB-001 toilet reaches it is potential performance under flushing volume of 4L and higher slope values.

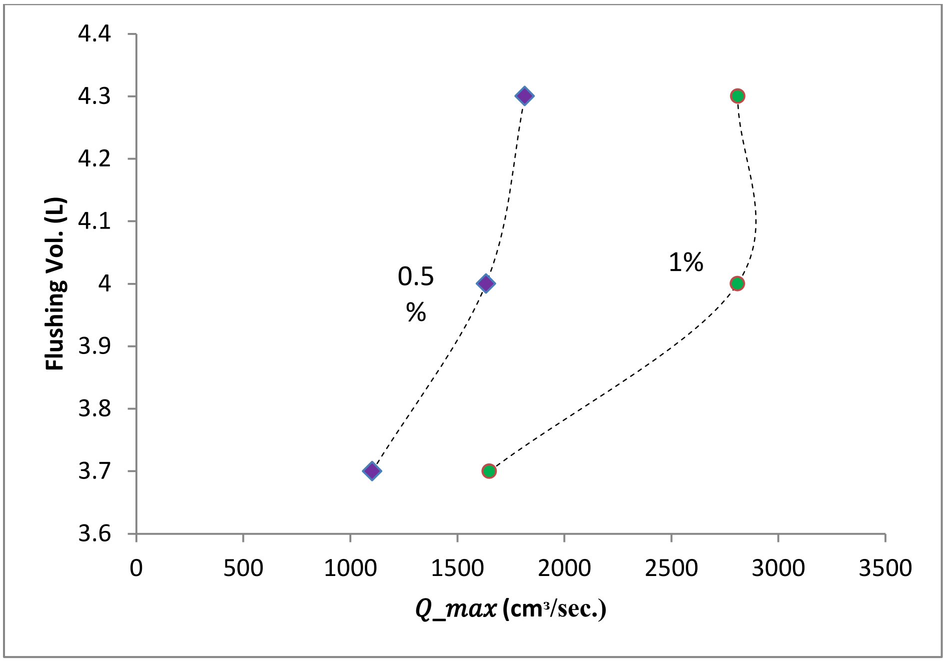



Figure 19 The effect of flushing vol. and slope on $\boldsymbol{Q_{max}}$ for YMB-001

## The effect of slope and flushing vol. on the clogging potential for YMB-001

Figure 20 shows the effect of flushing parameters on the clogging potential for toilet model YMB-001. The flushing volume showed to have much impact on the clogging potential compared to slope. Flushing vol. increase of 0.3L has increased the clogging potential from 176g to 224g, while slope increase by 0.5% has increased the clogging potential by around 25g. Moreover, the clogging potential increases significantly for flushing vol. less than 4L, while the trends decrease significantly for flushing volumes higher than 4L. This pattern is similar to the hydraulic characteristics C.g. and $Q_{max}$ were steep trends were only found for flushing vol. less than 4L.

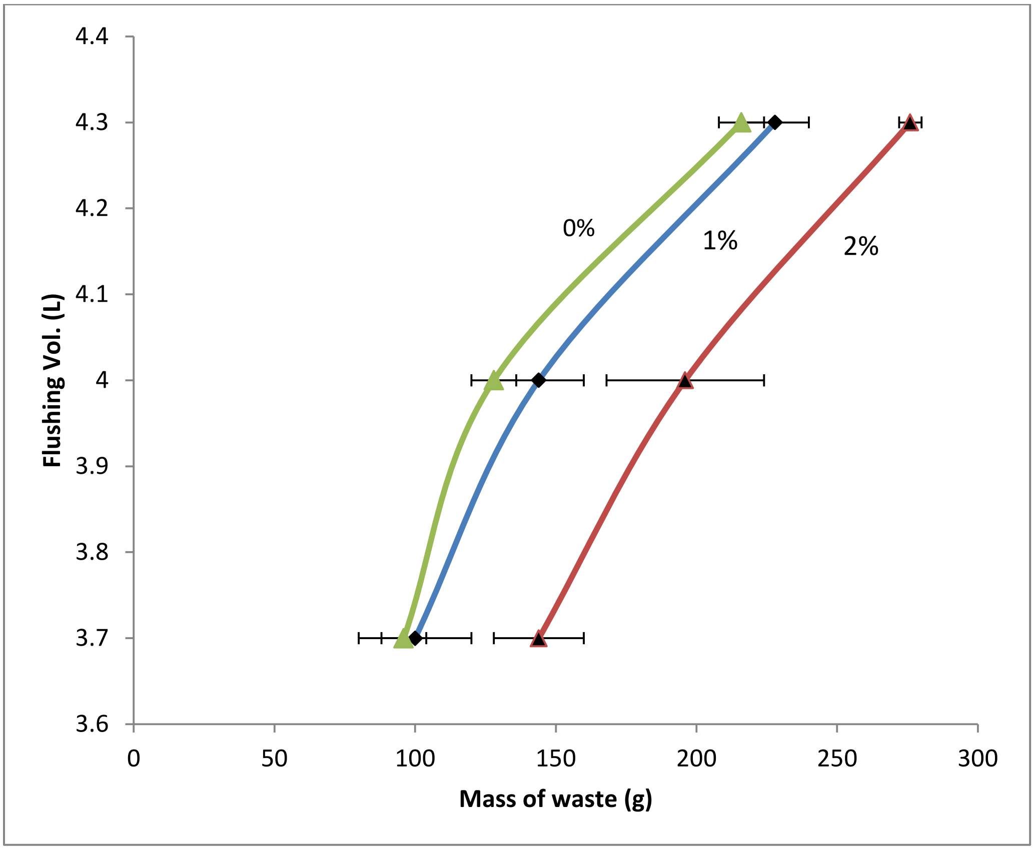



Figure 20 Clogging potential for YMB-001

## Comparison between hydraulic characteristics of toilet YMB-001 and YMF-002

Figure 21 shows C.g. under several flushing volumes for toilets YMF-002 and YMB-001 when the slope is set to 1%. The trend is similar for both toilets as the C.g. values do not change greatly for flushing volumes higher than 4 Litre. Furthermore, the results show that toilet YMB-001 has smaller C.g. values compared to YMF-002 under all of the experimented conditions. This indicates that toilet YMB-001 produces flushing waves that move faster than YMF-001.

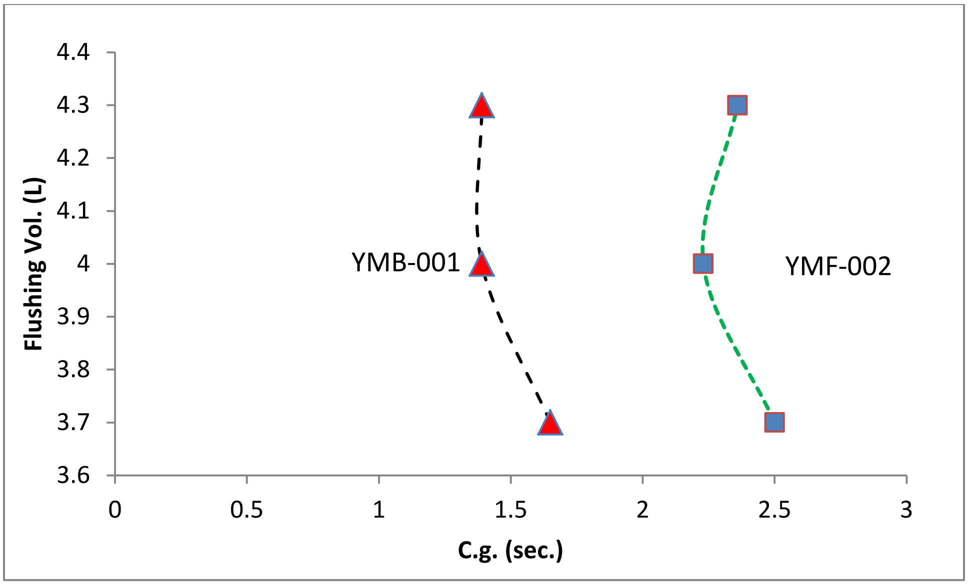



Figure 21 The effect of flushing vol. on C.g. for toilet YMB-001 and YMF-002 when slope is set at 1%

Figure 22 shows $Q_{max}$ against several flushing volumes for YMB-001 and YMF-002 toilet models, while fixing the drain slope to 1%. The results show that for YMB-001 the $Q_{max}$ increase rapidly for flushing volumes lower than 4L while the increase is barley notable for flushing volumes higher than 4L. However, flushing volume increase did not have significant effect on the value of $Q_{max}$ for toilet YMF-001. Finally, YMB-001 have higher $Q_{max}$ values than YMF-002 under different flushing conditions, as the trends were similar under different slope values.

Comparing the two results of the flow profile representatives C.g. and $Q_{max}$ for both toilets, it is clear that toilet YMB-001 produces more rapid flush waves with higher peak flow rate. This indicates that toilet YMB-001 has a better performance in carrying waste through drain pipes than YMF-002. YMF-002 model produces weaker flushing waves is because of the poor design of its bowl. The author believes that sharp edges along the bowl body is disturbing the water flow that is rushing from the toilet rims, which leads to losing the flushing energy at the bowl before it reaches the drain. When expecting toilet YMB-001 and comparing it with YMF-002 it is apparent that the former have a bowl with smoother edges that follows that water pattern rushing from the rims.

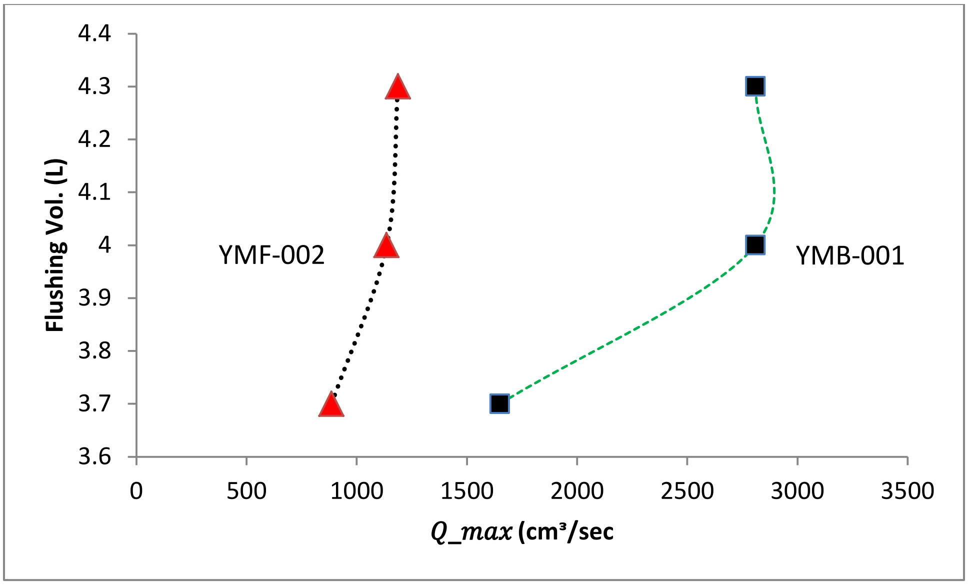



Figure 22 The effect of flushing vol. on $Q_{max}$ for toilet YMB-001 and YMF-002 when the slope is set at 1%

The results of the flow profile measurements and C.g. and $Q_{max}$values can be found in appendix 1.

### Comparison between the clogging potential of toilet YMB-001 and YMF-002

Figure 23 shows that clogging potential toilet YMB-001 and YMF-002. In general, toilet YMB-001 has higher clogging potential than YMF-002. This was predicted as the flow profile C.g. and $Q_{max}$ showed that YMB-001 produces more intense and peaked flushing waves than YMF-002. Another finding is that for flushing volumes higher than 4 litters the clogging potential did not increase as it did for lower flushing volumes. This indicates that clogging potential can be related directly to the flow profile C.g. and $Q_{max}$values as they both follow the same pattern.

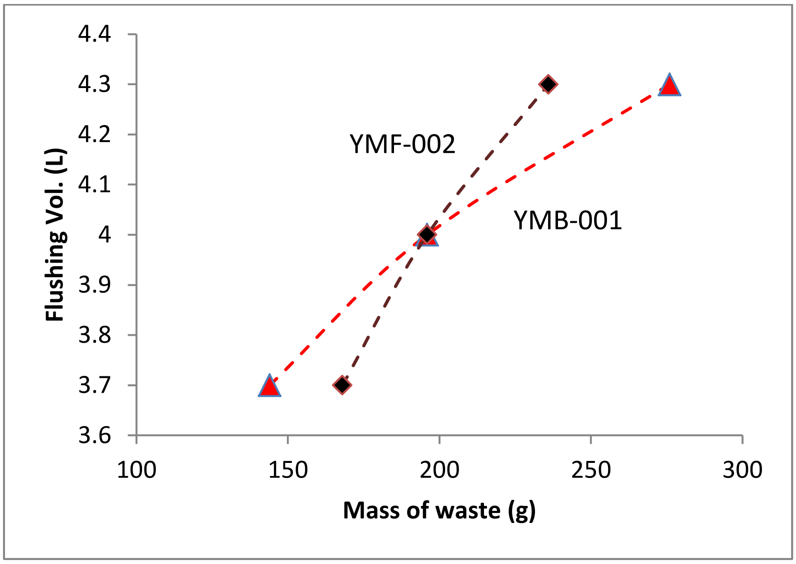



Figure 23 comparison between selected values from the clogging potential charts for toilet YMB-001 and YMF-002 when slope is 2%

.

In practice, to evaluate the performance of toilet models and compare one to another it is enough to determine the flow profile representative values C.g. and $Q_{max}$. Toilet models with peaked and short period flush wave have higher clogging potential. However, if the purpose is to determine the minimum flushing volume or slope that is required to flush certain amount of waste, or the maximum mass of waste that can be flushed under certain flushing condition, then calculating the clogging potential graph is necessary.

The full results of the clogging potential for toilet YMF-002 can be found in appendix 2.

# 4. Conclusion

The flow profiles for toilet YMB-001 and YMF-002 was calculated. Furthermore, these profiles were represented by two values C.g. the centre of gravity of the flow profile in the x axis and $Q_{max}$the maximum flow rate. Using these values it is possible to evaluate the flushing performance of the toilet under consideration and also compare it with other toilet models. After comparing the flow profiles for both toilet models, the results showed that

YMB-001 were producing stronger flushing waves than YMF-001 with small C.g. and high $Q_{max}$ values.

The clogging potential of toilet paper was measured for YMB-001 and YMF-002.The wet mass of T.P. was used as measure for clogging against flushing vol. and the drain slope. YMB-001 had a lower clogging potential than YMF-002 under all of the experimented flushing conditions. Moreover, slope did not have much effect on C.P. for toilet YMF-002. The reason is the poor design of the bowl. The flow path gets interrupted at the toilet bowl and most of the energy from the flushing gets dissipated before it reaches the drain pipe.

In order to minimize water consumption while avoiding clogging in the toilet drain system, it is necessary to calculate its hydraulic characteristics and the clogging potential. The hydraulic characteristic result give preliminary information about the performance of the toilet model and wither it is a good candidate among other toilet models. Furthermore, the clogging potential determines the minimum flushing conditions that need to be met so clogging can be mitigated.

# 5. Reference

Water Regulations Advisory Committee Recommendations for requirements to replace the Water Bye-Laws, a consultatian document (Department of the Environment and Welsh Office) (June 1998)

Water Efficiency Labelling and Standards (WELS) Regulator, 2007. *Water Rating Home* [online]. Available from: http://search.waterrating.com.au [Accessed March 2017].

Howarth, G., Swaffield, J.A. and Wakelin, R.H.M. (1980) Development of a flushability criterion for sanitary products, in Conseil International du Batiment CIBW62 Symposium, Brunel University, Uxbridge, UK, July 1980.

European Disposables and Nonwovens Association (EDANA) (2006) 2005 European Nonwovens Production and Deliveries. Report, summarized on the EDANA website (http:// www.edana.org); the full report is only available to EDANA members.

Littlewood K. Buttler D., Movement mechanisms of gross solids in intermittent flow, Water Science and Technology Vol 47 No 4 pp 45–50 © IWA Publishing 2003

Karadagli, Fatih, et al. "Effect of turbulence on the disintegration rate of flushable consumer products." Water Environment Research 84.5 (2012): 424-433.

Gauley, W., and Koeller J., 2009. *Maximum performance testing of popular toilet models* [online]. 15th edition, Available from: http://www.allianceforwaterefficiency.org/uploadedFiles/Resource_Center/Library/products/MaP/MaP_15/Map-15th-edition-Full-Rpt-2009-10-20.pdf [Accessed March 2017].

Korea Environmental Industry and Technology (KEITI) (2017). *Institute Eco Label Certification* [online]. Available from: http://www.keiti.re.kr/home/index.do [Accessed March 2017].

# Chapter 5 Conclusion

## 1. Conclusion

The objective of this study is to determine the clogging potential in toilet drain system found in house and office buildings and to investigate the effect of related hydraulic parameters on clogging. Furthermore, to create clogging charts and demonstrated it is role in reducing clogging potential by assisting the design of real-world toilet drainage systems. Finally, to calculate clogging charts for flushable consumer products such as toilet papers and to evaluate the effect of the hydraulic characteristic of the toilet under consideration on such charts.

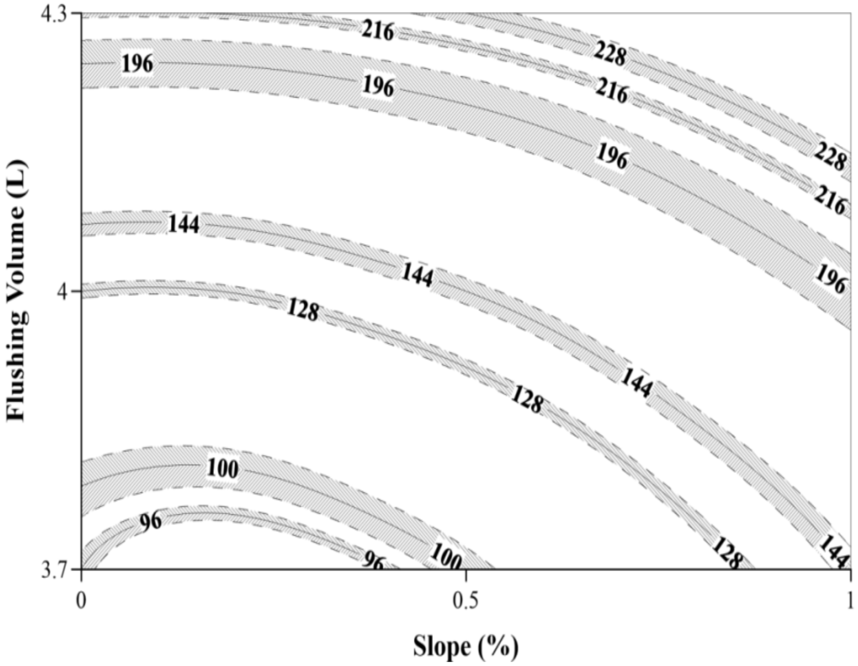
Based on this study:

1. The clogging potential was calculated for toilet YMB-001 and YMF-001 by calculating the minimum flushing conditions to carry waste mass without clogging the drain pipe.
2. Flushing volume had the greatest impact on clogging potential followed by pipe diameter and slope. Also, 100mm pipe had a lower clogging potential than 75mm pipe.

3. It was shown how clogging charts can be used to aid the design of real-world toilet drains in cases where there is limited spacing for slope or limited flushing vol.
4. The clogging potential was calculated for toilet YMB-001 and YMF-002 by calculating the minimum flushing conditions required discharging toilet papers from the toilet drain.
5. Hydraulic characteristics for YMB-001 and YMF-002 and converted to two practical values that was referred to as C.g. and $Q_{max}$ .
6. Analyzing the clogging potential charts and the hydraulic characteristic results, it was found that toilet models with intense and short period (low C.g and high$Q_{max}$) flush waves had better flushing performance.

# Appendix

## Appendix 1




Clogging potential chart for toilet YMF-002

# Appendix 2

Hydraulic characteristics results for toilet YMB-001 and YMF-002

| Toilet model | Slope | Flushing vol. | C.g. | Qmax |
|---|---|---|---|---|
| YMB-001 | 0 | 3.7 | 2.9 | 936 |
| | | 4 | 2.85 | 980 |
| | | 4.3 | 2.6 | 1010 |
| | 0.5 | 3.7 | 2.8 | 1103 |
| | | 4 | 2.1 | 1634 |
| | | 4.3 | 2.2 | 1816 |
| | 1 | 3.7 | 1.65 | 1650 |
| | | 4 | 1.39 | 2809 |
| | | 4.3 | 1.39 | 2810 |
| YMF-002 | 0 | 3.7 | 3.28 | 898 |
| | | 4 | 3.25 | 913 |
| | | 4.3 | 3.78 | 928 |
| | 0.5 | 3.7 | 2.87 | 1190 |
| | | 4 | 2.5 | 1120 |
| | | 4.3 | 2.4 | 1236 |
| | 1 | 3.7 | 2.9 | 1051 |
| | | 4 | 2.23 | 1136 |
| | | 4.3 | 2.36 | 11874 |

# Appendix 3:

## Experiment apparatus

# 초 록

## 조절수형 변기의 배수 시스템의 막힘 사능성

물 부족은 세계적인 문제다. 주택에서 변기 시설은 물 소비의 가장 큰 비중을 차지하는 시설 중 하나이다. 그러므로 그것은 동일한 성능을 유지하면서 물 소비를 줄이기 위해 계속해서 개량이 된다. Low Lush Toilets(6/3LPF)들은 그들의 전 모델인 13LPF 에 비해서 물을 상당히 적게 소비한다. 그러나 수량의 감소는 배설물의 이동을 어렵게 하고 낡은 하수 시스템에서는 자주 하수구를 막히게 한다. 더군다나 신세대 변기로 변기를 업그레이드 하기 위해 하수 시스템 전체를 교체하는 것은 경제적이지 않다. 이에 더해서 최근 변기의 사용에 적합한 화장지의 사용이 급격하게 증가하였다. 그것이 하수 시스템에 미치는 영향, 특히 물을 내릴 때 내려가는 폐기물의 량의 감소가 하수 시스템에 미치는 영향은 아직도 연구의 대상이다.

이 연구는 두 부분으로 나뉘어 시행되었다. 첫 번째 부분에서는 두 개의 변기 모델에 대해서 막힐 위험성(clogging potential)을 계산하고 hydraulic parameter 의 영향이 계산되었다. 그 후, 막히지 않고 배설물이 이동할 수 있는 최소한의 조건이 계산되었고, 막힐 위험성에 대한 그래프(clogging chart)를 작성하였다.

두 번째 부분에서는 두 개의 변기 모델에 대해서 유압의 성능을 각 계산하였고, 후에 물내림이 가능한 화장지의 표준적인 샘플로 선별한 화장지를 사용하여 막힐 위험성(Clogging Potential)을 계산하였다. 또한 변기의 유압적 특성과 화장지의 막힘 가능성의 연관관계를 조사하였다. 결국, 두 개의 연구에서 연구 결과가 실생활에서 사용될 수 있는 방법을 제시하였고, 물 소비를 줄이면서도 변기의 막힘을 방지하는 방법을 제시하였다.

첫 번째 연구에서는 막힘 가능성(clogging potential)에 가장 큰 영향을 주는 변수는 내리는 물체의 부피 (Flushing Volume) 였고,

파이프의 직경과 경사가 두 번째와 세 번째로 큰 영향을 미쳤다. 막힐 위험성에 대한 그래프(clogging chart)를 이용하여 경사의 한계가 있는 경우나 내리는 물체의 부피가 큰 경우 최소한의 물내림의 조건을 계산하였다. 더군다나 Flow Profile 을 이용해서 변기의 특성을 나타내고 C.g. 와 Q.max 의 값을 단순화했다. 분석 결과 물내림의 파장의 짧고 진폭의 경사가 가파른 경우 진폭이 낮은 변기에 비해서 막힐 확률이 줄어들었다.

**주요어**: 막힘 가능성; 막히는차트; 조절수형 변기; 변기의 배수 시스템; 변기의 배수 수송

**학번**: 2015-23306