Effect of Toilet Tissue Paper on Residential Sewerage-line Clogging

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Toilet paper is widely used in residences. The low biodegradability of toilet paper's pulp fibers can cause residence sewer lines to clog, which may be due to some additives or the presence of nonwoven fiber products. In this study, the disintegration rate of toilet paper was compared against various physical factors of the toilet paper sheet. The samples were disintegrated in water at varying pH levels. In the manufacturing of toilet paper, there must be a balance between the desired softness and the necessary wet strength. Twelve commonly used brands of toilet paper were purchased locally. Physical factors of toilet paper samples such as degree of polymerization, thickness, grammage, and softness were determined. The samples were evaluated based on 9 variables using correlation and multivariate linear regression analyses. A strong positive relationship was found between the degree of disintegration of toilet tissue paper and its physical factors. These were the degree of polymerization, the grammage, thickness, and the softness. Additionally, the amount of polymers applied to toilet paper decreased the degree of softness and adversely affected the redispersion of fibers. Thus, this work supports the idea that toilet paper can contribute to clogging of residential sewerage lines.

Keywords: Tissue paper; Viskozimeter of cellulose; Tap water; Accumulation; Bio-degradability

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INTRODUCTION

Toilet paper is one of the world's most widely used tissue papers. Due to the potential accumulation and low biodegradability of its pulp fibers, it has been found that toilet paper that contains either additives that inhibit its disintegration or nonwoven fiber material can lead to clogging of residence sewerage lines (Gupta *et al.* 2018).

Tissue paper is composed of low grammage (12 to 50 g/m²) sheets. The pulp may be virgin, recycled fibers, or combinations with or without creping. The usage of recycled fibers tends to decrease bulk and surface softness. For these reasons, German and Japanese consumers mostly have preferred to buy virgin toilet paper (Kishino *et al.*1999; de Assis *et al.* 2018). Tissue paper can have one or several plies, and it generally has a lignin concentration of about 1% (Contreras *et al.* 2018). Tissue papers are mainly categorized as toilet paper, paper towel, napkins, and cube tissue box wipes.

In addition, there are wet-wipe products categorized as cleaning products. Wet wipes are nonwoven fabric products comprise of a blend of staple synthetic fiber resins and natural short fibers from hardwoods. The synthetic fibers range from 15 to 90%, and they can include polyester, acrylic, polyamide, and polyolefin types (Manning and Wis 1992).

It is often the case that wet wipes are flushed down toilets because consumers assume that wet wipes to be composed of natural fiber papers. The Polymerization degree of cellulose (DP), water absorbency, softness, and disintegration are important properties for quality of tissue papers (de Assis *et al.* 2018; Tutuş *et al.* 2016).

Physical disintegration of toilet papers depends on turbulence in water and product characteristics. Simulation protocols were developed by Eren and Karadağlı (2012) and the flow conditions in the experimental system were compared to those in actual sewer lines. Modeling was used to estimate hydraulic parameters in systems where flow velocities change rapidly in short time intervals. They found that rotational speeds were about 70 rpm in the physical disintegration of toilet papers for flow conditions of household small sewer pipes.

Increasing grammage and high wet resistance of toilet paper make its water absorbency capacity higher. While a high water-retention capacity is highly desirable, it can serve as a disadvantage once the toilet paper is flushed, causing sewerage lines to become clogged by preventing the disintegration ability of the paper in water and sewerage (Fig. 1).

Fig. 1. Toilet paper in residential sewer sludge

According to 2017 data of the Cellulose and Paper Foundation, Turkey's tissue paper consumption increased by 39% between 2016 and 2017 (Cellulose and Paper Foundation, 2017). The monthly toilet paper consumption in the Netherlands is 1 kg per person (Ruiken *et al.* 2013). In a study conducted by Gupta *et al.* (2018), 72% of the total suspended-solids in every liter of wastewater per person per day is composed of toilet paper sludge. According to Champagne and Li (2009), the amount of cellulose in the primary sludge extracted from the municipal wastewater treatment process residuals is also high. The cellulose content in the activated wastewater sludge contains 50% solids (Faust *et al.* 2014).

Traditionally, toilet cleaning is first performed with pressurized flowing water from the thin pipe in the toilet system for the personal toilet cleaning of consumers. Then, toilet tissue paper is used both for drying to remove wetness and for cleaning to complete the toilet cleaning. Therefore, softness, high wet strength and absorbency are the priority quality parameters for tissue paper, as they are highly desired by the consumers.

A paper product is considered to be a wet-strength grade if it retains more than 15% and up to 50% of dry strength (de Assis *et al.* 2018). Different tissue grades prioritize certain properties. For example, in facial tissue paper, a high-quality paper structure is emphasized. In toilet tissue paper, softness, wet strength, and water absorbency are very important. Industrial cleaning papers tend to be high grammage, single-ply sheets with strong strength properties. Water absorbency and wet strength are key properties of cleaning towels. These key features present challenges in the manufacturing of each product. The key properties of tissue paper are grammage, absorbance capacity, softness, thickness, tensile strength, whiteness, brightness, elasticity, and appearance. One of the most important quality parameters consumers expect from toilet paper is high water resistance. However, there must be a balance between the softness and the wet resistance. While the inter-fiber bonds in the tissue paper must be strong to impart high wet resistance, shorter fibers and a bulkier sheet are critical for providing softness. Another way of improving tissue paper softness is through the use of chemical agents (Phan 1993; Boudreau and Germgard 2014).

Water-soluble organic polymers are used in the tissue paper industry to increase the drainage rate and to obtain optimum adsorption and wet resistance. The purpose of wet-strength agents is to improve resistance to breakage of the paper after wetting (Lindström *et al.* 2005). The way they accomplish this is by neutralizing "dissolved and colloidal anionic materials" in the pulp that otherwise would interact and hurt the effectiveness of the cationic wet-strength additives, which are added later to the system. While polymers enhance the wet strength, they decrease the softness by making it harder to disintegrate the paper fibers (Ondaral *et al*. 2015).

There are a wide range of polymer materials used in the manufacturing of toilet papers. The type of polymer material used and the amount of it applied directly affects the dissolution of toilet paper fibers. Polyamide-epichlorohydrin (PAE) and polyacrylamide (PAM) are the most common flocculation and drainage materials worldwide. Polyamines, such as dimethylamine-co-epichlorohydrin copolymer and polydiallyldimethylammonium chloride (PolyDADMAC), are also used as effective flocculation polymers. Bernier and Begin (1994) observed that when the sheet grammage increased, the necessary polymer dosage decreased.

The degree of polymerization (DP) is another important characteristic of tissue paper. The DP is defined as the the mass-averaged number of glucose units that compose the cellulose chain. The DP is directly related to the dissolubility of cellulose. Natural cellulose polymers have long glucose molecule chains that are stable and have a systematic structure. Hydrogen bonds between the molecules of OH groups on glucose units contribute to the crystal structure, which is insoluble in both water and other common solvents (Fengel and Wegener 1989; Eroglu and Usta 2004; Rinaldi and Schüth 2009; Bauer and Ibáñez 2014; Chen *et al*. 2018).

In this study, the disintegration rate of toilet paper was compared against various physical factors of the toilet paper sheet. The toilet paper samples were categorized by their DP, thickness, grammage, density, and softness. The samples were disintegrated in different water samples at varying pH levels.

EXPERIMENTAL

Materials

Toilet papers 12 different branded commonly used were selected and purchased from Sariyer, Istanbul markets, Turkey. The descriptive features of the various toilet paper samples are given in Table 1.

Table 1. Descriptive Features of the Toilet Papers

Number	Descriptive Features of the Toilet Papers
1	Two-ply, white, soft, printed, with creping
2	Three-ply, white, medium softness, printless, with creping
3	Two-ply, white, super soft, printed, with creping
4	Three-ply, white, soft, with creping
5	Two-ply, white, medium softness, printless
6	Two-ply, colorful, soft, with creping
7	Three-ply, white, soft, with creping
8	Two-ply, white, soft, with creping
9	Two-ply, white, super soft, with creping
10	Two-ply, white, medium softness with creping, soft tops, hard interiors
11	Two-ply, white, low softness, with creping
12	Two-ply, white, low softness, with creping

Most of the toilet paper samples were produced from white, two-ply papers with creping for both the printed and unprinted variations.

Methods

Tests were conducted related to the mechanism of disintegration of samples. The typical conditions of toilet paper disintegration in a toilet bowl and consumer feedback regarding the quality of toilet paper clogging sewer lines were considered. In addition, each simulation test involved twice more than the volume of sample needed for cellulose viscosity determination.

Toilet paper samples that weighed 0.20 g to 0.25 g were used for the dissolution testing procedure. The toilet paper samples were placed in five different water samples. Pure water with pH levels of 6, 7, 8, and 9 as well as tap water were measured in 100 mL quantities in a 400-mL beaker. The samples were stirred at a low speed (about 200 rpm) for 1 min and monitored for 24 h, but no significant differences were observed. This was because a sudden turbulence flow is needed to disperse the paper. Values (rpm) of in the disintegration experiment was measured with a hand tachometer (TM 4000 Line Seiki).

The degree of disintegration for the samples were classified among levels between 1 and 4, with 1 representing low disintegration and 4 representing complete disintegration.

The softness testing procedure was performed according to Wang *et al.* (2018). The average softness was obtained through performing three tests for each sample. The softness was evaluated by assigning scores from 1 to 5, with 1 being the roughest and 5 being the softest.

For determination of cellulose DP (degree of polymerization), intrinsic viscosity $[\eta]$ was measured according to the ISO 5351 standard (2010). Then the DP value was calculated from the intrinsic viscosity by using the formula: $DP^{0.905} = 0.75[\eta]$.

The thickness, density, and specific volume of the paper were determined using ISO 534 (2011). The grammage of the paper was determined using ISO 536 (2012).

Statistical analysis

The 12 toilet paper samples were evaluated based on nine variables (Table 2).

Table 2. Measurement Values of the Research Variables

X1	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*	*X8*	*X9*	*X10*
DP	**Grammage**	**Thickness**	**Density**	**Softness**	**pH 6**	**pH 7**	**pH 8**	**pH 9**	**Tap Water**
890.80	46.30	0.20	0.230	4.00	3.00	4.00	4.00	4.00	4.00
478.70	36.13	0.14	0.258	3.00	2.00	3.00	3.00	3.00	3.00
493.40	47.49	0.16	0.296	5.00	2.00	2.00	2.00	2.00	2.00
750.00	61.09	0.23	0.265	4.00	3.00	3.00	3.00	3.00	3.00
578.10	32.72	0.14	0.234	3.00	3.00	4.00	3.00	3.00	3.00
327.50	12.27	0.19	0.065	5.00	3.00	4.00	4.00	4.00	4.00
581.10	59.80	0.23	0.260	5.00	4.00	4.00	4.00	4.00	4.00
615.40	34.10	0.13	0.262	3.00	3.00	3.00	4.00	4.00	4.00
622.80	34.90	0.13	0.268	4.00	4.00	4.00	4.00	4.00	3.00
626.90	33.60	0.15	0.224	3.00	4.00	3.00	3.00	4.00	3.00
602.70	36.50	0.13	0.281	2.00	2.00	2.00	3.00	3.00	2.00
494.60	34.80	0.14	0.249	2.00	2.00	2.00	3.00	2.00	2.00

The variables listed in Table 2 were statistically evaluated using parametric relations analysis methods (correlation and multivariate linear regression analyses) (Ryan 2003; Olive 2017). Correlation is a bivariate analysis that measures the strength of association between two, numerically measured individual variables and the direction of the relationship. The most preferred correlation analyses are the Pearson correlation, Spearman Rank correlation, and autocorrelation. Regression analysis is a statistical method that examines the relationship between two or more variables of interest. However, a multivariate linear regression analysis examines the influence of two or more independent variables on a dependent variable. The research hypothesis in the correlation analyses were as follows: H_1: There is a statistically significant relationship between two different variables (*e.g.*, *X1* and *X2*).

The hypothesis was tested using the Pearson correlation coefficient (r) and significance value (p). If the p value was less than 0.05, the H_1 hypothesis was confirmed. Statistical correlation was measured. The coefficient r gives an indication of both the strength and direction of the relationship between variables (+ 0.5 < r > + 1.0: strong and positive direction statistical relationship; -0.5 < r > -1.0: strong and negative direction statistical relationship). The research hypothesis in the regression analyses was as follows: H_1: There is a linear relationship between the dependent variable (*e.g.*, variable *X5*) given in the model and the independent variables (*e.g.*, *X1*, *X2*, *X3*, *X4* and *X5*). Variables *X6*, *X7*, *X8*, *X9*, and *X10* were assigned as the dependent variables whereas *X1*, *X2*, *X3*, *X4* and *X5* were assigned as the independent variables in the regression analyses (Table 2). The regression equality model of the five regression analyses implemented can be seen in Eq. 1,

$$X_{\mathrm{i}} = \beta_{0,\mathrm{i}} + \beta_{1,\mathrm{i}}X1 + \beta_{2,\mathrm{i}}X2 + \beta_{3,\mathrm{i}}X3 + \beta_{4,\mathrm{i}}X4 + \varepsilon_{\mathrm{i}} \quad (i\colon 5, 6, 7, 8{,}9 \text{ and } 10) \qquad (1)$$

where *Xi* is the dependent variable *X6*, *X7*, *X8*, *X9*, or *X10*; *X1*, *X2*, *X3*, *X4* and *X5* are independent (explanatory) variables; β is the slope; and ε is the residual (error). The coefficient of determination (R^2), and F statistical significance values calculated by the regression analysis were examined and the suitability of the regression model was determined.

These statistical analyses were performed using SPSS 17.0 software (IBM, Armonk, NY, USA).

RESULTS AND DISCUSSION

Characterizing features of the toilet papers are shown in the Table 3.

Table 3. Characterizing Features of the Toilet Papers

Samples	DP	Grammage (g/m^2)	Thickness (mm)	Density (g/cm^2)	Softness*
1	890.8	46.3	0.20	0.230	4
2	478.7	36.13	0.14	0.258	3
3	493.4	47.49	0.16	0.296	5
4	750.0	61.09	0.23	0.265	4
5	578.1	32.72	0.14	0.234	3
6	327.5	12.27	0.19	0.065	5
7	581.1	59.8	0.23	0.260	5
8	615.4	34.1	0.13	0.262	3
9	622.8	34.9	0.13	0.268	4
10	626.9	33.6	0.15	0.224	3
11	602.7	36.5	0.13	0.281	2
12	494.6	34.8	0.14	0.249	2
Mean	588.50	39.14	0.164	0.2410	3.6
N valid	12	12	12	12	12
Std. Dev.	141.18	13.15	0.038	0.05918	1.084
Minimum	327.50	12.27	0.13	0.065	2.00
Maximum	890.80	61.09	0.23	0.296	5.00

*Softness levels: 1- the roughest, 2- rough, 3- moderate, 4- soft, and 5- the softest

The disintegration levels of the toilet paper samples in the various water samples were observed according to subparagraph 4 (“Disrupting the sewerage pipes, abrasive, corrosive substances, alkalis, acids, wastes with a pH value of less than 6 and higher than 10”), article 10 (“Residue and waste not to be sent to sewerage systems”), and Section 2 (“Prohibitions and restrictions”) of the Istanbul Water and Sewerage Administration regulation (Regulation No. 2560 dated Nov. 20, 1981) regarding discharging sewage water into sewage system (Anonymous 2018c). Therefore, simulation of toilet paper disintegration was designed in water with among pH 6 to 9.

The results of disintegration of the toilet papers are given in Table 4.

Table 4. Disintegration of the Toilet Papers

Sample	pH 6	pH 7	pH8	pH 9	Tap Water (pH 6.5 to 7)
1	3	4	4	4	4
2	2	3	3	3	3
3	2	2	2	2	2
4	3	3	3	3	3
5	3	4	3	3	3
6	3	4	4	4	4
7	4	4	4	4	4
8	3	3	4	4	4
9	4	4	4	4	3
10	4	3	3	4	3
11	2	2	3	3	2
12	2	2	3	2	2
Mean	2.92	3.17	3.33	3.33	3.08
Std. Deviation	0.79	0.84	0.65	0.78	0.79
Minimum	2.00	2.00	2.00	2.00	2.00
Maximum	4.00	4.00	4.00	4.00	4.00

The results of the correlation analyses are shown in Table 5.

Table 5. Results of Analysis of Correlation (r: Pearson Correlation coefficient and p: Pearson significant value)

Values		*X1*	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*	*X8*	*X9*	*X10*
X1	r	1	.590*	.281	.435	-.089	.284	.179	.188	.267	.191
	p		.043**	.376	.158	.784	.371	.577	.558	.402	.551
X2	r	.590*	1	.570	.673*	.230	.109	-.092	-.177	-.159	-.048
	p	.043**		.053	.017**	.471	.736	.777	.582	.622	.883
X3	r	.281	.570	1	-.223	.660*	.312	.375	.231	.224	.467
	p	.376	.053		.487	.020**	.323	.230	.470	.484	.126
X4	r	.435	.673*	-.223	1	-.301	-.176	-.462	-.413	-.395	-.484
	p	.158	.017**	.487		.343	.584	.131	.182	.204	.111
X5	r	-.089	.230	.660*	-.301	1	.379	.486	.215	.287	.467
	p	.784	.471	.020**	.343		.224	.109	.503	.365	.126

*Strong and positive direction relationship (0.5 < r > -

** Correlation was significant at the 0.05 level (2-tailed) (p-value < 0.05)

Table 5 shows that there was a moderately strong and positive linear relationship between the DP, the grammage (r=0.590) and density (r=0.435) (*X1*, *X2* and *X4*), and there was a strong and positive linear relationship between the grammage (r=0.590) and the density (r=0.673) (*X2* and *X4*). Similarly there was a strong and positive linear relationship between the thickness and the softness(r=0.660) (*X3* and *X5*). The dark-colored cells in Table 5 highlight these relationships (Table 5).

Information for this study was gathered through face-to-face interviews with sewerage institution officials, site directors, and professional company authorities that deal with clogging issues. It was found that residential sewerage lines, particularly those in big cities, were mostly clogged with toilet papers and particularly paper towels, and wet wipes with synthetic fibers (Anonymous 2018a, b). It can be said that the polymers that increased wet resistance prevented the disintegration of toilet paper in sewer lines by reducing the softness. In addition to toilet paper, high wet strength paper towels with high grammage and wet wipes comprised of synthetic fibers were found to have an important role in the clogging of sewerage lines.

It is important to consider the wet strength of the tissue paper at both the production and consumption stages.

The concentration of the polymer applied in the coating treatment and the grammage of the paper are particularly important parameters to consider (Furman and Winston 1993; Ramasubramanian and Crews 1998; Ramasubramanian and Shmagin 1999). In general, a higher softness in tissue papers indicates a higher quality product (Wang *et al.* 2018).

Overall, there was good disintegration of the toilet paper samples in the various water conditions. Samples 1 and 7 completely disintegrated. These samples had a moderate DP but above-average grammage, thickness, and softness values. Sample 6 had above average softness despite having about average or below-average low DP and grammage. For good disintegration of toilet papers, a linear relationship was found between the DP and grammage, the thickness parameters, which was mostly above the average. The softness performance was the highest (level 5 in Table 2) as above average within all these parameters. This suggests that softness can be used as a common control variable despite the linear relationship between the varying DP, grammage, and thickness values and a good level of disintegration. This view is similar to the interpretation of Wang *et al.* (2018).

Samples 2, 4, 5, 8, 9, and 10 experienced medium disintegration. Average and below-average softness values had a relationship with the DP, grammage, thickness and density value averages (Tables 3, 4, and 5).

Samples 3, 11, and 12 experienced poor disintegration. Apart from sample 3, the softness values of these samples were relatively low. It can be said that the poor disintegration of these samples may have been caused by the plies sticking to each other and the application of a wet strength polymer substance on the inner surfaces. The inner surfaces of the samples were not soft, despite the softness of the outer surfaces. A possible way to explain this is that the non-soft inner surface can be from made recycled fibers and applied wet strength chemical. The soft outer surface can be from made from virgin fiber (Lindström *et al.* 2005; Ondaral *et al.* 2015; de Assis *et al.* 2018).

The differences in the disintegration of the samples were attributed to the high amount of flocculation and wet strength polymer applied to compensate for the low grammage sheets. Samples with high softness values showed good disintegration in water, which revealed a strong linear relationship between softness and disintegration (Tables 3, 4, and 5).

The independent variables in the regression models accounted for a small percentage of R^2 (0.38- 0.62$\prec$0.70) of the variance in the dependent variables (*X6*, *X7*, *X8*, *X9* and *X10*). (Table 2).

The R^2 value was less than 0.70, and it was determined by F test that this relationship was not statistically significant. Therefore, Pareto analysis is not suitable for our study These models were not better than using averages as the best estimation according to the analysis of variance results (F sig > 0.05). The invariant independent variable coefficients were not used in the model (t sig. (p > 0.05) (Table 6).

Table 6. Results of Analysis of Multivariate Linear Regression

Depended Variable	R	R^2	F Test		Predictors	B	t test	
			Value	Sig. (p)			Value	Sig. (p)
PH6	.71	.50	1.203	.408	(Constant)	25.368	1.590	.163
					X1	.002	1.161	.290
					X2	.491	1.492	.186
					X3	-134.479	-1.535	.176
					X4	-94.935	-1.556	.171
					X5	.505	1.572	.167
PH7	.79	.62	1.954	.219	(Constant)	19.108	1.303	.240
					X1	.003	1.556	.171
					X2	.339	1.120	.305
					X3	-95.591	-1.188	.280
					X4	-71.239	-1.270	.251
					X5	.518	1.754	.130
PH8	.62	.38	.734	.624	(Constant)	-3.135	-.215	.837
					X1	.003	1.322	.234
					X2	-.141	-.467	.657
					X3	34.058	.425	.686
					X4	19.130	.342	.744
					X5	.073	.249	.812
PH9	.693	.480	1.109	.444	(Constant)	5.454	.341	.745
					X1	.004	1.794	.123
					X2	.042	.128	.902
					X3	-19.099	-.218	.835
					X4	-16.543	-.271	.796
					X5	.306	.949	.379
Tap Water	.740	.548	1.456	.328	(Constant)	9.030	1.303	.240
					X1	.003	1.556	.171
					X2	.134	1.120	.305
					X3	-36.237	-1.188	.280
					X4	-32.755	-1.270	.251
					X5	.306	1.754	.130

CONCLUSIONS

1. The disintegration of various toilet papers in different water conditions was investigated based on the DP, grammage, thickness, and softness attributes of the tissue papers. The degree of polymerization (DP) (r=0.590), grammage (r=0.673), thickness (r=0.660), softness (r=0.660), and density (r=0.673) parameters had a positive linear correlation relationship with good disintegration of the toilet papers.

2. The softness variable was observed and used as a control indicator in toilet paper disintegration. Softness was strongly affected by the use of wet strength polymers, which in turn affected disintegration.
3. Disintegration tended to be incomplete in the case of low-softness, two-ply tissue prosucts, which exhibited adhesion between the plies. Such products are mostly made from recycling fiber and employ polymers to help maintain their strength when wetted.

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