Food-Service Establishment Wastewater Characterization

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ABSTRACT: Food-service establishments that use on-site wastewater treatment systems are experiencing pretreatment system and/or drain field hydraulic and/or organic overloading. This study included characterization of four wastewater parameters (five-day biochemical oxygen demand [BOD_5]; total suspended solids [TSS]; fats, oil, and grease [FOG]; and flow) from 28 restaurants located in Texas during June, July, and August 2002.

The field sampling methodology included taking a grab sample from each restaurant for 6 consecutive days at approximately the same time each day, followed by a 2-week break, and then sampling again for another 6 consecutive days, for a total of 12 samples per restaurant and 336 total observations.

The analysis indicates higher organic (BOD_5) and hydraulic values for restaurants than those typically found in the literature. The design values for this study for BOD_5, TSS, FOG, and flow were 1523, 664, and 197 mg/L, and 96 L/day-seat respectively, which captured over 80% of the data collected. *Water Environ. Res.,* **78** (2006).

KEYWORDS: on-site wastewater treatment, restaurant, pretreatment system overloading, drain field hydraulic loading, organic loading.

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Introduction

Published literature indicates that designers' use of industry-accepted methodologies and design values for sizing treatment systems for restaurants has, in the past, resulted in systems that are inadequately designed with regard to hydraulic and organic loading (Stuth and Garrison, 1995). A study evaluating the failure rate of two restaurants (Siegrist et. al., 1984) against the mean age to failure rate for lower strength residential wastewater treatment systems of 18 years (Sherman et. al., 1998) indicates concern in allowing existing residential-based design guidelines to be used for commercial or industrial facilities. This is particularly true of treatment-system designs used in food-service establishments. Comparison of the above-mentioned studies shows that higher wastewater strengths can induce a faster decline of treatment-system performance. Furthermore, Converse et al. (1997) states "the design practice of commercial systems has normally been substantially the same as that utilized for household systems. However, recent studies indicate that wastewater from food service establishments may be much stronger." There also exists a greater variability of wastewater quality from restaurants (Nakajima et al., 1999).

In the state of Texas, the Onsite Sewage Facilities (OSSF) regulations outlined in Title 30, Texas Administrative Code (TAC), Chapter 285, identifies water usage rates for different types of establishments, including single-family dwellings, hospitals, laundries, and restaurants (TCEQ, 2002a). Texas OSSF regulations do note that water usage rates shall be used for estimating the hydraulic loading rates only and that commercial or institutional facilities must pretreat their wastewater to 140 mg/L five-day biochemical oxygen demand (BOD_5) before distribution in a final treatment and dispersal system (TCEQ, 2002a). Because water usage rates for residential facilities are listed with commercial facilities, and no guidance for various waste strengths is provided, this leaves a significant gap in information for designers. Municipal sewer regulations (Title 30 TAC, Chapter 317) do provide guidance for restaurant BOD_5 at 1000 mg/L; however, most on-site systems are not subject to these regulations (TCEQ, 2002b). This lack of information, coupled with published literature that indicates commercial systems serving the restaurant industry are failing, suggests that additional research is needed to better understand wastewater characteristics from restaurants (Angoli, 2000).

The lack of performance of on-site wastewater treatment systems serving restaurants can simply be occurring because of a lack of understanding of the hydraulic and organic loading that restaurants place on treatment systems. Not having thorough knowledge of wastewater characteristics creates concerns in the following three areas: (1) increased costs associated with system overdesign, (2) compromise of surface and groundwater quality, and (3) public health and safety issues. A literature review indicated that published information on restaurant wastewater characteristics based on actual data is very limited. Additionally, a report by Kommalapati (2001) suggests that literature concerning design parameters and values for high-strength wastewater that can be used for the design of modern treatment systems are virtually nonexistent.

The objective of this paper is to develop a statistically based methodology to analyze data from 28 Texas restaurants to determine design estimates of wastewater characteristics.

Materials and Methods

Sampling Methodology. Data collection consisted of taking wastewater grab samples from 28 Texas restaurants by three independent analytical laboratories (Blount, 2003). The San Antonio River Authority (SARA) (Texas) sampled 9 restaurants, the Lower Colorado River Authority (Austin, Texas) sampled 9 restaurants, and the City of Austin (Texas) sampled 10 restaurants. All three laboratories performed quality control and quality assurance measures.

The sampling methodology was established considering restaurant management practices and variation in peak hours of operation. The sampling schedule was used to capture effluent from a restaurant when it is actively generating wastewater. In general, sample collection occurred shortly after the noon meal to incorporate meal preparation and washing and rinsing of plates and silverware. Sampling occurred during June, July, and August 2002.

Each restaurant was sampled for 6 consecutive days, followed by a 2-week break, and then sampling again for another 6 consecutive days, for a total of 12 samples per restaurant and 336 total

Table 1—Analytical methods used by each contracted laboratory.

Entity	Method		
	BOD_5	FOG	TSS
SARA[a]	SM[d] 5210B	U.S. EPA[e] 1664	SM[d] 2540D
LCRA[b]	U.S. EPA[e] 405.1	U.S. EPA[e] 1664	U.S. EPA[e] 160.2
City of Austin[c]	SM[d] 5210B	U.S. EPA[e] 1664	SM[d] 2540D

[a] San Antonio River Authority, P.O. Box 839980, San Antonio, Texas 78283-9980.
[b] Lower Colorado River Authority, 3700 Lake Austin Blvd., Austin, Texas 78703.
[c] City of Austin, Laboratory Services Division, 14050 Summit Drive, Suite 121, Austin, Texas 78728.
[d] SM: *Standard Methods for the Examination of Water and Wastewater* (APHA et al., 1998).
[e] U.S. EPA: U.S. Environmental Protection Agency, *Methods for Chemical Analysis of Water and Wastes* (U.S. EPA, 1983).

observations. Grab sampling on consecutive days was conducted to capture variation during a typical week of operation rather than single points, as typically conducted with quarterly or monthly sampling routines. All samples were taken after the grease trap. Facility blueprints were not available for any of the establishments, and information provided by restaurant personnel with regard to commingling of gray- and black-water lines was not available; hence, it was not possible to determine, with any level of certainty, whether the samples were taken before or after commingling of the wastewater lines. For purposes of this study, commingling was assumed to have occurred, as the intent of this study is to determine suggestiveness of the descriptive analyses of the data.

The samples were analyzed for BOD_5; total fats, oils, and greases (FOG); and total suspended solids (TSS). Properly designed and sealed containers were used to transport samples to the laboratories for analyses. All samples were also preserved and handled before analysis according to the prescribed standard procedures for the analytical methods used. Analytical methods used by each laboratory are shown in Table 1.

Problems with specific data included 19 BOD_5 values that were reported by the City of Austin as having failed quality assurance/quality control (QA/QC) procedures established by that laboratory. These 19 values were not considered in the analysis. All values reported for FOG and TSS were used in the raw data analysis.

Daily flow values were obtained by taking the difference between daily meter readings. In instances where meter readings from consecutive days were not available, the average of other days was used. Also, in cases where the laboratory reported meter readings that were suspect (e.g., lower meter reading the second day), monthly averages were developed based on the restaurant's water use bill. Other data used includes the number of seats reported by restaurant personnel.

Data Reduction Techniques. *Five-Day Biochemical Oxygen Demand.* There were 336 BOD_5 sampling events in this study; however, 32 samples were eliminated before raw data analysis. Of the 32 samples removed, the City of Austin did not report two values; SARA did not report 11 values (4 values as a result of no flow); and 19 values from the City of Austin were removed because of failed QA/QC checks. The remaining 304 BOD_5 values were used in the raw data analysis. A statistical analysis of the BOD_5 data was performed using the standard gamma probability distribution model in Microsoft Excel (Microsoft Corporation, Bellevue, Washington), a distribution model commonly used to analyze skewed data. The data is skewed to the right and is bound at the lower limits by zero. Moreover, observing that the relative frequency for the higher values is substantially low, the gamma probability model was used to determine the probability of attaining the higher values. The analysis revealed that, based on 304 events, the chance of obtaining a BOD_5 value of 8790 mg/L or higher is less than 1 in 10 000 (gamma value = 1.88E-7 at 8790). Because of the remoteness of being able to obtain the higher numbers, 11 values were classified as outliers and subsequently removed from the analysis, leaving a remainder of 293 events. In addition, nine BOD_5 values were removed from the analysis because these samples were associated with outliers removed from the TSS or FOG data. It was assumed that if a value for any one parameter (BOD_5, TSS, or FOG) was classified as an outlier, then the entire sample was removed from the data set. The implemented data reduction procedures resulted in a final trimmed data set of 284 values, as shown in Figure 1.

Total Suspended Solids. There were 336 TSS sampling events in this study; however, four samples were eliminated before raw data analysis. Four samples were removed because of "no discharge" reported by SARA. There were several samples that had extremely high TSS values. As with BOD_5, the gamma probability was used (gamma value = 5.30E-14 at 15 100) to remove four outliers that ranged in value from 15 100 to 91 800 mg/L. Sixteen TSS values were also removed in the final analysis because of the removal of associated BOD_5 and FOG outliers, for a total of 312 TSS events, as shown in Figure 1.

Fats, Oils, and Greases. There were 336 FOG sampling events in this study; however, five samples were eliminated before raw data analysis. These data were removed because "no discharge" was reported by SARA for four samples. Also, the City of Austin reported a "non-detect" for one sample. There were several samples that had extremely high FOG values. As with BOD_5 and TSS, the gamma probability was used (gamma value = 1.37E-5 at 1129) to remove 13 outliers that ranged in value from 1129 to 700 000 mg/L. Seven FOG values were also removed in the final analyses because of the removal of associated BOD_5 and TSS outliers, for a total of 311 FOG events, as shown in Figure 1.

Flow. There were 336 flow measurements recorded in this study. As with the other parameters, an analysis was performed using Microsoft Excel to determine the probability of attaining the higher values. The gamma probability used to analyze the skewed data resulted in removing one outlier (gamma value = 1.04E-5 at 97). No values were removed in the final analysis because of the removal of outliers associated with BOD_5, TSS, or FOG as a result of the independent nature of flow measurements versus the other samples. The trimmed flow data with 335 samples are shown in Figure 2.

Results and Discussion

In summary, while the chance of obtaining the outlying values for BOD_5, TSS, FOG, and daily flow may be considered remote, it is not impossible. Two similar outlying BOD_5 values were reported during two sampling events at the same restaurant; therefore, the data is considered valid. For this study, it was assumed that there was such an improbable chance of these values occurring that they were removed to determine behavioral patterns in the data.

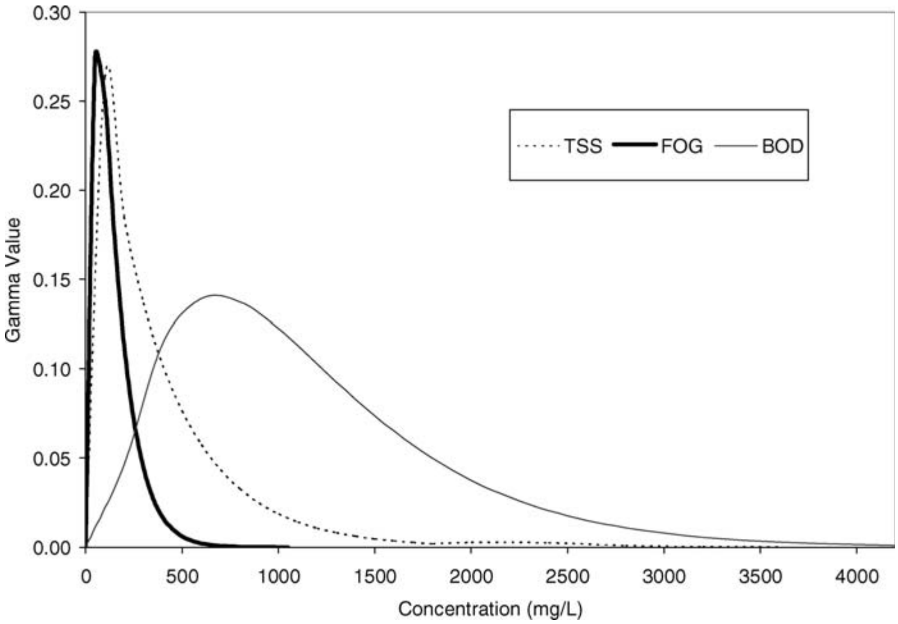

Figure 1—Gamma probability distribution model for trimmed BOD_5 data (n = 284), trimmed TSS data (n = 312), and trimmed FOG data (n = 311) collected from 28 restaurants.

Values obtained from the gamma model are shown in Table 2. The first level of analysis determined the descriptive measures for the raw data, which represents data as received from the laboratories except values removed for QA/QC reasons or other reasons associated with laboratory activities. This raw data set included the outliers.

The second level of analysis consisted of determining the same descriptive measures with the outliers exceeding the "1 in 10 000 chance of occurring" criteria being removed and the removal of an entire sample associated as an outlier for BOD_5, FOG, or TSS. For example, the FOG value of 700 000 mg/L was removed as an outlier, resulting in the removal of the BOD_5 and TSS value associated with that sampling event. Consequently, a total of 20 of 336 observations were removed. One daily flow observation was removed.

The development of the trimmed data set enabled a more reasonable estimate of design values (specific to this data set) using the geometric mean plus one standard deviation. This design value includes 82, 87, 82, and 81% of the BOD_5, TSS, FOG, and flow values, respectively, measured in this study.

This research suggests that design practices using domestic-strength effluent characteristics for sizing on-site pretreatment

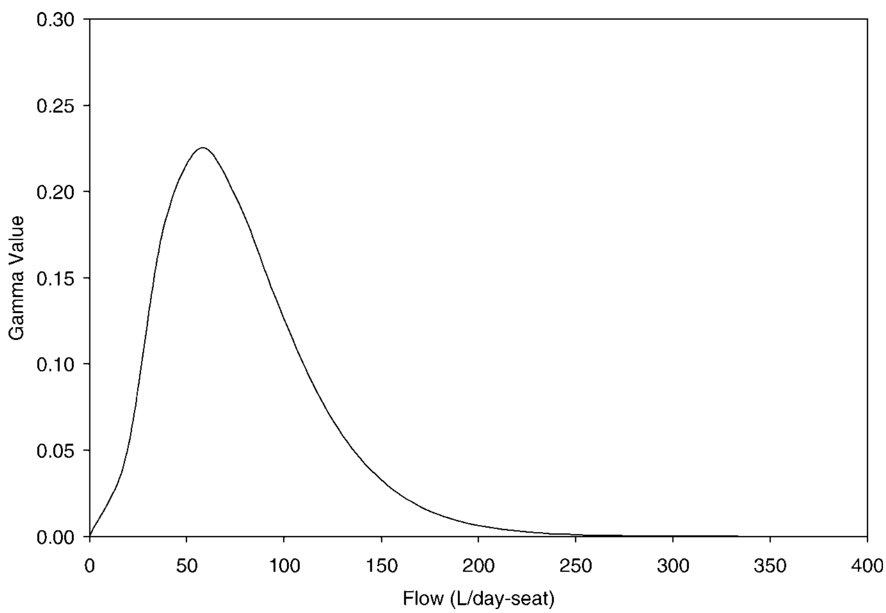

Figure 2—Gamma probability distribution model for trimmed flow data (n = 335) collected from 28 restaurants.

Table 2—Estimates for wastewater parameters for raw and trimmed data.

Wastewater parameter	Statistical parameter	Raw data	Trimmed data
BOD_5 (mg/L)	*n*	304	284
	Mean	1584	1040
	Geometric mean	932	833
	Standard deviation	2902	690
	Geometric mean + 1 Standard deviation	3834	1523
TSS (mg/L)	*n*	332	312
	Mean	1030	358
	Geometric mean	257	234
	Standard deviation	7113	430
	Geometric mean + 1 Standard deviation	7370	664
FOG (mg/L)	*n*	331	311
	Mean	4520	123
	Geometric mean	108	90
	Standard deviation	51 400	107
	Geometric mean + 1 Standard deviation	51 508	197
Flow (L/day-seat)	*n*	336	335
	Mean	68	68
	Geometric mean	57	57
	Standard deviation	42	39
	Geometric mean + 1 Standard deviation	99	96

systems and soil treatment area for restaurants will underestimate the required size, especially related to BOD_5. These research results are generally greater than other published design values for wastewater parameters (Table 3). Average TSS and FOG values appear to agree with the previous research. The flow value for this study is within the range of suggested values for Texas OSSF regulations.

The results of this study compare favorably to the results of a study by Siegrist et al. (1985), which measured effluent concentrations from 11 commercial facilities (6 restaurants, 1 motel complex, 3 country clubs, and 1 bar and grill). Siegrist et al. (1985) observed ranges in BOD_5 from 101 to 880 mg/L, TSS from 44 to 372 mg/L, and FOG from 24 to 144 mg/L. The results of the research also compare favorably to the results of a study by Chen et al. (2000) presented in Table 4, which used effluent from restaurants to study the separation of pollutants from restaurant wastewater by electrocoagulation.

Chen et al. (2000) presented the wastewater parameters with respect to cuisine type. Substantial variations among cuisine types may explain large standard deviations presented in Table 2. Although not considered in this analysis, cuisine type and other restaurant management practices (e.g., methods of washing; chemicals used in cleaning; specific water use, such as defrosting; use of water-saving devices; use of dishwashers, garbage disposals, and laundry washing machines; peak flowrates; and demographics) might explain variations in wastewater flow and composition. Future studies should consider these influences on the wastewater characteristics.

Conclusions

Wastewater characteristics (BOD_5, TSS, FOG, and flow) were measured from 28 restaurants in Texas. Three different strategies were undertaken to characterize the wastewater strength that will have use to regulators, practitioners, and researchers.

From a practitioner and regulator point-of-view, characterization of the wastewater might be necessary for estimating wastewater strength at a facility. This research shows that the geometric mean of sampled data will result in a value more characteristic of the central tendency of the data.

From a research perspective and in an attempt to estimate standardized design values, the data set was trimmed of outliers, and the trimmed data geometric mean plus one standard deviation was used. The data set was trimmed using a gamma distribution model with the criteria of an outlier exceeding a 1 in 10 000 chance of

Table 3—Comparison of wastewater parameters from this study (geometric mean plus 1 standard deviation) with published design values.

Wastewater parameter	Texas municipal regulations[a]	Texas OSSF regulations[b]	Burks and Minnis[c] (1994)		Tchobanoglous[c] (1991)			Goldstein and Moberg[d] (1973)	Present study
			Range	Typical	Weak	Med	Strong		
BOD_5 (mg/L)	1000	Not available	100 to 400	250	110	220	400	450	1523
TSS (mg/L)	Not available	Not available	100 to 400	220	100	220	350	Not available	664
FOG (mg/L)	Not available	Not available	50 to 150	100	50	100	150	Not available	197
Flow	19 (L/day-meal)	132[e]/57[f] (L/day-seat)	Not available	Not available	Not available	Not available	Not available	Not available	96 (L/day-seat)

[a] Title 30 Texas Administrative Code, Chapter 317 (Texas Commission on Environmental Quality Regulations, 2002b).
[b] Title 30 Texas Administrative Code, Chapter 285, *Water Usage Rate for Restaurants Without Water Saving Devices* (Texas Commission on Environmental Quality Regulations, 2002a).
[c] Typical composition of untreated domestic wastewater.
[d] Suggested BOD_5 concentration for restaurants.
[e] Full-service restaurant.
[f] Single-service restaurant (fast-food).

Table 4—Characteristics (average range of values) of restaurant wastewater.*

Wastewater parameter	Chinese restaurant	Western restaurant	American fast food	Student canteen	Bistro
BOD_5 (mg/L)	58 to 1430	489 to 1410	405 to 2240	545 to 1630	451 to 704
TSS (mg/L)	13.2 to 246	152 to 545	68 to 345	124 to 1320	359 to 567
FOG (mg/L)	120 to 172	52.6 to 2100	158 to 799	415 to 1970	140 to 410

* After Chen et al., 2000.

occurring. For this study, conducted in central Texas, the design values for BOD_5, TSS, FOG, and flow were 1523, 664, and 197-mg/L, and 96 L/day-seat, respectively, which captured over 80% of the data collected.

Future work in this area of wastewater characterization needs to consider the effect of various management practices and cuisine types.

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