Considerations and Challenges of treating high strength wastewater treatment – Comparing different approaches

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Introduction

Most states have not taken high strength wastewater characteristics into consideration when proposing guidelines and regulations for designing onsite sewage treatment and disposal systems. Various factors can cause high strength wastewater:

- High inputs of BOD, TSS, FOG, Nitrogen
- Lack of dilution from low waste strength inputs – use of low flow water fixtures
- Upset of the septic tank (hydraulic, chemical, sludge, etc),
- Operation and maintenance issues

However, the focus is put here on the commercial and non-residential buildings that can use water for different purposes than typical residential use, which can lead to unusual or high wastewater strengths.

A number of states are now recognizing that effluent BOD_5, TSS, and FOG concentrations in excess of domestic septic tank effluent may need to be addressed in a different manner. Many pretreatment possibilities exist. To what extent these “pretreatment” alternatives reduce high-strength wastewater is yet to be completely understood. The Environmental Protection Agency (EPA) and National Sanitation Foundation, International (NSF) are working on a testing protocol that may assist in determining the treatment capacity of these “pretreatment” alternatives.

High strength wastewater main contributors

Onsite wastewater treatment system design and sizing is typically based on wastewater design flow with the assumption that the wastewater strength is within standard ranges for domestic (residential) strength wastewater. While many applications are within the low or moderate strength ranges (table 1), many non-residential or commercial establishments may produce higher wastewater strengths or may include chemicals that may harm or reduce treatment performance.

Table 1

Parameters	Domestic/Low strength (Raw wastewater)	Moderate strength (Raw wastewater)	High strength (Raw wastewater)
BOD_5	100 - 300 mg/L	300 to 1,000 mg/L	> 1,000 mg/L
TSS	100 - 350 mg/L	> 350 mg/L	> 350 mg/L
TKN	40 – 60 mg/L	60 – 100 mg/L	> 100 mg/L
FOG	50 – 150 mg/L	> 150 mg/L	> 150 mg/L

Designers and owners of various non-residential or commercial enterprises should be aware of some unique and potentially damaging wastewater characteristics that may be encountered in the waste stream. These establishments may produce wastewater with high strengths (characterized by high BOD, TSS, and Fats, Oil and Grease influent numbers); while others may contain harsh chemicals used in processing or cleaning activities. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Fats, oils and grease (FOG), and Total Suspended Solids (TSS) are parameters that can indicate the wastewater strength and its biodegradability.

Among the types of establishments that may produce non-domestic or high-strength wastewater, there are:

- Food Establishments - Restaurants, fast food restaurants, coffee shops, deli's, convenience stores, cheese makers, breweries, wineries, bakeries, food courts;
- Hotels, motels, campgrounds, churches;
- Hospitals, nursing homes, dental offices, schools;
- Laundromats, funeral homes, taxidermy operations, slaughterhouses, pet kennels, beauty salons.

Organic matters

BOD is directly related to the amount of food products in wastewater. Unused coffee, dairy products, soda pop, juices or other high sugar content beverages have a high BOD concentration that can adversely impact a treatment/disposal system if not taken into account when the system is designed. Few examples are presented in the table 2 below.

Table 2

	BOD_5 (mg/L)	**pH**
Soda	Up to 79 500	2.4
Beer	Up to 80 000	
Whole milk	104 600	
Skim milk	67 000	
Orange juice	7.85 lb/100 lb	
Potatoes	4.20 lb/ 100 lb	
Potato chips	1.25 lb/ 100 lb	

Ref: Carawan, R.E., NC State University, Water and Wastewater Management in Food Processing (1979)

Obviously, efforts should be made to limit the amount of food wastes going to in-sink garbage disposals; removing leftover food and any oil and grease from plates and cookware before washing them. BOD_5 is directly related to the amount of food products in the wastewater.

To add to the complexity, not all restaurants are created equal. Table 3 below presents a summary of a sampling campaign performed in 2013, for a study conducted by the Harris county Public Infrastructure Department, on different types of restaurants.

Table 3

Restaurant type	**n**	**Average BOD (mg/L)**	**Average TSS (mg/L)**	**Average FOG (mg/L)**
Fast food	6	2 137	233	102

Pizza	1	1 856	321	183
Chinese	4	1 364	448	241
Mexican	9	1 254	668	190
American	1	1 063	297	147
American buffet	1	792	195	63
Steakhouse	2	601	160	77
Seafood	3	555	229	47
Typical residential range		100-400	100-350	10-65

In addition, unusual waste streams like breweries, wineries, cheese makers, and slaughterhouse wastes, if mixed with domestic wastewater, should be carefully evaluated to understand the characteristics of the waste stream. Sometimes these wastewaters are deficient in nitrogen, phosphorus, or even bacteria which are all needed in order to begin to treat the wastewater (University of Minnesota Onsite Sewage Treatment Program http://septic.umn.edu/). Consideration to collecting and disposing separately those wastewaters from domestic wastewater source should be given.

FOG

Although conventional grease traps are supposed to prevent grease from entering the septic tank or sewer line, high grease loads, emulsified grease, undersized grease traps, poor maintenance, and surges in the wastewater flow may cause grease and oils to escape the grease trap. Problems can occur when oil and grease liquefy at the high-water temperatures used to wash dishes and then congeal when it cools. The congealed oil and grease can then accumulate in sewer lines or in/on the onsite wastewater treatment systems, creating variety of issues depending on the type of system. The problem is exacerbated when highly efficient detergents, enzymes, and/or bacteria are used to emulsify the oil and grease keeping it in suspension until it reaches a point where it starts to cause issues. Emulsified oil and grease have been broken up into very small droplets and occurs either by mechanical, biological, or chemical action. Biologically and chemically emulsified oil will take a longer time to separate increasing the risk of carrying it to downstream components unless long quiescent periods are available to allow separation.

But what is the difference between fats, oils and greases.

Fats - Animal fat is relatively easy to hold in a tank and quite sensitive to temperature. It becomes a solid at 25°C and wastewater temperature is usually less than 25°C in the exterior tankage, ranging around 16°C. Animal fat will break down through a biological process but it takes four times more energy to break down than the organic matter typically measured by BOD. Fat is added to the system from cooking, clean up, and dish washing so commercial systems will typically have higher levels of fat than residential systems. If a system is supplied with a lot of animal fat, it will typically stay in the grease trap or septic tank. If it is contained in the grease trap or septic tank, it may not be observed in FOG measurements in downstream components.

Oils - Vegetable oil is not as sensitive to temperature as fat and can pass through grease interceptors or septic tanks more readily. Oil can also be broken down through a biological process but it takes 12 times more energy than the organic matter typically measured by BOD. There are many different types of oils used but vegetable is the most common. Vegetable oil is often used in the liquid form but it can also be solid shortening. The liquid form is harder to hold in a tank.

The ability of the oil to separate is influenced by temperature and by how the oil was generated and used.

Grease - Grease is petroleum-based and can be toxic to a system. Because grease is petroleum-based, it is difficult to break down but it can be separated. Grease comes from lotions, hair products, and soaps. Typically, there will be a higher percentage of grease in the FOG from residential systems when compared to most commercial systems. Grease can build up over time coating components and inhibiting treatment of other constituents in the wastewater.

Emerging Contaminants

Little is known about contaminants of emerging concern and their possible impacts on system performance. These include groups of products such as pharmaceuticals, personal care products, and manufactured by-products.

Harsh cleaning chemicals can harm septic tanks and treatment performance especially the use of quaternary ammonia and other harsh chemicals. Quaternary ammonium compounds or “QUATs” are chemicals that are used in a variety of different personal care products. They are used as conditioning agents to give skin and hair a smooth feel. They make clothes feel softer after being washed so they’re also a common ingredient in fabric softeners. The foodservice industry uses QUATs as a disinfectant. The cleaning habits and kitchen practices of commercial facilities can differ significantly from domestic practices, and in fact can differ significantly from commercial facility to commercial facility. Restaurants are especially difficult because health and safety is paramount in the operations. Most restaurants adhere to strict cleaning procedures to meet health requirements, which if not met, can mean that the business is forced to shut down. QUATs can be found also in shampoos, toilet cleaners, hand soap, shaving cream, baby wipes, body wash, sunscreens, moisturizers, disinfectant sprays, liquid fabric softeners, anti-cling dryer sheets, etc. Quats are formaldehyde releasing toxic chemicals that have been associate with multiple health risks including:

- Allergies & irritation (skin, eye, lung)
- Contact dermatitis – Studies estimate that between 13% and 34% of contact dermatitis cases may be linked to quats.
- Asthma
- Fertility Issues
- Birth Defects

Also, pharmaceuticals will likely be present in the waste stream due to the fact the majority of these compounds will be excreted by patients with the impact that can be observed on performance of septic systems.

Temperature

The temperature of wastewater is typically warm enough to encourage biological activity needed for treatment. Commercial dishwashers can be set at very high temperatures which may impact treatment and/or the ability of fats, oils, and greases to solidify in the grease and septic tanks.

pH

pH can be affected by cleaning chemicals and certain food wastes. If the pH is out of the normal range (typically 6.4 to 8), it can impact biological activity that is part of the treatment process and will contribute to put back in solution precipitated of Ptot when conditions become acidic.

Alkalinity, which is a property that stabilizes the pH in a solution, is also important particularly in the nitrification/denitrification process. Lack of alkalinity may inhibit nitrification process which is consumed in a 7 alkalinity to 1 N ratio. Alkalinity in water can vary quite a bit from one region to another one depending on its source (surface or groundwater) and soil geology. It is recommended to maintain a minimum residual alkalinity of 50 mg/L to prevent acidification of treated water and to maintain favorable conditions for the wastewater treatment process.

Flow

Flow variations can have an important effect on treatment if they are not taken into account and well assessed during the design phase of a system. There are numerous terms used to define hydraulics and flow that needs to be understood in the design and operation of an onsite system:

- Average daily flow rate: average volume of wastewater in a 24-hour period; calculated from values measured over a period of time;
- Daily flow rate: measured volume of wastewater generated from a facility in a 24-hour period; expressed as a volume per day;
- Daily design flow rate: estimated peak volume of wastewater for any 24-hour period; parameter used to size non-residential systems;
- Design flow rate: estimated volume of wastewater per unit of time for which a component or system is designed; commonly called 'design flow' – usually it is based on theoretical values extracted from local jurisdiction's regulation;
- Hourly peak flow rate: highest flows measured for a one-hour period;
- Instantaneous peak flow rate: highest recorded flow rate occurring within a given period of time;
- Surge flow: flow of effluent greater than average and occurring for short periods of time.

Depending on the application, flow can vary quite a bit during a day (restaurants) or a period of time (churches). Flow equalization is a treatment system component that includes sufficient effluent storage capacity to allow for uniform flow to a subsequent section of the treatment despite variable flow from the source. For systems with significant flow variations, flow equalization can be utilized to dampen the effect of peak flows.

Other considerations

Non-domestic strength wastewater may necessitate special considerations for operation and maintenance. Less conservative designs or higher-than-anticipated waste strengths or flows may require more frequent tank pumping intervals and more regular system maintenance activities.

Solutions: the Benefits of Combining Treatment Approaches

The regulatory framework is not always adapted to this type of project. Therefore, it is often not enough to simply apply a one fits all solution that would theoretically meet the code prescriptions. A thorough investigation of the various design challenges and a good understanding of the water usage by the facility is essential to alleviate the negative impact they could have on the septic system and provide a well-adapted wastewater treatment solution.

When designing for a particular wastewater treatment projet, engineers must choose among various technologies available, each having its own capacity in terms of flow rates and loads it can efficiently treat. That choice and design will rely on project specific criteria such as the expected performance, space avaible, acquisition and maintenance cost or operating complexity. The graphs in figure 1 present an example of application ranges for flows and concentrations with respect to different types of treatment processes provided by a given manufacturer: biofiltration, activated sludge, fixed film, and membrane bioreactor.

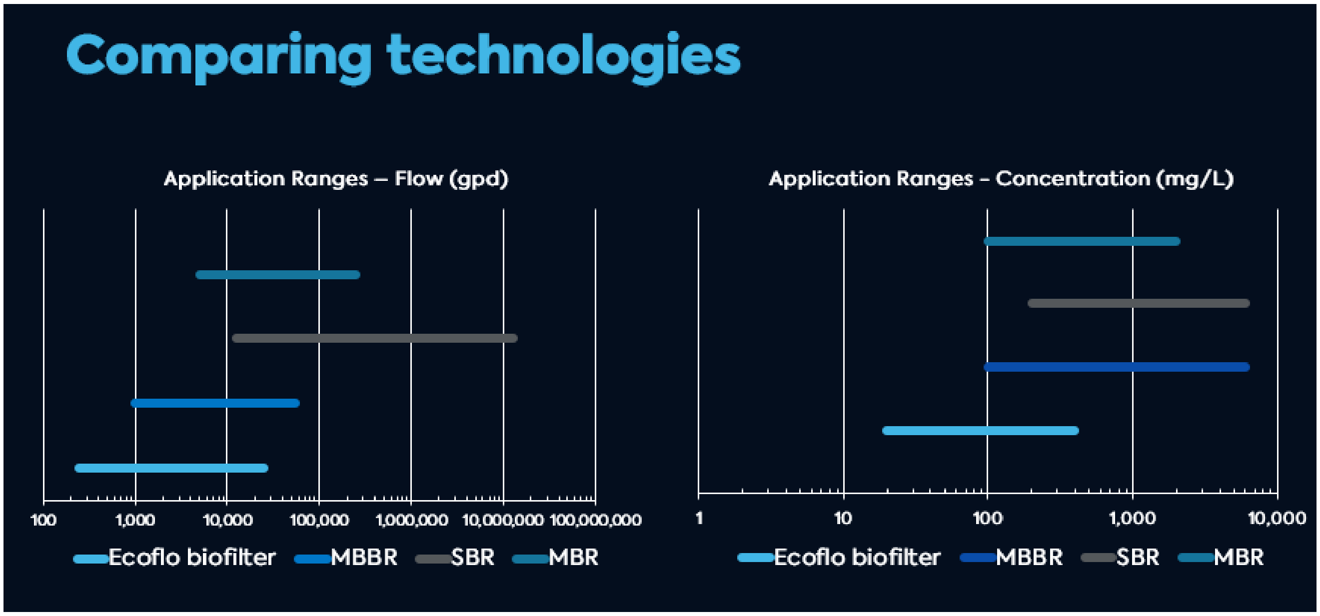

Figure 1

For instance, the graph on the left shows the typical hydraulic capacities, in gallons per day, that can be applied on these technologies:

- Ecoflo Biofilter: as low as 200 gpd up to 30,000 gpd
- MBBR: 10,000 gpd up to 60,000 gpd
- SBR: 13,000 gpd up to 13,000,000 gpd
- MBR: 5,000 gpd to 300,000 gpd

The graph on the right represents the influent BOD_5 concentrations in mg/L that these same technologies can reliably treat provided an adequate sizing :

- Ecoflo Biofilter: 20 mg/L up to 500 mg/L
- MBBR: 100 mg/L up to 6,000 mg/L
- SBR: 200 mg/L up to 6,000 mg/L
- MBR: 100 mg/L up to 2,000 mg/L

These are the optimal ranges of flows and concentrations for these particular technologies, but every project having its own specificities a technology could be selected all the same and designed outside its proposed range. That could happen to benefit from one's particular features or avoid the drawbacks of another.

For instance, a biofilter would be perfectly suited for a small flow project with typical domestic or slightly higher organic loads. It is a passive and robust technology that ensures the meeting of the most stringent treatment requirements while requiring a minimum of maintenance and operation. Above a given flow rate and/or organic load, the biofilter becomes less attractive as it requires too much space and becomes less economical. For such situation, more compact mechanically driven technologies, such as SBR (activated sludge) and MBBR (fixed film), become more attractive. However, the latter are less robust in terms of performance and less resilient to organic load and flow fluctuations. Finally, membrane filtration technologies are indeed very interesting in terms of treatment performance, allowing for very low BOD_5, TSS and pathogens residuals at its effluent. However, this process remains expensive both to acquire and operate and relatively complex and demanding in terms of operation.

So, these technologies can all be used independently, but the combination of these technologies makes it possible to overcome the shortcomings of each. The strengths of one technology make it possible to overcome the weaknesses of the other and thus improve the overall robustness of the treatment chain and ensure constant treatment performance at the effluent.The biofiltration technology can treat higher strength wastewater than domestic, but its limit remains much lower than other treatment technologies. It usually can sustain up to about 500 mg/L in BOD_5, in which case the design is done according to the organic loading rate and part of the treated wastewater is then recirculated upstream of the treatment system to decrease influent concentrations. A technology such as a biofilter can be designed for different purposes (secondary treatment or secondary effluent polishing) by adjusting the hydraulic loading rate applied on the unit (higher hydraulic loading rate on the polishing unit vs. lower hydraulic loading rate on the treatment unit). One can thus integrate that component downstream a secondary treatment system sized accordingly. As stated above, such approach benefits from both systems features while compensing for the weakness of the other. That could mean, for example, benefiting from the robustness and reliability of a polishing filter, ensuring stable effluent quality, and from the compactness of a MBBR that one may have slightly downsized because of the security factor brought by the polishing filter.

In addition to technically benefiting from each technology, combining technologies for high strength wastewater treatment may also be advantageous in terms of cost. The graph in figure 2 compares the cost for different treatment systems (involving the technologies mentioned above) per flowrate and organic loading, being designed as a stand-alone treatment system or combined. The x axis represents the organic load sent onto the system (shown in the log scale), whereas the y axis shows the design daily flow in cubic meter per day (10 m^3/day = 2,640 gallons per day). The sizes of the balls represent the cost per unit volume of water treatment (m^3), the smallest ball being at about 5,000 US$/$m^3$ compared to the largest one being at 20,000 US$/$m^3$.

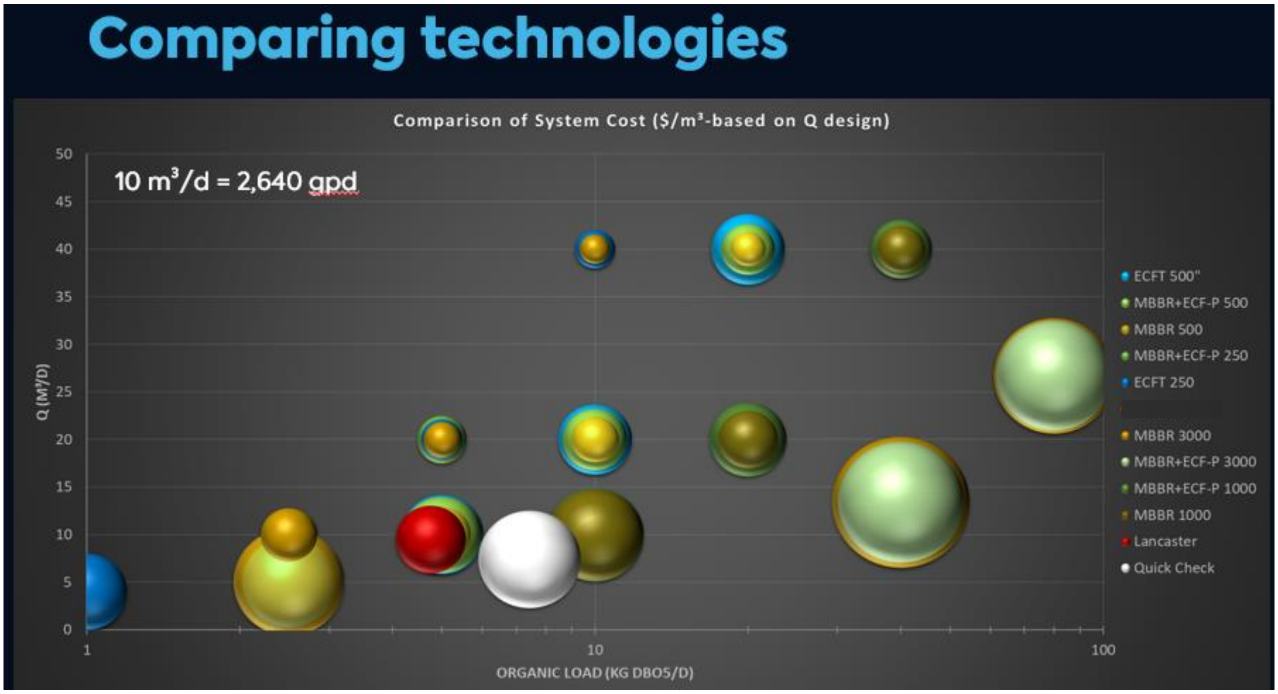

Figure 2

The different colors of the balls present the technologies mentioned above, which can be found in the legend on the right-hand side. They are defined further below:

- ECFT 500 — Ecoflo treatment unit with influent [BOD] of 500 mg/L
- MBBR+ECF-P 500 — MBBR + Ecoflo polishing unit with influent [BOD] of 500 mg/L
- MBBR 500 — MBBR alone with influent [BOD] of 500 mg/L
- MBBR+ECF-P 250 — MBBR + Ecoflo polishing unit with influent [BOD] of 250 mg/L
- ECFT 250 — Ecoflo treatment unit with influent [BOD] of 250 mg/L
- MBBR 3000 — MBBR alone with influent [BOD] of 3,000 mg/L
- MBBR+ECF-P 3000 — MBBR + Ecoflo polishing unit with influent [BOD] of 3,000 mg/L
- MBBR+ECF-P 1000 — MBBR + Ecoflo polishing unit with influent [BOD] of 1,000 mg/L
- MBBR 1000 — MBBR alone with influent [BOD] of 1,000 mg/L
- Lancaster — Existing project which consists of an MBBR + Ecoflo polishing unit with Influent [BOD] of 500 mg/L
- Quick Check — Existing project which consists of an MBBR with influent [BOD] of 1,000 mg/L

To summarize the colors, Ecoflo alone (which can go up to 500 mg/L in BOD_5 concentration) is blue, MBBR alone is yellow and MBBR combined with the polishing Ecoflo is green. The MBBR itself is assumed to treat down to 25 mg/L in BOD and TSS, explaing why it is usually combined to the Ecoflo polishing unit, which can sustainably bring the effluent under 10 mg/L in BOD and TSS when required.

Figure 2 shows that biofiltration and MBBR can be proposed on a range of loads, alone or combined, but also that their cost doesn't necessarily evolves linearly with these loads. That reflects the fact that at higher strength, design doesn't just rely on a given hydraulic retention time within the treatment component but also on the organic load that the biomass is able to manage efficiently, the aeration system required, etc. In addition, we observe that at certain ranges of flow and loading rates, the combination of technologies makes it possible to meet higher treatment levels and meet them in an even more economical way compared to the use of a single technology.

It is possible to observe in figure 2, for example, that for an organic load of 5 kg/d and a flow of 20 m³/d, the MBBR seems to be the most economical technology. On the other hand, we also observe that for an additional investment of approximately 10%, the MBBR could be substituted by the Ecoflo biofiltration technology with the advantages that the latter offers, namely a higher level of treatment (<10 mg/ L in BOD_5 and TSS vs > 25 mg/L for MBBR), robustness, passivity and simplicity of operation. However, the surface required for the implantation of the biofiltration approach is 50% larger than for the MBBR. Similarly, MBBR technology could be combined with polishing biofiltration, which would add to the robustness of the treatment system and its treatment efficiency. However, there is no substantial economic or implementation (footprint required) gain in pushing for such an approach in this scenario.

The benefits related to the combination of treatment approaches are revealed especially in the case of higher concentrations. For example, at concentrations of 3000 mg/L and organic loads of 40 et 80 kg/d, it is clear that the combined MBBR and Ecoflo biofiltration approach in polishing is a more economically advantageous approach, with a reduction in the required investments of close to 10%, while offering better treatment performance, robustness and reliability in term of treatment and operation.

Lancaster and Quick Check (both convenience stores with take-out food) are existing projects that have been installed and operating for a while. These projects have been added to the graph as reference points from actual projects. It is interesting to note that the Lancaster project, for comparable organic load and flow rate to be treated, of the same order of magnitude as the theoretical figures presented in the graph, Lancaster is much less expensive per m³ treated for a more robust combination of technology, while the Quick Check project is almost equal to theoretical evaluation.

Conclusion

It is imperative to keep in mind that treatment systems for high-strength wastewater are not designed in the same way as for typical domestic water. Several factors must be considered. Combining multiple processing approaches may seem counter-intuitive since at first glance, it appears to add complexity, more steps, more equipment and process mechanics, more lids, etc., with the associated perception that these elements lead to a marked increase in costs. However, in reality, the combination of treatment approaches increases the robustness of the treatment chain because the weaknesses are then compensated for and the advantages added up and often the costs are lower.