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Environmental overview of the Mexican Caribbean as a growing hotel sector and wastewater generator; challenges and alternatives

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— Abstract—

The Mexican Caribbean hosts millions of tourists per year, which is an important source of jobs in the region. Hotel wastewater has high concentrations of fats and oils from kitchens and restaurants. These compounds cause several reactions with wastewater components and represent a problem in biological wastewater treatment processes, specifically filamentous bulking events. Filamentous bacteria such as *Thiothrix* spp., *Microthrix parvicella*, type 1701, *Gordonia* spp., and type 0041 causes settling problems, carrying solids to the effluent, causing poor quality of treated wastewater. This study aims to analyze those problems and to underline technology such as grease interceptors and dissolved air flotation systems (DAF), which represent efficient and economical technologies for removing fat and oil at the inlet of treatment systems. It was concluded that in addition to the use of technologies, strategic training programs should be included for staff and guests in general, to promote better kitchen practices and healthy food habits to reduce the consumption of fat and oils food.

Keywords:

Hospitality; tourism; wastewater; bulking; activated sludge.

TOURISM, HOSPITALITY IN THE MEXICAN CARIBBEAN, AND WASTEWATER

The Ministry of Tourism (SECTUR) states that the hotel sector in Mexico represents 28.7% of the gross domestic product of tourism. The country is in the 7th position worldwide in hotel infrastructure (International Hotel Consulting Services, 2022, Ministry of Tourism, 2022). By 2022, there was an investment of 215 billion pesos in 521 tourism projects, generating 115 direct and indirect jobs. The states with the highest amounts of investment were Nayarit, Mexico City, Baja California Sur, Yucatan, Quintana Roo, and Guerrero (Ministry of Tourism, 2022). In the period 2019-2023, the country's hotel infrastructure grew from 23,600 establishments to 25,500 and it is estimated that this trend will continue in the coming years (Statista, 2024).

As a tourist destination, the Mexican Caribbean area is a global powerhouse, due to its landscapes, cultural richness, and economic accessibility. It includes destinations such as Cancun, Puerto Morelos, Isla Mujeres, Cozumel, the Riviera Maya, Bacalar, and other destinations (SECTUR, 2015, 2023). After the lifting of social distancing caused by the COVID-19 pandemic, hotels in these popular destinations saw an increase in occupancy of 45.5%, with an influx of 13,530,307 tourists in 2021, to 19,680,330, representing an economic spill of 19,425.90 million dollars (SEDETUR-QR, 2022). That is why tourism represents one of the largest sources of income for the country, only surpassed by international remittances (SECTUR, 2023; Statista, 2024). It favors the empowerment, integration, and income generation of vulnerable populations such as rural communities and Indigenous peoples (International Hotel Consulting Services, 2022; SEDETUR-QR 2022; Statista, 2024).

In the environmental field, the hotel sector represents a pollution problem, being one of the most important sources of wastewater production in coastal areas, with varied characteristics. The growing demand for drinking water falls on services, ranging from filling hot tubs and pools, and artificial ponds to washing sheets, table linen, cleaning rooms, and cooking utensils, among other activities. All this required water, after being used, will become wastewater (Abdul Khader & Chinnamma, 2021; Estévez et al., 2022). In areas of tourist importance such as Cancun, it is estimated that the use of drinking water in hotels is around 550 L * guest $^{-1}$ * night $^{-1}$, although these estimates may vary depending on the nature of the tourist destination (Sánchez Gonzales, 2022; Santacruz de León & Santacruz de León, 2020). This volume exceeds the average water used in domestic activities, which is around 144 L * person $^{-1}$ * day $^{-1}$ (Estévez et al., 2022).

The Ministry of Tourism of the State of Quintana Roo (SEDETUR-QR, 2022) reports that, in Cancun alone, there are 207 hotels, with a total of 43,109 rooms, and by 2022 it had an influx of 6,786,004 tourists. For this same year, in the Caribbean area, there were a total of 1,331 hotels, distributed in 11 municipalities, which received 19,680,330 tourists (SEDETUR-QR, 2022). According to the National Tourism Development Fund (FONATUR, 2018), the city of Cancun, one of the most developed in the Caribbean, has the infrastructure to treat 4,707,798 $m^3 * year^{-1}$ of wastewater, considering only the wastewater discharged to the drainage and sewerage system, however, there is no detailed official information on per capita water consumption, wastewater generation by hotel complexes, or private infrastructure for wastewater treatment in the region (Biosilva A. C., 2015; Sánchez Gonzales, 2022).

It is important to size the wastewater treatment capacities in these developing cities, including those of each hotel, as the trend of population increase and tourism projects in the Mexican Caribbean, exacerbate the uncertainty about the wastewater treatment infrastructure, and whether it will be able to fully cover the adequate treatment of wastewater in the short term, since water bodies in the Caribbean currently receive discharges of contaminated water, representing a serious environmental and public health problem (Biosilva A. C., 2015).

Pollutants such as fats and oils, present in hotel wastewater, appear as one of the main problems, both in damage to infrastructure (pipes and sewerage), in the operation of wastewater treatment systems, and in the environment when wastewater does not receive adequate treatment. On the one hand, in the presence of Ca^{2+}, fat usually solidifies and adheres to the walls of pipes, which, over time, causes obstructions and bad odors, while oils, due to their hydrophobic chemical properties, form a layer on the surface of water bodies, preventing the passage of light and oxygen, affecting the biochemical processes of aquatic life (Khoury et al., 2023; Klaucans & Sams, 2018).

This text aims to analyze the scenario in which the Mexican Caribbean is located as a developing tourist destination and the challenges to be faced due to the amounts of wastewater generated and its characteristics, specifically fats and oils, as well as to highlight the problems that these compounds represent in conventional biological treatments, as well as the technologies and/or methodologies available to face these problems, which are directly related to the sustainability and rational use of the valuable water resource.

CHARACTERISTICS OF HOTEL WASTEWATER

In Mexico, before being discharged into the environment, wastewater must be treated to comply with applicable regulations and reduce contaminants such as total suspended solids (TSS), biochemical and chemical demand for oxygen (BOD5 and COD), fats and oils (GYAs), temperature, pH, nitrogen, phosphorus, and pathogenic microorganisms (fecal coliforms and *Escherichia coli*), to name a few. At the federal level, the official Mexican standard NOM-001-SEMARNAT-2021 establishes the limits of contaminants in wastewater discharges in receiving bodies owned by the nation, while NOM-002-SEMARNAT-1996 establishes the maximum permissible limits of contaminants in wastewater discharges to urban or municipal sewer systems (Official Mexican Standard NOM-001-SEMARNAT-2021, 2022; Official Mexican Standard NOM-002-SEMARNAT-1996, 1998). Hotels installed in the Mexican territory must comply with at least one of the aforementioned standards, depending on where their discharges go, for they must resort to some type of wastewater treatment process, however, 80-90% of the wastewater generated in the Mexican Caribbean is discharged without any treatment (Biosilva A. C., 2015).

The main sources of hotel wastewater generation (ARH) come from the services that guests require and from the corresponding areas to cover their needs. Bathrooms (WC), bathtubs/showers, sinks, kitchens/bars, and laundry are identified as the most important services (Abdul Khader & Chinnamma, 2021; Estévez et al., 2022).

Abdul Khader & Chinnamma (2021) point out that in hotel wastewater, the main contaminants are OSH, BOD, COD, and GYAs. In their study in a boutique hotel, they reported the following characteristics in the ARH; pH 5, BOD 170 mg/l, COD 350 mg/L, SST 350 mg/L, and GYAs 7 mg/L.

Estévez et al. (2022), determined in a study carried out for four- to five-star hotels in Spain, the characteristics of the ARHs for each generation source, and contrasted the pollutants when there are water-saving measures and when they are not considered, this information is illustrated in Table 1.

In the cited study, it was determined that the highest concentration of contaminants in ARH comes from laundry and toilet water mixing, when water-saving methods exist. In this same study, it can be observed that the concentration of pollutants decreases when the amount of water used is greater (without saving methods). In practice, this does not represent a benefit because when more wastewater is produced, larger capacity reservoirs are required for its collection and/or more efficient treatments, increasing operating costs (Cabrera Acevedo, 2011). Estévez et al. (2022) did not consider the concentration of fats and oils in their study. They pointed out nutrients that are a fundamental part of eutrophication processes such as nitrogen and phosphorus (Leader et al., 2005). In Mexico, these nutrients are regulated and indicated by wastewater regulations as contaminants that must be reduced to low concentrations so that the water can be discharged to the soil or bodies of water (Official Mexican Standard NOM-001-SEMARNAT-2021, 2022).

Table 1
Wastewater characteristics of 4 to 5-star hotels

Composition	Source of wastewater (with water-saving methods)				
(mg/L)	Tub/shower	sink	laundry	mixture	WC
Total Suspended Solids	80.27	(Stool, urine, toilet paper)	1131.84	248.46	1171.52
Chemical oxygen demand (COD)	432.23	421.43	4214.29	1030.16	1472.82
Total nitrogen	2.84	2.32	14.81	4.63	299.89
Total Phosphorus	0.10	1.38	2.65	0.79	36.43
Composition	Source of wastewater (without water-saving methods)				
(mg/L)	Tub/shower	sink	laundry	mixture	WC
Total Suspended Solids	37.46	(Stool, urine, toilet paper)	396.14	96.20	555.94
Chemical oxygen demand (COD)	201.71	116.67	1475.00	398.86	702.23
Total nitrogen	1.33	0.64	5.18	1.79	142.31
Total Phosphorus	0.05	0.38	0.93	0.31	17.29

Note. Average water consumption in hotels (100 - 249 rooms) with saving methods: 12.35 $m^3 * day^{-1}$. Without saving method: 31.89 $m^3 * day^{-1}$. Saving methods such as low-flow faucets, efficient toilets, efficient irrigation, pressure regulation systems, leak detection, and rainwater collection for irrigation. Source: edited with data from Estévez et al., (2022).

The data pointed out by Estévez et al. (2022) contrast with those reported by Pharmawati et al., (2018) who mention that the characteristics of ARH are similar to domiciliary ones, with the following parameters and values; BOD 110-400 mg/L, COD 250-1000 mg/L, TSS 100-350 mg/L, ammonia nitrogen (NH3) 12-50 mg/L, and fats and oils (GYAs) 50-150 mg/L.

Differences in the physicochemical characteristics of wastewater vary from hotel to hotel, due to different factors, such as the nature of the services, the number of rooms, and their methods of water consumption. Of the studies mentioned above, little is said about the characteristics of the water from hotel kitchens and/or restaurants, specifically fats and oils. However, there is literature that addresses these contaminants studied in food establishments, whose characteristics complicate the treatment of ARH.

FATS AND OILS IN WASTEWATER

One of the great challenges in hotel wastewater treatment lies in fats and oils (GYAs), whose main source is restaurant and kitchen service activities, such as the use of oils, lard or shortenings, meat processing, sauces, broths, dressings, cheeses, butter, and fried food (Gurd et al., 2019). Some types of fats found in the modern diet are illustrated in Table 2, these make up the menus in hotel kitchens and restaurants.

GYAs will have different states (solids or viscous liquids) depending on the degree of saturation of their carbon chains and their length; when short-chain fatty acids predominate, fats tend to be "softer" with low melting points compared to those with long-chain fatty acids. For example, palm oils have a melting point ranging from 27 - 45 °C, while coconut oil has a range of 23 - 26 °C (Sharma et al., 2022). The chemical nature of fats, oils, and grease means that their presence in sewage systems causes clogging problems due to the formation of deposits.

Table 2

Fats present in the modern diet

Type of fat	Saturated	Monounsaturated	Polyunsaturated	Trans*
Common names	"Bad" fats	"Good" fats	"Good" fats	"Bad" fats
Chemistry	Without double bonds	With double bonds	With two or more double bonds	
Sources	- Meet fat - Whole milk, cheese, cream, butter - Baked goods (pancakes, cakes) - Deep-fried fast food - Palm and coconut oil	- Avocado, nuts (peanuts, almonds, hazelnuts, and nut spreads) - Margarine (canola or olive oil-based) - Canola, olive, and peanut oils	- Fish and seafood - Polyunsaturated margarine - Vegetable oils (soybean, sunflower, corn, and safflower oils) - Brazil nuts and seeds	-Pies, cookies, cakes, fried foods, milk, cheese, and beef and lamb cuts

Nota. *Trans fats only form naturally in the stomachs of sheep and cows, so they are present in small amounts in milk and in beef and lamb cuts. Source Sharma et al., (2022).

According to Table 2, it can be noted that the colloquial grouping of the fat groups present in foods is only referred to as "bad" because of its relation to health problems (metabolic or cardiovascular) when the daily diet is based on an abusive consumption of these foods. The inclusion of fats and oils in the diet is necessary, as they are an essential part of cellular components and metabolic processes. However, it is important to note that, although most of them have a "natural" origin, we must moderate their consumption and consume other foods of vegetable and animal origin.

In this context, five major GYAs groups of importance in the human diet can be pointed out, which are illustrated in Table 3.

Table 3
Main groups in fats and oils

Group	Description
Free Fatty Acids	Carboxylic acids with long hydrocarbon chains. They occur in their esterified form as a major component of lipids. The most common have from 8 to 22 carbon atoms in their chains, and one or more unsaturations (double bonds). In restaurants, free fatty acids represent a 15% concentration in their effluents, lowering the pH of the water.
Triacylglycerol	Grass acids are generally presented as esters of glycerol, known as triglycerides. They are non-polar and insoluble in water. Fats and oils are complex mixtures of triacylglycerols, whose composition varies depending on the organism of origin; animal or vegetable.
Wax ester	Waxes include various types of medium and long-chain compounds, including hydrocarbons (TCH_3), alcohols ($R-CH_2OH$), aldehydes (R-CHO), acids (R-COOH), and esters (R-COOR'). There are waxes of vegetable and animal origin.
Phospholipid	The amphiphilic nature of phospholipids provides them with properties of interest in the pharmaceutical, cosmetic, and food industries. Although these compounds are removed in the refining of oils, part of them end up being part of the mixtures in the GYAs in water treatment.
Sterols and sterol esters	Strictly speaking, sterols such as cholesterol are not lipids but have similar physical properties to fats and oils. These can be esterified to long-chain fatty acids by oxidation reactions, hence they are also grouped together with the other compounds that form GYAs in wastewater.

Note. Prepared with information from Husain et al., (2014).

Table 3 shows GYA's main characteristics present in basic foods of the human diet. As mentioned above, considerable amounts of food waste will be produced in hotel kitchens, and derived from utensil cleaning activities, or direct discharge of fats and oils, these compounds will end up in wastewater lines, which will mainly have two destinations, a wastewater treatment plant or a body of water or soil, allowing the reaction of these compounds with those found in the water.

CHEMICAL REACTIONS RELATED TO GYAS IN WASTEWATER

Husain et al., (2014) point out in detail the nature of the reactions involved in the process of frying food, mainly due to the content of salts in food and the nature of free radicals in cooking oils.

Free fatty acids are chemically active and are easily saponified in the presence of sodium hydroxide and potassium hydroxide, both of which act as strong metallic soap-generating agents. Sodium and potassium are found naturally in raw foods, and by frying them some sodium ions can be extracted by the free fatty acids present in frying oils, forming sodium oleate (sodium soaps). Sodium oleate reduces the surface tension between the frying oil and the thin layer of water on the surface of the fried food, causing polar lipids to migrate from the frying oil to the fried food. In addition, sodium soaps stimulate the foaming of frying oil and this accelerates oxidation. The oxidation reaction that is caused by heat, light, and heavy metals, is a chain of radical reactions that occur quickly during the frying of food.

First, the oil's peroxy-, alkoxy- and alkyl-free radicals react with oxygen or RH (see Equation 1)

Equation 1

$$R\cdot + O=O \rightarrow R\text{-}OO$$
$$R-OO + R-H \rightarrow R-OOH\cdot + R\cdot$$
$$R-O + R-H \rightarrow R-OH\cdot + R\cdot$$

The reaction is initiated by the attack on the oil's alkyl group, followed by a chain reaction, resulting in a hydroperoxide (-OOH) group in the chain (see Equation 2).

Equation 2

$$R-OOH \rightarrow R-O\cdot + \cdot OH$$
$$2R-OOH \rightarrow R-O\cdot + R-OO\cdot + H_2O$$

The resulting hydroperoxides are reacted again by the combination of two radicals to form aldehydes, ketones, and fatty acids (see Equation 3).

Equiation 3

$$R\cdot + R\cdot$$
$$R\cdot + R\text{-}O\cdot$$
$$R\cdot + R\text{-}OO\cdot$$
$$R\text{-}O\cdot + R\text{-}OO\cdot$$
$$R\text{-}OO\cdot + R\text{-}OO\cdot$$
$$R\text{-}O\cdot + R\text{-}O\cdot$$

These reactions during the frying of food generate free fatty acids, usually found in used oils, and are part of the GYAs content in wastewater. Subsequently, these free fatty acids will react with an alkali, such as sodium hydroxide to form metallic soap (see Equation 4).

Equation 4

$$R-COOH + NaOH \rightarrow R-COONa + H_2O$$

Likewise, small amounts of triacylglycerols are saponified (hydrolyzed) forming metal soaps.

Equation 5

$$C_3H_5(COOR)_3 + 3NaOH \rightarrow C_3H_5(OH)_3 + 3NaOOCR$$

Sodium contributes to the saponification of GYAs and produces hard soap, which is deposited in small layers in pipes, causing maintenance problems. Sodium content can increase in wastewater due to the use of salt in food preparation. Detergents and sanitizers also contain large amounts of sodium hydroxide (NaOH), which is a strong alkaline catalyst, which potentiates saponification reactions (Sultana et al., 2024a). Another relevant element is calcium, since its ions (Ca^{2+}) and free fatty acids also perform saponification reactions, forming calcium soaps. This reaction is mainly influenced by temperature and pH, and the sources of the reagents which significantly affect the strength, appearance, quantities, and physicochemical properties of GYAs deposits in pipelines (Sultana et al., 2024a; Yusuf et al., 2023).

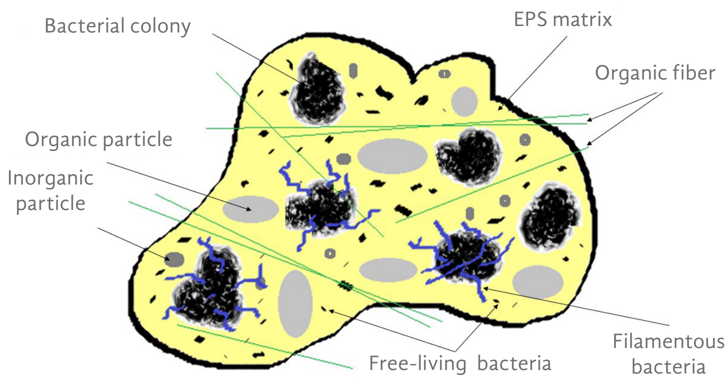
Wastewater from hotel kitchens and restaurants are waters rich in organic content, due to the content of GYAs. Their composition will be diverse by the type of menu handled, in addition to other factors such as kitchen cleaning practices (amount of water used, separation of solids, use of dishwashers and cleaning products, etc.) (Gurd et al., 2019). GYAs' problems can escalate to maintenance issues due to pipe plugging, but also negatively impact the water treatment process due to all the compounds derived from the GYA reactions that took place in the water collection system.

BIOLOGICAL WASTEWATER TREATMENT SYSTEMS

Typically, wastewater treatment systems are those processes in which wastewater solids are partially removed and/or transformed by the decomposition of complex, degradable organic solids to relatively stable or mineralized organic compounds (Sonune & Ghate, 2004). Wastewater treatment processes may vary depending on the type of water to be treated. According to the characteristics of hotel wastewater, one of the most common are conventional biological treatments, where microorganisms are used instead of chemicals to remove contaminants present in the wastewater, these methods intend to reduce the accumulation of chemicals and prevent eutrophication in water bodies (Schaider et al., 2017; von Sperling, 2007).

In biological wastewater treatment systems, most microorganisms are found in the form of microbial aggregates, such as sludge floc, biofilms, and granules. This is due to extracellular polymeric substances (EPS), a high molecular weight polymer complex, which has been observed in these media (Sheng et al., 2010). The presence of EPS influences the physicochemical properties of microbial aggregates, including structure, surface charge, flocculation, sedimentation properties, adsorption, and dewatering (Sheng et al., 2010).

Activated sludge processes are widely used in wastewater treatment plants (WWTP), where aeration units are used for the conversion of soluble organic compounds into settleable solids, followed by clarification processes, usually tanks where solids are separated from the liquid (Arcos A., 2013; Deepnarain et al., 2020). Ideally, aerobic processes are able to convert organic molecules into CO_2, H_2O, inorganic nutrients (N, P), biomass, and other products such as EPS. In activated sludge, the floc structure varies according to different factors, but commonly consists of bacterial colonies surrounded by an extracellular EPS network, in addition, the floc can include organic fibers and inorganic particles as seen in Figure 1 (Alrhmoun, 2014).



Note. Own elaboration with data from (J. Guo et al., 2014; Shchegolkova et al., 2016).

Figure 1. General structure of floc in activated sludge

It is common to find filamentous bacteria in the activated sludge floc, which can provide a support structure in the three-dimensional shape of the floc (Figueroa et al., 2015; Pacheco Salazar et al., 2003). Likewise, unicellular protozoa such as flagellates, amoebae, and ciliates can be observed, as well as complex organisms such as metazoans (rotifers), nematodes, and some worms, which are part of activated sludge systems (Curds, 1973; Isac et al., n.d.; Martin-Cereceda et al., 1996). Sedimentation efficiency is crucial in activated sludge WWTPs and governs the potential and capacity of the entire treatment system. Technically, the sludge sedimentation properties are described by the sludge volumetric index (SVI), which expresses the amount (in mL) occupied by one gram of solids suspended in the mixed liquor (SSTLM), usually in 1 L of sample for 30 minutes. When activated sludge has SVI values above 150 mL/g, it can be noted as sludge with '*bulking*', which hinders the whole activated sludge process (Deepnarain et al., 2020; Torrescano Spain, 2009).

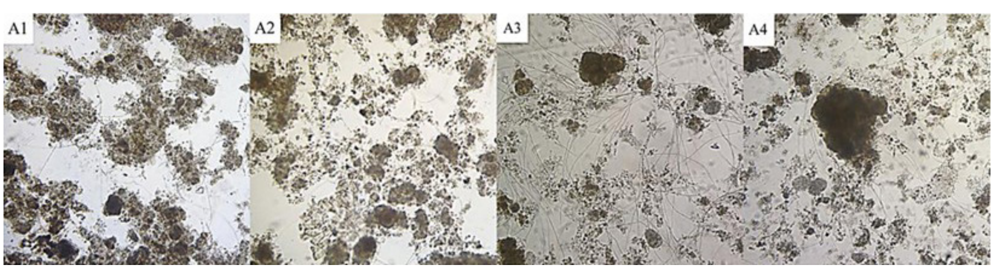
FILAMENTOUS MICROORGANISMS IN BIOLOGICAL SYSTEMS

Excessive growth of filamentous bacteria is associated with sedimentation and foaming problems. Sludge bulking is characterized by a growth of filamentous bacteria in the vicinity of the liquid floc medium, inhibiting the formation of dense segregates. Foaming is caused by sludge flocs floating to the surface of the aqueous medium, segregating into a relatively stable sludge layer at the water-air interface (Alrhmoun, 2014). An example of foaming is illustrated in Figure 2.

Note. Nilsson, (2015).

Figure 2. Example of foaming in a conventional biological treatment system

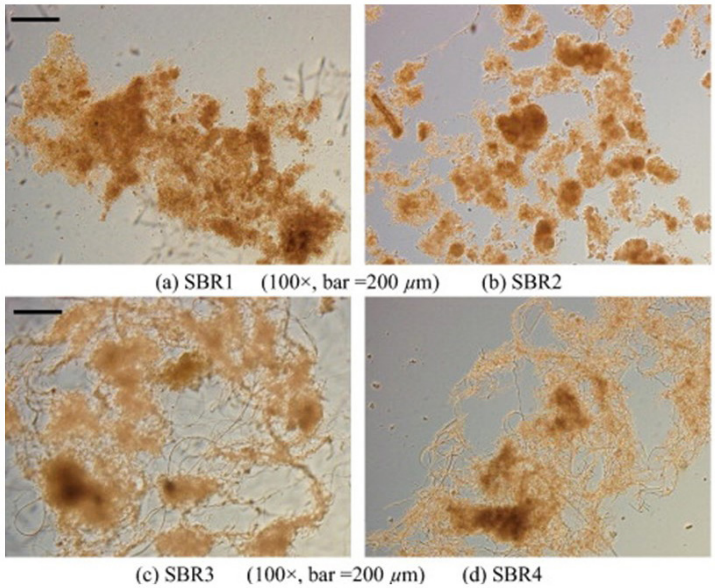
At the microscopic level, bulking can be identified when the floc presents scattered characteristics without aggregation and filamentous microorganisms are observed around the floc (J. Guo et al., 2014). In his study, Yao et al., (2019) illustrate in detail when the sludge presents filamentous bulking, in Figure 3, samples of a regular floc (Fig.3 A1 and A2) and another with filamentous bulking characteristics (Figure 3 A3 and A4) are observed.



Note. Edited from Yao et al., (2019).

Figure 3. Microscope view of floc types (100x)

On the other hand, Guo et al. (2014) analyzed the floc of sequenced batch reactors (SBR) at the laboratory level. Figure 4 shows the differences between a regular floc and a floc with the presence of filamentous microorganisms.



Note. SBR; Sequenced Batch Reactor. Source: edited from Guo et al., (2014).

Figure 4. Observation of floc in batch reactors

Figure 4 (a and b) shows flocs considered desirable in a good water treatment system, while Figure 4 (c and d) shows a characteristic floc with the presence of filamentous microorganisms. Guo and his team of collaborators reported that in the reactors that presented filamentous floc, the effluent had COD above 100 mg/L. The entrainment of solids and the low quality of the effluent are the results of having a sludge with bulking, this is supported by other studies, pointing to the problems of filamentous bulking as the most important in conventional biological processes of activated sludge (Aonofriesei & Petrosanu, 2007; Lu et al., 2023; Nilsson, 2015).

Several filamentous microorganisms causing bulking are noted in the literature. 021N- type sulfur bacteria and *Thiothrix spp*. are able to use organic substrates and reduced sulfur compounds as energy sources, together with heterotrophic bacteria adapted to sludge that receive high organic loads ("AM" Food/Microorganism ratios > 0.15 Kg of DBO5 Kg^{-1} SSTLM $día^{-1}$), for example, *Sphaerotilus* spp. and *Haliscomenobacter hydrossis*. In addition, species such as *Microthrix parvicella*, type 1701, *Gordonia* spp. and type 0041 for being responsible for filamentous bulking events (Alrhmoun, 2014; Aonofriesei & Petrosanu, 2007; Bjo et al., 2002; Deepnarain et al., 2020; Nilsson, 2015).

The proliferation of filamentous microorganisms is due to operation-related parameters such as low oxygen concentration, high AM ratio, N and P deficiencies, low pH, soluble residual DBO, and high concentrations of fats and oils (G. Liu et al., 2018; Pacheco Salazar et al., 2003). In this context, it can be noted that the presence of GYAs in ARHs enhances problems due to filamentous bulking in conventional biological treatments. Due to the physicochemical characteristics previously analyzed, waters from kitchens and restaurants have low pH, in addition to generating competition for dissolved oxygen in aerobic systems between GYAs and microorganisms that require this element for their breathing processes (Cabrera Acevedo, 2011; Nilsson, 2015).

WASTEWATER OVERVIEW OF HOTELS IN THE MEXICAN CARIBBEAN

In infrastructure, according to the Inventory of Municipal Potabilization and Wastewater Treatment Plants in Operation (National Water Commission, 2022), Quintana Roo has 29 municipal water treatment plants, but there is no information regarding how many hotels are connected to the municipal sewage network to send their wastewater to these plants, or if they have their own treatment plants.

In the matter of wastewater, the Law of Ecological Balance and Environmental Protection of the State of Quintana Roo, in its article 129 establishes that "when there are no municipal systems for the evacuation of municipal wastewater, the owners of hotels, subdivisions, condominiums, residences, industries, and similar, must install systems for the treatment and recycling of their wastewater, whether individual or communal, to satisfy the particular conditions determined by the competent authorities" (Law of Ecological Balance and Environmental Protection of the State of Quintana Roo, 2018). In this regard, hotels located in the Mexican Caribbean, which are in the territory of the state of Quintana Roo, are required to have a WWTP in their facilities. According to the research by Biosilva A. C., (2015), hotels with wastewater treatment infrastructure are operated by in-house staff or licensed companies. These hotels face significant challenges in the operation of their treatment plants which, as discussed, conventional biological processes are susceptible to inefficiency due to delicate operating conditions.

Deficiencies of dissolved oxygen in biological systems, due to an excess of GYAs and filamentous microorganisms, lead to an increase in energy consumption, due to the increased use of aerators, blowers, etc.

Problems also arise in the management of the biosolids generated in the process, starting with an increase in sludge concentration (SSTLM) in the aeration tanks, which subsequently require greater purges (removal in volume of sludge from the system) to maintain optimum levels of SSTLM * $m^{3 -1}$ concentration in the bioreactors, and thus be able to improve oxygen dissolution so that the quality of the treated water is not compromised. This overproduction of sludge will result in a higher demand for inputs used in the dewatering process (flocculants and coagulants), and complications in the storage, removal, and final disposal of biosolids (Flores-Alsina et al., 2009; J. H. Guo et al., 2010; Y. Liu et al., 2020).

Figure 5 illustrates the overview of the current situation in the Mexican Caribbean analyzed in this text. This interrelation of components leads to a possible scenario; environmental imbalance, increased risks to public health, and lower water availability.

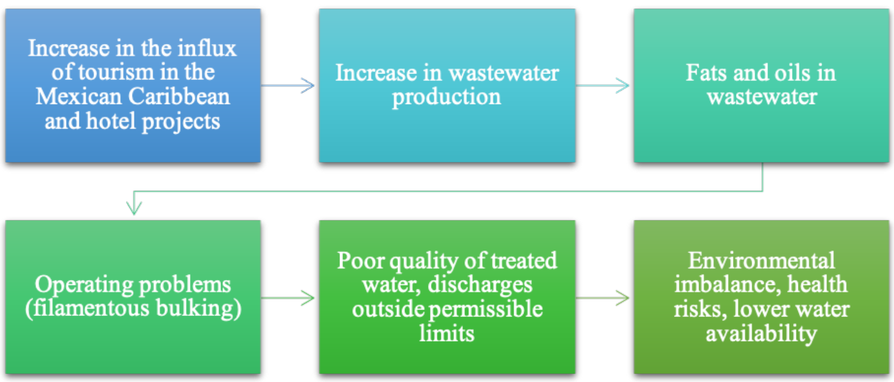


Figure 5. General scenario of the Mexican Caribbean and its environmental challenges

The protection of the environment and public health is the main objective to regulate wastewater discharges from hotels, because they represent a high risk of diseases, mainly pathogenic ones, and also cause a negative impact on ecosystems. Untreated ARHs contain bacteria, viruses, and parasites that can cause gastrointestinal and respiratory infections, among others. The risk increases when the points of wastewater discharges are at the following points:

- Agricultural areas; since irrigation water sources can be contaminated, and in this way reach crops (Werneck et al., 2017).
- Coastal areas or areas with rivers, streams, lakes, etc.; these areas are the ecological niches of various species, whose position in the trophic chain allows the pollutants to which they are exposed to reach humans (UN, 2017).

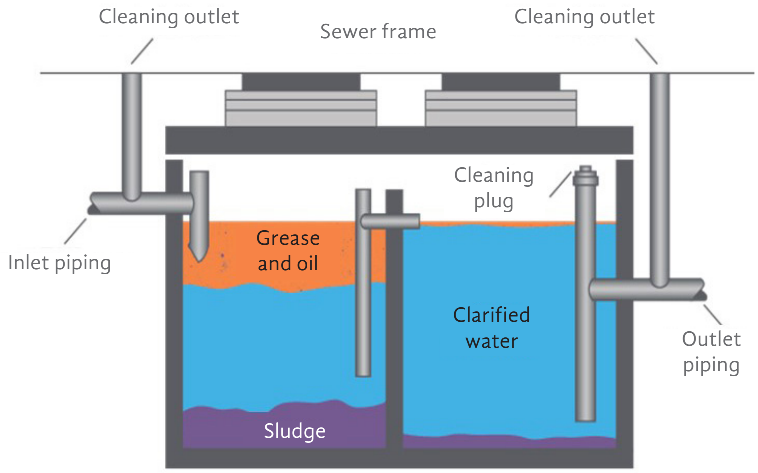
The effects of wastewater pollution are more severe in vulnerable groups, whether due to age; children and infants, as well as older adults, are more susceptible to disease, in addition to people with chronic diseases or disabilities. Not to mention that, in economically vulnerable populations, access to drinking water and good nutrition trigger health situations that, by adding the "pollution" factor, pose challenging scenarios for an already saturated public health system (UN, 2017).

The Caribbean area has karst soil, with formations of caverns, cenotes, and underground rivers, which easily exposes underground water bodies to contamination by wastewater discharges, which transports diseases to all fauna and flora (aquatic and terrestrial) that are close to the discharge sites, hand in hand with eutrophication in surface and underground bodies of water that receive high concentrations of organic matter. The above problems worsen the natural landscape, mainly in areas where economic exploitation is the landscape, as is tourism in this area (Biosilva A. C., 2015).

Hotel companies must take the necessary measures to improve their water treatment infrastructure, reduce water consumption, and improve their practices in food production and cleaning in their kitchens, with the goal of reducing operating and maintenance expenses of their facilities and their water treatment systems, all without losing the objective of complying with the demands required by Mexican regulations on wastewater, whose purpose is to preserve the integrity of the ecosystem, on which they directly depend. The technologies available in wastewater treatment are diverse, but they are efficient and affordable for the hotel sector, two main ones were identified, and are presented in this context as the window of opportunity to solve the problems that ARHs represent.

TECHNOLOGIES FOR COPING WITH FATS AND OILS

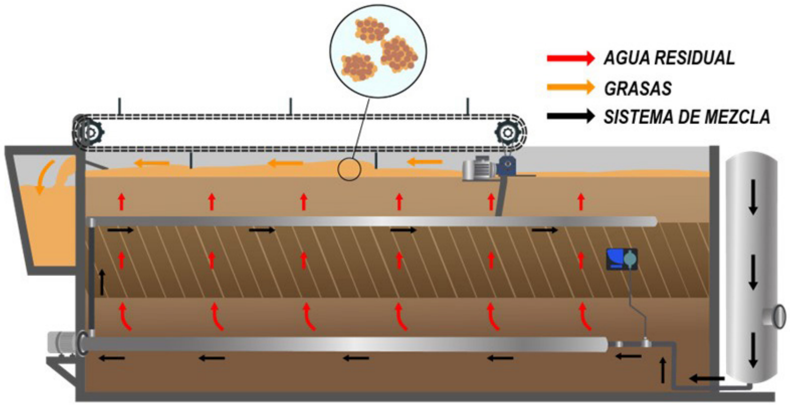
The most common and appropriate technologies are grease interceptors, which are installed in restaurants and kitchens, to prevent greases and oils from ending up in wastewater collection tanks, pipes, and finally in the WWTP. Typically a grease interceptor is a device installed in the hydraulic system to trap or intercept greases and oils from the water. The foundation is physical separation, while wastewater cools, GYAs harden, and food solids settle and form sludge. Water without GYAs and sedimentable solids advances to subsequent compartments and follows its flow until it reaches the treatment systems (Sultana et al., 2024b; Yusuf et al., 2023). A general schematic of a fat interceptor is illustrated in Figure 6.



Note. Liquid Environmental Solutions, (s/f).

Figure 6. Sketch of a grease interceptor system

The main disadvantage of a grease interceptor is that it requires constant removal of the materials that this device traps, or else they will end up in the hydraulic system and water treatment systems. This problem is solved by having a portfolio of suppliers that specialize in the removal of this waste, since, generally in hotels there are no spaces designed for the treatment of solids. The biggest advantage of these interceptors is that they handle higher flow rates than conventional grease traps and are ideal for the hotel sector that demands the preparation of large quantities of food, and consequently the cleaning of kitchen material in a short time. On the other hand, Dissolved Air Flotation (DAF) systems separate solid particles, such as GYAs, designed for industrial and urban wastewater clarification. The separation process is a physicochemical method where coagulants and micro or nano air bubbles are applied to separate solids on the water surface. It is very efficient and using the right operating parameters, TSS and GYAs removal can reach 90%, while BOD and COD reduction reach 40 to 55% (Palaniandy et al., 2010; Penetra et al., 1999; Rattanapan et al., 2011). This system improves the conventional water treatment process by minimizing the organic load that the bioreactors will receive, whose immediate benefits will be a greater dissolution of oxygen and less appearance of filamentous microorganisms, which will result in a better clarification of the treated wastewater, which can be reincorporated into the environment without complications. Figure 7 illustrates a general schematic of the DAF operation.



Note. (Synertech Water Resources, s/f).

Figura 7. Esquema general de un DAF

As shown in Figure 7, the fats are collected at the top and separated from the water for further treatment. DAFs stand out from other technologies due to their attractive low maintenance cost and energy consumption, and this can be adapted so that the collected grease can be sent to grease digestion sumps, and depending on the specialization of the facility, biogas can be generated (by anaerobic methods), or the digested grease can simply be mixed with the sludge purge to end up in the sludge dewatering process.

Technology in wastewater engineering offers different options to address problems arising from wastewater with excess fats, oils, and grease in conventional biological processes, but the situation can be addressed strategically. One strategy is to train personnel involved in the food preparation process (chefs, cooks) and kitchen cleaning (assistants, stewards), implementing methods for separating and recovering oils, which can be revalued in different ways. Another way, and perhaps the most complex, is for the population in general to reduce the consumption of fried foods or foods with high fat and oil content, which, on a large scale, would represent an improvement in eating habits, a decrease in cardiovascular diseases, and even overweight.

CONCLUSIONS

As a developing country, Mexico has a window of opportunity in the Caribbean to be a world leader in the hotel sector. At the same time, it faces a major challenge in maintaining a balance between the use and conservation of its natural resources, specifically water. In this paper, the characteristics of hotel wastewater were identified, as well as the main problems that they bring to wastewater treatment systems: filamentous bulking, which makes the operation of conventional biological systems difficult. Grease interceptors and DAFs were identified as functional technologies to directly decrease the concentration of fats and oils at the inlet of water treatment systems. Without neglecting training and awareness strategies for personnel and consumers to ensure the quality of the wastewater treatment systems, and at the same time maintain a balance between water use and conservation.

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