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Wastewater Energy Recovery Technologies in Food Industry

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APPENDIX

COD: Chemical oxygen demand (COD) is a parameter that measures the demand for dissolved oxygen in the water to achieve the oxidation of chemical organic materials.

BOD: is a measure of the amount of oxygen required to remove waste organic matter from water in the process of decomposition by aerobic bacteria (those bacteria that live only in an environment containing oxygen).

ASP: activated sludge process

SBR: sequential batch reactor

RBC: rotating biological contactor

TF: trickling filter

DHS: downflow hanging sponge reactor

ACP: anaerobic contact process

UASB: up-flow anaerobic sludge blanket

AF: anaerobic filter

AFBR: anaerobic fluidized bed reactor

HAR: hybrid anaerobic reactor

IRR: Internal rate of return (IRR) is a parameter in the field of financial analysis to evaluate whether an investment is profitable. IRR is the discount rate that can zero the net present value (NPV) of all cash flows.

Present value: Present value (PV) is the value nowadays for a future sum of capital in a specified rate of return (i).

WWTP : Wastewater treatment plant

Abstract

Modern manufacturing is strongly connected with the consumption of huge amounts of energy. Therefore, it is imperative to develop innovative, environmental technologies to produce and recover this energy. Consequently, possible energy recovery from wastewater is an attractive solution for the industrial sector.

Commonly, current industrial water treatment facilities seem to have weaknesses. This thesis aims to reveal the capacity and requirements of water treatment exploitation, focusing on the area of the Food Industry. Initially, a detailed literature review of the current state-of-art will be carried out to introduce the sector of industrial wastewater treatment and also present the currently available energy recovery technologies. Afterward, the existing technologies for exploitation are presented for the area of the Food Industry. Further on, a preliminary techno-economic and environmental analysis of the proposed energy recovery technologies will be carried out.

Based on the obtained results, optimal solutions will be proposed for the optimization of the energy recovery technologies in Food Industries.

Περίληψη

Η νέα εποχή της βιομηχανίας συνδέεται με την κατανάλωση υψηλών ποσών ενέργειας, καθιστώντας επιτακτική την ανάπτυξη καινοτόμων και συνάμα περιβαλλοντικών τεχνολογιών παραγωγής και ανάκτησης ενέργειας. Προς την κατεύθυνση αυτή, η ενέργεια που δύναται να προκύψει από την επεξεργασία υγρών αποβλήτων αποτελεί μία ιδιαίτερα ελκυστική ιδέα στο χώρο της βιομηχανίας. Δεδομένου ότι οι υπάρχουσες μονάδες επεξεργασίας υγρών αποβλήτων παρουσιάζουν αδυναμίες, σκοπός της παρούσας διπλωματικής εργασίας είναι να αναδείξει το δυναμικό εκμετάλλευσης των βιομηχανικών αποβλήτων, με έμφαση στη βιομηχανία τροφίμων.

Αρχικά, θα πραγματοποιηθεί εκτενής βιβλιογραφική ανασκόπηση της υπάρχουσας κατάστασης στο χώρο των βιομηχανικών αποβλήτων καθώς και των διαθέσιμων τεχνολογιών ανάκτησης ενέργειας. Ιδιαίτερη έμφαση θα επιδοθεί στις τεχνολογίες ενεργειακής εκμετάλλευσης των αποβλήτων από βιομηχανίες τροφίμων.

Επιπρόσθετο σκέλος της παρούσας εργασίας αποτελεί η προκαταρκτική τεχνο-οικονομική και περιβαλλοντική μελέτη των προτεινόμενων τεχνολογιών. Με βάση τα αποτελέσματα που θα προκύψουν θα προταθούν οι βέλτιστες λύσεις ενεργειακής αξιοποίησης των αποβλήτων τροφοβιομηχανιών, σε όρους περιβαλλοντικούς και οικονομικούς.

1 WASTEWATER

Wastewater is water that has been utilized for the benefit of humanity. Wastewater originates from domestic, industrial, and municipal activities. It is also considered that surface runoff and any sewer inflow constitute wastewater. This thesis is centered on factory wastewater and mainly on the Food industry [0-1].

Although producing Food may seem innocent in the terms of pollution, it is verified that waste from food processing industries causes harm to the environment for several reasons that will be described below.

Figure 1.1 Exit pipe from wastewater treatment system, source: Industrial Wastewater Systems & Treatment - Aerofloat [2].

1.1 Reasons for wastewater treatment in Food Industry

Untreated wastewater from the Food Industry can strongly damage the ecological balance, therefore it is deemed necessary for all industrial wastewater to be treated with the optimal method, appropriately adjusted to the demand of every system. The reasons are described in the paragraph below.

Firstly, all the types of organic matter but mostly fats, oils, and grease must be separated as they are characterized the heaviest. The reason is that the existing pure water and ecosystem would be harmed by all these types of matter. Dissolved oxygen, for instance, is needed for decomposition of the organic load and by adding all these types of organic matter in an aquatic system the necessary oxygen for the survival of local organisms is strongly affected. The consequences would be easily seen when sampling in the aquifer by analyzing several values such as BOD (biochemical oxygen demand) for example. Besides that, in some cases where the wastewater is not treated appropriately, excessive numbers of Nutrients such as phosphorus, nitrogen, and NH3 could lead to cause eutrophication, or enormous fertilization of the water, which can cause abatement in the aquatic flora and fauna or even alter habitat due to this disruption. In some other cases, chlorine compounds and inorganic chloramines lead to toxicity in the water which can be really damaging to the aquatic ecosystem but also being greatly effective for humans.

Untreated wastewater from the Food Industry can cause even disastrous results such as Bacteria, viruses, and diseases capable of causing pathogenesis in humanity. Another fact that must be taken into serious consideration is the heavy metals that can be found in the exit of many industries, Metals, such as mercury, lead, cadmium, chromium, and arsenic can lead to toxicity for most species [3,4]. Consequently, optimal wastewater treatment is mandatory for the reduction of ecosystem harm which is an unfortunate fact nowadays.

1.2 Categories of wastewater

It is a fact that various sorting exists for the classification of wastewater. Ordinarily, the types are divided into domestic (wastewater from households), municipal wastewater (from hotels, shops, etc.), and industrial wastewater. Focusing on the industrial sector, twelve sources of wastewater are recognized and deposited in **Figure 1.2** according to the University of Stuttgart [5].

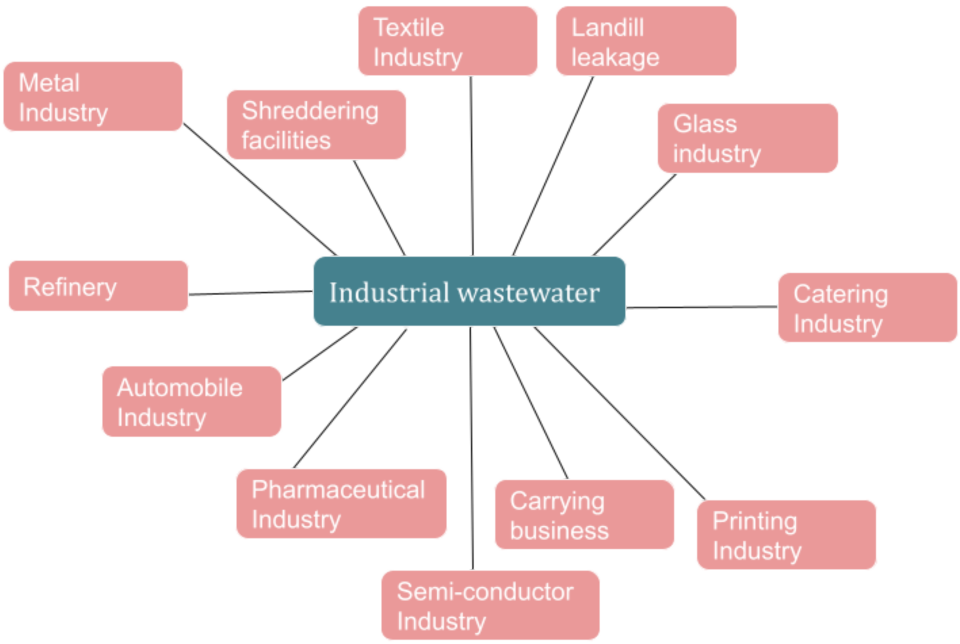


Figure 1.2 Classification of industrial wastewater according to the University of Stuttgart [5].

2 Food industry wastewater

When evaluating the sources dealing with food wastewater it is clear that the quantity and quality of wastewater are extremely different from one another because of the process policy, the process of vegetable washing, for instance, generates waters with high loads of particulate matter and some dissolved organics and they may also contain surfactants. Animal slaughter and processing produce organic waste, such as blood, and gastrointestinal contents. This wastewater is frequently contaminated by significant levels of antibiotics and growth hormones from the animals and by a variety of pesticides used to control external parasites.

In general, wastes from the food industry contain biodegradable organic matter in the form of dissolved and suspended solids, fats, and oils [6].

Food industry wastewater is characterized by high organic discharge and suspended matter content, although compared with other industrial wastewater, food wastewater can be indicated as wastewater with a lighter organic load and not so pernicious for the environment. On the other hand, it must also be taken into serious consideration the fact that it can be lethal when in extravagant composition because a great concentration of effluents can cause harm to the ecosystem and provide reduction of the growth and survival of biota. According to the information mentioned above, biological treatment is the most relevant for the avoidance of environmental fatality, when factory wastewater is treated.

A brief representation of the wastewater produced from food processing is shown in **Table 2.1** .

Table 2.1 Production of wastewater in the Food industry [4-6].

INDUSTRY	FLOW (m^3/tonne of product)
Cannery	
Green beans	50-70
Fruit vegetables	4-35
Food and beverage	
Bread	2-4
Meatpacking	15-20
Slaughterhouses USA, EUROPE	4-17
Milk products	5-10
Beer	10-20
Whisky	60-80
Wine	1-4

The food industry consists of various types according to the products and services offered in the world. The most common separation is presented below.

- Edible oils- olive oil mills
- Milk processing and dairy by-products
- Grain processing
- Wastewater from slaughterings and meat processing.
- Fruit and vegetable
- Brewery companies
- Beverage processing
- Sugar and confectionery products

Each type of industry creates different wastewater which is affected by the processes followed for each case. The next essential knowledge for the determination of the most suitable line of treatment for every food industry is the characteristics of wastewater. The wastewater characteristics for each category of wastewater are evaluated in the paragraphs below. At this point, it should be clarified the fact that all the values for the parameters are measured before any wastewater treatment.

2.1 Edible oils

Wastewater from edible oils can provoke the aforementioned problems. The quantity of the raw material that the final treated product derives from, and mainly the quality of wastewater, greatly affects the extent of this harm. The major parameters measured when edible oils are treated, are BOD and suspended solids (SS), other parameters examined in some cases are pH, COD, TKN, NH3, total P, oil-grease, sulfate, and color (more information about those parameters are described in Appendix 1. A representative view of what are the characteristics of wastewater from edible oil plants is shown in **Table 2.2**, but this may vary extensively due to the nature of the final product and the procedures that took place for the final product [7].

Table 2.2 Characterization of wastewater from sunflower oil plant and corn oil plant [7].

Parameter	Sunflower oil		Corn oil	
	min	max	min	max
pH	3.53	4.5	2.72	2.85
Total COD (mg/L)	8345	9700	11580	15450
Soluble COD (mg/L)	5195	5560	5140	6700
Total BOD (mg/L)	1500	1900	1250	2278
Soluble BOD (mg/L)	1450	1800	1100	1207
SS (mg/L)	1516	1985	1058	2990
TKN (mg/L)	458	625	1125	1458
NH3 (mg/L)	18	51	38	62
Total P (mg/L)	52	420	275	775
Oil grass (mg/L)	533	760.2	307.8	498.6
Sulfate (mg/L)	10800	11750	11900	12300
Color (Pt-Co)	224	272	868	1700

2.2 Olive treatment and olive oil (olive oil mills)

Practically, Mediterranean countries are the predominant producers of olive oil, statistically, 97% of the world's olive oil comes from these countries. There are about 25000 olive mills worldwide, proving that wastewater treatment of olive mills is essential.

The organic discharge of wastewater from olive mills depends on many factors. Firstly, the method of extraction, type, and maturity of olives, the region of origin, and topology, are the most common variables that affect the characteristics of olive oil mills wastewater.

On average, organic content can be evaluated as harmful correlated with other food industry wastewater. The actual values of the parameters are referred to below. It was found that BOD boundaries vary around 16-110 kg/L, COD from 1.9 to 220 kg/L, Suspended solids from 1 –9 g/ L, Total Solids (TS) varied from 5.9 to 103.2 kg/L, pH between 3 and 5.9, COD/BOD5 ratio vary between 2.5 and 5. Olive mill wastewater also contains polyphenols (PhC) ranging from 0.1 to 17.5 kg/L-1, and long-chain fatty acids. Lignin and tannin are responsible for characteristic dark colors. The great extent of these pollutants leads to toxicity for most microorganisms. A typical characterization of this type of sewage is presented in **Table 2.3** [7-9].

Table 2.3. Characterization of wastewater for olive mills according to "Olive mill wastewater characteristics: modeling and statistical analysis"[7].

Parameters	OLIVE OIL 1	OLIVE OIL 2	OLIVE OIL 3	OLIVE OIL 4	OLIVE OIL 5	OLIVE OIL 6
Ph	6.85	5.02	4.24	5.02	4.92	5.5
COD (kg/m^3)	9.08	44.6	20.6	134	135	23
BOD (kg/m^3)	4.75	NON DETECTABL E	11	40	42	7.9

TS (kg/m^3)	7.3	33.1	15.1	117	106	18.8

2.3 Milk processing and dairy by-products

This process consists of the conversion of milk into products such as yogurt, cottage cheese, cream and butter products, ice cream, milk, and whey powders, lactose, condensed milk, or pasteurized and sour milk, and various types of desserts [9].

The dairy industry tends to be a significant source of industrial food wastewater, especially in Europe. The wastewater may contain pathogens from contaminated materials or production processes. The contents could be soluble organics, suspended solids, and trace organics.

The white color would describe wastewater from the dairy industry. The marginally alkaline nature of the waste should be mentioned and more emphatically the fact that this would become acidic because of fermentation of milk sugar to lactic acid.

In addition, sanitizers are used during the cleaning procedures that are strongly important for those industries, rendering wastewater treatment an integral part of the industry.

According to researchers, 2.3 liters of wastewater/kg of product is released into the environment [10].

Biochemical oxygen demand and chemical oxygen demand can be

characterized among others as two great indicators to measure how hazardous dairy-by wastewater can be.

High temperature and high proportional organic discharge are among other characteristics of milk processing companies. Indicatively, Chemical oxygen demand (COD) values up to 5451 mg/liter, 3049 mg/liter Biochemical oxygen demand (BOD), Total suspended solids (TSS) at 100–1,000 milligrams per liter (mg/l), phosphorus

(10–100 mg/l), and total nitrogen (about 6% of the BOD level), more details are referred in Table 2.4 [9].

Finally, the correspondence between product and COD would be:

- 1 kg of milk fat = 3 kg COD
- 1 kg of lactose = 1.13 kg COD
- 1 kg protein = 1.36 kg COD.

Table 2.4. Measurements of various parameters for the characterization of wastewater for every dairy product according to [10].

Diary products	pH	Total BOD (g/L)	Total COD (g/L)	TS (g/L)	TSS (g/L)	TN (g/L)	TP (g/L)	Alkalinity as CaCo3 (g/L)
Mixed diary	4 up to 11	0,24 up to 5,9	0,5 up to 10,4	0,71 up to 7	0,06 up to 5,8	0,01 up to 0,66	0 up to 0,6	0,32 up to 1,2
Milk	7,18	0,8	2,54	-	0,65	-	-	-
dairy/sewage 7:3	6,7 up to 9,1	1,08 up to 2,81	2,04 up to 4,73	-	0,53 up to 1,13	-	0,02 up to 0,03	-
Fluid milk	5 up to 9,5	0,5 up to 1,3	0,95 up to 2,4	-	0,09 up to 0,45	-	-	-
Yogurt	4,53	-	6,5	-	-	-	-	-
butter	12,08	0,22 up to 2,65	8,93	-	0,7 up to 5,07	-	-	-
ice-cream	5,1 up to 6,96	2,45	5,2	3,9	3,2	-	0,014	0,22

cheese	3,38 up to 9,5	0,59 up to 5	1-63,3	1,92 up to 53,2	0,19 up to 2,5	0,018 up to 0,83	0,005 up to 0,28	-
cottage cheese	7,83	2,6	17,65	-	3,38	-	-	-
cheese whey	3,92 up to 6,5	27 up to 60	50 up to 102,1	55 up to 70,9	1,27 up to 22,15	0,2 up to 1,76	012 up to 0,53	-
hard cheese whey	5,8	9,48	73,45	-	7,15	-	-	-
soft cheese whey	5,35	26,77	58,55	-	8,31	-	-	-
cottage cheese whey	4,5	-	79,0	68,0	-	2	-	-
cheese whey wastewater	4,6	35,0	-	-	-	-	0,64	-
whey processing effluent	5 up to 9	0,59 up to 1,21	1,07 up to 2,18	-	0,08 up to 0,44	-	-	-
milk permeate	5,55 up to 6,52	-	52,94 up to 57,46	11,61 up to 15,39	1,94 up to 3,4	0,3 up to 0,4	0,35 up to 0,45	2,5
condensate	8,3	-	-	-	-	0,006	0,000 1	-
washing wastewater	10,37	3,47	14,64	-	3,82	-	-	-

2.4 WASTEWATER FROM MEAT AND POULTRY PROCESSING

Commonly, 56.781.176.7600 liters of water are used for meat and poultry processing per year. The United States Environmental Protection Agency characterized abattoir wastewater as one of the most hazardous pollutant sources.

All these proceedings consume water to a great extent and unfortunately, most of this used water contains effluents, really dangerous for the fauna and flora. Consisting of high values of COD due to the presence of blood, tallow, and mucosa, high content of nitrogen (from blood), and phosphorus, wastewater from meat processing industries rendered as number one target for optimal wastewater management.

Chemical analysis showed the following values for various parameters of Slaughterhouses. It is clarified that the results shown in **Table 2.5**, are typical but these parameters may vary because of the diversity in the procedures of each meat processing company and the following quality policy.

Table 2.5 Parameters of wastewater from poultry processing [11].

Parameter	Value
pH	8,02
BOD (mg/L)	1602
COD (mg/L)	5422,25
TSS (mg/L)	3438,2
TN (mg/L)	361,25
PO4 (3-) (mg/L)	12,25
F- (mg/L)	0,49
NO3 (mg/L)	2,24

2.5 Wastewater from fruit and vegetable processing

For the characterization of fruit and vegetables, various parameters are analyzed, the most common are Organics, Biochemical Oxygen Demand (BOD), Suspended Solids (SS), Volatile solids & Settleable solids, pH, and temperature [12].

The high variance of operations in this industrial sector and the great variety of fruits and vegetables form respectively many classifications of wastewater. Although, on average, wastewater from fruit and vegetable production is low in nitrogen.

Most wastewater is produced in the first stage of processing. The pollutants from fruit and vegetable processing subsist mainly from carbohydrates, such as sugars, starches, pectin, vitamins, and minerals with a great variety of compositions. The percentage of organic matter that comes in dissolved form ranges from 70 to 80% [13].

Specifically, wastewater generated during production is characterized by pH values in the range from 5.8 to 9.4 and the COD value from 1030 up to 5630 mgO2/dm3 , BOD5 value ranges from 500 to 5 000 mgO2/dm3 [14], always clarified that these values may differ in many cases. Another effective parameter for the final values is the cleaning of production lines. A brief representation of this wastewater is shown in **Table 2.6**

Table 2.6 Parameter values of wastewater from fruits and vegetables industries [15].

Parameters	Unit	Fruits and vegetables		
		1 st industry	2 nd industry	3rd industry
BOD	mg/dm^3	860	2200	3200
COD	mg/dm^3	919	3350	3700
N total	mg/dm^3	40	48	60
P total	mg/dm^3	9.4	14.8	16
TSS	mg/dm^3	249	356	420
Ph	mg/dm^3	5.5 up to 7.2	4.3-7.1	4.6-7.9

2.6 Beverage industry

Wastewater from beverage factories can be characterized as effluent water because of carbohydrates, such as sugar, pectin, flavorings, and coloring additives but also chemicals such as sucrose, maltose, lactose, glucose, fructose, artificial sweeteners, fruit juice concentrates, preservatives, and mineral salts, exist when the chemical analysis is executed. The aforementioned materials are the main reasons for the high organic load of wastewater from the beverage industry [15]. Waste sugar is often the greater influencer of the high BOD (Biochemical Oxygen Demand) value. The greatest percentage of the waste sugar appears during cleaning and spillage procedures. Finally, it should be clarified that the production of syrups remains the most harmful operation of the beverage industry for the environment because it generates rejections rich in sucrose. Wastewater from beverages is shown in **Table 2.7** [16].

Table 2.7 Wastewater characteristics in the Beverage industry from three different industries [21].

Industries	pH	Total alkalinity	BOD (mg/l)	SS (mg/L)
A	10,6-11,4	390	380	170
B	10-11,2	250	660	160
C	10,4-11,2	220	250	340
Average		**290**	**430**	**220**

2.7 Brewery

The organic discharge varies a lot in Breweries because it is strongly dependent on the nature of the grain and the quantity of the production. Typically, wastewater from the brewery industry is characterized as regularly biodegradable. The Ph level is mainly affected by the chemicals used for cleaning, Nitrogen, and Phosphorous concentration is influenced by the management of raw grain or by cleaning operations. COD values would commonly range around 2000-6000 mg/L, BOD 1200-3600 mg/L, TSS 200-1000 mg/L, pH 4.5-12, more details are deposited in **Table 2.8** .

Table 2.8 Parameters values of wastewater from brewery productions [15].

Parameters	Typical brewery
COD (mg/L)	2000-6000
BOD (mg/L)	1200-3600
TSS (mg/L)	200-1000
T (CELSIUS)	18-20
pH	4.5-12
Nitrogen (mg/L)	25-80
Phosphorous (mg/L)	10-50
liquid effluent/Beer (m^3)	2-8

2.8 Sugar and confectionery

The confectionery industry remains one of the most extensive types of industry worldwide. The wastewater composed in this section mostly leads to the aquatic world with inadequate treatment, threatening all the species. The result of such handling is a high concentration of phosphorus, nitrogen, COD, and BOD. This sewage can be characterized as biodegradable, with the main constituent being organic compounds and suspensions. The organic substances usually included in the wastewater of those factories are sugars, fats, and dyes. The COD index is usually valued with the limits of 1000-12000 mg/L, while BOD5 is up to 500-8000 mg O2/L.

Occasionally, procedures in confectionaries consist of washing and disinfecting, in that way pH, nitrogen, and phosphorus values constantly incur changes, the important parameters for the characterization of this wastewater are presented in **Table 2.9** [18].

Table 2.9 Parameter values of wastewater from confectionery [18].

Industry	BOD (mg/L)	COD (mg/L)	Conduction µS/cm	pH	NH4, N-	Phosphorous (mg/L)
Candy manufacturing plant in Mexico	8000	2500				
Chocolate manufacturing I Mexico		3608	750	7,4		
Confectionery plant Poland	5400	10996	633	4,1	28,5	13,2

Dairy- sweet snacks and ice cream industry effluent	442-523	8960-11 900	794-1082	5,6-7,1	89-120	78-157
Sugar industry, Ethiopia		3682		5,5		5,9
Confectionery factory-sugar line, Turkey		20025	680	3,8		
Sugar industry, Pakistan	3132	12211		9,5		

Organic load from gum industries can be characterized as high, the important parameters for wastewater from the gum industry are presented in Table 2.10

Table 2.10 Parameter values of wastewater from the gum industry [19].

Parameter	Unit	Sugar line	Gum line	Gumdrop line
COD	mg/L	20025	10300	6410
Soluble COD	mg/L	17470	8365	3765
TSS	mg/L	900	625	1165
Conductivity	µS/cm	680	689	295
pH		3.83	4.1	5.16
N03N	mg/L	78	96	50
NO2N	mg/L			
Sulfate	mg/L	14	35	30
Phosphate	mg/L			
Chloride	mg/L	55	60	16
Ammonium	mg/L	0.22	15.4	2.8

TKN	mg/L	95	160	68
TP	mg/L	4.5	5	0.64
Potassium	mg/L	15	15	1.6
Calcium	mg/L	40	50	45
Magnesium	mg/L	8.3	12	11
Copper	mg/L	0.24	0.11	0.38
Zinc	mg/L	0.8	1.6	1.4
Sodium	mg/L	93	60	23

2.9 Review of the aforementioned Food Industry types

Assemplying all the deposited important information about every type of Food Industry, it is clear that even though at first glance Food effluents seem “innocent” because of their high biodegradability, it is proved that the extent of production nowadays makes it impossible for every factory to release untreated wastewater. Mainly, in many cases, wastewater management is emphatically important as they demonstrate the highest rate of pollution when compared with the other kind of food industries. In conclusion, the optimal solution for this wastewater management is the one-way road to confront this environmental crisis that is caused by wastewater.

3 Conventional Water treatment methods in the industry

Commonly, wastewater characteristics studied above with the combination of parameters such as the flow of wastewater form the optimal treatment or in many cases the compilation of treatments used. The decision of the most relevant water treatment method would be the next step of this research, keeping in mind that the target of this thesis is the energy recovery from the food industry. Wastewater from food processing factories is characterized by high organic matter, therefore in some cases, aerobic treatment is the optimal solution in other cases anaerobic treatment is the choice with the most advantages but it can be denied that a blended anaerobic and aerobic system with the combination of anaerobic pretreatment can lead to an excellent result on many cases. According to the sources, the central idea of treatment in the food processing section includes the methods of regulation, aeration, and settling tanks.

Figure 3.1 shows an indicative policy for water treatment in food processing with the use of aeration, which is the most common method. Certainly, many variations exist, due to the strong variety of industries processing food and their requirements. In the case of excess sludge production, during industrial procedures, biological wastewater treatment methods are adopted [20]. The reason behind this policy is the generation of minimum sludge. In agreement with , **Table 3.1** presents a brief description of treatment methods applied in various industries.

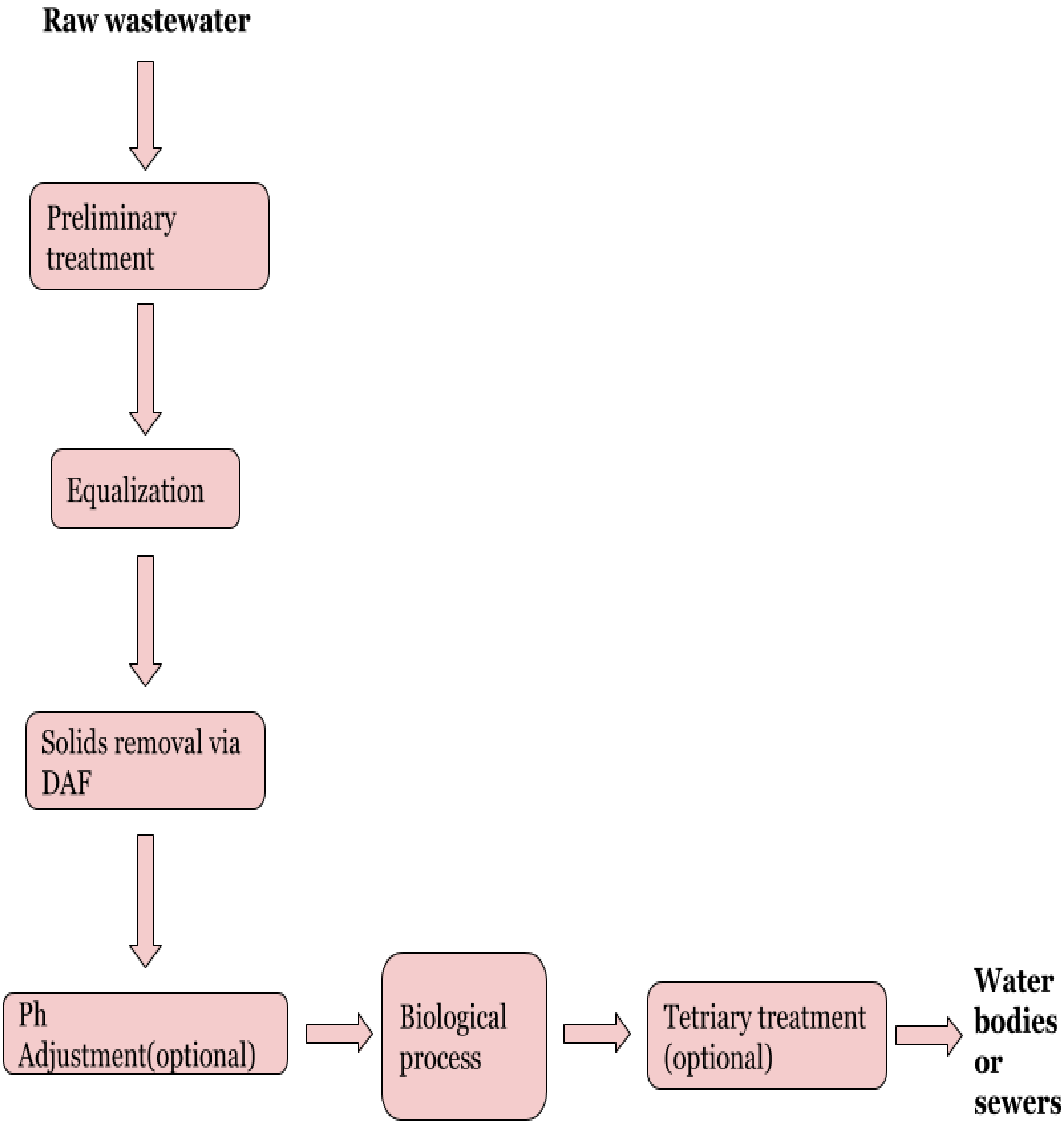


Figure 3.1 A typical illustration of the Food industry water treatment process via aeration.

Table 3.1 Examples of treatment methods for different industry categories [21].

Industries	Wastewater	Major pollutants									Typical treatment methods
		pH	BOD	COD	SS	Oil	N	P	Color	Others	
Food	Brewery		○	○	○						AS, AD
	Beverage		○	○							AS, AD
	Vegetable oil		○	○		◎					OS, AS, AD,
	Milk/daily product		○	○							AS
	Starch		○	○	◎						AS
	Daily dishes		○	○							AS
	Confectionary		○	○							AS
Petroleum refinery	Refinery Deforming			○		◎				smell	OS, AS, AD,
Chemistry	Petrochemistry	○	○	○							N, FL, AS, AD
	Chemical fertilizer	○	○	○	○		◎	◎			N, AS, DN, PR
	Polymer chemistry	○	○	○							N, AS, AD
	Organic chemistry	○	○	○		○					N, FL, AS, AD
	Oil/fat			○	○	○					OS, FL, AS
	Pharmaceuticals		○	○	○						AS
Steel	Blast furnace			○	○						CS, FI
	Steel, hot mill			○	○	○					OS, FI,CS, FI
	Col mill	○				○					N, FI
	Cokes		○	○		○	◎		○	phenols	N, OS, AS、FI
Paper/pulp	SKP		○	○	○				○	smell	IC, AS
	KP	○		○	○				○	smell	CS, FL, BL
	SCP, CGP		○	○	○				○	smell	CS, FL、AS, IC
	Washing/screening				○						FL, AS
Dyeing	Desizing		◎	○	○						CS, FL, AS
	Scouring			○							CS, FL, CH
	Bleaching			○							CS, FL, CH
	Dyeing			○					○		N, CS, FL、O3
Machinery	Semiconductor	○	○	○						fluoride	N, AS, CS, FI, MF, O3
	Automobile					○					FL, FI, MF
	Plating	○								cyanide	N, FL, CS, CH, O3
Fiber	Wool		○	○	○						CS, AD、IC
	Synthetic fiber	○	○	○							N, CS, FL, AS

It is clarified that highly sewage products are marked by a doubled circle and that in the case of advanced treatment methods such as filtration and activated carbon, absorber and membrane separation are used. In **Figure 3.1** symbols used in the last column of **Table 3.2** are explained.

Table 3.2 Annotation of **Table 3.1**.

Method	Symbol
Neutralization	N
Oil Separation	OS
Filtration	FI
Aerobic Biological treatment	AS
Anaerobic Biological treatment	AD
Membrane Separation	MF
Chemical Treatment	CH
Denitrification	DM
Phosphorus Removal	PR
Black liquor Recovery	BL
Ozonation, Chlorination	O3
Incineration	IC
Coagulation-Settling	CS
Dissolved Air Floatation	FL

3.1 Preliminary treatments

Screening operation is happening during preliminary treatments in general, using vibrating rotary or static screens with a scale of 1 mm to 10 mm holes. Screening exists to conserve the system from solid matter such as rags, paper, plastics, and metals that can destroy the equipment or agitate the efficiency of the system. Constantly in some cases, screening procedures must occur cooperatively for greater efficiency, in some cases, 40-50% of suspended solids are managed to be abolished. Rotary drum screen equipment representation is shown in **Figure 3.2**.

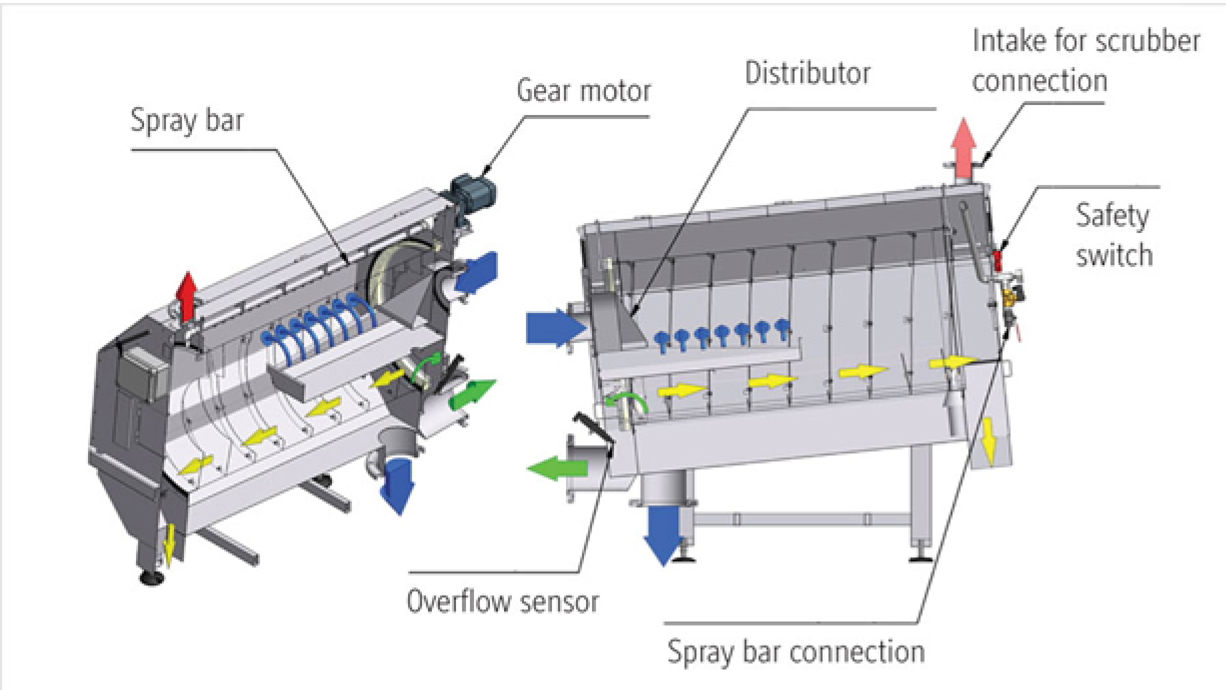


Figure 3.2 Rotary drum screen equipment for wastewater treatment [22].

3.2 Flow Equalization

Ordinarily, the equalization stage prepares the wastewater for organic loading contraction before biological processes. Consisting mainly of a holding tank and pumping equipment, equalization is the reason why wastewater streams that arrive from different sources are homogenized, odor formation is prevented and the flow rate is controlled. Also in some cases, chemicals are deposited in the equalization tank for better suitability of the effluent in the DAF that is a system described below. Commonly, high demands are examined for mixers due to fluctuation in the water level of the equalization tanks [23,24].

Figure 3.3 Equalization basin in the industry [22].

3.3 Solids removal via DAF

Dissolved Air Flotation (DAF) has been known as one of the most effective and robust ways to remove suspended solids (TSS), decrease the load and by extension the biochemical oxygen demand (BOD5), phosphorus (P), or nutrients from industrial wastewater. Dissolved Air Flotation is based on a physical/chemical process, where the injection of air into the water stream with chemical assistance (mostly coagulants) causes the particles/flocks to float to the surface. This floating sludge layer is then automatically and continuously counteracted by a scraper mechanism. The DAF system will produce a treated effluent virtually free of the most TSS, and remove a large portion of the BOD, an example of DAF is shown in **Figure 3.4** [25].

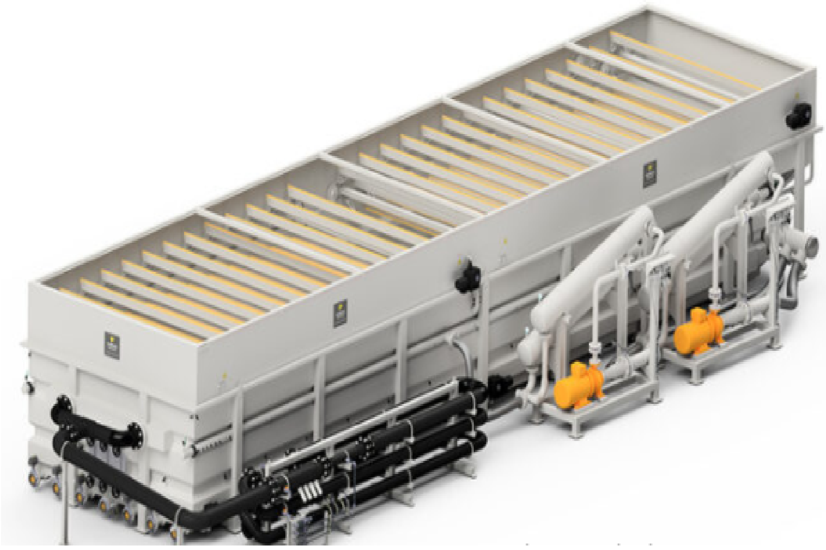


Figure 3.4 Example of the Nijhuis Dissolved Air Flotation System (type NOF) source: Nijhuis Industries [25].

Figure 3.5 DAF system example at a bacon processing facility, source: Nijhuis Industries [25].

3.4 Ph adjustment

Ph adjustment constitutes a preventive measure for pipeline corrosion and also secures the safety of the drinking water conditions leading to human and environmental health. Neutralization of pH may also be mandatory in the water treatment process for the achievement of the most successful conduct of processes such as coagulation and to attain optimal results in the operation of DAF. On the contrary, the redundant basicity of water could contain precipitates of carbonates and hydroxides.

Many pretreatment systems require that the pH must be adjusted as an initial step in the treatment process, such as Coagulation and flocculation processes for the highest removal percentage of oil, phosphates, and suspended solids from the food industry.

Acidic wastewater can be neutralized with sodium hydroxide (NaOH), lime (CaO), magnesium hydroxide ($Mg(OH)_2$), and calcium hydroxide ($Ca(OH)_2$). Alkaline wastewater can be neutralized with sulfuric acid (H_2SO_4), hydrochloric acid (HC1), and carbon dioxide (CO_2). The chemicals used mainly are H_2SO_4 and NaOH. Commonly continuous flow-type systems are adopted with one or two neutralization tanks. This division arises from the different flow rates and how much pH may vary from batch to batch. A simple single tank continuous flow with pH neutralization via automation is shown in **Figure 3.6**

A pH sensor measures the value of pH with also the capability of metering pump activation that adds acid or caustic in the tank, by using the feedback of the designed control system . Ph neutralization is dependent on many factors, the most important are the electrodes, holders, and the correct pumps to feed the system [24,26,27].

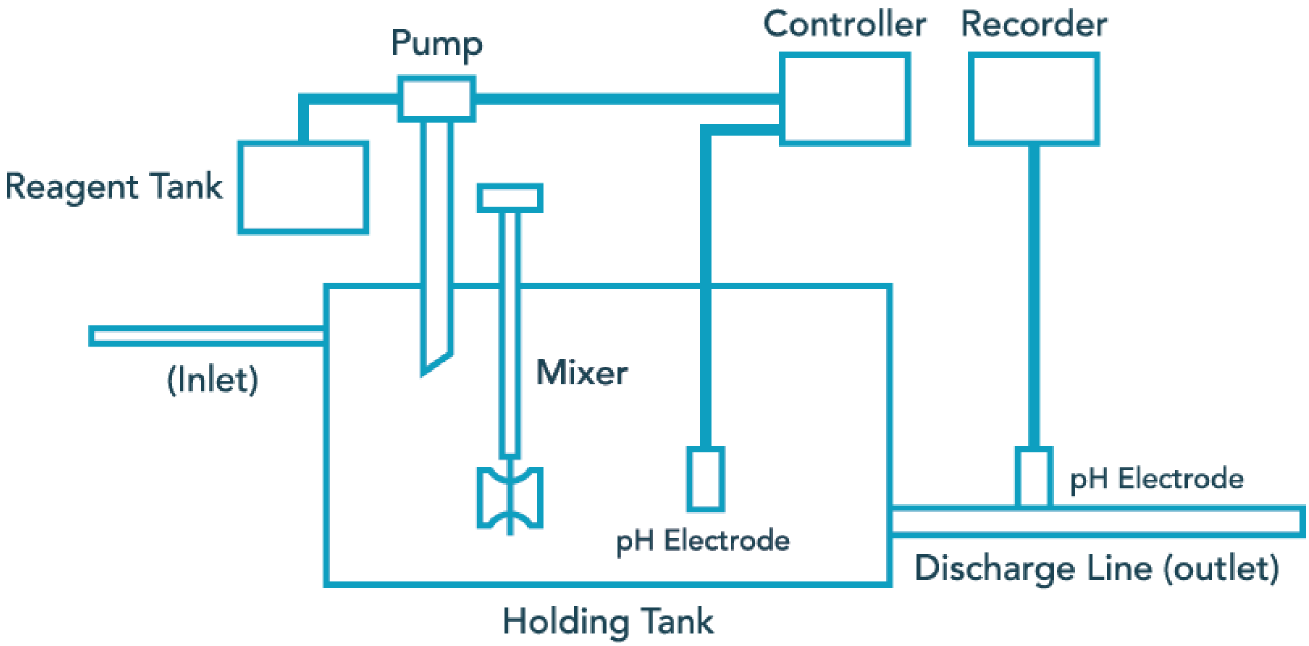


Figure 3.6 Representation of continuous flow pH neutralization process [24].

3.5 Biological treatment processes

The secondary treatment is also titled a biological process. Industrial wastewater is highly variable in the terms of composition, depending on the specific industry involved, and is controlled by regulations regarding pre-treatment.

Biological treatment processes are based on bacteria, nematodes, and other microorganisms that destroy organic matter. A representative description of the most typical organisms appears in **Table 3.4**. Strong demand for energy sources is needed for these organisms to exist but also reproduce and remove adequately the organic loading. One classification of microorganisms is shaped according to their way of respiration. Free oxygen, for instance, is used by aerobic organisms, the same happens in facultative organisms, in some cases nitrate oxygen is used. However, anaerobic organisms do not use respiration but proceed by using sulfate or carbon dioxide to accept an electron.

Biological wastewater treatment is not characterized as a new method. Through the years, this procedure managed to be used widely in the Food Industry with both aerobic and anaerobic biological processes attaining the greatest possible percentage of reduction in the organic matter. Frequently, biological treatments should conform with the legal framework and include stages of Chlorination, UV treatment, and filtration with the most common methods being carbon filtration and reverse osmosis. In some other cases, UV light is used for the subside of chemical residues and pharmaceutical compounds . Different classifications of biological processes exist, one of them would divide into aerated or non-aerated procedures and suspended growth, attached growth, or a hybrid of Suspended and attached growth. Many biological treatment systems have been developed and used for the treatment of high-loading wastewater generated by food industries. With the combination of the aforementioned, **Table 3.3** and **Figure 3.7** is formed.

Before deciding on the use of biological treatment technology for wastewater, biodegradability needs to be assessed. The COD/BOD ratio is a useful tool for making such a decision. For example, if the COD/BOD ratio is 2.5 then the wastewater may be considered suitable for biodegradation and a treatment technology based on a process like activated sludge can be adopted. A COD/BOD ratio above 2.5 but below 5.0 suggests that some molecules are refractory to biodegradation and biological treatment may still be adopted but with the provision of a much longer residence time of the wastewater in the biotreatment unit. A COD/BOD ratio exceeding 5.0 may be an indicator of the presence of toxic substances that are highly likely to reduce the metabolic activity of the microbes in the biomass.

Thus, in this case, direct biological treatment should be avoided as the microbes will not survive in the environment. A pre-treatment using chemical reagents or adsorbent additives may reduce the level of toxicity thereby permitting downstream biological treatment albeit with reduced effectiveness [28,29].

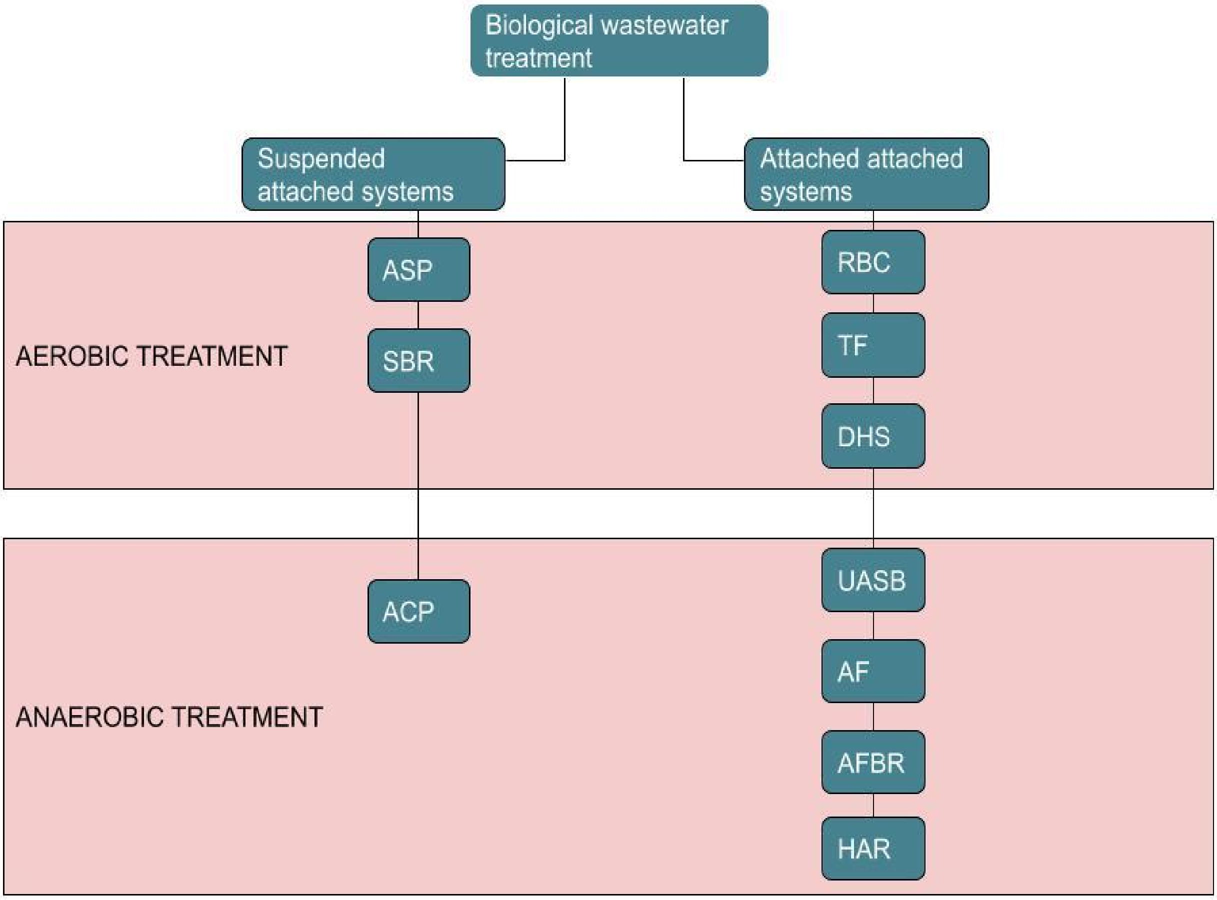


Figure 3.7 Classification of aerobic and anaerobic biological treatment processes in the figure according to Metcalf & Eddy Inc., 2004 [28].

Table 3.3. Classification of all biological treatment processes according to Metcalf & Eddy Inc., 2004 [36].

	Suspended growth	Attached growth	Hybrid	Lagoon
Aerobic process	activated sludge, aerated lagoons aerobic digestion	trickling filters RBCs Packed bed reactors	Trickling filter/activated sludge	aerobic lagoons
Anoxic process	Suspended growth denitrification	attached growth denitrification		
Anaerobic process	anaerobic contact processes anaerobic digestion	anarobic packed and fluidized bed	Upflow sludge blanket/attached growth	anaerobic lagoons
Facultative				facultative lagoons

Table 3.4. Explanation of the possible microorganisms existed in water and wastewater treatment according to Metcalf & Eddy Inc., 2004 [28].

Organism	Description
Bacteria	Bacteria are single-cell, prokoyotic organisms that use soluble food
Protozoa	Protozoa are single-celled microbes without cell walls and are eukaryotes. Most are aerobic chemoheterotrophs. Protozoa are generally larger than bacteria and often consume bacteria as an energy source. Therefore they are useful in obtaining a clear effluent since they feed on single-celled bacteria and particulate organic matter
Fungi	Fungi are aerobic, multi-cellular, non-photosynthetic chemoheterotrophs and they are eukaryotes. These organism use organic matter as a substrate (food). They require less nitrogen and can grow at lower pH values. Therefore they are very important for composting
Algae	Algae are single-celled and multi-cellular photosynthetic eukaryotes. The ability of algae to produce oxygen provides part of that required by bacteria in stabilizing the organic material
Rotifers	Rotifers are heterotrophic animal eukaryotes. They are very effective in consuming dispersed and flocculated bacteria and small particles of organic materials

3.6 Aerobic Biological treatment

Aerobic treatment of wastewater is a competent, plain procedure that produces high-quality secondary effluent. Aerobic treatment of wastewater is an oxygen-based method for removing effluents hazardous to all living species. Devices providing aeration into the system such as air blower or compressor are mandatory for the successful oxygenation of the microorganisms, who consume organic matter and convert it into carbon dioxide and new biomass cells. It is assumed that this type of process is suitable for industries such as food, beverage, and chemical. Regularly aerobic biological treatment can be classified into two main sections, suspended growth processes, and attached growth (or biofilm) processes, a schematic example of a Biological Treatment tank is presented in **Figure 3.8** [26,28,40,39].

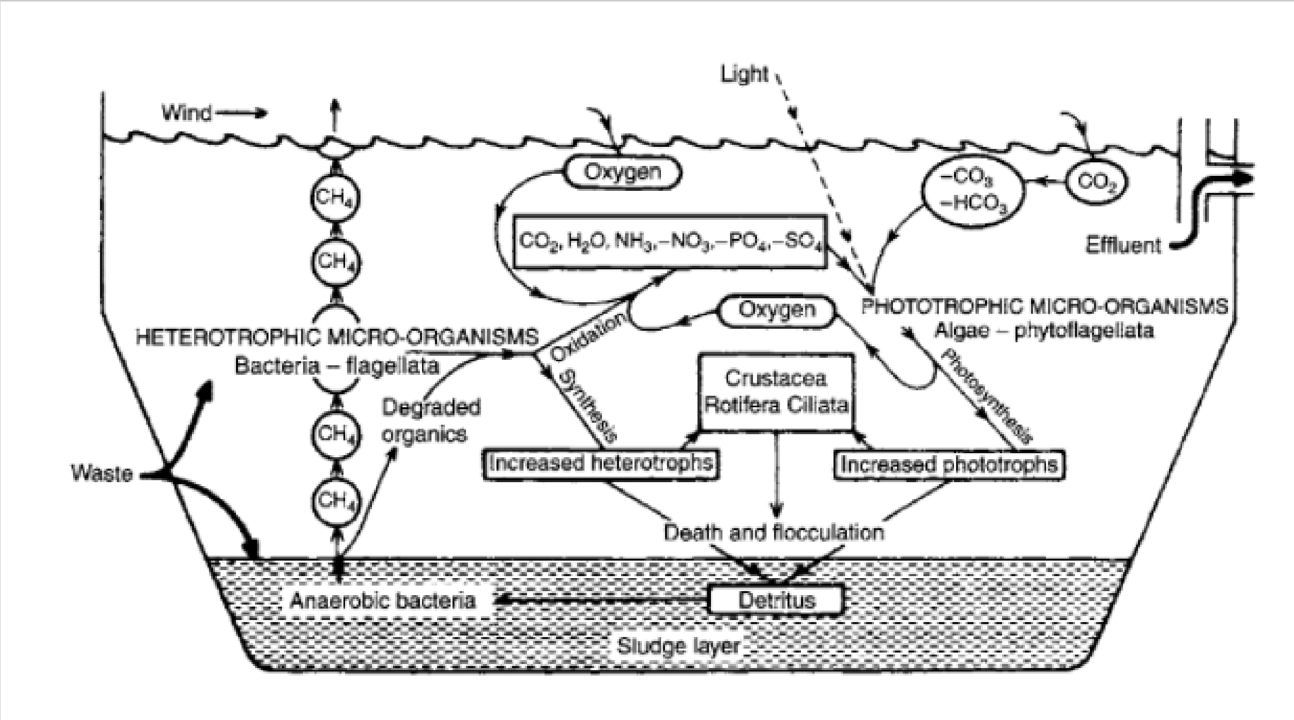


Figure 3.8. Representation of an aerobic system according to Biological and Chemical Wastewater Treatment Processes [38].

3.7 Suspended growth methods

3.7.1 Activated sludge

The activated sludge process is a suspended growth biological treatment process that catalyzes the decomposition by providing the optimal quantity and quality of sludge, energy, and aeration by preserving activated microbial. Oxygenation is achieved via diffused or mechanical aeration and organic material is their food source also the method of flocculation may participate in this stage. Commonly, typical activated sludge processes constitute aeration and a clarification tank with the three basic components being the complete mix bioreactor, the sedimentation unit, and the sludge-recycle system.

The procedure starts with the wastewater flowing into the aeration tank, this mixed liquid include the aforementioned heterotrophic microorganisms, the air is provided optimally to destroy the organic compounds into carbon dioxide, water, ammonium, and new cell biomass. The next step is the flow of the treated from the aeration tank to the clarifier tank, activated sludge is disputed in this tank, isolated from the wastewater, and a percentage of this sludge will return to the aeration tank for the equalization of the microbes, the superfluous sludge will be removed from the settling tank and will be deposited mostly in the sludge tank. Typically, around 50-75% is the return sludge percentage, always adjusted with the settling characteristics. While an overabundance of sludge is produced the system becomes less efficient, consequently this factor must be taken into serious consideration. On the contrary, if the sludge in the aeration tank is less than the safety boundaries formed for each case separately, the clarification tank will overflow into the receiving system and the activated sludge will not be adequate to decompose the organic matter. The retention time in the aeration tank can vary a lot because of the extravagant differentiation in the followed procedures. The process is represented in **Figure 3.9.** [26,28,40,39,36,37].

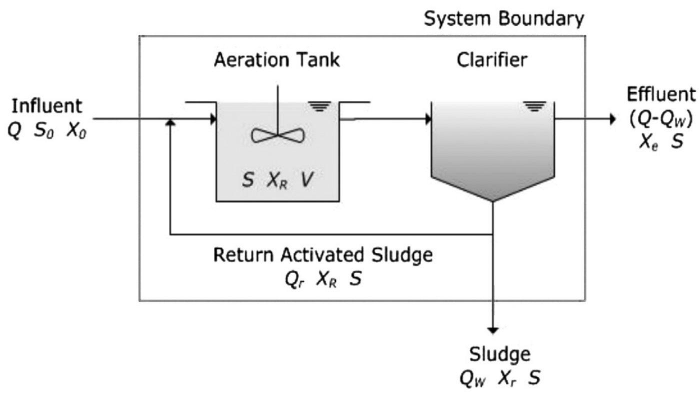


Figure 3.9 Activated sludge process according to [37].

3.7.2 Aerated lagoon

An aerated lagoon is a suspended-growth typed process, oxygen is provided by a system of air injection. An underground basin with the aeration system attached under the earth constitutes the equipment of an aerated lagoon. Aerated lagoons are 3–6 m deep, with hydraulic retention times ranging from 5 to 30 days.

Compared with the activated sludge method, the concentration of the microorganisms is much smaller, which is attributed to the fact that there is no return sludge. Also, it is observed that even though the retention time of an activated sludge ranges around hours, on an aerated lagoon varies between 5-30 days, concluding in an excessive in the terms of time method to attain the same quality of effluent. The fact mentioned above may occur as an advantage in the case of complex organic chemicals needed to be degraded. Therefore, organisms in aerated lagoons cannot be easily agitated because of the size of the tank compared with those in the activated sludge process. The schematic representation of this system is shown in **Figure 3.10** [26,28,40,39,36,37].

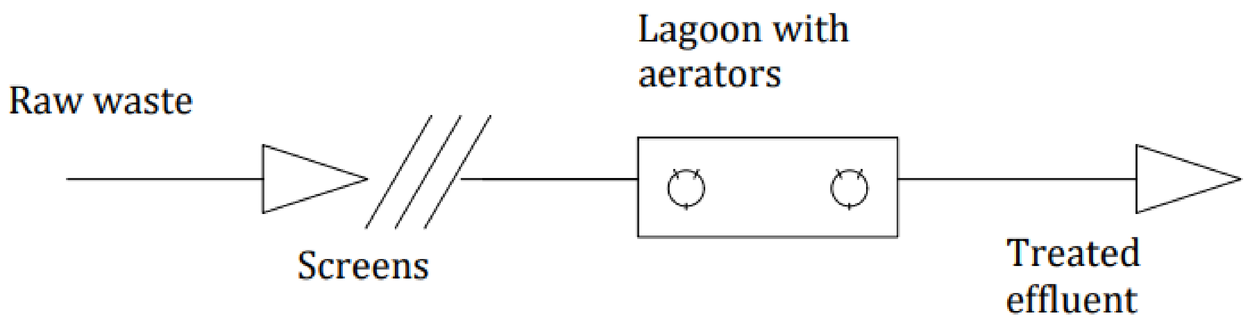


Figure 3.10 Aerated lagoon system according to [40].

3.7.3 Attached growth systems

By attached growth, inert packing material usage is entailed, while microbes grow, and remain attached to the solid support. Those microorganisms are responsible for the removal of the organic material, that material for instance can be a bed of rocks, gravels, slags, or a variety of different plastics and synthetic substances.

The attached growth systems are considered to be more efficient for heavy food processing wastewater, when in comparison with the conventional suspended methods. The utilization of biofilm reactors for the breakout of the organic discharge and also for denitrification have gained great interest lately [26,28,40,39,36,37].

3.7.4 Trickling filter (TF)

A trickling filter is an aerobic attached growth biological treatment process considered one of the oldest, carried out in the secondary treatment where settleable and floatable solids have already been isolated. Typically, it consists of a settling tank, a filter medium, influent wastewater, a distribution system, an underdrain system, a clarifier, and a pipe to recirculate. The filter medium is composed of a bed made of inert material such as a bed of rocks or one of the aforementioned materials, nowadays PVC media is preferable. The wastewater is deposited above the filter medium by a rotating or a fixed distributor system, layering this area thinly as it flows down through the filter. The distribution cylinder rotates, and the microorganisms interact with the flow of wastewater and air so that the biological treatment would take place. Air is provided from the ventilation port as shown in **Figure 3.9.** The wastewater falls through the bed where it is collected and is further cleaned or not. The recirculation supply is responsible for the aliveness of the microorganisms as it controls the wetting rate which is a very important factor in this system. Size, composition, uniformity, and depth strongly affect the output of the system.

The strong benefit but also the distinguishing feature of trickling filters is the minimization of energy achieved as there is no energy consumption for agitating mechanisms. This method can be generally characterized as advantageous as the only power used in the form of electricity is the power to transfer liquid to and from the unit and in distributing it over the packed bed, in that way this method is economical. Commonly when designed and used with the optimal conditions it is proved that they use 30-50% less energy with the same reduction of organic discharge and higher removal levels can be achieved by increasing the media depth and the recycle ratio.
The trickling filter unit must be covered in some cases where the climate is cold for more efficient results, a schematic representation is placed in **Figure 3.11** [36,37,44,45].

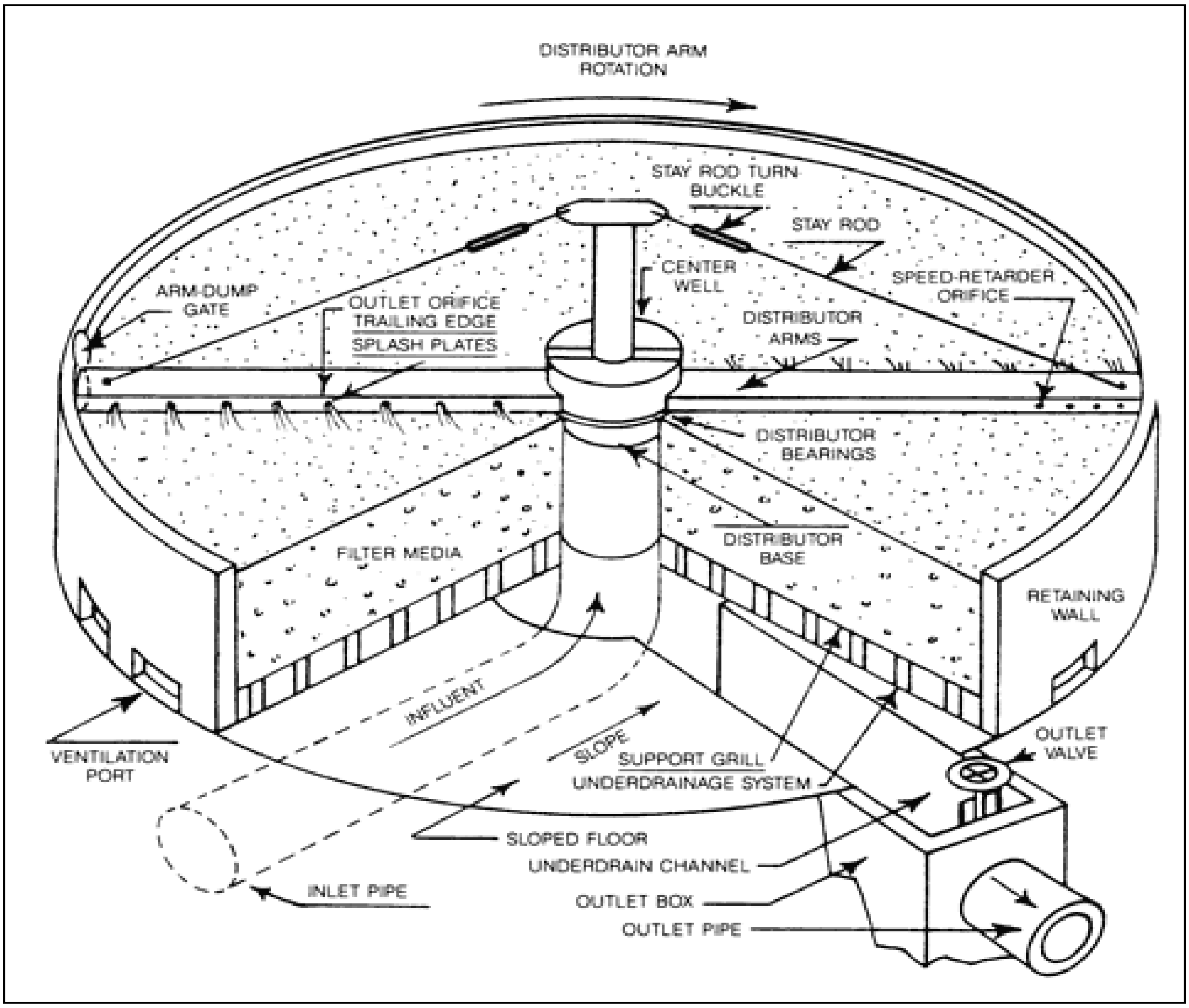


Figure 3.11 Trickling filter representation [44]

3.7.5 The Rotary biological contactor (RBC)

The rotating bioreactor contactor (RBC) is composed of disks, lattice construction, or a container of plastic balls. The working principle of RBCs (Rotating-disc biological contactors) is the same as trickling filters, as the discs where the microbes develop in a slowly revolving system. In that case, circular discs with a diameter that varies from 0.5 to 5 meters, produced from polymers such as PVC or PE are connected with the same horizontal with the common spot being the center of the discs, the angular speed values approximately 1 to 12 rpm, while remaining in a percentage of 50-80% drowned in the wastewater to be treated. Although RBCs are mainly used for aerobic treatment, the capability of both water and atmosphere exposure of the discs creates an aerobic and anaerobic environment for the organisms. In that way, both nitrification removal (for the aerobic environment) and denitrification removal (for the anaerobic case) can be achieved, resulting in ammonia conversion to nitrogen.

RBCs can achieve almost 90% removal of organic loading, but many disadvantages are limiting the usage of this system. The most important is that continuous power supply should be applied, and also the practical needs inevitable for the operation of the treatment, such as cleaning the surfaces, lubricating the rotating parts, and management by skilled people, leading to costly processing that cannot be applied in every case.

The microorganisms in the wastewater attach to the surfaces of the discs where they grow resulting in a whole layer of biofilm. While the discs rotate, this layer passes through the water that needs treatment, and finally removes the organic discharge but also as it moves, oxygen is added making this treatment aerobic. RBC systems can be run in either batch or continuous-flow mode.

The efficiency of this system can be achieved by setting the hydraulic retention time and the rotation speed of the disks. When rotation of discs, oxygenation, food source, and optimal hydraulics exist this method can treat industrial wastewater with a BOD of 4000-5000 mg/L and biodegrade 90% of organic matter. Commonly, if there is a great population of microbes, this method can biodegrade 810 times better than trickling filters, a schematic representation of this system is shown in **Figure 3.12** and **Figure 3.13** [26,28,40,39,36,37].

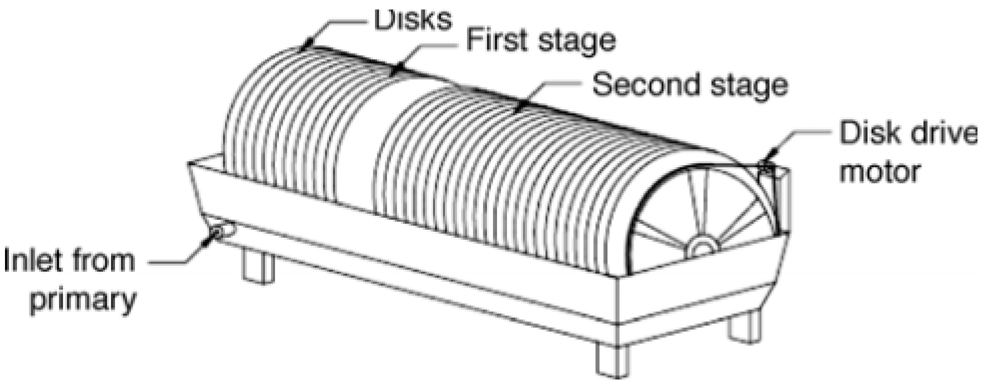


Figure 3.12 Typical Rotary biological contactor according to Yildiz, B. S. (2012). Water and wastewater treatment: biological processes. Metropolitan Sustainability, 406–428

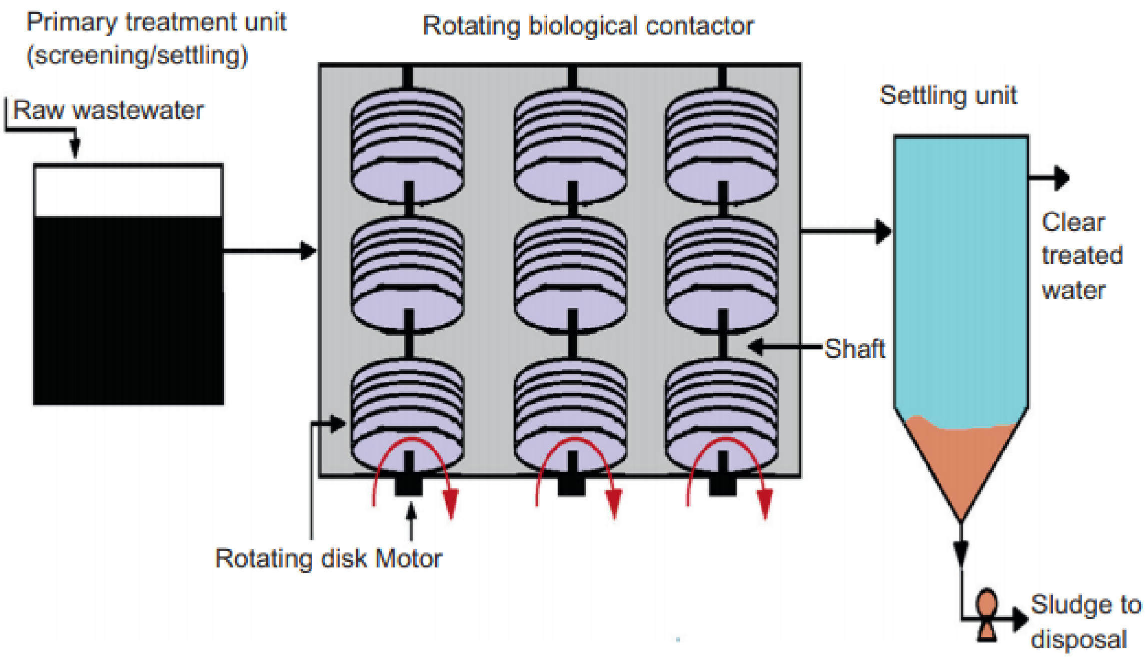


Figure 3.13 Representation of a Rotary biological contactor system [37].

3.7.6 Fluidized bed reactor (FBR)

In fluidized bed reactors, the main idea is a solid bed of media in which a biological mass is developed. This bed consists of inert materials such as sand, coal, or plastic and sometimes active material such as GAC standing for Granular activated carbon. Fluidized beds are a method widely used in aerobic and anaerobic cases. Aerobic systems are supplied with air through the bottom of the reactor.

Fluidized beds can be characterized as advantageous systems compared with packed beds because of the production of bubbles that can penetrate the bed smoothly leading to the usage of smaller particles of bed media meaning that the biofilm area is enlarged with more efficient removal of organic matter. Besides, this layer of material develops as the biofilm grows. When regulation of growth must be done, particles from the top of the bed are removed, washed, and revisited at the bottom of the reactor. The aliquot parts of the Fluidized-Bed Reactor are presented in **Figure 3.14** [26,28,40,39,36,37, 44].

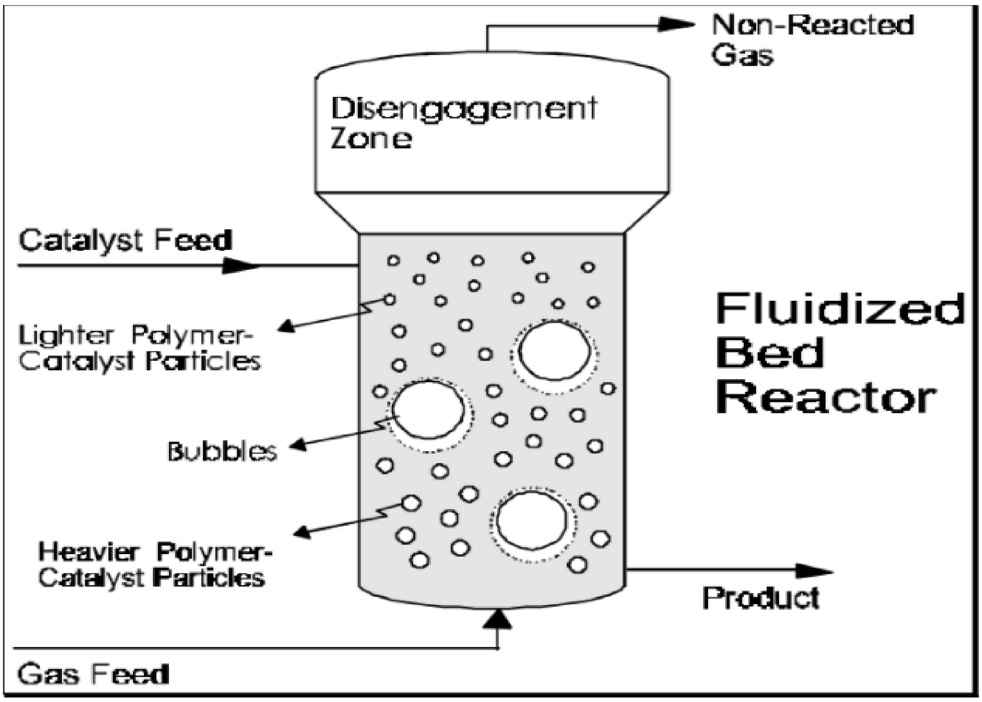


Figure 3.14 Representation of the parts of a Fluidized Bed Reactor [42].

3.7.7 Fixed packed bed reactors

A packed bed reactor consists of a bed of media in which a biological mass is developed, overlaying a support media and inlet chamber to which wastewater influent is introduced through an up-flow. They are advantageously used to increase the biomass concentration within the reactor and are preferred when the maximum specific growth rate is close to the dilution rate applied.

The use of carriers allows for significantly increasing the microbial residence time and reduces the washing-out risk at short hydraulic retention times. Air can either be injected into the inlet chamber or placed across the reactor floor. Microorganisms, principally bacteria, actinomycetes, and fungi, are attached to that media. To ensure the correct operation of the system, it is important to maintain the moisture content and temperature at steady levels, a schematic presentation occurs in **Figure 3.14** [26,28,40,39,36,37,25]

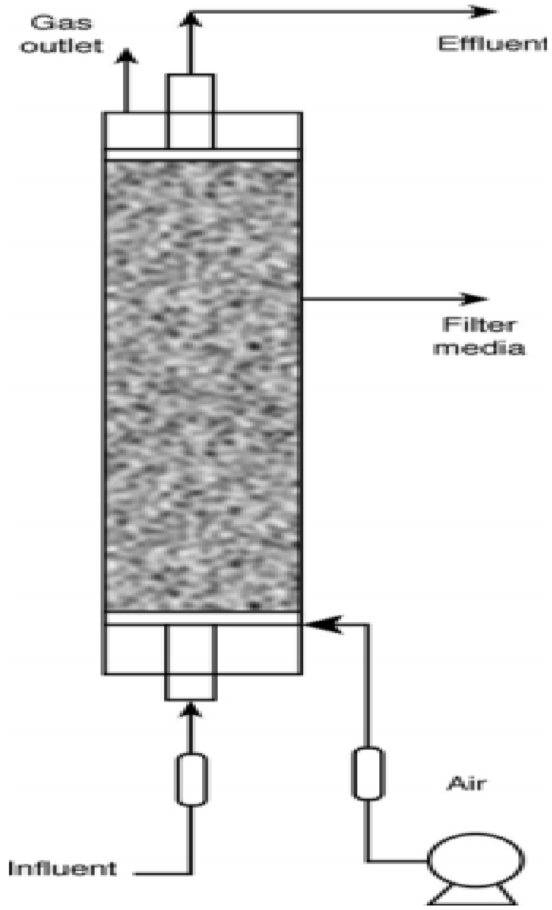


Figure 3.14. Aerobic Fixed packed bed reactor according to Yildiz, B. S. (2012). Water and wastewater treatment: biological processes. Metropolitan Sustainability, 406–428.

3.8 Other reactors in Food Industry

Other reactors widely used in Food processing Industries also included in the suspended growth systems are the aerobic jet loop reactor (AJLR) and sequencing batch reactor (SBR) [25,26].

3.9 Anaerobic water treatment

Many biological treatment systems have been invented and adopted for the treatment of high load wastewaters generated by food industries but it would be very useful to take a closer look at the anaerobic water treatment methods that under the correct circumstances can generate energy capable to recover 100% of the energy consumed to treat wastewater but also can be used for the benefit of the industrial plant.

The biomethane potential test should be used to measure the efficiency of the anaerobic treatment, for several liquids and solid organic materials. Usually, 28 samples are tested in the laboratory. The whole experiment lasted 30 days. The results from a biomethane potential test reveal methane or biogas that can be anaerobically converted from a concentration of organics in a substrate. After this test is held, the potential methane can be predicted for the analyzed waste. It is known that various methods are used to check the efficiency of the treatment [59].

3.10 Anaerobic digestion

Anaerobic digestion is characterized as a dynamic combination of microbiological, biochemical, and physical-chemical processes using waste capable of biodegradation but also producing energy production. The anaerobic process decreases the content of organic discharge from wastewater before they are released into the environment.

This method releases biogas by transforming raw effluent which has pathogen and nutrient organic substrate, into a less pathogenic result. The result from anaerobic digestion which is also a source of energy consists of 65% methane and the rest percentage is carbon dioxide but also other trace gases. The rest substrate can be a satisfactory fertilizer and in some cases can form the bedding material [60,61].

The produced methane, which is the main outcome of anaerobic digestion, can be utilized as a source for industrial activities or as the driving force for automotive vehicles and also for the generation of electricity. **Figure 3.15** presents the stages of an anaerobic digester.

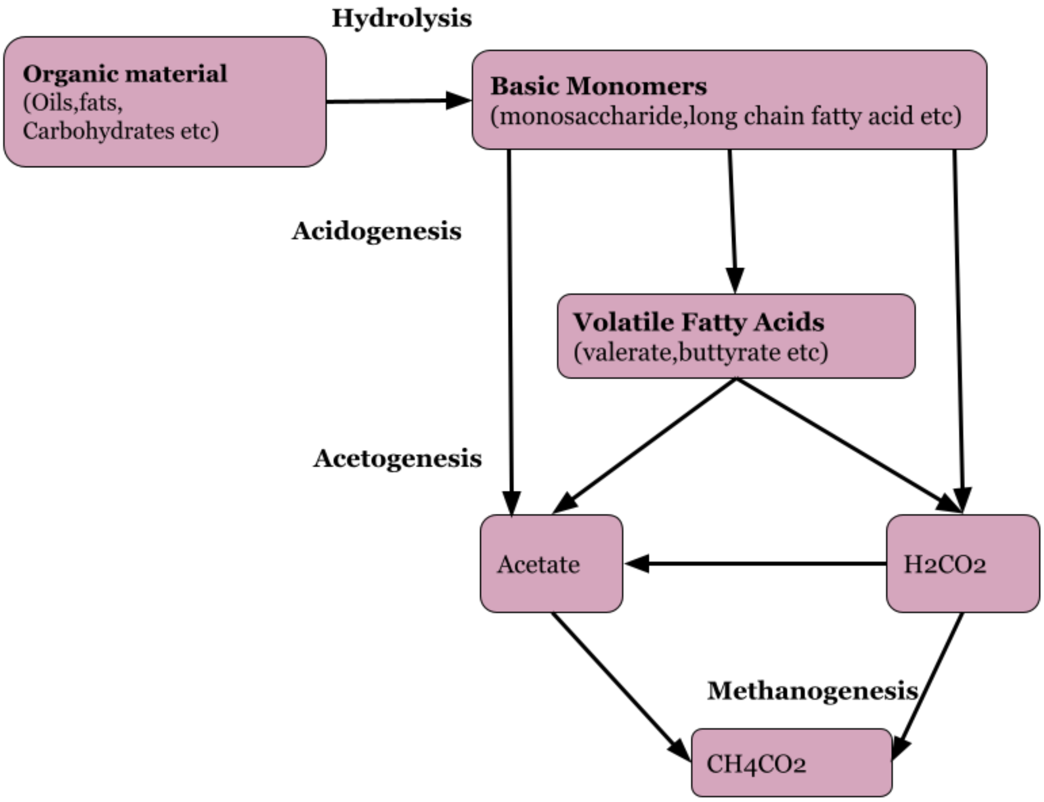


Figure 3.15 Description of the anaerobic process in wastewater treatment [55].

Hydrolysis is the first reaction that happens in an anaerobic digestion process. The reaction of hydrolysis is described by equation 1.

$$(C_6H_{10}O_5)_n + nH_2O \rightarrow nC_6H_{12}O_6 + nH_2 \quad (1)$$

The second step is the fermentation of simpler organic to organic acids and hydrogen by the usage of acidogenic microorganisms, this procedure is also known as acidogenesis. The volatile fatty acids conversion into acetate and hydrogen composes the next stage of acetogenesis, this process is undertaken by acetogenic bacteria, the reaction is described by equation 3.

$$2\,CO_2 + 4\,H_2 \rightarrow CH_3COOH + 2H_2O \qquad (3)$$

The last stage is the form of methane from acetic acid and hydrogen and carbon dioxide (equation 4). It is of great importance for methane production but also for acetogenesis to have the appropriate thermodynamic and environmental conditions more specific information will be deposited below.

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O \qquad (4)$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

A gas tank is the collector of those biogases, then it can be moved to the national gas system or sent to the cogeneration system for the production of electricity or even sent out for combustion as it is. According to more recent sources, as the anaerobic digester treats the organic discharge, the product of this procedure consists of 50-75% CH_4, 30-45% CO_2, and 2-7% of elements as H_2S and H_2.

This technology can be tripartite in wet digestion, dry digestion, and dry matter digestion. In the first case, the dry matter of the initial substance must be less than 10%, in the case of dry digestion, the dry matter percentage must be 20% or less and the last case is characterized as semi-dry.

3.11 ADVANTAGES OF THE METHOD

Anaerobic digestion is an economically convenient method that is known as one of the non-greenhouse gases procedures leading to technology with low environmental impact and also an advantageous procedure. The methane formed has a great heat of combustion. Biodegradation of organic matters with the lack of oxygen can form a product that can be a soil fertilizer easily used in many applications. This method produces minimum biomass sludge compared with the anaerobic technologies, with 90% being the biogas. Therefore, hydrogen and methane are considered future energy vectors, and anaerobic digestion is the only process in the sector of water treatment that can form a biogas mix of CH4 and C02.

3.12 DISADVANTAGES OF ANAEROBIC DIGESTION

As with all the methods, anaerobic digestion has some disadvantages and in most cases limitations that make this method inappropriate for several cases. Composite materials may need pre-treatment but also post-treatment before the deposition of the waste in the environment. Also, optimal control must be executed in various parameters such as pH, temperature rate of wastewater flow, and also in many cases inhibitors of the production must be used.

The aforementioned advantages and disadvantages must be taken into serious consideration before the approval of such investment [28,29,30-35,36].

3.13 Important factors for this technology

Temperature

Given the fact that the temperature of the system is of great importance as it can be effective for many parameters, the optimal temperature must be achieved. The population of the microorganisms, the substrate utilization rate, and biogas production are some of the parameters that can be affected. There are four categories of temperature examined. These are the psychrophilic temperatures: 10–20°C, mesophilic temperatures: 20–45°C with an optimum at 35°C, thermophilic temperatures with a range of 50–65°C and optimal at 55°C, and excessively thermophilic temperatures that vary between 65° C and 70° C. Commonly, mesophilic temperatures are the most efficient as they can provide satisfying results with low energy, they are also characterized as more stable in the terms of the process and the sensitivity to every environmental change is not important. Also, mesophilic organisms are more sensitive in the affection of ammonia accumulation compared with thermophilic organisms.

pH

PH is an important factor for the efficiency of an anaerobic digester, as the pH truly affects the population of the microorganisms, the ideal pH must be provided. The environment of the organisms must be characterized as neutral so that the optimal population growth will occur, this range generally is between 6.8 to 7.2, although every organism has a special Ph that is known as ideal.

Hydraulic retention time composes another great factor for anaerobic digesters. It is strongly dependent on the temperature of the technology and also on the substrate composition, equation 5 describes how the value of HRT is formed, V stands for the volume (m3), and Q is the daily flow (m3/day).

$$HRT = \frac{V}{Q} \quad (5)$$

The definition of Hydraulic retention time is the time required for utter removal of the organic discharge.

The organic loading rate is defined as the content of volatile solids that compose the daily feeder of the reactor per cubic meter of digester volume. The organic loading rate value is presented by the following equation 6, where OLR is the organic loading rate [kgVS (m3day)^−1], V is the volume [m^3], Q is the daily flow [kg/day], VS is the volatile solids [kgVS(kg)^−1]

$$OLR = Q * \frac{VS}{V} \quad (6)$$

It is of great importance to control the feeding rate, even though it results in high biogas submission, an overload in the digester can lead to consequences such as impeding the process of hydrolysis and affecting the performance of methanogenic bacteria.

Moisturization

Water is mandatory for the removal of organic substances as it is the solvent element but also catalyzes the mass transfer and diffuses the microorganisms, without the prohibition of the interaction of surface-microorganisms that happens during the process.

C/N ratio

This ratio describes the relationship between the amount of carbon and nitrogen contained in a quantity of organic matter, this rate can be altered by the type, and also how complex the substrate can be. A high ratio concludes in high carbon content, and also low gas yield as during the methanogenesis the nitrogen is consumed. On the contrary, a low ratio of C/N results in high protein concentration and high gathering of ammonia, C/N ratio must be valued between 20 and 25 [28,29,30-35,36].

3.14 Reactor types

Fixed bed reactor

As aforementioned in the aerobic fixed bed reactor, this method has a bed of material that can be inert or biodegradable, usually made by materials such as activated carbon and ceramics. The fluid dynamics in the reactor are affected by the porosity of the materials.

In the case where the production rate must be increased, recirculation of the biomass must be done because the mass transfer has been reduced. However, the main drawbacks of this system are the high cost of the investment and operation, but also the energy consumption [36].

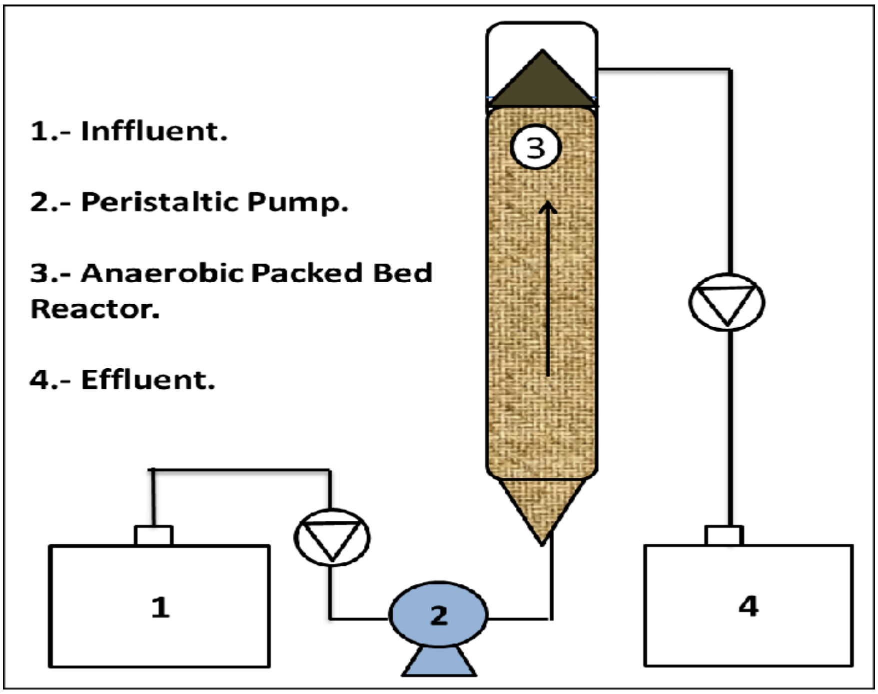


Figure 3.16 Fixed packed bed reactor according to [36]

UASB reactor

The UASB type is characterized as an advantageous reactor, it can be capable of maintaining a satisfying amount of biomass with a stable biomass/substance ratio. Also, this reactor combines simplicity and cost efficiency, but also this technology achieves the avoidance of reduction in the formed biogas as time goes by leading to wide usage for water treatment and specifically in the pharmaceutical industry. A thick mud bed placed at the bottom of the reactor supports the contact of wastewater with biomass.

However, the drawbacks of this reactor must be referred to as they can be restrictive in some cases. Long starting periods, and also high retention times with an excessive population of organisms are the most important disadvantages.

Fluidized bed reactor

High solid retention time, good mixing inside the reactor, and satisfying microbial biomass transfer inside the wastewater are the beneficial facts of this reactor. This inexpensive investment can be used when the wastewater is suspended or biodegradable, making them ideal for many Food Industries.

Anaerobic filters

The great retention of biosolids makes the anaerobic filters one of the most common reactors utilized in the Food, Pharmaceutical, and Chemical industry. Although as with every technology, anaerobic filters tend to have disadvantages capable of making them inappropriate for some cases. The main disadvantage of this type of reactor is the obstruction of the system by biosolids and other substances. The organic loading rate varies around 8-16 kg COD/m3 per day. which means ten times higher compared with technologies that use air.

Completely mixed anaerobic digester

The main differentiation of this method compared with the other anaerobic technologies is the identification between hydraulic retention time and retention time for solids, both values around 15-40 days. The organic loading rate in this digester can be found from 1 to 5 kg COD/m3 per day.

This technology is mostly used under the circumstances of high solids concentration.

Other reactors

Continuous stirred-tank reactor

Using agitating motors, microorganisms and wastewater are contracted without sedimentation of possible solids. The most important disadvantage is the efficiency of this reactor as it has limitations on the production of biogas due to ceaseless agitation and the energy consumed to maintain this unstoppable stirring. It is of great importance to maintain the speed of 50 rpm to achieve the best possible output [37].

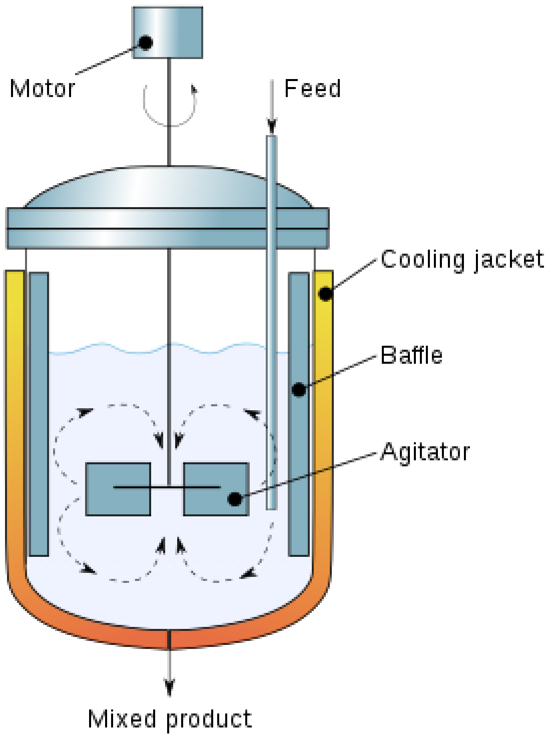


Figure 3.17 Schematic representation of Continuous stirred-tank reactor [37].

3.15 Comparison of aerobic and anaerobic treatment

In most cases, anaerobic systems are more advantageous compared with aerobic technologies. Specifically, anaerobic treatment is more energetically efficient, as it is capable of reforming energy through the biogas and also advantageous in the terms of energy consumption, anaerobic systems need less energy. On the other hand, aerobic systems are strongly beneficial because of the excessive soluble biodegradable organic matter removal rate that they can achieve. Also, aerobic technologies coagulate well leading to a reduction of the concentration of suspended solids and producing a high-quality effluent. In addition the aerobic methods have high sludge production when contrasted with the anaerobic. Besides, aerobic treatments are advisable in cases with low COD while aerobic methods can oppose high organic loading wastewater. Various features of anaerobic and aerobic treatment are represented in **Table 3.4** below [32,34,38].

Feature	**Aerobic**	**Anaerobic**
Organic removal efficiency	high	high
Effluent quality	excellent	moderate to poor
Organic loading rate	moderate	high
Sludge production	high	low

Nutrient requirement	high	low
Alkalinity requirement	low	high for certain industrial waste
Energy requirement	high	low to moderate
Temperature sensitivity	low	high
Startup time	2 to 4 weeks	2 to 4 months
Odor	less opportunity for odors	potential odor problems
Bioenergy and nutrient recovery	no	yes
Mode of treatment	total(depending on feedstock characteristics)	essentially pretreatment

Table 3.4 Comparison of aerobic and anaerobic treatment in various criteria [32].

3.16 Tertiary treatment

Adhering the **Figure 3.1,** Tertiary treatment is the next wastewater treatment step that follows the aforementioned secondary treatment. Especially phosphorus reduction for instance is judged as necessary in the case of lakes and rivers where PO4 may lead to eutrophic environments, that is managed by this stage of treatment.

In that stage, the treated quality is improved before it would be reused or deposited into the environment. That implies the removal of inorganic compounds, such as nitrogen and phosphorus, and also every substance remaining even after secondary treatment. Besides, in that stage bacteria, viruses, and parasites damaging to all living species are abolished with various methods such as UV radiation or chlorination that disinfect the final wastewater product by inactivating pathogenic microorganisms. This stage is also chosen for decolorizing.

The description of this procedure is the following:

Firstly, filtration is conducted to alienate the remaining suspended substances. Sand filtration and ultrafiltration are examples of filtration methods. In the case where residual toxins exist activated carbon is necessary to remove every toxicity. A typical method for removing dissolved phosphorus is through precipitation.

The system in this stage consists of two types of chemical treatment, flocculation, and precipitation.

- Coagulation or flocculation is the reaction of the addition of liquid aluminum sulfate and/or polymeric material into the wastewater. The outcome would be the particles to consolidate and attach, creating a sludge that can be removed by the filtrating or settling treatment methods. The flocculation starting point is when neutralized particles begin to collide and fuse to form larger ones, the reaction can be described by equation 5.

The most common coagulants are alum and ferric sulfate.

$$AL_2(SO_4)_3+3Ca(OH)_2 \rightarrow 2\ AL(OH)_3+3CaSO_4 \quad (7)$$

$$Fe_2(SO_4)_3+3Ca(OH)_2 \rightarrow 2Fe(OH)_3+3CaSO_4$$

- Chemical precipitation in wastewater treatment is the conversion of the form dissolved materials in water into particles in solid form. The use of precipitation is to remove ionic constituents from water by the addition of counter-ions to reduce solubility. It is used primarily for the removal of metallic cations, but also for the removal of anions such as fluoride, cyanide, and phosphate, as well as organic molecules such as the precipitation of phenols and aromatic amines by enzymes and detergents and oily emulsions by barium chloride.

The removal of Phosphorus and Nitrogen is not a chemical procedure and is included in the tertiary treatment.

The last stage of tertiary treatment is disinfection. The most common methods are UV light ozone and chlorine. Attention must be paid to avoid the overdose of chlorinated-organic compounds as they can be damaging to living species [39,40,41,42].

4 Energy from industrial wastewater

Wastewater contains a significant amount of chemical, thermal and hydrodynamic energy [58]. Treatment and transport of wastewater currently consume approximately 4% of the total electrical power produced in the US In Europe, WWTPs contribute to approximately 1% of the total electricity consumption in cities

The wastewater treatment plants use anaerobic digestion to generate heat and electricity on-site as aforementioned. During anaerobic digestion, microorganisms break down organic materials from wastewater. The methane gas produced from this process is then used to generate heat and electricity that is used in plant operations [43]. It is a fact that apart from anaerobic technology other methods exist that can lead to energy generation. Specifically, hydrogen production in dark fermentation is a technology that can generate energy. Also, microbial fuel cells can generate energy that can be utilized. More detailed information will be deposited below

4.1 Hydrogen production in dark fermentation

This technology uses fermentation to produce hydrogen by dividing bigger organic substances into smaller ones. This process is based on a synthrophic activity of bacteria that happens under anaerobic circumstances. Acidogenic bacteria are the protagonists in this process. The most important factor to decide whether this method is advantageous or worth to be invested in a food processing industry is the efficiency and the amount of energy production concerning the cost of investment. It is proved that the energy production is dependent on the pretreatment of the mix used for biocatalyst and on the pH during the reaction. Other important factors are the pH of the operation, the characteristics of the wastewater, and also the organic loading rate. The main disadvantage of this method is that the conversion efficiency is characterized as low. Specifically, it is proved that the ratio is 1 to 2 mol of H_2 /mol of glucose, which forms

10-20% removal of the COD and the rest to remain as various volatile fatty acids and solvents, such as acetic acid, ethanol e.t.c. Under optimal conditions that exist hypothetically the remaining organic matter will be 60-70%. The hydrogen production can be improved with enriched acidogenic consortia and by the combination of the methanogenic process immediately after dark fermentation.

4.2 Microbial fuel cells

Biochemical and electrochemical enzymatic reactions are instruments to convert chemical energy into electrical energy. MFC is a reactor that produces electricity from organic matter. Microorganisms such as bacteria, microalgae, fungi e.t.c are participating in a catalytic role to increase the degradation of matter, organic and inorganic Microbial electrochemistry (ME) is based on Faraday and capacitive processes. The mechanisms of ME technologies are direct extracellular electron transfer and mediated extracellular electron transfer, which takes place in the anodic chamber, whereas fewer mechanisms are reported to occur in the cathodic chamber. Protons (H+) and electrons (e−) are generated in the anodic chamber by the oxidation of a microbial biofilm of organic matter. The aforementioned ions are also used in a reaction to create hydrogen and methane also the anodic biofilm creates a catalytic effect in the chamber and performs a forward reaction. Electrons are delivered from the electrogenic biofilm of the anode, and the electrons arrive in the cathode with an electrical circuit externally. Anodic electrons result in the reduction of H2O, hydroxyl ion (OH−), and hydrogen gas (H2) produced by protons in the cathodic chamber. A high rate of anodic electron transfer is dependent on the metabolic processes of the microbes that are utilized, and on their ability to utilize the particular substrates. **Figure 4.1** shows the basic electricity production in an MFC [44].

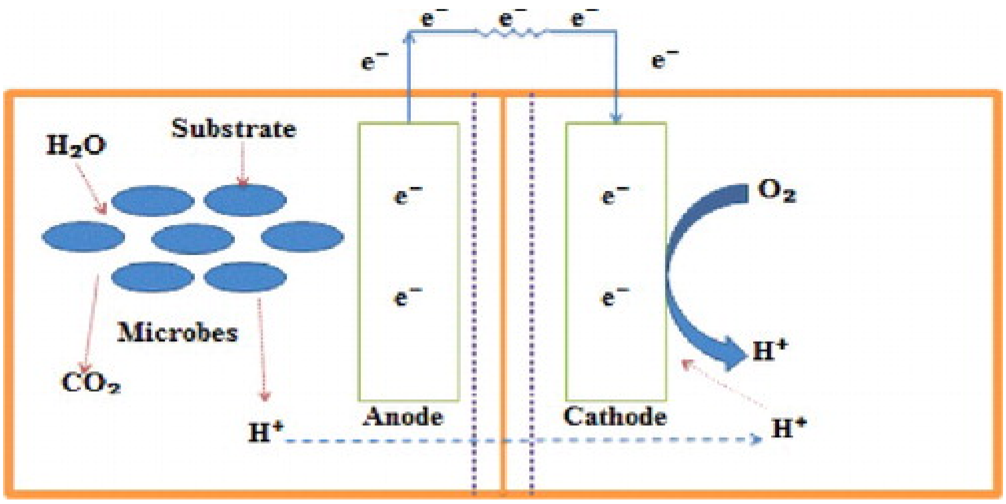


Figure 4.1 Basic scheme of electrical production [44].

4.3 Factors influencing MFCs

The basic factors that effects the MFCs are:

- Anode
- Cathode
- Membrane materials
- pH
- Temperature

Connection of MFCs with energy production from wastewater management

Commonly, while comparing bioelectrochemical systems, MFCs seem to be the most efficient for wastewater treatment. In this system, wastewater acts as a surface for the microbes to grow. MFC is a technology that has gained great interest lastly from scientists and engineers worldwide as the differentiation offered is enough to make the scientific community invest in the research of this method. In addition, the byproducts of this technology can be further utilized. The byproducts can be bioflocculants , bioelectricity, bioplastics, methane, bio-hydrogen, and biosurfactants.

Nowadays, a lot of research is held out as it is clear that various designs are invented leading to different results depending on the wastewater and substrate used. Diffientantion seems to affect the power density, effectiveness of substrates concentration on loading rate, and coulombic efficiency. The MFCs systems show satisfying wastewater removal efficiency, which varies around 71–92% of COD removal. In research where the input waste was acidogenic food wastewater with 5000 mg/L COD achieved to remove 90% of the total waste [44].

The MFCs can be divided into two categories, according to their requirement (or not) of mediator transfer electrons. The mediators are utilized for the enhancement of the electrochemical activity during the process. The most common mediators are methyl viologen, methyl blue, and neutral red with the majority of them being toxic, the use of mediators is characterized as controversial.

In addition, even in laboratory-scale applications of this technology, the results in the terms of productivity and waste degradation are not satisfying. On the other hand, the utilization of air-cathode MFCs arranged in banks that consist of a majority of MFCs are explored for power output improvement [45].

4.4 Microbial electrolysis cells

Although the energy in MFCs is produced in the form of electricity by utilizing the metabolic action of bacteria during the process of decomposition of organic compounds in MECs (microbial electrolysis cell), the aforementioned metabolic activity is reversed to produce methane or hydrogen by using potential difference across the electrodes. The generated electrical energy is applied to enhance the voltage generated by the previous decomposition. The offered electrical energy should be adequate to electrolyze the water for hydrogen generation or methane production by the condition of carbon dioxide reduction [45].

5 Case study

Scope

In this section, a wastewater plant will be designed, the electromechanical equipment will be deposited, the optimized points of the aforementioned equipment will be highlighted and finally two recovery proposals will be presented.
In addition, the section below is about chemical analyses that have been conducted during my internship and is about three different wastewater treatment plants from three different industries. For each industry different parameters from several stages of the treatment are studied, highlighting the most critical measurements for each case . Finally the bibliography of this thesis is congruent with the values of the parameters that have been described through the internship.

5.1 Meat processing Industry

This plant consists of the following stages: equalization, solid removal with the use of DAF and biological process.
In the following table, parameters from a meat processing company are studied in the timeframe of 1 month. Specifically, Chemical Oxygen Demand after the water treatment varies from 27 to 44 mg/L, pH is characterized as slightly alkaline as it values from 7,1 to 7,4. Moreover, the free chlorine of the outlet water is around 0,1 mg/L in this type of wastewater. All the aforementioned values emerge from the measurements that have been conducted during my internship. In addition, according to the laws that are established by the competent authority, each industry must meet some limits for each parameter to ensure the quality of the deposited water after the water treatment. All the values from the parameters that have been measured are in the boundaries that

have been established. In conclusion, wastewater management, in this case, has achieved the target of pureness for the deposited treated water.

Table 5.1 Values of outlet from Meat processing wastewater plant outlet [46].

MEAT PROCESSING INDUSTRY (TREATED OUTLET)			
COD mg/L	TOTAL NITROGEN mg/L	pH	FREE CL OF OUTPUT mg/L
27	4	7,2	0,12
33	2,6	7,1	0,11
44	6	7,4	0,13

5.2 Ice-cream Industry

In this case several stages of the treatment are studied. Firstly, the raw wastewater is measured, concluding that the inlet of the system is characterized heavy in the terms of organic load. This plant consists of the following stages: equalization, solid removal with the use of DAF, and biological process. In addition, the result after the Dissolved air flotation system stage is a removal percentage of 0,59. It is of great importance that in this case this removal percentage is achieved through chemical equalization in the counterpart stage. After this treatment, the permitted limits are not exceeded for the outlet of this wastewater treatment plant. The timeframe of these measurements is one month.

Table 5.2 COD value from each stage of treatment in an ice-cream industry [46].

ICE-CREAM INDUSTRY				
COD INLET mg/L	COD DAF mg/L	COD aeration 1 mg/L	COD aeration 2 mg/L	COD OUTLET mg/L
5685	2300	92	67	12

5.3 Confectionery Industry

In this case, COD and pH before and after treatment are compared. Moreover, a great ratio of COD removal has been achieved after the wastewater management, and the pH ranges from neutral to slightly alkaline values compared with the pH value of the raw wastewater which was acidic. In this case, no limit has been exceeded according to the regulations terms and conditions that have been established by the competent law for this area and this industry.

Table 5.3 COD and pH value from inlet and outlet of a confectionery industry wastewater plant [46].

CONFECTIONERY INDUSTRY			
COD INLET mg/L	Ph INLET	COD OUTLET	pH OUTLET
2002	6,3	53	7,2

5.4 Design of wastewater plant for Dairy industry

In this section of the thesis a new wastewater treatment plant will be designed and the electromechanical equipment will be selected. The main difficulty in this section is to design a plant that can be as applicable as possible for similar new plants. Furthermore, energy recovery methods and utility recovery methods will be applied with a techno-economic study to evaluate the efficiency of this investment respectively.

The case study is about a medium-scale dairy industry with mixed dairy products. Collecting all the mandatory data is very important to design, select and establish suitable equipment. The most critical designing data that must be taken into serious consideration are the following:

Critical Designing data

Max Flow rate: 1100 m^3/h
Average flow rate: 1000 m^3/h
Average BOD_5 : 630 mg/L

After the consideration of those parameters the most suitable methods and technologies for wastewater treatment of this dairy industry wastewater must be selected, always contemplated with the bibliography that is deposited above.

Also, the most critical factor that must be highlighted is the measured parameters of the output water must be under the boundaries that are established by the law according to the area and other conditions. Finally the designing plan should comply with higher designing data than the aforementioned to achieve accomplishment of the treatment properly in every case. Following the most common regulations and limitations for industrial areas that have a river as a receiving point for the outlet treated water in Athens the following stages are formed.

In **Figure 5.1** the selected treatment stages are presented.

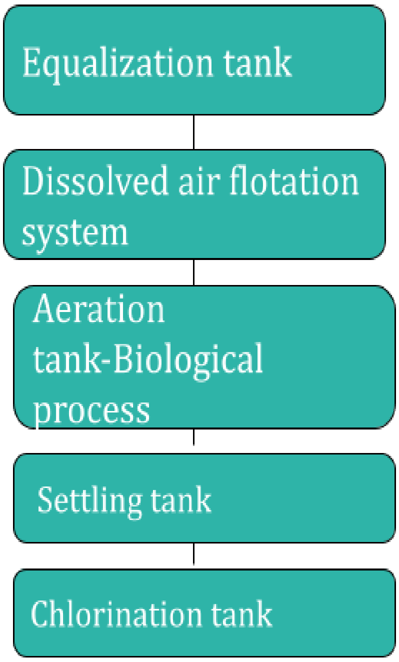


Figure 5.1 Stages of the Designed wastewater plant.

After all the aforementioned procedures the redundant sludge will be pressed through a press filter machine. In **Figure 5.2** a common belt filter press machine is illustrated. With this technology, the remaining sludge will be pressed and removed by the tank.

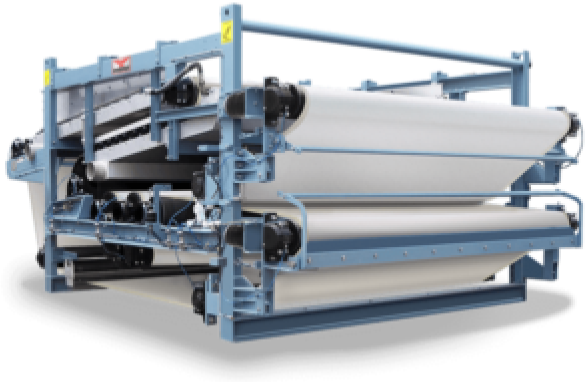


Figure 5.2 Belt Filter press machine Illustration [49].

5.5 PARAMETERS CALCULATION OF THE NEW WASTEWATER TREATMENT PLANT

It is widely known that every industry has to comply with the terms, conditions, and regulations that are foreseen by the law. Depending on many criteria such as the location of the industry and the possible receiving waters of the treated liquid, there are formed public documents that include all the conditions and terms that every wastewater treatment plant must follow.

In this case study, all the parameters will be determined with the most usual limits and obligations about the outlet-treated water in the context that was already described.

It is of great importance to calculate all the parameters that affect the operation of the wastewater treatment plant and to optimize the design of the new wastewater plant. Afterward, the electromechanical equipment that would be utilized must be formed. In the following table, the mandatory parameters are presented.

All the calculation is made under the consideration that the production may increase and be adequate in the case of malfunction.

VOLUME	QD	BOD5	MLSS	F	T	F/V	F/M	DSR	SRT	AIR EQ1.	AIR EQ2
ACTIVE VOLUME IN AERATION TANK (M3)	DAILY VOLUMETRIC PROVISION	CONCENTRATION IN THE INLET OF AERATION TANK	MLSS BIOLOGICAL PROCESS	DAILY LOADING	HYDRAULIC RESIDENCE TIME	FOOD TO VOLUME	FOOD TO MASS	DAILY SLUDGE PRODUCTION	SLUDGE RESIDENCE TIME	VOLUMETRIC AIR REQUIREMENT PER HOUR	VOLUMETRIC AIR REQUIREMENT PER HOUR
(M3)	(M3/DAY)	(MG/L)	(MG/L)	(KG BOD5 /DAY)	(D)	(KG BOD5/M3 AERATION TANK*DAY)	(KG BOD5/ KG MLSS * DAY)	KG MLSS /DAY	(D)	(M3/HR)	(M3/HR)
1920	1100	600	4100	660	1.75	0.34	0.084	264	29.818	3300	3318.4

Table 5.2 Parameters calculation of the designed wastewater treatment plant [46,47,48].

It is clarified that the oxygen content in the atmospheric air is 21% and the special weight of air is 1,23 kg/m^3, those values are used for the calculation of the parameters described above. In addition, there have been made the following assumptions:

the BOD5 Removal	82	%	
Sludge production efficiency	0.4	kg MLSS/kg BOD	
Hours of blower operation	20	hr/day	
Air requirement	100.0	m3 air/kg BOD	
O2 Requirement	2.0	kg O2/kg BOD	
Dispersion efficiency	0.07		(fine bubble diffuser)

Clearly, the calculated parameters are tested in extreme conditions to be adequate and applied in every unpredictable situation. For instance, differentiation in the operation of the blowers or a possible malfunction in the industry that leads to high BOD5 concentration in the inlet of the plant can be confronted. Denitrification will be achieved in the aeration stage.

5.6 Basic Electromechanical equipment of the plant

Aiming to apply recovery in energy and utilities for the plant, it is essential to form the available equipment to decide the efficiency of every recovery. The power of each electromechanical equipment is mandatory. Every piece of equipment in the first column is representative of a real application.

In **Table 5.4** the electromechanical equipment of the new wastewater plant in the dairy industry will be described. The first column is the name of the equipment, the second column is the number of units for each part and the last two columns are the power and total power in kW for every piece of equipment [46,47,48].

Table 5.3 Electrochemical equipment of the designed wastewater treatment plant [46,47,48].

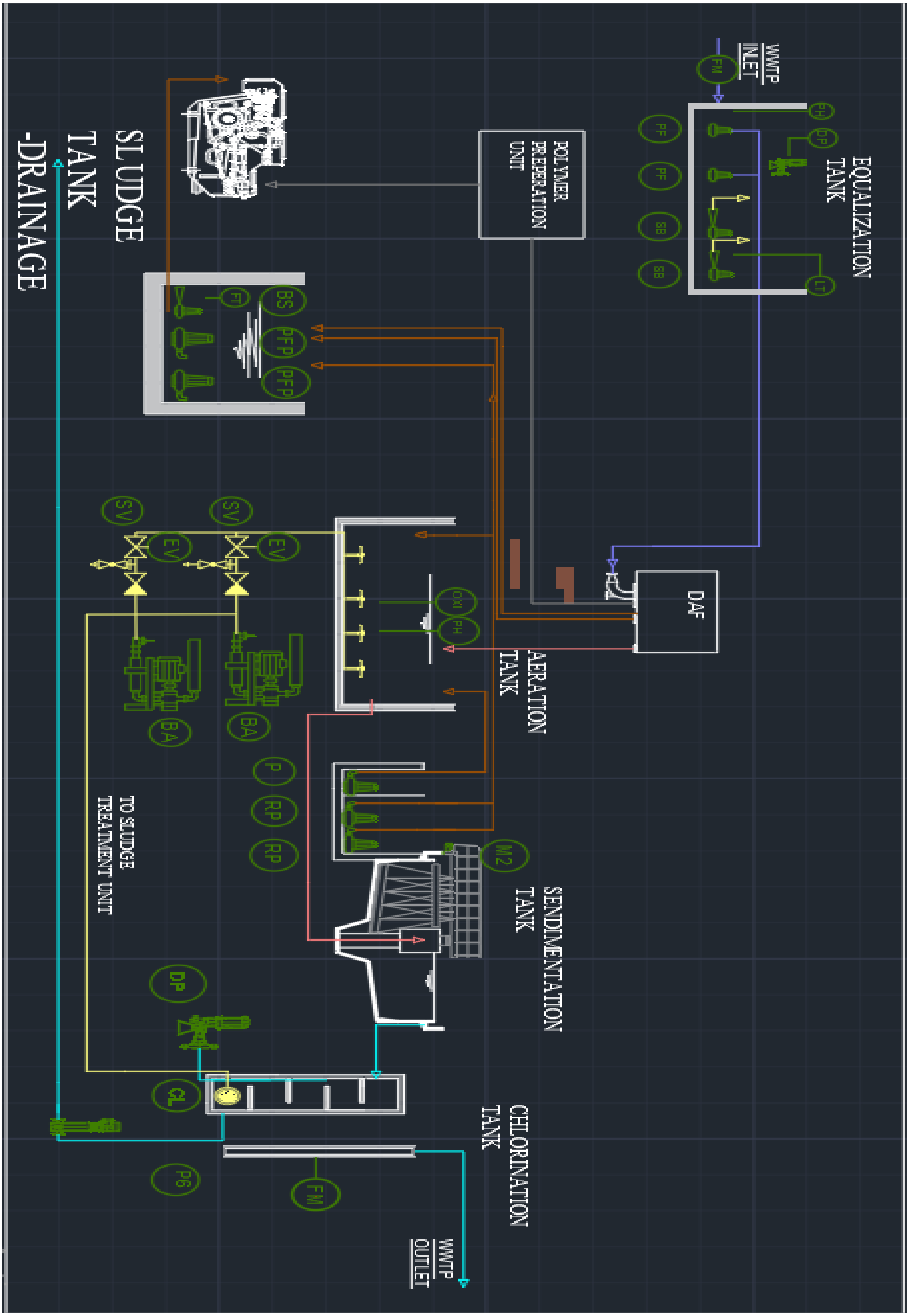
A/A	EQUIPMENT	UNIT	POWER (kW)	TOTAL POWER (kW)
	EQUALIZATION TANK			
SB	SUBMERSIBLE BLOWER	2	5.9	11.8
FM	INLET FLOW METER	1		
LT	LEVEL TRANSMITTER	1		
PF	FEEDING PUMPS	2	4	8
DP	DOSE PUMP FOR CHEMICALS OF EQUALIZATION	2	0,1	0,2
PH	pH METER	1		
	ELECTROMECHANICAL EQUIPMENT OF DAF			20.58
	AERATION TANK			
BA	BLOWERS	2	27.28/1000 m^3	
	VENTILATORS FOR BLOWERS	2		
EV	BLOWER ELECTROVALVE	2		
SV	SAFETY VALVE	2		
PH	pH METER	1		
OXI	OXYGENE METER	1		
	SENTIMENTATION TANK			
M	MOTOR OF SENTIMENTATION TANK	1	0.37	0.37
RP	RECIRCULATION PUMP	2	3.5	7
P	PUMP FOR FLOATING MATTER IN SENTIMENTATION	1	0.55	0.55
	CHLORINATION TANK			
DP	DOSE PUMP FOR CL	1	0.1	0.1
FM	OUTLET FLOW METER	1		
CL	FREE CLORIUM SENSOR AND INSTRUMENT	1		
	DEHYDRATION			
PFP	PRESS FILTER PUMP	2	4	8
PFP	PRESS FILTER	1	0.55	0.55
	SLUDGE STORAGE-DRAINAGE			
BS	BLOWER FOR SLUDGE STORAGE	1	5,9	5,9
FT	FLOW TRANSMITTER	1		

Another part of the wastewater treatment plant is the production of the flocculation that feeds the filter press machine and also the dissolved air flotation system with polyelectrolyte. A completed polyelectrolyte production plant consists of several machines and devices. Firstly, an agitator is mandatory to achieve a full mixture of polyelectrolyte which is in the form of small granules and water. Secondly, two pumps are crucial to exist, for 100% redundancy with the addition of electrovalves to automate the system. Also, a flow transmitter and flow meter must be included to have full control of the polyelectrolyte production and to prevent all possible events.

An illustration in AutoCAD for the designed plant will be presented in **Drawing 5.1** below, the electromechanical equipment is shown in the appropriate position for operation and all the needed pipes are highlighted with representative colors according to the context of each case. More specifically, purple stands for raw effluent, brown is the sludge, pink for the water under treatment, blue is treated water, and yellow is the pipes that have air. This drawing does not include valves and pipe fittings to apply to other case studies always with the adjustment of all parameters.

The aforementioned equipment is calculated to have 100% redundancy in the most essential parts to accomplish the unstoppable operation of the plant.

It is clarified that every part of the wastewater treatment plant should be included in the automation. Automation is crucial and it is an irremovable part of the design plan, to have the optimized use of the electromechanical equipment. The reason behind this strong policy in the design is the fact that the parts are interconnected and affected by one another. For instance, while the oxygen meter reaches a value that is above the set limit, the blower should close for energy saving, non-aimlessly equipment usage, and more satisfying operation. In addition, while a part malfunctions automation with the help of an operator must solve the problem through the replacement of the part with the spare. It is deemed necessary for each part of the plant to be remotely controlled to achieve cooperation of the electromechanical equipment and to always be notified of unpredictable events. With the installation of the pumps, it is essential to add inverters to the most crucial equipment such as feeding pumps of the equalization and blowers.


WWTP INLET
FM
EQUALIZATION TANK
PH
DP
PF
PF
SB
SB
LT
POLYMER PREPERATION UNIT
DAF
SLUDGE TANK -DRAINAGE
BS
PFP
PFP
FT
AERATION TANK
OXI
PH
SV
SV
EV
EV
BA
BA
P
RP
RP
M2
SENDIMENTATION TANK
TO SLUDGE TREATMENT UNIT
DP
CL
CHLORINATION TANK
P6
FM
WWTP OUTLET

Drawing 5.1 Representation of the designed plant in AutoCAD [46,47,48].

5.7 Recovery technologies of the designed wastewater treatment plant

Nowadays where the energy cost and unavoidably the utilities cost are increasing exponentially, recoveries in every part of a production plant are critical. The question that must be studied is whether the particular recovery is considerable enough and is strongly efficient in a logical period.

In this stage of the thesis, recovery methods for energy and utility saving will be presented by the use of two different technologies. Their techno-economic cost will be calculated and finally, the time for depreciation will be determined. The first recovery technology is a pump that is capable of feeding the press filter line for washing and other procedures during the press filter stage. The second recovery technology is a vortex turbine that can generate energy for the wastewater treatment plant.

5.7.1 Treated water utilization for the procedures of filter press machines

It is widely known that every industry has to comply with the terms, conditions, and all the regulations that are foreseen by the law. With the aforementioned considered, in this case study, the designed plant will provide the receiving waters with outlet water that can be utilized for the benefit of the plant.

Although this case study, cannot provide admissible treated water to be enforced in the industrial water, this outlet water can be used to wash the filter press machine and to avoid using pure water for this mandatory procedure of the plant operation.

The implementation of this recovery technology should begin with the selection of a suitable pump that will lead the treated water from the outlet of the plant to the water line of the filter press.

For this purpose, the most appropriate pump would be a single-head, multistage centrifugal pump that can transfer the treated water to the destination which is the filter press. It is of great importance for this technology to be embedded in the automation of the plant, as to be used in the most suitable hours according to the operation program and being offline in the hours that this flow from the treated water will be needed for the recovery technology that will be presented below.
A more detailed review of the selected pump will be provided in **Figures 5.3** and **Figure 5.4.**

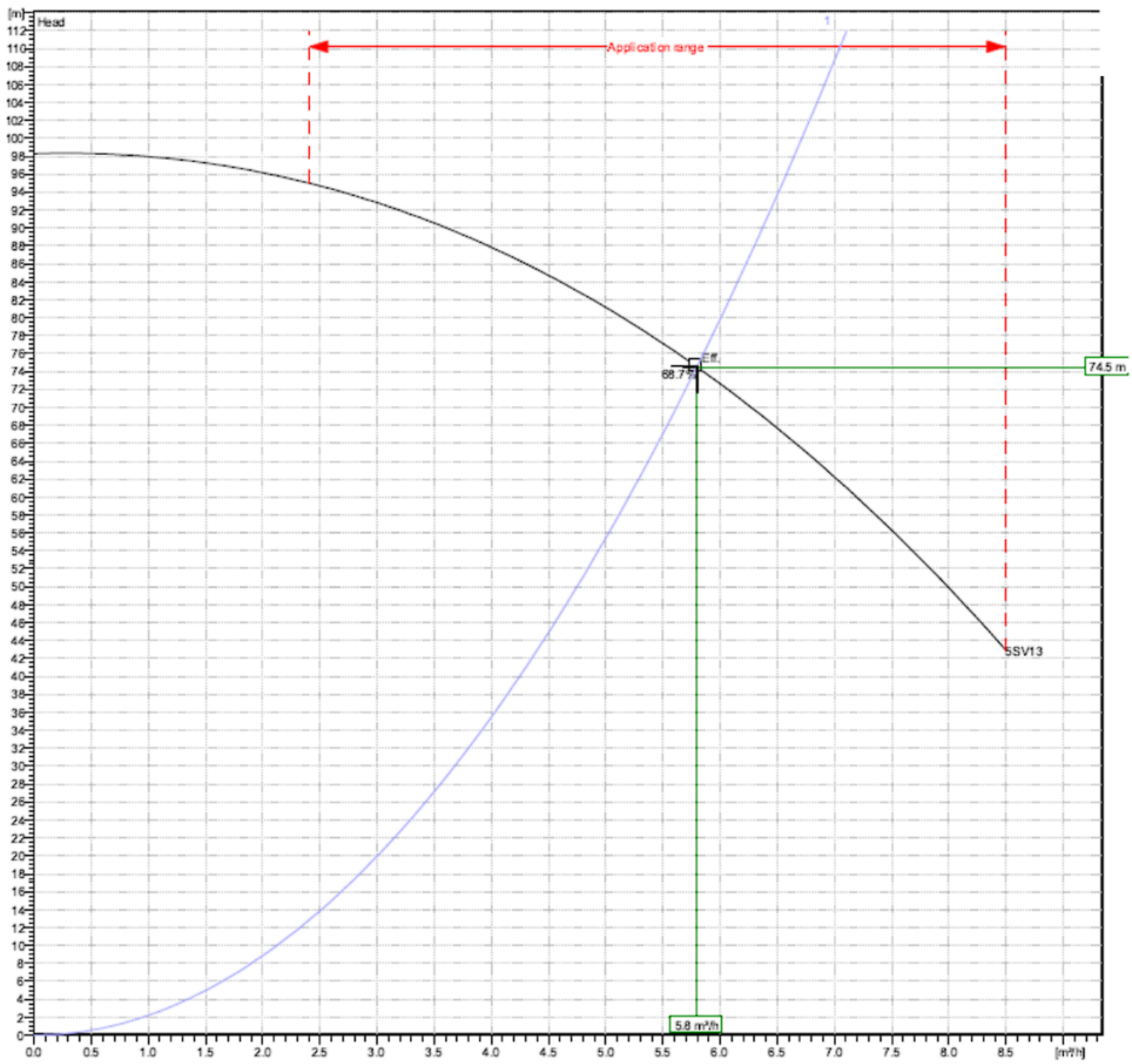


Figure 5.3 Performance of the selected pump [50].

In **Figure 5.3** the Best Efficient Point sets the flow of 5,8 m^3/h in the head of 74,5 m. In that case, this pump can be used in a considerable distance. There is no restricability for a variety of wastewater treatment plants. In **Figure 5.4**, appears a representative drawing for a pump with these characteristics.

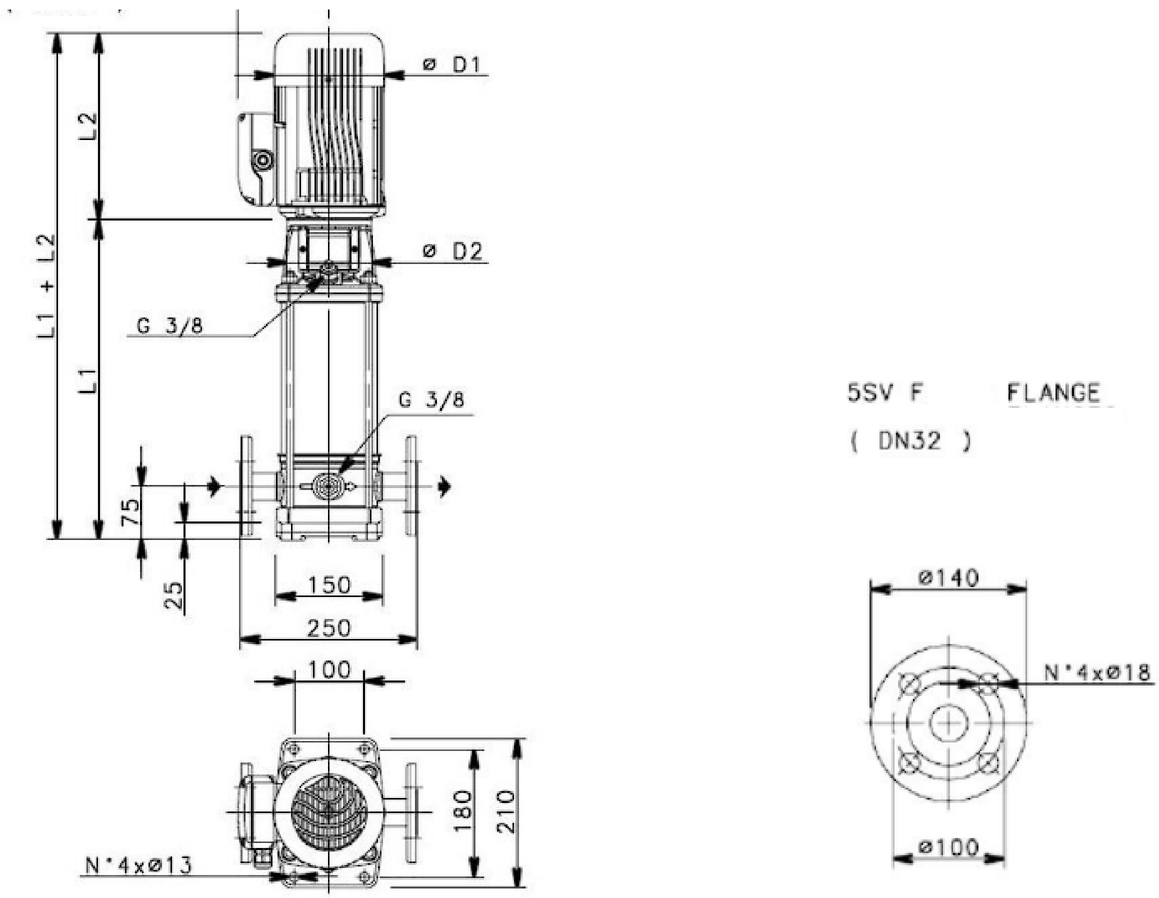


Figure 5.4 Drawing of the selected pump [71].

5.7.2 Techno-Economic analysis for this recovery

In this section, the cost of this investment will be calculated, pipe fittings, and the cost of pipes will not be included as this investment can be applicable in several plants with several diffirentations in their pipe equipment . The installation of this pump would cost 1750 approximately. Five years is the timeframe, the first two years the warranty is activated and for the next three years, a pessimistic case for the possible cost is shown in **Table 5.4**.

Cost	Power	Price
Single-headed, multistage, centrifugal pump	1,8 kW	1750 Euros
Possible malfunction		250 Euros

Table 5.4 Cost of the investment [50,51]

It is a fact that a possible malfunction is not realistic for a new pump, but this “pessimistic scenario “ for this investigation must result in efficiency in every case.
Considering as a fact the timeframe of 5 years, in **Table 5.5**, the cost for 5 years of conventional washing procedure is presented. Two different cases are examined, the “pessimistic” one for this investment and the realistic scenario, leading to a more representative view of the cost. It is clarified that all the cost data are calculated by the price list of the official water provider, always adjusted in the specifications of this application, for this cost calculation only the extra costs that are mandatory for this procedure are included to have a more realistic cost computation. All the cost calculation is presented in the following table. The fact that the press filter machine can not work every day is taken into consideration [52].

Table 5.5 Cost without the investment [52,53]

The conventional way of washing the press filter machine										
Type of cost	**Cost per year**									
	PESSIMISTIC SCENARIO					REALISTIC SCENARIO				
	1st YEAR	2nd YEA R	3rd YEAR	4th YEAR	5th YEAR	1st YEAR	2nd YEAR	3rd YEAR	4th YEAR	5th YEAR
Consuming cost for Industries (Euro/m^3)	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Hours of water utilization for this purpose/ year	182	182	182	182	182	364	364	364	364	364
Approximately cubic meters essential for the procedure	5	5	5	5	5	6	6	6	6	6
Total costs per year	**891.8**	**891.8**	**891.8**	**891.8**	**891.8**	**2140.3**	**2140.32**	**2140.3**	**2140.3**	**2140.3**
Total cost	Pessimistic scenario	4459				Realistic scenario	10701.6			

5.7.3 Present value method-PW

Present value method is a widely known method to calculate the efficiency of a method and to make the decision for a techno economic study. Net cash flows of the future are predicted. It is of great importance for an investment to depreciate quickly as the more the years pass the more the net cash flows cannot be predicted.
The equation of PW is the following:

$$PW = \sum_{n=1}^{N} (B - C)/(1 + i)^{n} - Co$$

Where :

Co: Is the initial investment cost
B-C is the yearly net benefit
N: time of investment
i: Minimum efficiency grade

If the PW>0, the investment is profitable, if the PW=0 the investment is characterized as neutral which means that it won't be costly to invest but it won't give capital back. Unfortunately, if the PW<0 the investment must not be completed.
It is clarified that the Minimum efficiency grade is unclear and is affected by the investor. For this case study, several values of i are tested for the "pessimistic" and the realistic scenario and are deposited in **Figure 5.5.a** and **Figure 5.5.b**. The values that form the Figures and the selected i values are **Table 5.6.a** and **Table 5.6.b** respectively.

Table 5.6.a Chart for the Values of Figure 5.5.a

`	Value of i			
	i 0.01	**i 0.04**	**i 0.2**	**i 0.4**
Y 0	-1750	-1750	-1750	-1750
Y 1	-867.0	-892.5	-1006.8	-1113
Y 2	7.2	-67.9	-387.5	-658
Y 3	872.7	724.8	128.5	-333
Y 4	1729.7	1487.1	558.6	-100.8
Y 5	2340.4	2014.6	816.5	18.4

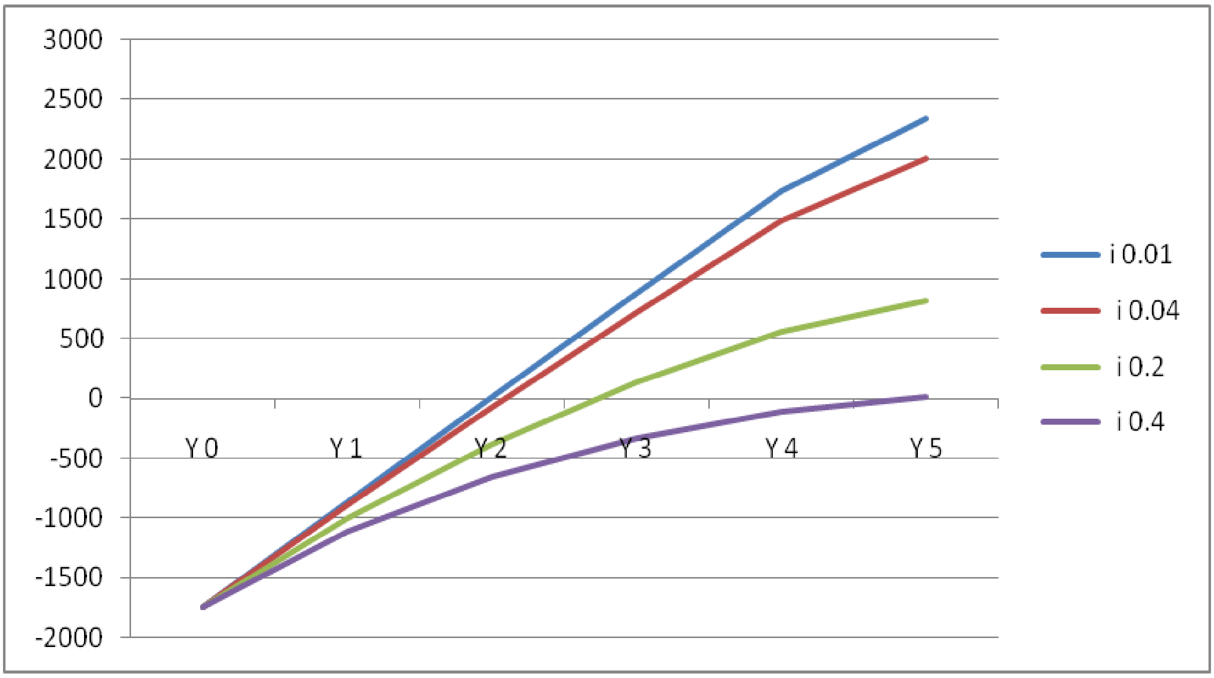


Figure 5.5.a Net cash flows for several values of i "pessimistic" scenario.

All the tables and charts are made by tools of Microsoft Excel.

Table 5.6.b Chart for the Values of Values of Figure 5.5.b

	Value of i			
	i 0.01	**i 0.04**	**i 0.2**	**i 0.4**
Y 0	-1750	-1750	-1750	-1750
Y 1	369.1	308	33.6	-221.2
Y 2	2467.2	2286.8	1519.9	870.8
Y 3	4544.6	4189.5	2758.5	1650.8
Y 4	6601.4	6019.1	3790.7	2207.9
Y 5	8400	7572.8	4550.3	2559.4

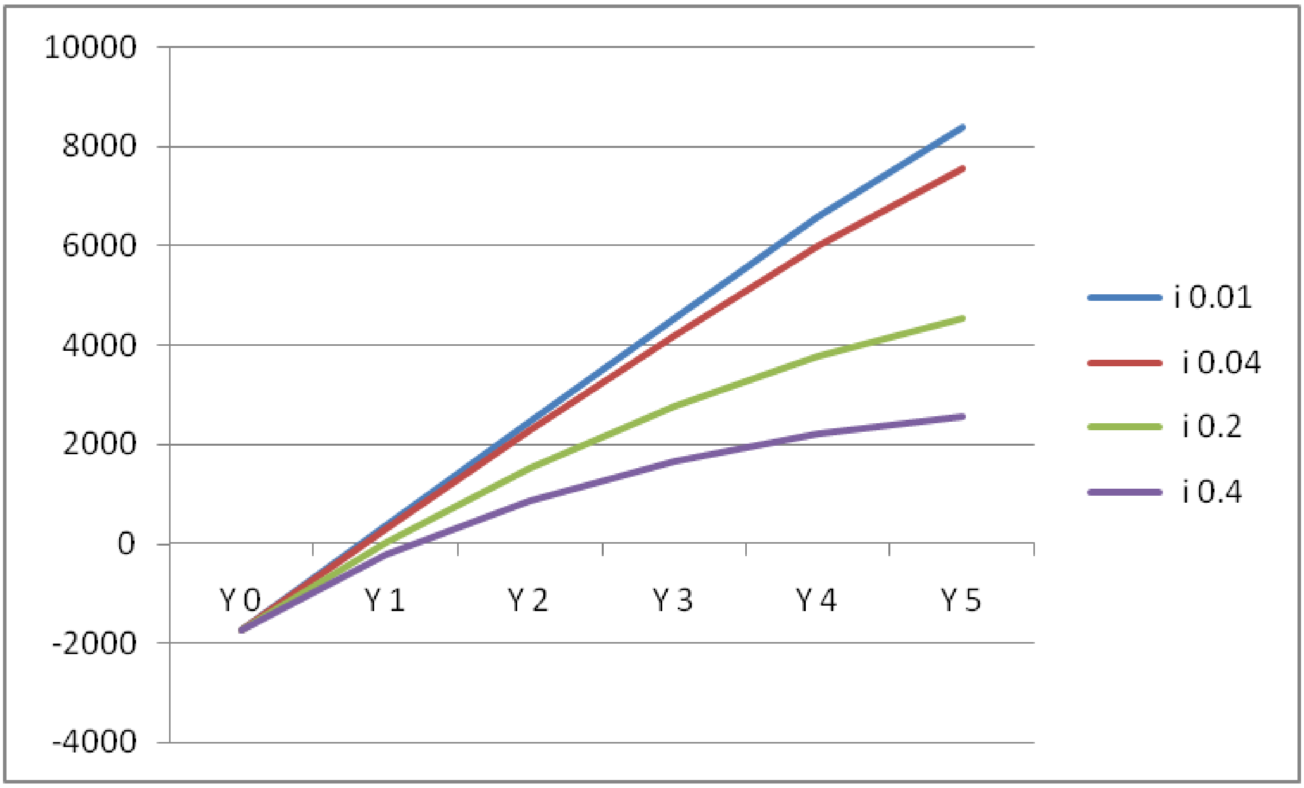


Figure 5.5.a Net cash flows for several values of i realistic scenario realistic scenario.

The realistic scenario is even more encouraging as up to the end of year 1 all the cases are depreciated. In conclusion, it is proved that this investment is beneficial in the timeframe that has been selected.

5.7.4 Internal rate of return-IRR

Utilization of this method helps with the evaluation of the investment as we calculate the i that can zero the present value. In addition, we contrast the value that the investor needs with our calculated i, to conclude whether it is efficient or not.
The syllogism is the following:

- PW=0
- $\sum_{n=1}^{N}(B - C)/(1 + i)^{n} - Co = 0$

All the needed data are shown above, with the help of the Internal rate of return function of excel, 40,64 % in the resulting percentage for the "pessimistic" scenario and 15,02% is the IRR percentage for the realistic scenario. According to the bibliography, if this percentage is higher than the established percentage that is set by the investment team it is characterized as a profitable investment [54,55].

5.7.5 Payback Time

The "pessimistic scenario" shows that the depreciation of the investment will be completed during year 1 when it is up to 0.04 and in year two for i 0.2 and in year 4 when i is 0.4. The realistic scenario is even more encouraging as up to the end of year 1 all the cases are depreciated. In conclusion, it is proved that this investment is beneficial in the timeframe that has been selected in each case. The investor will decide the optimal i but it is clear that as long as the i that has been calculated from the Internal rate of return is higher than the i that is given the investment is beneficial.

5.8.1 Generate power by the exploitation of the wastewater treatment plant flow

The outlet flow of the case study is adequate to be further advantageous in hydrodynamic terms. Specifically, with the intense flow of 40 cubic meters per hour, it is proved that with a vortex turbine technology, up to 15 kW can be generated as long as this vortex turbine is rotating optimally. For a more concrete explanation of this technology in **Figure 5.6** a brief representation of the most important parts of the turbine is deposited.

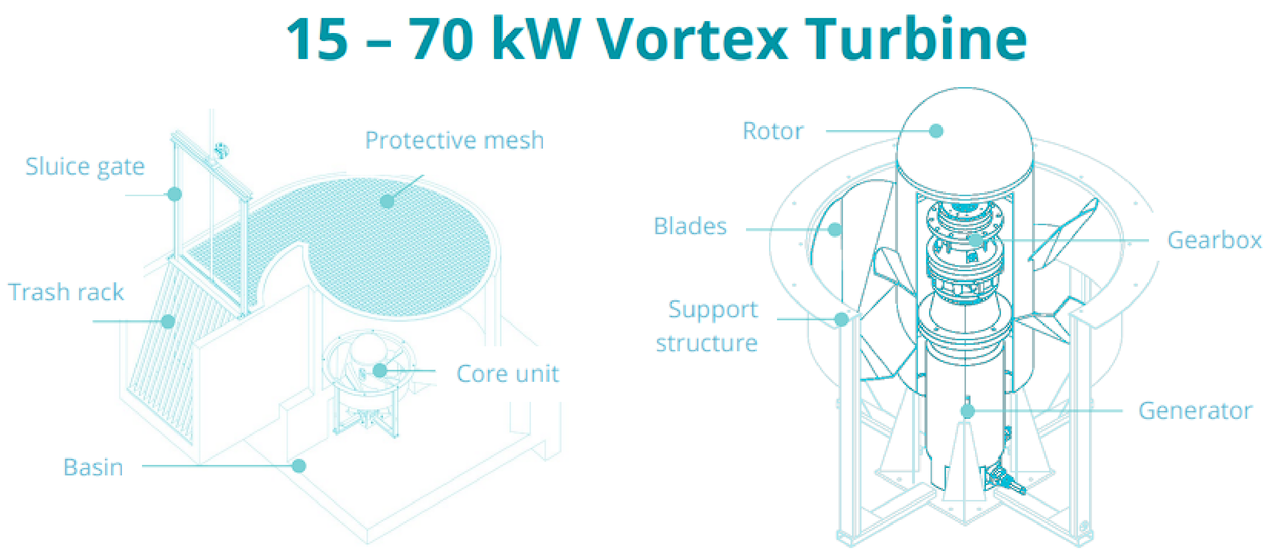
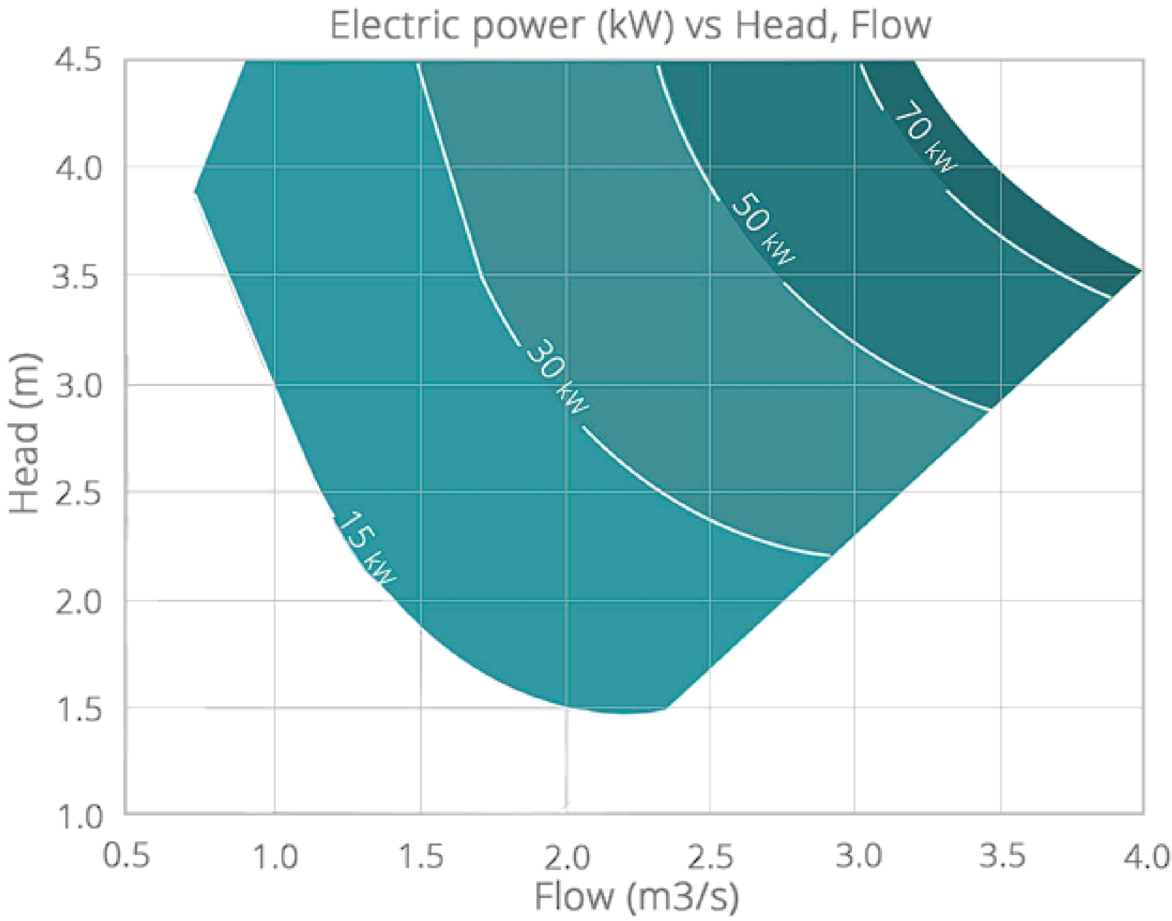


Figure 5.6 Brief representation of Vortex Turbine 15kW [56]

The outlet water will flow from the trash rack while the sluice gate is open, this will cause the water to rotate the vortex turbine, and with this kinetic energy, the power will be generated.

In The **Figure 5.7** the operation diagram of the Vortex Turbine is described.



For the flow of this case study, 15kW can be generated in the head of 4 meters. Clearly, for other wastewater treatment plants with even more flow per hour this vortex turbine technology can give up to 70kW of power.

5.8.1 Techno-Economic study for Vortex turbine technology

Nowadays regarding the economic and energy crisis, the energy costs are unstable, and it is of great importance for an investment to pay back in a short time. For this study, a timeframe of 3 years is chosen. The cost for commissioning the turbine at first is equal to Co, the price cannot be an exact amount of money as it is affected by the turbine provider and it can range. The assumption that is made is that the original energy provider will discount the generated energy at the same price as the selling price. In addition, the selling price of the electricity is approximately 0.058 euro/kWh approximately, always depending on the provider and the selling price according to the industry consuming.

5.7.2 Present value method-PW

For the calculation of present value, the Internal rate of return and payback time, 10500 euros is the set price of the initial capital for this investment. In addition, the cost of maintenance is formed with the use of the table below. The table presents the maintenance program of a 15kW Vortex turbine [56].

Table 5.7 Maintenance of Vortex Turbine [56,57]

Maintenance item	Maintenance interval
Gearbox oil change	After every 6 months
Retightening all bolts	Once every year
Generator visual check	Once every year
Replacement of seals	After every 2 years
Re-greasing of gearbox bearings	After every 2 years
Electrical controls check	After every 2 years
Replacement of bearings	After every 3 years

The maintenance cost for the first three years is approximately 4199,8 euros, always adjusted to the maintenance cost of the turbine provider. For the aforementioned Co, present value for several i percentages is formed in the **Table 5.8.** and the relating chart in **Figure 5.8** .

	Yr 0	Yr 1	Yr 2	Yr 3
0,01	-10500	-5761,7	-1560,5	2307,8
0,02	-10500	-5808,2	-1689	2066,7
0,05	-10500	-5942,2	-2055,0	1387,8
0,1	-10500	-6149,4	-2607,5	386,8

Table 5.8 Present value for several values of i.

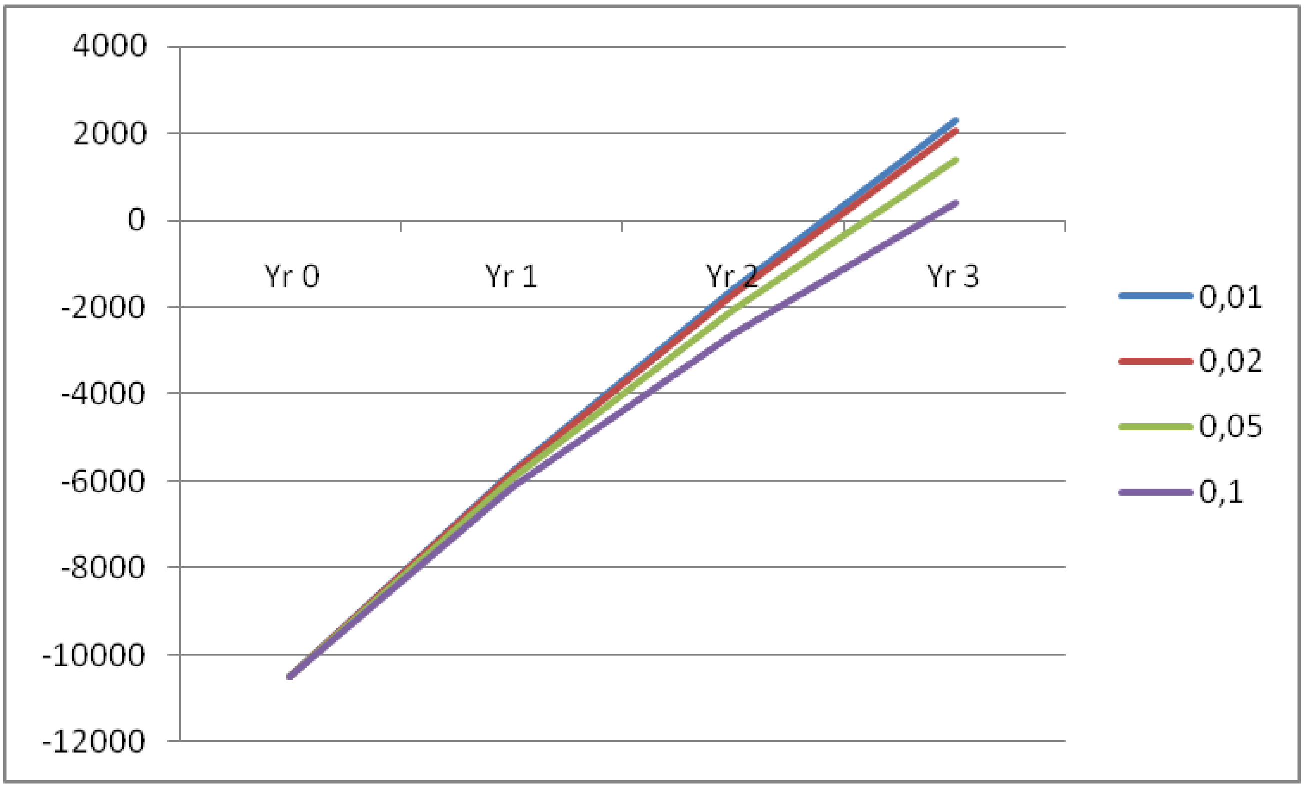


Figure 5.8 Schematic representation of present value.

It is proved that in the selected timeframe for several values of i, the investment is profitable, even though there is a high maintenance cost.

5.8.3 Internal rate of return-IRR

The syllogism is the following:

- PW=0

$$\sum_{n=1}^{N} (B - C)/(1 + i)^n - Co = 0$$

In this case where the assumption of Co is equal to 10500, the value of IRR is 12,15%. Every investment that has i percentage that is less than the value of IRR will be efficient.

5.8.2 Payback time

In every case the payback time will not exceed the three year timeframe, which is acceptable according to the facts that are proposed above. The timeframe of three years is safe as the energy cost and value of electricity are constantly increasing.

5.8.3 Generated energy usage

The 15kW of generated energy is a significant amount of energy that should be utilized for the benefit of wastewater plant or even better for every benefit of the industry. It is of great importance to be utilized in a way that no energy would be wasted. With the aforementioned being considered, the most optimal usage is to be deposited in the electricity supplier with the agreement of a discount in the class of 15kW for the estimated time of supplement. The estimated working time of the vortex turbine is stable in general, the only way that the turbine will not rotate is while the centrifugal, multistage pump is working because the flow will not be enough for the vortex turbine to work.

6. Conclusions

Nowadays the environmental impact of the food industry is important. In addition, it is proved that a high percentage of the food in the Western world that has been through the process is not consumed completely, while the food for all humanity is not enough. In the terms of liquid effluent, it is mandatory to develop technologies and methods for treating this wastewater most efficiently. Clearly, in recent years these technologies and methods are being invented and even optimized at a satisfying rate.

The design of a new wastewater treatment plant is essential but also a demanding project. All the parameters must be taken into serious consideration but mostly the result that will exist in the outlet must not exceed the legal limits and boundaries of the law.

On the other hand, energy and utilities are precious commodities nowadays but mostly the last months are exponentially costly. It is deemed necessary to evolve methods and technologies to recover this consumed energy and utility.

The utility recovery that is presented in this thesis is proved to be efficient in a short time even in the "pessimistic scenario", making this investment applicable and essential for the recovery of the used water.

The energy recovery investment in the timeframe of 3 years is classified as efficient, based on the present value and internal rate of return.

Finally, the proposed optimizations are a certain amount of the overall improvements that can be established.

6.2 Future work

The future of wastewater treatment is always under development, as is a sector that can always be further optimized.

On the other hand, anaerobic treatment is widely applied nowadays and it would be very important to further investigate a techno-economic study for this investment in the Food Industry and even contrast the anaerobic designed plant with the aerobic plant in the terms of investment cost and recoveries of energy and utilities that can be provided in each case. While this comparison is studied the energy that can be generated from the anaerobic plant must be also calculated.

In addition, other recoveries in an aerobic wastewater treatment plant must be examined as the energy crisis is characterized as a gigantic problem nowadays.

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