

	PROPOSAL FOR A WASTEWATER TREATMENT PLANTS (WWTP), WITH SUSTAINABLE AND AUTOMATED ENERGY DESIGN FOR MARGINALIZED AREAS	Energetic technology
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PROPOSAL FOR A WASTEWATER TREATMENT PLANTS (WWTP), WITH SUSTAINABLE AND AUTOMATED ENERGY DESIGN FOR MARGINALIZED AREAS

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ABSTRACT:

Water scarcity and the lack of treatment systems for regeneration and discharge have an alternative design of wastewater treatment plants, WWTP. In this context, it is explored to integrate photovoltaic energy and a web system for automation and control according to Mexican official standards. For this, a model of WWTP is proposed, the photovoltaic system with solar panels, and the use of a web system that uses a PHP programming language with javascript input and output management embedded to HTML. This model for its simple design conditions with optimal orientation makes the project ideal for three or six-year periods for remote communities such as the area of Chilon, Mexico.

Keywords: WWTP, Solar Panels, Automated, Web Systems.

RESUMEN:

La escasez de agua y la falta de sistemas de tratamiento para la regeneración y descarga tienen una alternativa de diseño de plantas de tratamiento de agua residual, PTAR. En este contexto, se explora integrar energía fotovoltaica y un sistema web para la automatización y el control de acuerdo con las normas oficiales mexicanas. Para ello, se propone un modelo de PTAR, el sistema fotovoltaico con paneles solares, y el uso de un sistema web que utiliza un lenguaje de programación PHP con administración de entrada y salida javascript embebido a HTML. Este modelo por sus condiciones de diseño simple con óptima orientación hace del proyecto el ideal para periodos trienal o sexenal para comunidades alejadas tal como la zona de Chilón, México.

Palabras clave: PTAR, Paneles solares, sistemas web, automatizado

1. - INTRODUCTION

Water pollution, one of the main current problems, directly compromises water supply sources and generates shortages for the population. In Mexico, raw and treated water is discharged through canals, open valleys, and aquifer recharge zones that pass through agricultural lands [1]. This is an opportunity for the construction of wastewater treatment plants, WWTPs, which are important for the care of the environment and the health of the inhabitants [2]. WWTPs are considered the main consumers of energy, 70% of the consumption is associated with the production, use, and materials for their maintenance [3]; a disadvantage for WWTP builders in addressing the problem of water pollution [4], is the investment in terms of financing costs, which is not a viable scenario for a developing country like Mexico. Federal financing programs for drinking water and sanitation projects in urban and rural communities are limited, giving priority to drinking water supply programs and increasing sewerage system connections, where such financing is governed by federal construction and operation laws [5]. In the last decade several construction projects mostly based on cooperative evaluation methodologies [6], combined WWTP/PVWWTP [7], and sometimes monitored PV systems [8]. The objective of this work was to design a treatment plant model with photovoltaic solar panels automated through an integrated web system, WWTP-PV-WebA for wastewater treatment operations and treated discharges applying the Mexican Official Standard for discharge control, this will minimize the impact of pollution in the water bodies of Chilón [9].

2. - METHODOLOGY

2.1. Initial parameters for the design of the WWTP

2.1.1. Discharge volume

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Table 2.1 shows the wastewater discharge data from households obtained from the quantity in liters of water discharged from the dwellings. Since there is no connection to the discharge network, the surface conditions were taken into account: the slope of the terrain, unevenness, and soil characteristics, according to the National Water Commission [5]. Based on two measurements of water tanks considering 34 toilets of 8 L and 16 L with different diameters of direct discharge to the receiving water bodies. [10]. A safety factor of 1.2 was used to calculate the wastewater flow (Q) (see Equation 2.1) and the flow rate (Q_f) (Equation 2.2) [11,12]:

$$Q = (\text{No. of habitants})(\text{Discharge L/habitant})/(3785000) \quad (2.1)$$

$$Q_f = Q(\text{factor } 1.2) \quad (2.2)$$

Q y Q_f en MGD (Millions of gallons per day)

Diameter (cm)	Section	Toilets (L)			
		8 16		8 16	
		Contribution per download		Minimum sewage water expense	
		(L/s)			
20	1	1.0	1.5	1.0	1.5
25	1	1.0	1.5	1.0	1.5
30	2	1.0	1.5	2.0	3.0
38	2	1.0	1.5	2.0	3.0
46	3	1.0	1.5	3.0	4.5
61	5	1.0	1.5	5.0	7.5
76	8	1.0	1.5	8.0	12.0
91	12	1.0	1.5	12.0	18.0

Table 2.1. Measurements of domestic wastewater discharge from 8L and 16L toilets [5].

2.2. Design of the Wastewater Treatment Plant (WWTP)

2.2.1. Design of the WWTP

It was taken from the existing population of 137,262 inhabitants in Chilón [9]. Due to the population size, housing distribution, lack of infrastructure, and lack of previous planning, a WWTP that could cover the treatment requirements for the size of the entire population was discarded. It was decided to estimate a population of 2,000 inhabitants (less than that mentioned in [1]) with a typical water consumption of 300 L/person (greater than 124 L/habitant [2]), and a discharge flow rate of 0.1548 MGD.

2.2.2. Design Criteria

The design criteria were based on wastewater composition, oxygen requirements, shape and dimensions of the aeration tank, size of the blower, power required to obtain treated water in a condition to be discharged back to the receiving body [11]. The feed/microorganism ratio (F/M) was considered for the extended aeration settler requirements with a range of 0.05 to 0.15 Lb BOD /day/Lb/SSL₅ M; the reactor mixed liquor suspended solids (MLSS) concentration with a range of 2,000 to 8,000 mg/L; the estimated mixed liquor volatile suspended solids concentration (MLVSS) was 70% with respect to the MLSS concentration while maintaining a volumetric sludge index (VSLI) of 80 to 120 mL/gr after 60 min of sedimentation [12].

2.2.3. Oxygen requirements for the settling tank

The range for the activated sludge process was between 0.8 - 1.1 lb O₂/lb. COD, applied for both peak and design conditions. The organic loading of the system (Equation 2.3), COD Loading of the system in the influent (Equation 2.4), Total Suspended Solids Loading entering (Influent) the system (Equation 2.5), Organic Nitrogen Loading (Equation 2.6), and Ammonia Nitrogen Loading (Equation 2.7) [11,12] shown below were calculated [11,12]:

$$F = Q * DBO_5 * 8.34 \quad \text{Lb BOD}_5 / \text{day} \quad (2.3)$$

$$F_{CDO} = Q * CDO * 8.34 \quad \text{Lb COD/day} \quad (2.4)$$

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$$TSS\ inf = Q * TSS * 8.34 \quad \text{Lb /day}_{TSS} \quad (2.5)$$

$$Load_{organic\ nitrogen} = Q * N_{organic} * 8.34 \quad (2.6)$$

$$Load_{N-NH_3} = Q * N - NH_3 * 8.34 \quad (2.7)$$

Where:

- F = Organic load of the system (Lb BOD₅ /day)
- Q = Average flow per day (MGD)
- BOD = Biochemical Oxygen Demand.
- BOD₅ = Biochemical Oxygen Demand at 5 days (mg/L) (Average).
- F_{COD} = Chemical Demand Load of the system (Lb COD/day).
- COD = Chemical Oxygen Demand (mg/L).
- $TSS\ inf$ = Total suspended solids load of the influent to the system.
- $N_{organic}$ = Organic Nitrogen.
- NH -NH₃ = Ammoniacal Nitrogen.

2.3. Aeration Tank Design

2.3.1. Aeration tank

For the efficient operation of the WWTP, we considered the type of wastewater to be treated, calculate and use operation units, for the activated sludge process we estimated and calculated parameters such as the F/M ratio which is the measure of the amount of food for the microorganisms in the aeration tank with extended aeration; the mass (M) which is the amount of MLSS for maintenance of the reactor (Equation 2.8); Reactor volume (Aeration tank size) (Equation 2.9); Total volume of the aeration tank with a free surface area of 1.64 ft (Equation 2.10); Hydraulic holdup or design flow (Equation 2.11) obtaining the value of Hydraulic holdup at maximum flow [11].

$$M = F / (F/M) \quad (\text{Lb MLSS}) \quad (2.8)$$

$$V = \frac{M}{MLSS} * 8.34 \quad (\text{m}^3) \quad (2.9)$$

$$Vt \quad (\text{m}^3) \quad (2.10)$$

$$T_r = V/Q \quad (\text{h}) \quad (2.11)$$

Where:

- F/M = Feed/Microorganisms Ratio (from 0.05 to 0.15 Lb BOD₅ /day/Lb/MLSS for extended aeration).
- M = Mass of MLSS in the reactor (Lb MLSS).
- MLSS = Mixed liquor suspended solids (mg/L).
- V = Aeration tank volume, m³
- Vt = Total volume of the tank with a free surface for operation (m³)
- T_r = Hydraulic retention time at design flow (characteristic value for extended aeration from 18 to 36 h).

2.3.2. Oxygen Requirements

To establish the size of the blower according to the oxygen requirements of the settling tank, the actual oxygen requirement (LbO₂/day) calculated by Equation 2.12 and the standard oxygen requirement by Equation 2.13 was determined based on an atmosphere 14.696 psi as inlet pressure [12]:

$$A.O.R. = O_{2\ dissolved} * F_{CDO} + (4.6 * (Load_{N_{organic}} + Load_{N-NH_3})) \quad (2.12)$$

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$$S.O.R = A.O.R \left/ \left(\alpha (1024)^{T-20^{\circ}C} * \left(\frac{\beta(C_{smid}) - Or}{C_{smid}} \right) \right) \right. \quad (2.13)$$

Where:

- A.O.R* = Real Oxygen Requirement (Lb O₂ /day) .
S.O.R = Standard Oxygen Requirement (Lb O₂ /day).
 α = Correction Factor for Oxygen Transfer for Purge. Typical Value 0.75
 β = Correction factor for salinity and surface tension. Typical range between 0.95 and 0.98.
C_{smid} = Saturation solubility of dissolved oxygen in clean water at an average depth in an aeration tank, corrected for depth, water temperature and barometric pressure (mg/L).
Or = Residual dissolved oxygen in operation (mg/L).
stmidc = Saturation concentration of dissolved oxygen in clean water at 20° C and 1 Atm (mg/L).
T = Operating water temperature in °C.

2.3.3 Blower power

The standard air flow rate (Equation 2.14), air flow weight (Equation 2.15), air flow rate corrected for inlet conditions (Equation 2.16), inlet pressure was calculated considering the height of the site above sea level, HSSL an elevation of the study area of 879.99 m (2887.14 ft) (Equation 2.17) were determined (Equation 2.17). The air temperature at 20 °C and the maximum air inlet temperature to the blower of 30 °C were considered (Equation 2.18). the air blower power required for activated sludge tank. See Equation 2.19. [11,12].

$$SCFM = \frac{S.O.R}{C_{oxy} - a_{ire} * \%efi * h_i} \quad (2.14)$$

Where:

- SCFM* = Standard air flow rate (ft³ /min).
C_{oxy} - a_{ire} = LbO₂/ft³ of air = 0.0175
 $\%efi$ = Percent oxygen transfer efficiency per ft of immersion depth for fine bubble diffusers (%).
h_i = Air diffuser immersion depth (ft).

$$W_{air} = P * SCFM / RT \quad (P * SCFM) = (W_{aire} RT) \quad (2.15)$$

Where:

- W_{air}* = Weight of air flow (Lb mass/min).
P = Standard atmospheric pressure (14,696 psi).
R = Specific gas constant (for air it is 53.3 (ft. Lb. °F / lb. M x °R)).
T = Ambient air temperature at 528 °R (20°C = 68 °F).

$$ICFM = W_{air} RT_a / P_a \quad (2.16)$$

Where:

- ICFM* = Air flow rate corrected for inlet conditions (ft³ /min).
W_{air} = Weight of air flow (Lb M/min).
P_a = Inlet pressure due to psi rise (Equation 2.17).
R = Specific gas constant (for air it is 53.3 (ft. Lb. F / lb. M x deg. R)).
T_a = Blower inlet air temperature in °R.

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$$P_a = \frac{P - HSNM}{P * 144} \quad (2.17)$$

Where:

P = Standard atmospheric pressure (14,696 psi)

$HSSL$ = Height Above Sea Level (ft)

$$T_a = T_{amb} * 1.8 + 32 + 460 \quad ^\circ R. \quad (2.18)$$

Where:

T_a = Blower inlet air temperature in $^\circ R$.

T_{amb} = Ambient temperature in $^\circ C$.

$$P_W = W_{air} R T_a / 550 (ne) \left[\left(\frac{P_2}{P_a} \right)^{0.283} - 1 \right] \quad (2.19)$$

P_W = Power required by the blower (hp).

W_{air} = Air flow weight (Lb/s)

R = Specific gas constant (for air it is 53.3 (ft. Lb. $^\circ F$ / lb. M x $^\circ R$)

T_a = Blower inlet air temperature in $^\circ R$.

P_a = Inlet pressure due to elevation psi, atm (Equation 3.17).

P_2 = Outlet pressure psi (atm).

$n = (K - 1) / K$ = 0.283 for air

K = 1.395 for air

550 = Lb.ft/s.hp

e = Efficiency (the usual range for compressors is 0.70 to 0.90).

$$P_2 = P_{Blower \text{ discharge pressure (static pressure from diffuser immersion depth)}} + 2 \text{ psi}_{\text{pressure drop of pipelines}} \quad (2.20)$$

2.3.4. Design of settling tank size

For a population of 2000 inhabitants, the flow rate (Q) and the sedimentation surface load, C_s , were considered, with a flow range between 15 and 32 m³/day. Calculated dimensions, Equation 2.21 [11] using the requirements established for the construction of a WWTP.

$$A_{sed} = \frac{Q}{C_s} \quad (m)^2 \quad (2.21)$$

2.4. Solar Panel Design

The photovoltaic system, PVS, consists of solar panels, storage batteries, a charge controller and the power inverter. To determine the PVS for the WWTP, the horizontal/tilted plane irradiance was calculated, see Table 2.2.

For horizontal planes of solar irradiation		
Solar Declination (δ)	$\delta = 23,45 \times \sin \frac{360(d_n + 284)}{365}$	(2.22)
Excentricity factor (ε_0)	$\varepsilon_0 = 1 + 0,033 \times \cos \left(\frac{360 \times d_n}{365} \right)$	(2.23)
Extraterrestrial solar irradiance (H_0)	$H_0 = \left(\frac{T}{\pi} \right) \cdot I_0 \cdot \varepsilon_0 \left[- \left(\frac{\pi}{180} \right) \cdot (\omega_s \cdot \sin(\phi) \cdot \sin(\delta)) - (\cos(\phi) \cdot \cos(\delta) \cdot \sin(\omega_s)) \right]$	(2.24)
Clarity index (K_{Tm})	$K_{Tm} = \left(\frac{G_0}{H_0} \right)$	(2.25)
Diffuse fraction (F_{Dm})	$F_{Dm} = 1 - 1.13 K_{Tm}$	(2.26)
Diffuse radiation (D_0)	$D_0 = F_{Dm} \times G_0$	(2.27)

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Direct irradiance ($H_{dm(0)}$)	$H_{dm(0)} = G_0 - D_0$	(2.28)
For inclined planes of solar irradiation		
Angle of sunrise on a horizontal plane (ω_s)	$\omega_s = -\arccos(-\tan(\delta) \times \tan(\phi))$	(2.29)
Correction factor (K)	$K = \frac{\omega_{ss} \frac{\pi}{180} [\text{sign}(\phi)] \sin \delta \sin(\phi - \beta) + \cos \delta \cos(\phi - \beta)}{\omega_s \frac{\pi}{180} \sin \delta \sin \phi + \cos \delta \cos \phi \sin \omega_s}$	(2.30)
Sunrise angle on an inclined plane (ω_{ss})	$\omega_{ss} = \max[\omega_s; -\arccos(-\tan(\delta) \times \tan(\phi - \beta))]$	(2.31)
Direct solar radiation ($H_{(\beta,\alpha)}$)	$H_{(\beta,\alpha)} = H_{dm(0)} \times K$	(2.32)
Diffuse solar radiation ($D_{(\beta,\alpha)}$)	$D_{(\beta,\alpha)} = D_0 \times \left(\frac{1 + \cos(\beta)}{2} \right)$	(2.33)
Solar radiation albedo ($AL_{(\beta,\alpha)}$)	$AL_{(\beta,\alpha)} = \rho \cdot G_0 \cdot \frac{1 - \cos(\beta)}{2}$	(2.34)
Global radiation ($G_{(\beta,\alpha)}$)	$G_{(\beta,\alpha)} = H_{(\beta,\alpha)} + D_{(\beta,\alpha)} + AL_{(\beta,\alpha)}$	(2.35)

Table 2.2. Horizontal sunrise and inclined plane parameters for solar panels taken from [13].

2.4.1. Calculation of the number of Solar Panels

The power of the aeration tanks was considered and a safety factor of 30 % was established with an optimum tilt angle of 17 ° of the asimet according to The European Commission's Science and Knowledge Service, (ECSAKS, 2020) and from the Energy Portal taking the peak solar hour and solar panel power [14].

$$\text{Solar Panels number} = \frac{C_d F_s}{HSP * W_p} \quad (2.36)$$

Where:

C_d = Daily current consumption (W)

W_p = Power of panel (W)

HPS = Peak solar time.

Fs = Safety factor (30%).

2.4.2. Calculation of the Quantity of Solar Batteries

The required current was obtained using a 48 V battery with useful storage = 50% of 650 Ah, Equation 2.37.

$$Id = \frac{E}{Vt} \quad (2.37)$$

Where:

Id = Current required (A)

E = Daily consumption of the plant (kW)

Vt = Battery Voltage (V)

2.5. Web System Design for Automation

Automation has become one of the main technology developments for controlling processes to improve efficiency and performance [8]. A database manager (DB) MariaDB, PHP (client/server) and HTML with JS client code were used to manipulate the site objects, such as textboxes, radio buttons, checkboxes, listboxes and buttons, in the validation of controls and error checking of input information, reducing the verification load at the DB level, validation of text/number only input, hiding password input, clearing of content when pressing the save or exit button, limiting the number of characters allowed in textboxes, not allowing decimal points and commas. The use of the PHP program will provide a level of security in automated operation.

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3. RESULTS AND DISCUSSION

3.1. Design of the WWTP

3.1.1. Water Control Conditions

The water coming from isolated communities is not treated or not treated at all, with no control of discharges into the water bodies. For the sizing of the WWTP, physicochemical parameters were established for the control of treated water such as maximum concentrations and pH [15]. See Table 3.1

Maximum concentration mg/L	Mexican Official Standard NOM-AA
300 of BOD ₅	028
400 COD	030
100 of SS	034
20 of N ₂	079
20 of N _{2total}	026
pH from 5 to 8	008

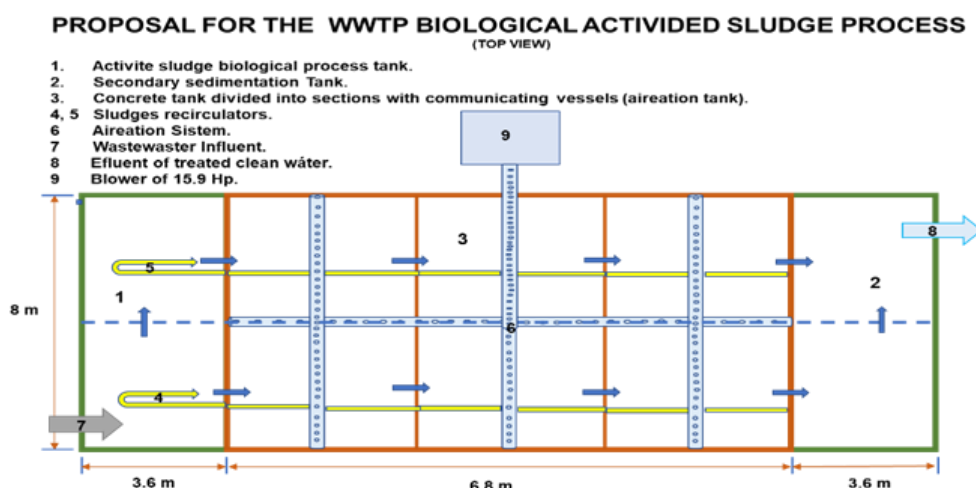
Table 3.1. Values of maximum concentrations and pH range. **Source:** [14].

2.1.2. Calculation of discharge volume

The discharge volume for the population of 2,000 inhabitants was calculated from the data in Table 3.2.2 and an average direct wastewater discharge from households in the population of 300 L/person was obtained, which is higher than the data reported in municipal discharge averages for populations with 2,500 inhabitants [1,16].

2.1.3. Sizing of the WWTP

Therefore, the dimension of the WWTP was obtained in the form of a rectangular concrete tank 8 m wide x 14 m long x 4.5 m high and a volumetric capacity of 504 m³ with an internal secondary settler for activated sludge of 8 m wide x 3.6 m long x 4.5 m high with a volumetric capacity of 115.1 m³ interconnected to the aeration tank by a blower with a power capacity of 15.9 hp suitable for air supply, with oxygen requirements of 1,674 LbO₂ /day, for a calculated influent input (ICFM) of 407.25 (ft/min) or 124.13 (m/min). See Figure 3.1.



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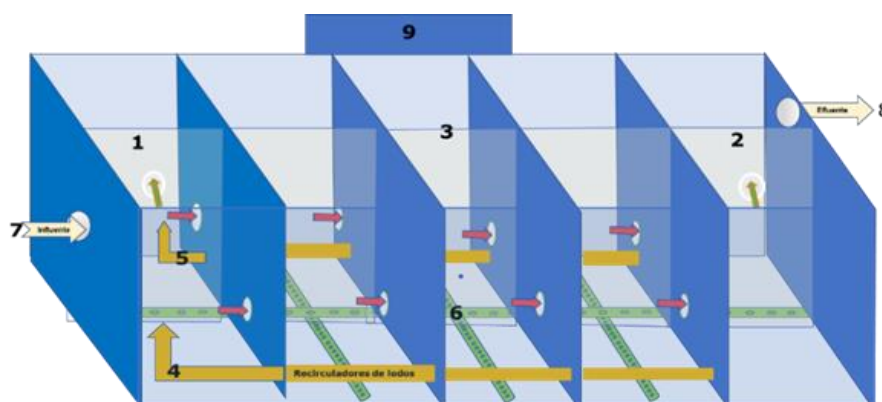


Figure 3.1. Schematic of the rectangular activated sludge biological process WWTP obtained for construction in Chilón.

3.1.4. Design parameters on oxygen requirements for the WWTP

The digestion process involves the stabilization of the organic matter contained in the sludge and aeration for an extended period fed by blower pumps. The design concentrations of the parameters calculated according to the Mexican Official Standard [15] were established for the estimated population of 2,000 inhabitants [16]. See Table 3.2.

Design parameters Oxygen		Requirements
Peak Conditions	1 a 1.2	Lb O ₂ /Lb BDO ₅
Design conditions	1.2	Lb O ₂ /Lb BDO ₅
F	387.4	Lb BOD ₅ .day
Load _N Organic	25.8	Lb BOD ₅ .day
COD applied	1.2	LbO ₂ /Lb CDO
F _{CDO}	516.7	Lb COD.day
Influent TSS load to the system	129.1	Lb /day _{TSS}
Load _{N-NH₃}	25.8	Lb.day

Table 3.2. Parameters of the design concentrations required for the digestion process [12].

3.1.5. Design parameters required for the settling tank

The volume of the aeration tank, V_T , was 494.4 m³ with a free surface of 5.4 m; a volume of the reactor tank, V_r , 439.55 m³, maximum hydraulic retention time, T_r , of 15 m³/h with hydraulic retention of 18 h (estimated under the range of 18 to 24 h) parameters that will improve the aeration process of the activated sludge with estimated mass of 3,941 Lb with adequate energy consumption with the ratio of the mass of suspended solids, M_{SSLM} , and the aeration volume, $V_{Taeration}$ as reported in the literature [11, 12].

3.1.6. Oxygen Requirements for Design WWTPs

The estimated reactor design has an influent of 407 ft/min requiring an oxygen aeration capacity of 875 LbO₂ /day and an O₂ standard of 1,624 Lb/day with inlet pressure needs of 13.33.psi due to site elevation, at 528 °R and a blowdown temperature of 546 °R.

3.1.7. Compressor air power capacity design

The power required for the blower or air compressor was calculated, P_w was 15.9 hp with an air flow (W_{air}), of 26.87 Lb/s, at a pressure, P_2 , of 20.73 psi, and an inlet influent (ISCM) of 407.25 ft/min, with a sustained constant K of 1.397 and n of 0.283 which will provide an estimated efficiency of 0.7 that will allow a good performance of the activated sludge digestion process.

3.1.8. Design of the secondary settling tank

For the construction of the internal settling tank, a surface area of 28.8 m² (A_{sed}) is required (Figure 3.1), for a WWTP with a volume of 115.1 m³. The MLSS concentration was estimated at 4,000 ppm; the F/M ratio of 0.01 Lb BOD₅ /day/lb/MLSS; the MLVSS concentration of 2,800 ppm and the sludge volumetric index after one hour of sedimentation of 100 ppm. The sludge age will have a period of 28 days sludge age is considered taking into account the settler biomass, cell retention time and intermittent sludge purge

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[16], the period at that range can generate a removal between 93 to 98 % of BDO_5 , while for COD up to 95 % [2], as for TSS the concentration can vary, this can be reduced by considering grease and oil separation grids omitted for being domiciliary waters [16].

3.2. Solar Panel Design

3.2.1. Calculation of Irradiation Parameters

Data acquisition for irradiance was performed in four stages: a) using ECSAKS web software [12], b) using irradiance maps, c) using the PVGIS NSRDB database of the ECSAKS 2020 web platform, and d) applying formulas. The ECSAKS 2020 web platform provides graphs with monthly and daily irradiance values, monthly and daily temperature, useful for the calculation of solar panel requirements. With the geolocation we obtained the latitude (17.105°), Altitude: 880 masl (meters above sea level), longitude (-92.271°) of the area and Time zone: UTC-06, America/Mexico City from the freely available Solar Irradiance GIS Maps [17], daily and annual values, Table 3.3.

Data	Daily	Annual
Direct normal irradiation (kWh/m^2)	4.842	1628.7
Global horizontal irradiation (kWh/m^2)	5.437	1984.7
Diffuse horizontal irradiation (kWh/m^2)	2.048	747.6
Global titrated irradiation with optimum angle (kWh/m^2)	5.636	2957.2
Optimal inclination of PV modules ($^\circ$)	17 - 180	17 - 180
Air temperature ($^\circ C$)	20.8	20.8
Ground elevation (m)	880	880
Latitude $\phi = 17.105^\circ$		
Solar panel tilt angle $\beta = 17^\circ$		
Soil reflection $\rho = 0.2$		
$dn = 60$	day 1 of March	day of the year, value from 1 to 365
Solar constant $I_0 = 1367 W/m^2$		
global horizontal irradiance $G_{dm(0)} = 5640 Wh/m^2$ (PVsyst)		
Altitude: 880 meters above sea level		

Table 3.3. Values of daily and annual solar irradiation received in the Chilón area. Source: [17].

The irradiance maps show long-term electric potential, Global Horizontal Irradiance and Normal Direct Irradiance for the period of the years 1999 to 2018. The PV electric potential found was determined to be between 4.2 and 4.6 $kWh/kW \cdot day$; the global horizontal irradiance between 5.4 and 5.6 $kWh/m^2 \cdot day$, and the normal direct irradiance between 4.2 and 4.4 $kWh/m^2 \cdot day$, see Figure 3.2. According to the World Bank group, ESMAP [18], the combination of the average shortwave radiation includes visible light and ultraviolet radiation, the solar energy radiation indicated in Chilón is between 4.0 kWh and 5.6 kWh sustained during very sunny seasons.

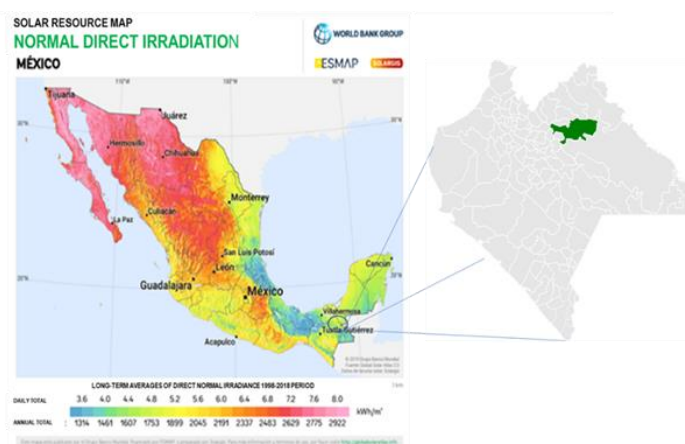


Figure 3.2. Map of solar radiation averages of the Mexican Republic with an increase of Chilón.

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Source:[18].

3.2.2. Optimal parameters calculated for the design of solar panel construction

Values obtained from the optimal characteristics for the construction of the solar panels. The results are reported in Table 3.4 below. They correspond to the calculations using the equations in Table 2.2 for irradiance reaching the solar panel $G = 5,625.45 \text{ Wh/m}^2$. It is mentioned that these values are important for the sizing of the solar panel module since they improve the energy production because it has been shown that an increase in irradiance in hours can provide the energy necessary to meet the needs of a WWTP [19, 20].

Parameters	Optimum value
δ	- 8.293702°
ε_0	1.016908
H_0	9346.162796
K_{Tm}	- 0.603456
F_{Dm}	0.31809
D_0	1794.0558 Wh/m^2
$H_{dm(0)}$	3845.9442 wh/m^2
(ω_s)	- 87.428963 °
K	1
ω_{ss}	-87.428963 °
$H_{(\beta,\alpha)}$	3845.9442 $\frac{\text{wh}}{\text{m}^2}$
$D_{(\beta,\alpha)}$	3845.9442 $\frac{\text{h}}{\text{m}^2}$
$AL_{(\beta,\alpha)}$	24.644544 wh/m^2
$G_{(\beta,\alpha)}$	5625.448013 wh/m^2

Table 3.4. Optimal parameters for solar panels, for horizontal and inclined planes of solar irradiation. Source: [18].

Figure 3.3 shows the monthly averages of the highest solar irradiance peaks reached in August in a horizontal plane of 204.6 $\text{Wh/m}^2/\text{month}$; the optimum irradiance in an inclined plane of 197.57 $\text{Wh/m}^2/\text{month}$; the irradiance in a plane with an angle of 178.15 $\text{Wh/m}^2/\text{month}$ and the irradiance in a plane with an angle of 193.21 $\text{Wh/m}^2/\text{month}$. The peaks with lower irradiance were reached in the period September - December, similar to the peaks obtained by Alvarez and collaborators [21].

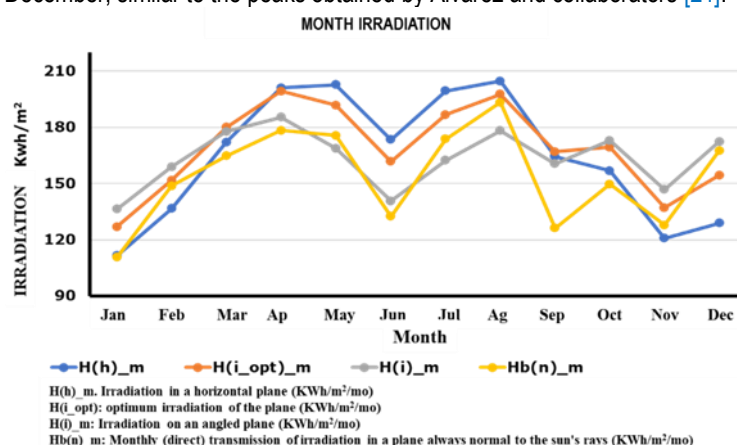


Figure 3.3. Monthly irradiation data for Chilón. Source: [14].

Figure 3.4 shows the global radiation obtained from the sum of direct radiation + albedo radiation + diffuse radiation obtained, corresponding to the averages of global irradiance, $G(i) = 868.1 \text{ Wh/m}^2$; direct irradiance, $G_b(i) = 626.4 \text{ Wh/m}^2$; and diffuse irradiance, $G_d(i) = 228.8 \text{ Wh/m}^2$. The behavior of global, direct and diffuse irradiance reaches its maximum average irradiance at 18 h on day 19.

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The first 12 h are considered as null data, and from 12 h onwards the irradiance starts to reach its maximum point at 18 h where it starts a drop at 22 h thus considering a period of maximum irradiance between 12 and 22 h with an average global irradiance between 100 to 200 Wh/m² adequate for the energy production of the PVs [9, 22].

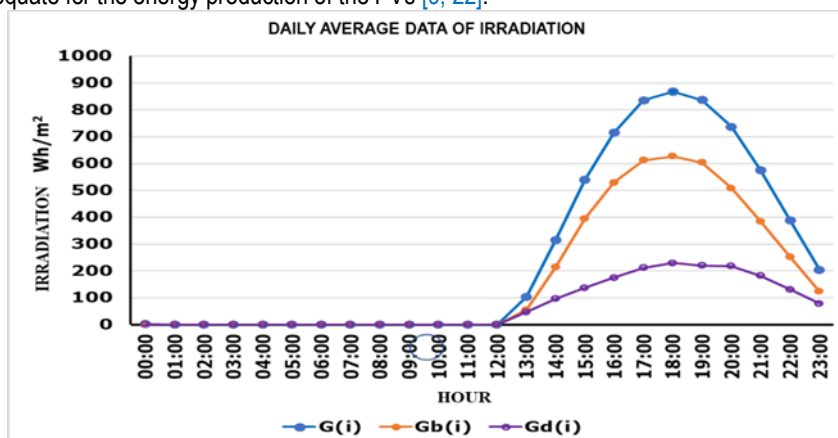


Figure 3.4. Daily average daily irradiance data over an inclined plane. Source: [14].

3.2.3. Solar Panel Design and Calculation

The PVS design in Chilón consisted of calculating the number of solar panels sufficient to capture the energy required to move the WWTP blowers with needs of 15.9 hp equivalent to 11,856.63 W estimating a 10% of slack equal to 13,124.32 W. With a peak hour of 5 and global irradiation of 868.13Wh/m² /day. For the elaboration of the solar panel module the following characteristics of the materials were considered: polycrystalline solar panel Amerisolar brand 1956 x 992 x 40 mm with a weight of 25.5 Kg, model 6P with a nominal power (PMPP) of 340 W, voltage type 24V, maximum voltage of 37.5 V (VMPP) with maximum current of 9.07 A (IMPP), vacuum voltage of 46.1 V with maximum current of 9.5 A (ISC), temperature coefficients: PMPP of -0.41%/°C, I_{sc} 0.05 %/°C, and V_{oc} of -0.31 %/°C. In the case of energy conversion, a pure sine wave inverter ideal for direct current batteries with a maximum capacity of 10,000 W, with a life time of 25 years is proposed

$$= 13,124.32 \text{ W} * 1.3/5 * 340\text{W}$$

No. of solar panels

$$= 17,061.6 \text{ W}/1,700\text{W}$$

$$= 10 \text{ solar panels.}$$

The number of solar panels required for the number of watts produced was determined by a series connection with a power of 340W [23], see Figure 3.5 .

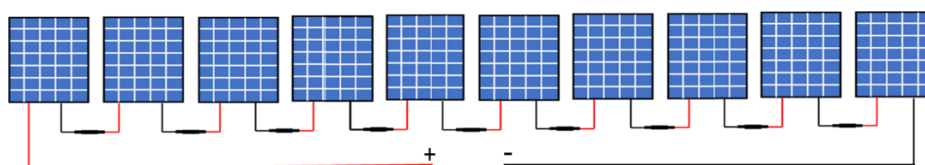


Figure 3.5. Diagram of the arrangement of solar panels in series.

3.2.4. Calculation of the Quantity of Solar Batteries Required

Since the discharge ratio of the batteries is 50%, the current is calculated as a function of power and voltage, if one has an energy harvesting capacity of the solar panels of 38.26 kWh.day, then the irradiance to electrical energy conversion calculation. see Equation 2.37, from kWh to Amperes, as shown below:

$$I = W/V = 13,124.32 \text{ W} / 48\text{V}$$

$$= 273.42 \text{ A}$$

This is the current required per WWTP.

$$I = 273.42 \text{ A}$$

We apply in Eq:

$$\text{Battery Bank} = (1) (273.42 \text{ A}) / (0.5)$$

$$= 546.84 \text{ A}$$

Number of Batteries

$$= 390.6 \text{ A} / 650 \text{ A} = 0.84 \text{ batteries}$$

$$= 1 \text{ battery}$$

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10 solar panels of 340W will produce 10,059.2 W/day constantly, see Figure 3.6 of the schematic with the two solar inverter batteries.

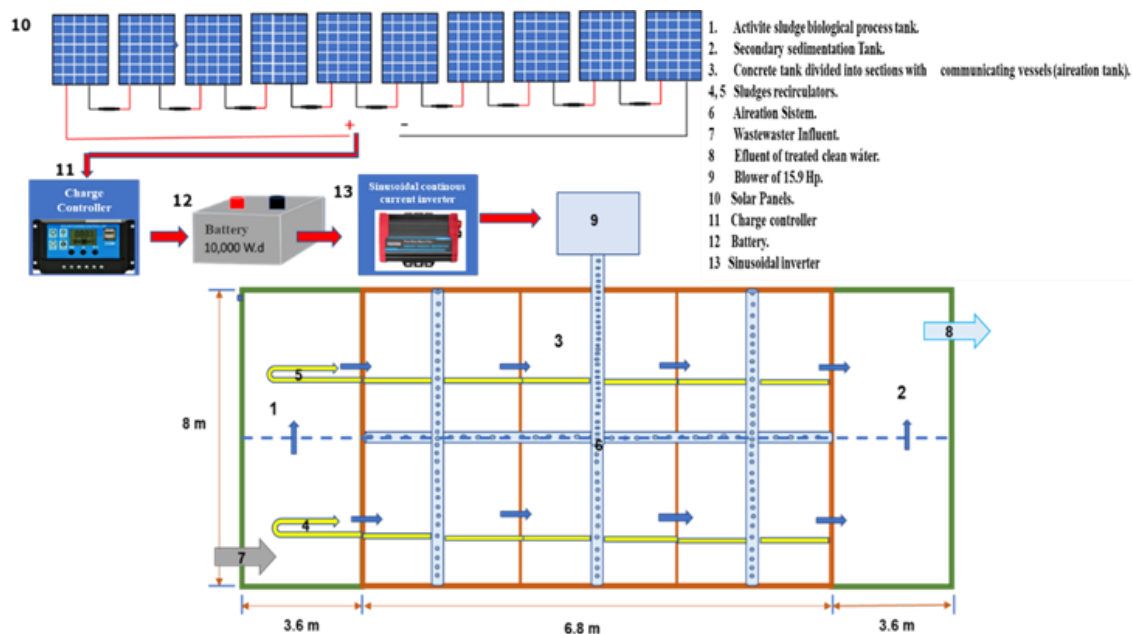


Figure 3.6. Integrated diagram of the WWTP and solar panel layout.

3.3. Web System for Automation

3.3.1. Automation

The control of the WWTP requires a treated wastewater inlet/outlet flow control system. A flow diagram of each of the processes was generated for the use of two controlled blowers for alternate air supply operation and flow meters to record the accumulated volume of treated water. The automation was adapted to a PHP-based web system; JS, embedded in HTML, was used to manage the controls, where the following are recorded: (a) plant flow rates; (b) fill levels for primary treatment; and (c) secondary; (d) measurement of primary and, (e) secondary retention times, (f) clarified water outflow, (g) water residence time in activated sludge; h) Recording of the filling levels of the activated sludge container; i) Measurement of residual chlorine in the clear water; j) Recording of the filling levels of the chlorine container; k) Recording of the filling level of the roughing container; l) Measurement of the time of water in the roughing container. see Figure 3.7.

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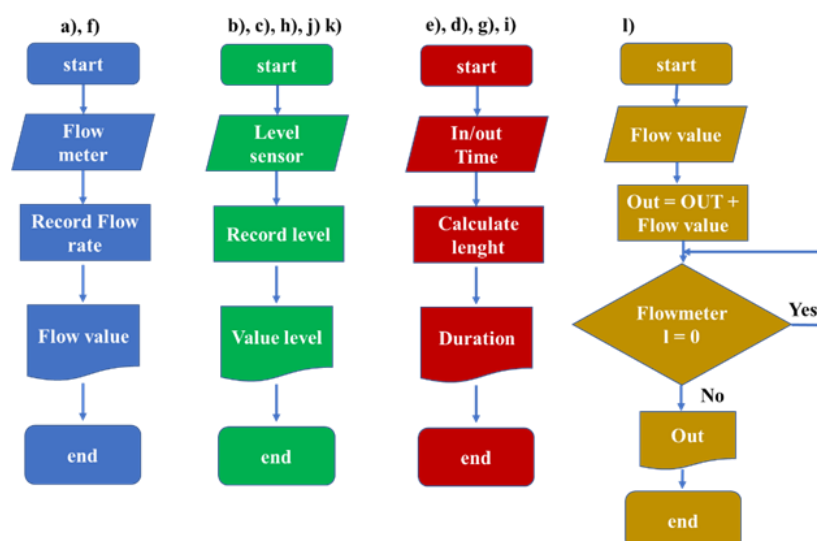


Figure 3.7. System flow diagrams for the automation process.

4. DISCUSSION

The WWTP-PV-WebA systems allow the integration of renewable energy sources, however, the automation is focused on the Photovoltaic systems because they are required for solar energy collection, looking for the planes and angles of solar irradiation for better energy collection as mentioned in the literature [9, 21]. Several studies [8,21,22,24,25] presented as renewable energy alternatives to reduce WWTP energy costs show that between 60 to 75% of the energy consumption is realized in the aeration system (air blowers) [2,3].

The design dimensions of the WWTP consider municipal populations with 2500 inhabitants, with estimates made for 2030 with goals not reached due to government periods, lack of resources, and lack of solvency of municipalities in Mexico [1,7,21].

Grid automation has a positive impact on the environment and the health of the inhabitants because it reduces carbon emissions and other gases produced by conventional energy generation by consuming fossil fuels [26]. The WWTP-PV-WebA design project sets a precedent for design factors that are suitable for populations far from technology, helping to meet the energy needs of remote areas. The dimensioned values of power, aeration 15.9 hp, treatment processes and automation through web systems, highlight that autonomous sustainability factors could benefit the treatment of domestic wastewater, compliance with quality standards of treated wastewater to be discharged to the river basin, decreasing the negative effects on the environment providing climate benefits [26,27,28,29]. Due to its geographical location, Chilón, Mexico, is located in one of the best irradiation zones along with the Yucatán peninsula [30], for its use as a renewable, sustainable and environmentally friendly source, so it is possible to implement the construction, energy and automation project in this area.

5. CONCLUSION

According to the results obtained for populations of 2,000 inhabitants with a lack of connections to residential discharge networks, a design was achieved for the construction of a sustainable WWTP-PV-WebA with controlled discharges, which complies with the NOM-2001-SEMARNAT [15]. Based on the PVS results obtained, the number and arrangement of suitable solar panels in series was determined. In the case of automation, a web system with PHP, JS and HTML code base was developed as the main tool for the control of the WWTP. Therefore, it is concluded that the WWTP-PV-WebA design is considered feasible to build for three or six-year government periods since, according to the dimensions and projections, the continuity of the project can be guaranteed in distant areas, such as Chilón [31,32]. A future study is expected to develop the project and collect the data it yields.

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