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Stimulation of activated sludge biomass using artificial visible light

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ABSTRACT

Visible light is a potential innovative method for developing the activated sludge (AS) system. AS is consisted of a complex community of diverse microbes that respond differently to light based on wavelength, intensity, and exposure time. The present study examined the possibility of stimulating activated sludge using visible light radiation. Five light wavelengths (white, solar, red, blue, and green lights) are provided with three intensity levels. Mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS) were used as indicators to evaluate activated sludge performance. From the experimental results, 15–20 days achieved high biomass productivity for all wavelengths. There was a direct relationship between AS biomass and intensity, except white light, the proportion was inverse. Green, blue, and red light achieved maximum stimulation of MLSS reached (48.57, 48.29, and 33.57%) relative to control at (130±3.41, 100±2.9, and 40±4.89 W m^{-2}). Besides, the highest stimulation of MLVSS under green, white, and solar light was (84.54, 55.01, 39.33%) relative to control at (115±3.17, 24±3.72, 40±3.1 W m^{-2}). The maximum growth rate (μ) of MLSS and MLVSS achieved under white and green lights reached (0.096235, and 0.115377 d^{-1}) at (24±3.72, 115±3.17 W m^{-2}), during 5 days, respectively. Van and the developed models could predict a high correlation exceeding (r = 0.98) with white and solar light.

Keywords: activated sludge, biomass, intensity, light, stimulation, wastewater, wavelength.

INTRODUCTION

Population growth is one of the most visible trends of the current century. It affects energy, natural resources, the global economy, urban expansion, industrialization, and climate change, which are expected to reduce global water supplies by 40% in 2030 (Kwon et al., 2020; Shamshad & Rehman, 2025). In 2017 more than 80% of wastewater was released into the environment without adequate treatment (Connor, 2017) due to over-eutrophication, bioaccumulation of hazardous chemicals, and oxygen depletion (Cai et al., 2013; Tiwari and Pal, 2022). Consequently, polluted effluents must be treated and reduced to internationally permissible limits (Al-Abd Rabbah, 1999).

Activated sludge (AS) systems are distinguished by high-quality water (El Moussaoui, 2022) requiring limited installation and operation space and low odour and pests (Noyola et al., 2012). However, the energy consumption of aeration may be (50–90%) of all operating costs (Drewnowski et al., 2019).

One promising way to develop AS systems is by combining several biological processes with light-emitting diode (LED) light in specialized reactors, known as "photobioreactors" (Ariza, 2018; Ishaqueet al., 2024). It may be applied to solve many environmental and industrial issues, such as carbon dioxide emissions, required aeration and operating costs, and modification of physical and chemical properties of wastewater (Sathinathanet al., 2023; Ishaque et al., 2024). Photobioreactors remain a concern because of the limited specialized studies and the complex activated sludge community (Xia et al., 2018). The wavelength, intensity, exposure time, photoperiod (light:dark), and type of LED light were the most influential operating

factors on the formation, stability, sedimentability, and removal efficiency of pollution in algal and bacterial granule systems and their enhancement to withstand fluctuations caused by effluent batches (Rehman and Dixit, 2020; Tong et al., 2024). Photokinetics helped *Chlamydomonas reinhardtii* remain suspended without a mechanical stirring system (Carvajal et al., 2024). With short exposure, AS biomass was increased with green and red lasers, and many microbial species were destroyed with overexposure (Kupchishin et al., 2018). Violet (380–450 nm), blue (450–485 nm), cyan (485–500 nm), green (500–565 nm), yellow (565–590 nm), orange (590–625 nm), and red (625–740 nm) light resulted varying increases in microalgal biomass, depending on the composition of their unique photosynthetic pigments and complementary pigment complexes (Wang et al., 2023a). Red and white lights enhance *Chlorella vulgaris* biomass in the closed bioreactor, faster growth rates increased up to 0.36 d^{-1} (Metsoviti et al., 2020). Blair et al., (2014) showed that *Chlorella vulgaris* growth was better under blue LED light and exposure time of 10–14 days compared to clear white, red, and green LED light wavelengths. Ma and Jian, (2023) found that *Chlorella* biomass improved with a gradual increase in LED light intensity followed by a gradual decrease in growth at 150 μmol $m^{-2}·s^{-1}$, and then a sharp reduction in biomass exceeding 175 μmol $m^{-2}·s^{-1}$. Lighting modification improves microalgae productivity due to changes in *chlorophyll*, *carotenoids*, and pigment proteins (Hotos, 2023). Yang and Zhao (2023) discovered that the light-induced efficiency of microorganisms to remove organic pollutants after 8 days was 85% higher than in dark culture; the bacteria also demonstrated good hydrolysis ability of several insoluble active pharmaceuticals, such as *fluoxetine* and *diclofenac*, reaching 88% and 20%, respectively. Katam et al., (2023) found that the three levels of intensities (100, 200, and 300 μmol $m^{-2}·s^{-1}$) of blue, red, white, and yellow light affected the growth of algal–bacterial consortium and improved wastewater treatment except for white light, 84% of organic carbon removal was observed at a blue light (300 μmol $m^{-2}·s^{-1}$), 51 and 80% removal of nitrogen and dissolved phosphorus were observed at a red light (100 μmol $m^{-2}·s^{-1}$), respectively. LED light at 450 nm effectively inactivated Gram-positive and Gram-negative bacteria (Maclean et al., 2009). (He et al., 2021) found that the use of red and blue light due to an increased lipid content of *Chlorella pyrenoidosaa* also achieves a high growth rate at 5000 lux, and (8 light:16 dark) hour, in the same way, continuous illumination of rector improves wastewater treatment compared to natural light sources for *Scenedesmus obliquus* and *Chlorella pyrenoidosa*. Jung et al., (2019) found that the blue light increased the production of biomass for *P. tricornutum* reaching 0.97 g/l (μ = 0.047 h^{-1}), followed by *I. galbana* reaching 0.79 g/l (μ = 0.04 h^{-1}), and *D. tertiolecta* reaches 0.55 g/l (μ = 0.028 h^{-1}). Keramati et al., (2021) exposed microalgae to a flashing LED light at 1 Hz and 1000 Hz due to removed nitrate (68 and 97%) and phosphate (47 and 70%), respectively. Govarthanan et al., (2019) found that the growth of *Erythrobacter spp.* was optimized under blue light at 470 nm, and the other bacterial growth was optimized at the light of blue > white > green > red > yellow > unlit (control). The specific growth rate of *Pseudomonas syringae* was faster when exposed to blue LED light at 470 nm (Kuo et al., 2012). The highest growth rate of *Chlorella pyrenoidosa* was achieved using blue light (μ = 0.51 d^{-1}), followed by white light (μ=0.24 d^{-1}) and red light (μ=0.22 d^{-1}) (Kendirlioglu and Cetin, 2017). Atta et al., (2013) found that the growth rate of *C. vulgaris* algae increased with increasing blue LED light intensity from (100 to 200 μmol $m^{-2}·s^{-1}$) with a photoperiod of 12L:12D. However, a further increase in light intensity to (300 μmol $m^{-2}·s^{-1}$), led to a decrease of growth rate.

This paper presents a novel method to investigate the possibility of stimulating the growth of activated sludge biomass under modern conditions in batch reactors exposed to visible LED light beams (white, solar, red, blue, and green) at an exposed time of (0, 5, 10, 15, and 20 days) (Wang et al., 2023b). MLSS and MLVSS were measured to observe the growth rate of sludge according to the study by Asgari et al., (2023). Six experimental groups were used under similar conditions in a self-controlled and manual system tightly isolated from the external environment. The effect of the wavelengths, intensities, and exposed time on specific growth rates was studied. Meanwhile, Van and modified Van (developed) models simulated MLSS and MLVSS concentration. The results of the experimental data, the developed model, and the Van models were discussed.

EXPERIMENTAL PROGRAM

System setup

This paper adopted a batch photoreactor system made from plastic with a transmittance of more than (95%) and a working volume (3 liters). It is illuminated by LED light (see Figure 1, Figure 2c). The reactor is isolated from the surrounding environment by a cabinet to prevent the arrival of light radiation from other sources. Cabinet dimensions (1900L × 950W × 400H mm) divided into six shelves (see Figure 2a). A variable resistor is used to regulate the intensity. An Arduino was used to regulate temperature. In the first stage, acclimatization culture is used to obtain stable activated sludge. In the second stage, activated sludge was treated via different wavelengths of LED light for 20 days, with control (without treatment). MLSS and MLVSS concentrations were measured. In the third stage, the activated sludge was discarded and replaced with a new sample.

Sampling, and physicochemical analysis

Cultural was raw wastewater. Twenty liters were monthly collected from a channel depth of (0.1–0.3 m) from the sewage system of Al-Hawija, and Al–Zab cities belonging to Kirkuk Governorate. Bacteria or parasites were examined to ensure no toxicity or chemicals have inhibitory or harmful effects (Lopez-Vazquez et al., 2016). The physical and chemical properties were analyzed according to the standards of the Iraqi Ministry of Environment, and Standard Methods for Examination of Water and Wastewater (Rice et al., 2012) (Table 2).

Experimental procedure

The experimental procedures are described below:

Raw wastewater was acclimated to achieve an activated sludge phase with a concentration range of (2000 to 3500 mg/l) (see Figure 2a) as

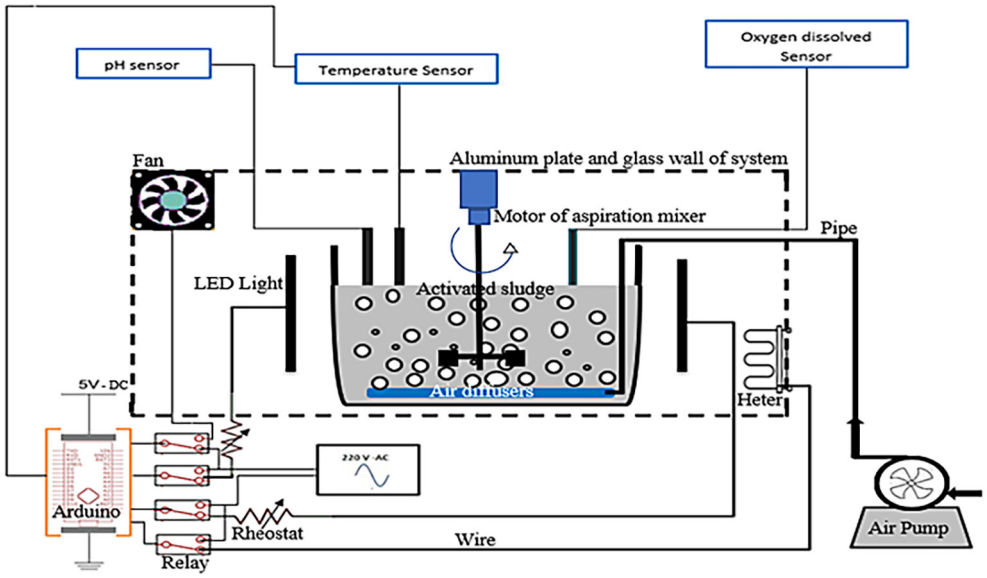

Figure 1. Schematic diagram of the experimental setup of activated sludge

Table 1. Operating parameters values of the present work

Group	LED light	Wavelength (nm)	Test			Exposed time (days)
			Light intensity levels (W/m²)			
			Low (1)	Moderate (2)	High (3)	
Activated sludge exposed to various wavelengths of LED light, at different times. Wavelength and intensity are fixed.	White	620-650	24±3.72	48±3.81	96±4.02	0, 5, 10, 15, and 20
	Solar	560-590	20±4.01	40±3.10	60±5.43	
	Red	620-700	20±3.03	30±3.21	40±4.89	
	Blue	430-480	80±2.70	100±2.90	120±2.07	
	Green	480-560	100±2.78	115±3.17	130±3.41	

Table 2. Mean values (±standard deviation) physicochemical properties of samples

Sample position	pH	EC (mohs/cm)	Temp. (°C)*	COD (mg/l)	BOD (mg/l)	TDS (mg/l)	TSS (mg/l)	PO_4^{3-} (mg/l)	NO_3^- (mg/l)	NH_3^- (mg/l)
Al-Hawija	6.156	3207.33	23.9	1720	478.5	2190	1061.33	44.467	2	20.8
	±0.1405	±130.693	±0.509	±180.55	±21.5	±277.96	±138.123	±20.724	±1.471	±11.492
Al–Zab	6.552	2133.8	22.9	1122.6	412.5	1832.2	634.4	7.962	1.887	19
	±0.114	±285.793	±0.829	±91.384	±55.39	±452.9	±197.137	±2.636	±1.073	±10.318

Note: *Relevant to these tests (Table 2) only, not to treatment conditions.

described by Tokumura et al., (2009) and Kamali et al., (2022). Activated sludge was remixed for 15 minutes at (1500 cycles/minute) and then distributed into six reactors (one reactor for each wavelength (white, solar, red, blue, green), in addition to the control reactor (no treatment)). The reactors were exposed to different parameters according to values specified in Table 1. The system was kept at (26°±0.5–33±0.5 °C). Acidity, aeration, and feeding were constantly monitored every 6 hours. An air distributor supplied dissolved oxygen (DO) (3.5–5.5 mg/l) to avoid hypoxia (Aimale-Troy et al., 2024). pH was maintained between 6.8 and 7.8. The equipment included: thermometer (DP-1K55-796C), DO meter (HANNA HI 2400: Bench meter), and a digital pH meter (pH-280: Pen type). The intensity was measured via MESTEK, LM610; 0 ~ 100000 Lux, China made). MLSS and MLVSS were examined using many laboratory devices and instruments as described by Rice et al. (2012) and Lopez-Vazquez et al., (2016).

Experimental sets

Table 1 includes the operating variables for experimental sets. These sets were examined according to the values of the operating variables. Reactors were exposed to LED light (white, solar, red, blue, and green) for 20 days under three levels of intensity (low, moderate, and high intensity) (Pham and Nguyen, 2020; Asgari et al., 2023).

Analytical methods

MLSS and MLVSS were evaluated every 5 days for 20 days according to the Standard Methods for Examination of Water and Wastewater (Rice et al., 2012).

RESULTS AND DISCUSSION

Result of MLSS

The results of MLSS concentration at different wavelengths of LED light, exposed time 0, 5, 10, 15, and 20 days, and three intensity levels (low, moderate, and high) are shown in Figure 3–5. Two-way analysis of variance (ANOVA) revealed that the variation of light wavelength was significant ($p < 0.05$) with exposed time. The initial MLSS concentration of three intensity levels was (2966.667, 3133.334, and 3066.667 mg/l) on 0 days, respectively. Generally, the biomass of butch cultures increased from days 1 to 20. In the low–intensity, MLSS concentration was best under white light reaching 8133.334 mg/l, (control, 6433.334 mg/l) at 20 days, see Figure 3,

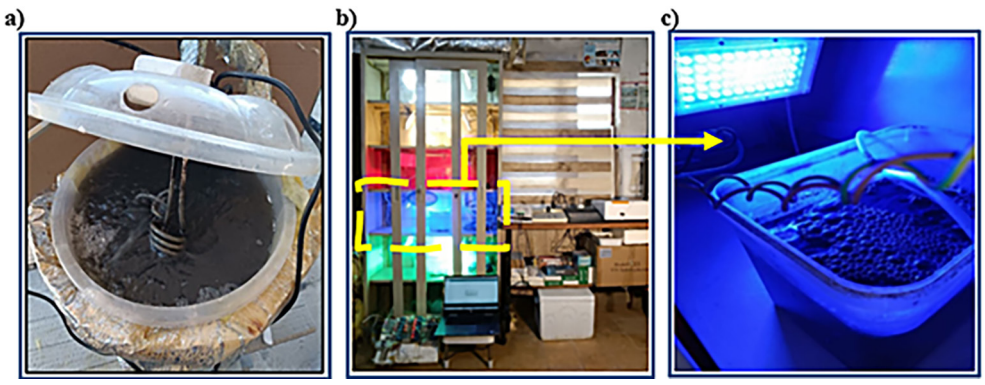

Figure 2. (a) Acclimation of activated sludge; (b) the experimental setup; (c) enlargement of the highlighted section of the photo (b)

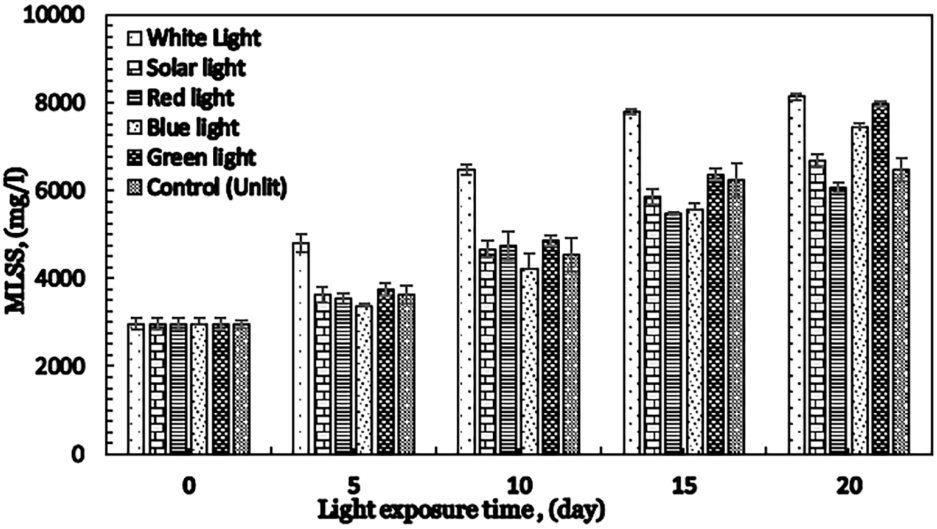

Figure 3. MLSS concentration trends with different LED lights at 1-level intensity

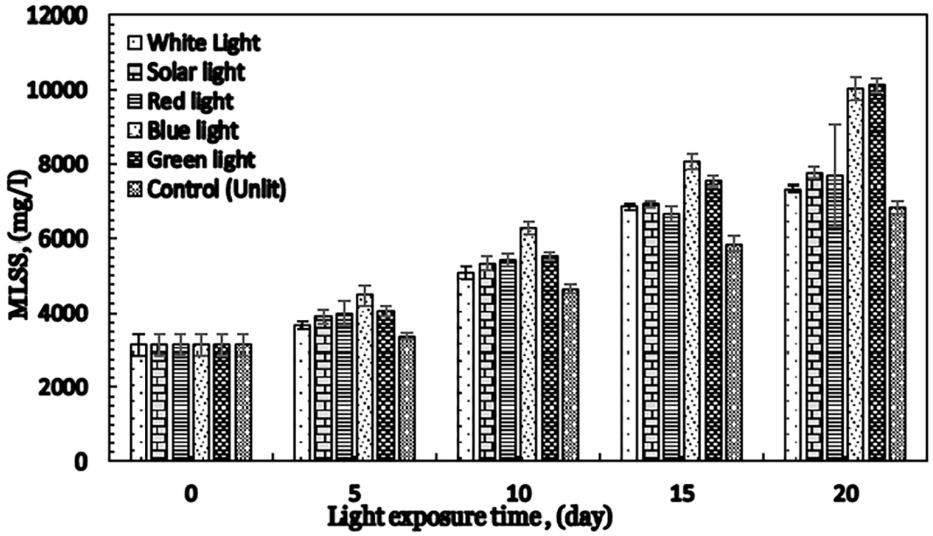

Figure 4. MLSS concentration trends with different LED lights at 2-level intensity

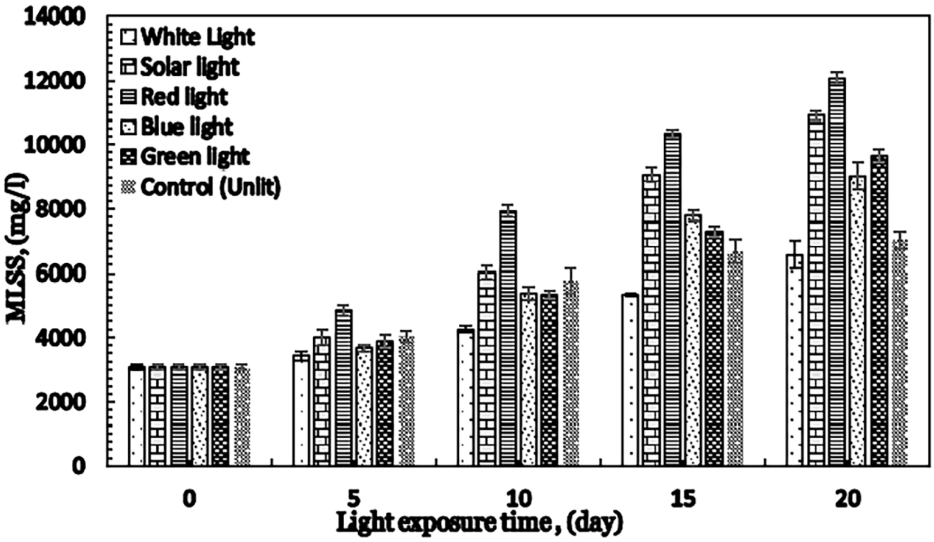

Figure 5. MLSS concentration trends with different LED lights at 3-level intensity

this is in the excellent agreement of Kupchishin et al. (2018); Katam et al. (2022); Sanchez-Sanchez et al. (2023). In moderate-intensity, MLSS concentration reached maximum with green and blue lights 10133.334, and 10033.334 mg/l (control, 6833.334 mg/l) at 20 days, respectively. In the third intensity level, the maximum concentration of MLSS with red and solar LED light reached (12066.667, and 1033.334 mg/l) (control, 9033.334 mg/l) at 20 d respectively. Of note, MLSS with white light was decreased with increasing intensities of levels 2, and 3, Figure 4, Figure 5. This is in excellent agreement with the data of Scott et al. (2010) and Katam et al. (2022), unlike increasing intensity with the rest of the wavelengths. Several experiments were performed using exposure time more than 20 days, which did not significantly affect biomass. Careful examination of the experimental data showed that an exposure time of less than 5 days gives low efficiency in building biomass effectively. Microorganisms may need increased light energy or exposed time to build colonies strong enough to face unfavorable conditions of wastewater accumulation and disturbance in acidity and stability of the medium during the test. There is a good agreement with the results of Blair et al. (2014).

Results of MLVSS

MLVSS concentration at different wavelengths of LED light and exposed time of 0, 5, 10, 15, and 20 days for three intensity levels (low, moderate, and high) are shown in Figure 6–8. ANOVA revealed that the variation of light wavelength was significant ($p < 0.05$) to exposed

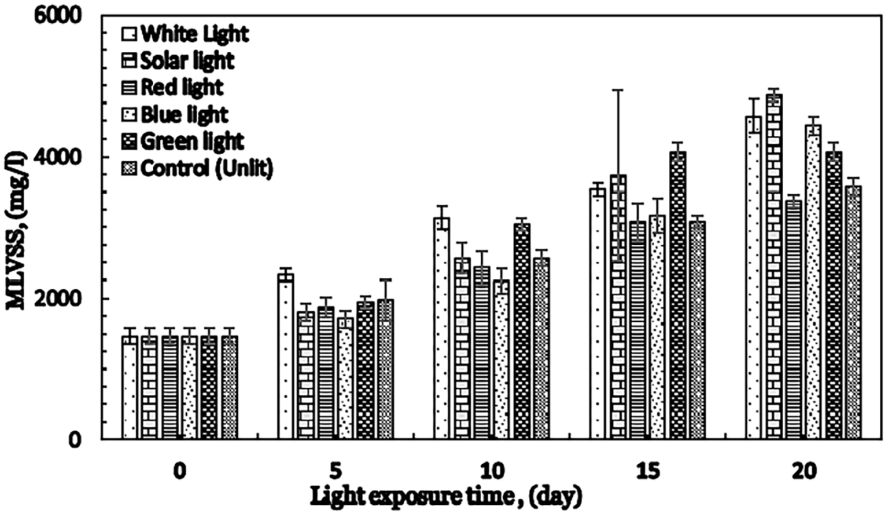

Figure 6. MLVSS concentration trends with various LED lights at 1-level intensity

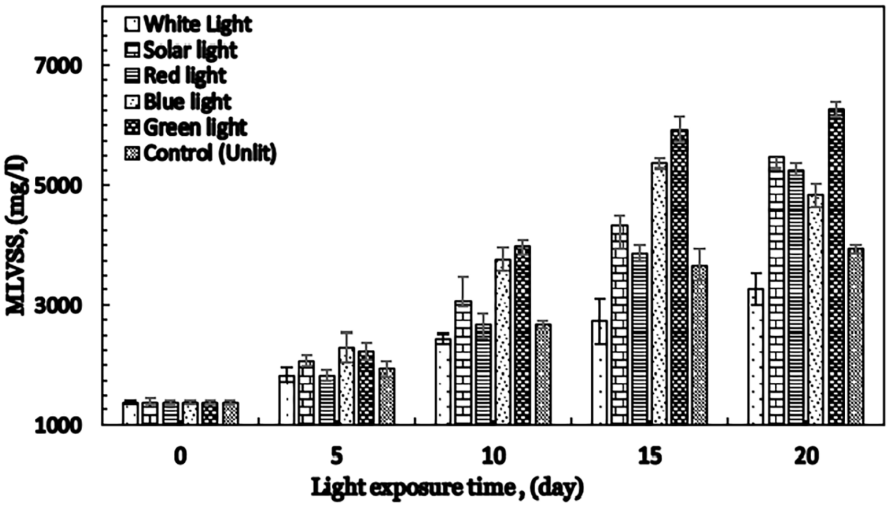

Figure 7. MLVSS concentration trends with various LED lights at 2-level intensity

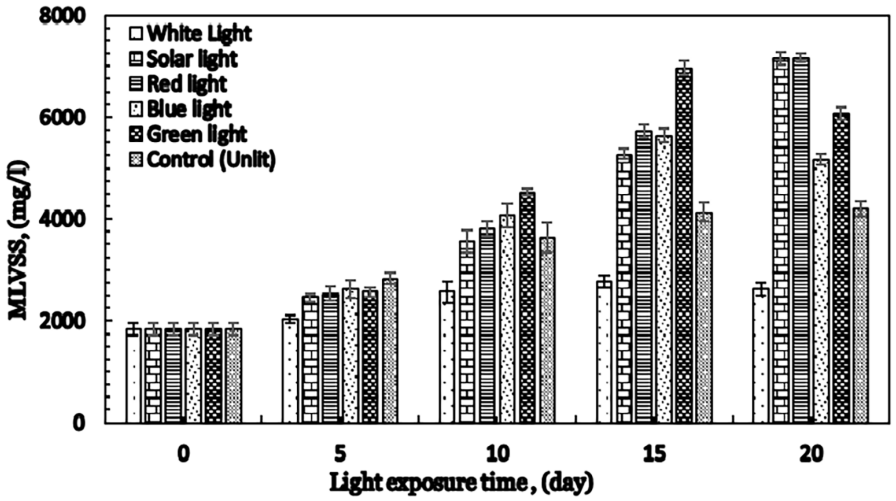

Figure 8. MLVSS concentration trends with various LED lights at 3-level intensity

time. The initial MLVSS concentration of three intensity levels were 1466.667, 1366.667, and 1833.334 mg/l at 0 days respectively. Generally, MLVSS increased from 0 to 15 days and may continue to 20 days. In the low-intensity, MLVSS concentration was best under the blue and white light reach of (4833.334, and 4753.334 mg/l) (control; 3566.667, and 3066.67 mg/l) at 20, and 15 days, respectively, completely agreeing with the data of Blair et al. (2014). Then, green and red lights reached (7966.667 and 7433.334 mg/l) at 20 days, respectively. In moderate intensity, the maximum concentration is achieved under green light, (10133.334 mg/l), in 20 days. Following that, blue, red, and solar reached (10033.334, 7766.667, and 7766.667 mg/l) at 20, 15, and 20 days, respectively.

The specific growth rate for various LED light

Table 3 shows the stimulation and inhibition of the specific growth rate (μ) of MLSS and MLVSS relative (to control) for a single wavelength of LED light with time at three intensity levels (low, moderate, and high). Among wavelengths, the white, red, and solar LED lights achieved the highest growth of MLSS reaching (0.096235, 0.08539, and 0.08539 d^{-1}) at 5,

Table 3. Specific growth rate (μ) of MLSS and MLVSS with time exposure to LED light

LED light	Intensity (W m^{-2})	Specific growth rate (μ) of MLSS at a time of					Specific growth rate (μ) of MLVSS at a time of				
		0 day	5 days	10 days	15 days	20 days	0 day	5 days	10 days	15 days	20 days
White	24±3.72	0	0.09623	0.07792	0.0591	0.05042	0	0.1093	0.0879	0.07839	0.0567
	48±3.81	0	0.05214	0.05925	0.0483	0.04251	0	0.0587	0.0576	0.04372	0.0404
	96±4.02	0	0.0283	0.04198	0.03689	0.03807	0	0.0106	0.0336	0.03208	0.0217
Solar	20±4.01	0	0.0564	0.04530	0.04545	0.04048	0	0.0811	-0.0144	0.01165	0.0077
	40±3.1	0	0.0839	0.06214	0.0436	0.04538	0	0.0921	0.1138	0.08691	0.0693
	60±5.43	0	0.0853	0.06931	0.0785	0.0634	0	0.0593	0.0867	0.07035	0.0614
Red	20±3.03	0	0.03496	0.04671	0.04074	0.03576	0	0.0255	0.0658	0.06462	0.05339
	30±3.21	0	0.04883	0.055	0.05033	0.04473	0	0.0356	0.0901	0.08602	0.06931
	40±4.89	0	0.09317	0.0961	0.0817	0.06903	0	0.0207	0.0962	0.0699	0.0681
Blue	80±2.7	0	0.02529	0.0347	0.04195	0.04592	0	0.0899	0.0726	0.0628	0.05962
	100±2.9	0	0.0709	0.0693	0.06304	0.05819	0	0.0827	0.109	0.08328	0.06992
	120±2.0	0	0.03573	0.0559	0.06223	0.05401	0	0.0207	0.0577	0.0736	0.0564
Green	100±2.7	0	0.0711	0.0573	0.04769	0.04939	0	0.0841	0.0693	0.05924	0.05339
	115±3.1	0	0.0753	0.0916	0.07058	0.05868	0	0.11537	0.0986	0.10664	0.07341
	130±3.4	0	0.0752	0.0815	0.06664	0.05401	0	0.06729	0.0836	0.08086	0.05983

10, and 5 days under low, medium, and high-intensity levels, respectively. The highest stimulation of MVLSS obtained exposed to green, white, and blue LED light reached (0.115377, 0.109309, and 0.109045 d^{-1}) at (5, 5, 10 days) for 1, 2, and 3 – levels intensity, respectively. The specific growth rate (μ) was measured by a culture of activated sludge over time and was determined through a first-order kinetic model, Equation 1 (Rice et al., 2012).

$$\mu = \frac{ln\frac{C}{C_0}}{t_2 - t_1} \quad (1)$$

where: μ – first-order reaction rate coefficient (d^{-1}); C_o – initial concentration of organic material at t_1 (mg/l); C – final concentration of organic material at t_2 (mg/l); t – the number of days (day).

Growth model

The growth rate depended on light intensity and initial biomass (Asadi et al., 2019; Esteves et al., 2024). Van model (Van, 1955) (Equation 2) was used to compare theoretical results with

Table 4. Predicting the average specific growth rate under various intensities using different models

LED light	Model type	Mathematical model formula	Power density (I_{av}) (W/m^2)	MLSS				MLVSS			
				$\mu_{calculated}$	$\mu^a_{experimental}$	r (person correlation)	p-value	$\mu_{calculated}$	$\mu_{experimental}$	r (person correlation)	p-value
White	Develop model[b]	$\mu = \mu_{max}$ [c] (exp((0.55+(I/I_{max}))), for person correlation ((-1)-0)	24	0.0623	0.070923	0.98104	<0.05	0.06229	0.08310	0.98637	<0.05
			46	0.0485	0.050554			0.04851	0.05014		
			96	0.0294	0.036320			0.02942	0.02453		
	Van Oors	$\mu = \mu_{max}(1-exp(-I/I_m))$	24	0.0307	0.070923	(-) 0.981		0.03066	0.08310	(-) 0.9864	
			46	0.0545	0.050554			0.05454	0.05014		
			96	0.0876	0.036320			0.08763	0.02453		
Solar	Develop model	$\mu = \mu_{max}$ (exp (-(1/(0.55+I/I_{max})))), for person correlation (0-1)	20	0.0447	0.046913	0.9862	<0.05	0.04469	0.02152	0.7423	<0.05
			40	0.0609	0.058782			0.06094	0.09055		
			60	0.07270	0.074174			0.07272	0.06948		
	Van Oors	$\mu = \mu_{max}(1-exp(-I/I_m))$	20	0.03930	0.046913	0.9856		0.03930	0.02152	0.7445	
			40	0.06745	0.058782			0.06745	0.09055		
			60	0.08763	0.074174			0.08763	0.06948		
Red	Develop model	$\mu = \mu_{max}$ (exp (-(1/(0.55+I/I_{max})))), for person correlation (0-1)	20	0.05349	0.039549	0.93	<0.05	0.05348	0.05235	0.6797	. <0.05
			30	0.06424	0.049739			0.06423	0.07028		
			40	0.07272	0.085017			0.07272	0.06376		
	Van Oors	$\mu = \mu_{max}(1-exp(-I/I_m))$	20	0.05455	0.039549	0.9286		0.05454	0.05235	0.6824	
			30	0.07315	0.049739			0.07314	0.07028		
			40	0.08760	0.085017			0.08763	0.06376		
Blue	Develop model	$\mu = \mu_{max}$ (exp (- (1/(0.55+I/I_{max})))), for person correlation (0-1)	80	0.06094	0.036986	0.7295	<0.05	0.06094	0.07128	(-) 0.5229	<0.05
			100	0.06728	0.065364			0.06728	0.08624		
			120	0.07272	0.051987			0.07272	0.05213		
	Van Oors	$\mu = \mu_{max}(1-exp(-I/I_m))$	80	0.06745	0.036986	0.7316	<0.05	0.06745	0.07128	(-) 0.5198	<0.05
			100	0.07838	0.065364			0.07838	0.08624		
			120	0.08763	0.051987			0.08763	0.05213		
Green	Develop model	$\mu = \mu_{max}$ (exp (-(1/(0.55+I/I_{max})))), for person correlation (0-1)	100	0.06496	0.056397	0.7295	<0.05	0.06500	0.06651	0.2187	<0.05
			115	0.06904	0.074060			0.06905	0.09853		
			130	0.07272	0.069361			0.07272	0.07292		
	Van Oors	$\mu = \mu_{max}(1-exp(-I/I_m))$	100	0.07439	0.056397	0.7316	<0.05	0.07439	0.06651	0.2216	<0.05
			115	0.0813	0.074060			0.08139	0.09853		
			130	0.0876	0.069360			0.08763	0.07292		

Note: [a] is the average specific growth rate of three levels of intensities for MLSS or MLVSS concentration at (0, 5, 10, 15, 20) days using Equation 4.3 to calculate (μ); [b] developed model by modifying the Van model (1955); [c] μ_{max} = ln (2)/time.

experimental data, depended to *person correlation*. Tests proved that the model may be utilized with high probability to simulate the effect of exposure to certain wavelengths. Usually, the Van model assumes that the growth rate should increase as a function of the population with increasing light intensity for the exponential growth phase. Therefore, the Van model was developed as an accurate predictive model, Equations 3, Equation 4, to simulate the influence of the negative or positive on activated sludge community under various light intensities (other environmental conditions were constant) using the Excel program and *Casio Fx 5800 P* calculator. The maximum predicted growth rate was calculated using the Equation 5. The results of the calculations are listed in Table 4.

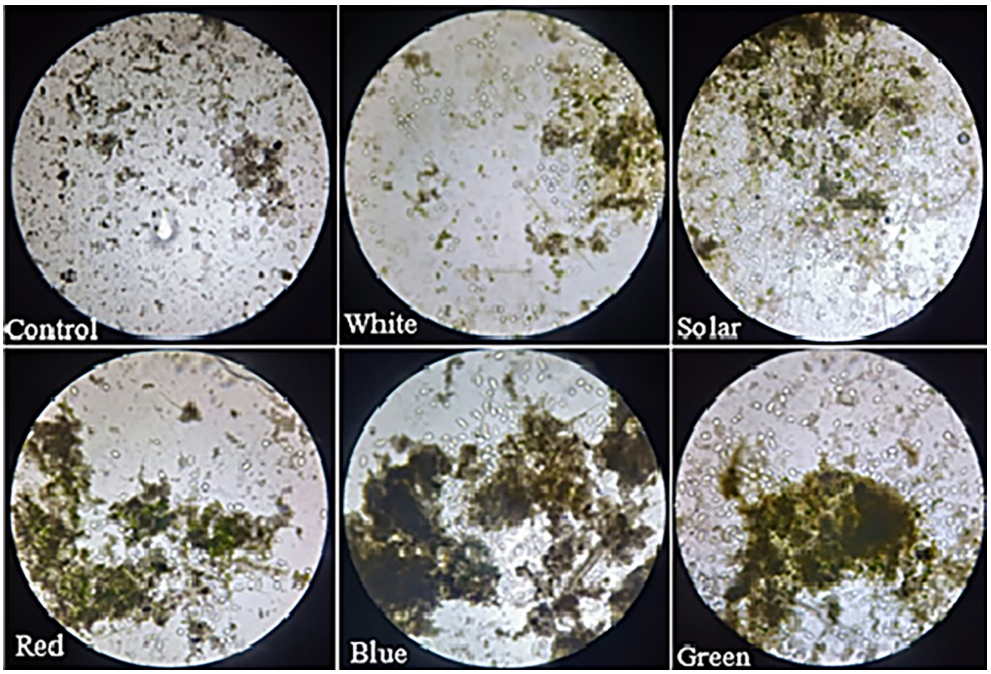

Figure 9. Microscopic images (10×) after exposure to LED light, 3 – level intensity for 5 days

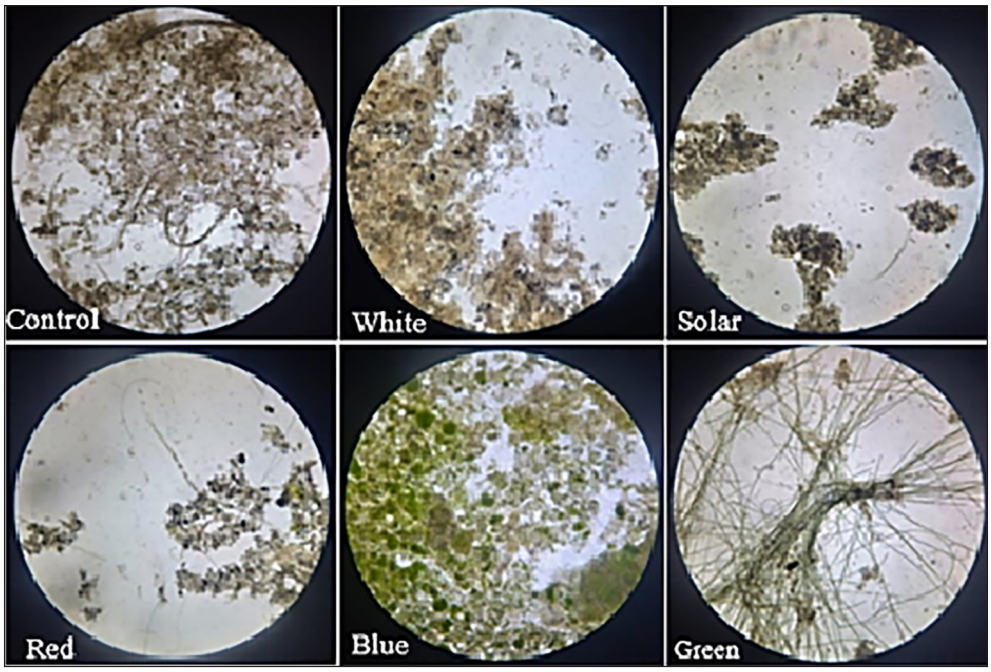

Figure 10. Microscopic images (10×) after exposure to LED light, 3 – level intensity for 20 days

$$\mu = \mu_{max}.(1 - e^{-\left(\frac{I}{Im}\right)}) \quad (2)$$

$$\mu = \mu_{max}.e^{(0.55+\frac{I}{\mathrm{Im}})}$$
for *Person correlation* ((-1)–0) (3)

and

$$\mu = \mu_{max}.e^{-(\frac{1}{0.55+\frac{I}{Im}})}$$
for *Person correlation* (0–1) (4)

$$\mu_{max} = \frac{ln(2)}{Time} \quad (5)$$

where: μ_{max} – maximum specific growth rate (d^{-1}); μ – specific growth rate (d^{-1}); I – average intensity of irradiation (W m^{-2}); I_{max} – maximum intensity of radiation (W m^{-2}).

The developed model showed a positive correlation exceeding (0.98) between μ_{MLSS}, and μ_{MLVSS} and intensity of weight LED light, in contrast to the Van model which showed a high correlation, but negative, otherwise, there was a good agreement in the prediction value, a maximum correlation was excess (0.98, and 0.92) for both models with μ_{MLSS} of solar and red light, respectively. However, the models were in a poor position in predicting μ_{MLVSS} of blue and green LED light with increased intensity. Although, the Van model was used to predict the microalgae growth rate. However, it successfully predicted the growth of the activated sludge biomass for both MLSS and MLVSS. Figures 9, Figure 10 show the effect of exposure to visible light (white, solar, red, blue, and green light) and control (without treatment) at 5 and 20 days of activated sludge community and the resulting transformations at a 3-level intensity level.

STATISTICAL ANALYSIS

Statistical analysis used correlations, one-way, and two-way analysis of variance (ANOVA) significant differences between the levels of study using Excel version 21 at p–value < 0.05.

CONCLUSIONS

The effectiveness of visible LED light on AS biomass was investigated in this paper. The results revealed that the exposure period between (15–20 days) achieved the best biomass productivity for all wavelengths under study (white, solar, red, blue, and green light). In particular, it is observed that there is a direct correlation between MLSS and MLVSS and increasing intensity, except for white light, which was inversely proportional. MLSS and MLVSS concentration reached a maximum with 3-level intensity (red $_{MLSS,\ MLVSS}$; 12066.667, 7166.667 mg/l), and which decreased slightly (solar $_{MLSS}$, $_{MLVSS}$; 10900, 6266.667 mg/l), (control $_{MLSS}$, $_{MLVSS}$; 9033.334, 6066.667mg/l). In 2-level intensity, green and blue LED light reached maxima concentration (green $_{MLSS}$, $_{MLVSS}$; 10133.334, 6766.667 mg/l) at 15 days (blue $_{MLSS}$; 10033.334 mg/l) (control $_{MLSS}$, $_{MLVSS}$; 6833.334, 3933.334 mg/l) on 20 days, respectively. In the 2-level intensity, the maximum MLSS and MLVSS concentrations were 8133.334, and 4833.334 mg/l under white and blue LED light (control $_{MLSS}$; $_{MLVSS}$; 6466.667, 3566.667 mg/l), respectively. The specific growth rate (μ) of MLSS and MLVSS relative (to control) for a wavelength of light with time at 1, 2, and 3 – levels of intensities (low, moderate, and high). Among wavelengths, the white lights achieved the highest growth of MLSS reaching (0.096235 d^{-1}) relative (to control) at 5 days under low intensity. The highest stimulation of MVLSS was obtained when exposed to green LED light, reaching (0.115377 d^{-1}) at 5 days with moderate intensity. Van and developed models were proposed for simulating the fit growth curve of MLSS and MLVSS. These models could predict with an excellent correlation rate that exceeded (r = 0.98) under white and solar LED light exposure.

The paper confirmed the effectiveness of visible light in biological treatment units. Algae, parasites, bacteria, wastewater physical properties, and sludge properties change according to the wavelength used. A model is required to simulate growth stages for microbial under various light intensities. The study highlighted the need for smart reactors to periodically remove sludge, ensure light penetration, and prevent nutrient poisoning. The technique could be applied to continuous flow reactors for further exploration.

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