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# Treatment of Hospital Wastewater Using Activated Sludge with Extended Aeration

María Custodio[1*], Walter Cuadrado-Campó[2], Richard Peñaloza[1], Carmela Vicuña-Orihuela[2], Elmer Torres-Gutiérrez[2]; Edith Orellana[3]

[1] Facultad de Medicina Humana, Centro de Investigación en Medicinade Altura y Medio Ambiente, Universidad Nacional del Centro del Perú, Av. Mariscal Castilla No. 3909, Huancayo, Perú

[2] Universidad Nacional Autónoma Altoandina de Tarma, Jr. Huaraz 431, Tarma, Perú

[3] Facultad de Ciencias Forestales y del Ambiente, Universidad Nacional del Centro del Perú Av. Mariscal Castilla No. 3909, Huancayo, Perú

* Corresponding author e-mail: mcustodio@uncp.edu.pe

## ABSTRACT

Hospital wastewater is of a complex nature and is generally discharged into urban sewage systems. This study evaluated the removal efficiency of organic and biological contaminants from a hospital wastewater treatment plant using extended aeration activated sludge. The study was conducted at a treatment plant scale, with 14 hours of feed. The plant consists of a pre-filter, a collector and crumbler tank, a homogenization tank, two biological reactors of 80 000 liters capacity each, two settlers and a contact disinfection chamber. Three flow rates of 3 L/s, 4 L/s and 5 L/s were tested in each biological reactor, with application of three concentrations of residual chlorine with sodium hypochlorite to the effluent of the settling tanks (0.3 ppm, 0.4 ppm and 0.5 ppm). The removal efficiency of suspended solids varied according to flow rate. The reactor with a flow rate of 3 L/s and 0.5 ppm of residual chlorine achieved the highest removal of suspended solids (91.95%), biological oxygen demand (97.52%) and fecal coliforms (99.99%). Finally, the quality of the hospital wastewater is within the limits of the national and international environmental quality thresholds.

**Keywords:** suspended solids, bacterial load, activated sludge, removal efficiency, hospital wastewater.

## INTRODUCTION

Hospitals play an essential role in human welfare through the health services they provide, but they are also responsible for generating large volumes of wastewater (Parida et al., 2022). In developed countries, a hospital generates 400–1200 L of wastewater per bed per day, while in developing countries a hospital generates 200–400 L/capita/day compared to 100–400 L/capita/day of domestic wastewater generation (Kumari et al., 2020). Hospital wastewater is different in nature compared to wastewater from other sources (El Morabet et al., 2020). The complexity of this type of wastewater has become a global problem due to its stability and persistence in the environment (Rodriguez-Moza and Weinberg, 2010; Verlicchi et al., 2015). In addition, the size of the hospital greatly influences the nature and volume of liquid and solid hospital waste.

Hospital wastewater contains a large amount of emerging, organic and biological contaminants (antibiotic-resistant bacteria, antibiotic-resistant genes, persistent viruses, among others) (Lien et al., 2016; Majumder et al., 2021; Alderton et al., 2021). There are very few regulations related to hospital wastewater in the world established to define how to manage and treat hospital effluents prior to disposal (Verlicchi et al., 2015; (Carraro et al., 2018; Khan et al., 2021a). Traditional urban wastewater treatment plants, which represents a significant risk to public health and aquatic ecosystems that receive these effluents (Perrodin et al., 2013; Luo et al., 2014) do not remove some of these pollutants. The entry of these contaminants into the water resource and food chain through various forms is considered a serious threat to humans and other organisms (Sarizadeh et al., 2021).

Hospital wastewater treatment methods vary in different regions of the world. In most of them, it is discharged unregulated into urban drainage systems and finally released into municipal wastewater treatment plants, where the effluent is mixed before final treatment (Khan et al., 2021a). Currently, studies reveal that the intrinsic toxicity of hospital effluents can be 5 to 15 times higher than that of an urban effluent, as well as the potential inhibition of activated sludge from wastewater treatment plants (Kumari et al., 2020). The fate of emerging organic pollutants in different parts of the world includes freshwater basins, wastewater streams, lakes, rivers, reservoirs, estuaries and marine waters (Ooi et al., 2018).

Globally, there are some guidelines and legislation related to hospital wastewater management and treatment methods. However, in many countries the legislation does not contain limitations on the various indicators (Grandclément et al., 2017; Carraro et al., 2016). However, the elimination of pathogens is the main objective of wastewater treatment for wastewater reuse (Eggen et al., 2014). As a general rule, to assess the degree of contamination of a standard wastewater sample, legislation approves the fundamental physicochemical indicators (temperature, pH, total suspended solids, chemical oxygen demand, biochemical oxygen demand, total nitrogen, total chlorine, adsorbable organic halogens, disinfectants, detergents, heavy metals, total and fecal coliforms, *Escherichia coli*, etc.) and establishes that they be tested prior to disposal. However, the efficiency of wastewater treatment systems is evaluated by their ability to bring these indicators to acceptable levels (Santoro et al., 2015). In this context, the removal efficiency of organic and biological pollutants from a hospital wastewater treatment plant was evaluated using extended aeration activated sludge.

## MATERIALS AND METHODS

### Study area and sampling strategy

The wastewater treatment plant of the Ramiro Priale Priale National Hospital – ESSALUD is located in the central region of Peru, at the geographical coordinates latitude 12° 3' 1.31" S and longitude 75° 13'16.75" W, at an altitude of 3260 meters above sea level. The temperature of the study area generally varies from 5°C to 20°C, with monthly precipitation ranging from 32 mm to 254 mm, with the driest months being June to August and the rainiest months from January to March. The extended aeration activated sludge plant consists of a pre–filter, a collector and shredder tank, a homogenization or equalization tank, two biological reactors of 80 000 liters capacity each, two sedimentation tanks, and a contact disinfection chamber.

Wastewater sampling was performed in the influent to the biological reactors (P1), biological reactors (P2), effluent from the settling tanks (P3), and effluent from the disinfection chamber (P4) (Figure 1a). In the influent to the biological reactors (Figure 1b), three flow rates of 3 L/s, 4 L/s and 5 L/s were experimented for 10 hours and 14 hours of prolonged aeration. The sampling was of the simple systematic type because the flow rate is constant. At each sampling point, 400 ml of wastewater were collected per hour, obtaining one-liter composite samples in Pyrex brand borosilicate glass bottles with sterilized screw caps (Figure 1). The collected samples were kept

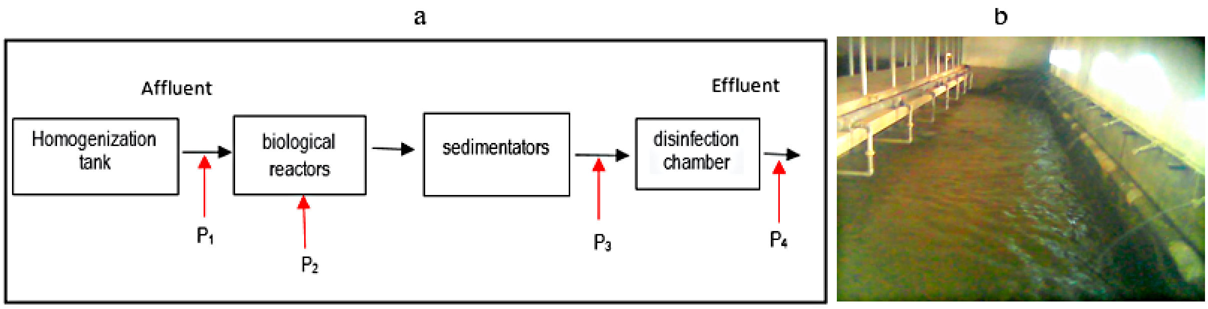

**Figure 1.** Hospital wastewater treatment plant; (a) Sampling points of the treatment plant; (b) Biological reactors

refrigerated at 4°C until processing in the laboratory within 4 h after collection. In the disinfection chamber, concentrations of 0.3 ppm, 0.4 ppm and 0.5 ppm of residual chlorine were applied with sodium hypochlorite for each flow rate.

### Determination of physicochemical parameters

Samples were analyzed using standard methods for drinking and wastewater analysis. Suspended solids (SS) were determined by the total suspended solids method dried at 103–105°C (2540–D), using a Memmert heating and drying oven. Biochemical oxygen demand ($BOD_5$) was determined by the respirometric method (5210–D) using Lovibond oxidirect $BOD_5$ measuring equipment and fecal coliforms (9221–C) by the most probable number (MPN) method (APHA/AWWA/WEF, 2012).

### Determination of pollutant removal efficiency

The pollutant removal efficiency was determined by means of the material balance equation (Davis, 2005; Haddar et al., 2014).

$$\%\ \text{removal} = \frac{Xi_{in} - Xi_{out}}{Xi_{in}} \text{x}100 \qquad (1)$$

Where: $Xi_{in}$ and $Xi_{out}$ – the parameters before and after were treatment. The parameters are suspended solids (mg/L), $BOD_5$ (mg/L) and fecal coliforms (MPN/100 ml).

### Data analysis

The design used in this study was a completely randomized factorial analysis with two factors, the treatments consisting of water flow rates (3 L/s, 4 L/s and 5 L/s) and residual chlorine concentrations (0.3 ppm, 0.4 ppm and 0.5 ppm) and the sampling events (two observations). The F test ($p < 0.05$) was used to evaluate possible differences between treatments (Lopes et al., 2011). The significant difference between treatments was determined by Tukey's test ($p < 0.05$) for the comparison of means with the software R (R Core Team, 2022). The functional analysis of the parameters evaluated and the factors under study were given in relation to their significance according to the ANOVA test (Mackie, 2001). Principal component analysis PCA was used to assess the relationship between different physicochemical variables and multiparametric distribution (Rawat & Joshi, 2019) these analyses were performed using OriginPro software (OriginLab, 2022).

## RESULTS AND DISCUSSION

### Characterization of physicochemical and microbiological parameters of hospital wastewater without disinfection

Table 1 shows the values of the parameters under study under three flow rates at the outlets of the homogenization tank, biological reactor and settler. The mean suspended solids (SS) concentrations in the homogenization tank effluent were similar ($p > 0.05$), revealing that there is no flow rate effect. In the biological reactor effluent, the mean SS concentrations showed significant differences ($p < 0.05$). In the effluent of the sedimentation tank, a similar trend of significant difference ($p < 0.05$) of SS concentrations was recorded, showing good sedimentation properties of suspended particles (Abou-elela et al., 2013). These results are similar to those reported by Carraro et al. (2016) and Chonova et al. (2016) who specify that the variability of

**Table 1.** Suspended solids concentrations, biological oxygen demand and fecal coliform in hospital wastewater treatment plant without disinfection

| Sampling phase | Parameters | Flow rates (Mean ± SD) | | |
|---|---|---|---|---|
| | | 3 L/s | 4 L/s | 5 L/s |
| Homogenization tank effluent | Suspended solids (mg/L) | 86.68 ± 2.22 d | 72.98 ± 1.89 d | 80.00 ± 2.34 d |
| | $BOD_5$ (mg/L) | 383.4 ± 1.64 c | 418.84 ± 1.12 b | 537 ± 1.55 a |
| | Fecal coliforms (MPN/100 ml) | 700 ± 5.0 f | 840 ± 4.0 e | 1100 ± 7.0 d |
| Biological reactor effluent | Suspended solids (mg/L) | 340 ± 1.47 c | 390 ± 3.30 b | 520 ± 2.78 a |
| | Fecal coliforms (MPN/100 ml) | 3500 ± 6.0 a | 1700 ± 5.0 b | 1100 ± 5.0 d |
| Effluent from settling tanks | Suspended solids (mg/L) | 7.9 ± 0.14 f | 18.8 ± 1.5 ef | 34.40 ± 1.18 e |
| | $BOD_5$ (mg/L) | 10.00 ± 1.0 e | 15.30 ± 1.0 de | 18.44 ± 0.94 d |
| | Fecal coliforms (NMP/100 ml) | 1700 ± 7.56 b | 1300 ± 7.48 c | 1100.0 ± 4.44 d |

SS concentration is a function of wastewater flow rate. The mean $BOD_5$ concentrations showed significant differences ($p < 0.05$) in the homogenization tank effluent. This behavior revealed that the flow rate is a factor that influences the $BOD_5$ concentration, and that this distribution is maintained in the effluent of the sedimentation tank for this parameter. These results are consistent with several studies that refer that the lower the flow rate, the lower the $BOD_5$ concentration, since the oxygen uptake rate correlates with the influent loads (Abu ghararah, 2008; Verlicchi et al., 2015; Hocaoglu et al., 2021). Furthermore, they coincide with Boillot et al. (2008) who report that the concentration of $BOD_5$ measured in hospital effluents (10 to 18.44 mg/ml) is quite low compared to an urban effluent (100 mg/ml – MINEN, 2010). With respect to fecal coliforms, significant differences ($p < 0.05$) were recorded throughout the process according to mean concentrations and flow rate. In the effluent of the sedimentation tank, a significant decrease of fecal coliforms was observed. This decrease reveals the presence of other microorganisms that favor the decomposition of organic pollutants, which improves the process of elimination of biogenic compounds (Michalska & Mrozik, 2018).

## Treatment of hospital wastewater by residual chlorine application

Hospital wastewater was treated continuously at the treatment plant based on the application of three concentrations of residual chlorine (0.3 ppm, 0.4 ppm and 0.5 ppm) and flow rate (Table 2). The SS and $BOD_5$ results for the 3 and 4 L/s treatments with 0.5 ppm residual chlorine removed significant concentrations of these parameters. The results revealed that SS, $BOD_5$ and fecal coliforms presented values below the maximum permissible limits for hospital effluents (150 mg/L, 100 mg/L and fecal coliforms 10 000 MPN/100 ml, respectively) (Khan et al., 2021b). This behavior is probably due to the antimicrobial activity of the antibiotic and disinfectant residues present in the hospital effluents. In addition, at this concentration of residual chlorine and the three flow rates, a significant removal of fecal coliforms was observed. However, the $BOD_5$ in the outflow water of the three treatments at 5 L/s was higher than that of the other flows. On the other hand, the discharge of hospital wastewater with $BOD_5$ concentrations above the maximum allowable limits could affect the ecological health of the receiving water bodies (Agboola et al., 2016; Al-Kubaisi et al., 2021). Therefore, the addition of chlorine in treated water is necessary to eliminate pathogenic bacteria (Verlicchi et al., 2015) and maintain safety for reuse (Desye et al., 2021). Although less effective in eliminating viruses, as they have a higher tolerance to chlorine compounds than bacteria.

The analysis of variance of the removal efficiency for each study parameter is shown in Table 3. The flow factor showed significant effect ($p < 0.05$) on the values of suspended solids (SS) and biochemical oxygen demand ($BOD_5$) removal

**Table 2.** Water treated parameters assessment under factor of application of residual chlorine and flow in outlet disinfection tank

| Disinfection | | | |
|---|---|---|---|
| Parameter | Application of residual chlorine | | |
| | 0.3 ppm (mean) | 0.4 ppm (mean) | 0.5 ppm (mean) |
| With a flow rate of 3 L/s | | | |
| Suspended solids (mg/L) | 7.5 | 7.5 | 7 |
| $BOD_5$ (mg/L) | 10 | 9.5 | 9.6 |
| Fecal coliforms (MPN/100 ml) | 270 | 84 | 0 |
| With a flow rate of 4 L/s | | | |
| Suspended solids (mg/L) | 18.3 | 18 | 18 |
| $BOD_5$ (mg/L) | 15.2 | 15.25 | 14.91 |
| Fecal coliforms (MPN/100 ml) | 220 | 76 | 0 |
| With a flow rate of 5 L/s | | | |
| Suspended solids (mg/L) | 33.7 | 33.68 | 33.65 |
| $BOD_5$ (mg/L) | 17.82 | 17.44 | 17.5 |
| Fecal coliforms (MPN/100 ml) | 240 | 72 | 0 |

**Table 3.** Summary of ANOVA results expressed as F-statistics: Flow, residual chlorine concentration (RCC), interaction of Flow × RCC for parameters in water of treatment systems in percentage

| F-statistics | | | |
|---|---|---|---|
| Factors | SS | $BOD_5$ | FC |
| Flow | 4206.74** | 41.5** | 193.14** |
| RCC | 0.5 | 0.25 | 2944.72** |
| (Flow x RCC) | 0.2 | 0.07 | 91.15** |
| CV (%) | 18.88 | 0.5 | 15.1 |

**Note:** significance level ** 0.01, * 0.05.

efficiency. While in fecal coliform (FC) removal, significant interactive effects ($p < 0.05$) were observed between the factors of flow rate and residual chlorine concentration ($p < 0.05$).

Table 4 shows the removal efficiency of the studied parameters and the respective significant difference ($p < 0.05$). The decreasing order of SS removal efficiency in the treatments was 3 L/s > 4 L/s > 5 L/s. The highest SS removal efficiency in the 3 L/s flow rate treatments was observed at 0.5 ppm residual chlorine with a mean value ranging from 91.34% to 91.95%. The $BOD_5$ removal efficiency in the treatments was 3 L/s > 5 L/s > 4 L/s. The highest $BOD_5$ removal efficiency was recorded at 0.4 ppm residual chlorine (3 L/s) and the mean values ranged from 97.39% to 97.52%. These results are in agreement with the $BOD_5$ removal efficiency reported for municipal wastewater of 90– 98% (Pahlavanzadeh et al., 2018; El Morabet et al., 2020). The highest FC removal efficiency (99.99%) was recorded in the treatments with 0.5 ppm residual chlorine at all three flow rates. However, the FC removal efficiency (%) observed at the three flow rates at 0.4 ppm was high (88 ± 1.41 – 93.45 ± 0.35). In general terms, these results are similar to the observations reported by Rivas et al. (2011) who complementing urban wastewater treatment used coagulant agents to improve SS removal in aerobic processes and by Thirugnanasambandham and Ganesamoorthy (2019) who reported 93% removal in anaerobic processes. In the case of the hospital wastewater considered in this work, SS showed good sedimentation properties without the external addition of coagulants.

Among the events studied, $BOD_5$ and SS parameters were significantly flow-dependent. $BOD_5$ fitted a quadratic curve with respect to flow rate (Figure 2a), showing a minimum peak at the 4 L/s flow level and indicating that at lower flow the $BOD_5$ removal efficiency is better. While the linear regression for SS was a better fit to the flow rate, the linear regression for $BOD_5$ removal efficiency is better at lower flow rates (Figure 2b). In addition, this parameter showed that the lower the flow rate, the higher the suspended solids removal efficiency. Considering the significant effect of the factors (flow and RCC) on the FC removal efficiency parameters, the models were converted into equations as shown in Figure 2. The coefficients of determination of the model curves were raised to 0.98 and 0.99 for FC. All F–test values were well below 0.05 as shown in Figure 5. FC concentrations tend to rise with increasing RCC and flow rate (Figure 3).

Treated hospital wastewater tends to be less loaded than municipal wastewater (Chonova et al., 2016). However, the danger lies more in the presence of bacteria multiresistant to antibiotics (Carraro et al., 2016) and impact on human

**Table 4.** Comparison of the mean values of removal efficiency between the interaction of flow and residual chlorine concentration (RCC) and their respective standard deviations

| F-statistics | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow - RCC | SS (%) | | | | $BOD_5$ (%) | | | | FC (%) | | | |
| 3 L/s -0.3 ppm | 91.34 | ± | 0.91 | a | 97.39 | ± | 0.55 | bc | 61.43 | ± | 0.07 | a |
| 3 L/s -0.4 ppm | 91.34 | ± | 0.48 | a | 97.52 | ± | 0.20 | c | 88.00 | ± | 1.41 | d |
| 3 L/s -0.5 ppm | 91.95 | ± | 0.49 | a | 97.49 | ± | 0.13 | bc | 99.99 | ± | 0 | f |
| 4 L/s -0.3 ppm | 74.93 | ± | 0.74 | b | 96.36 | ± | 0.06 | a | 73.80 | ± | 1.13 | b |
| 4 L/s -0.4 ppm | 75.34 | ± | 0.34 | b | 96.35 | ± | 0.07 | a | 90.50 | ± | 0.71 | d |
| 4 L/s -0.5 ppm | 75.34 | ± | 0.65 | b | 96.45 | ± | 0.10 | a | 99.99 | ± | 0 | f |
| 5 L/s -0.3 ppm | 57.87 | ± | 0.95 | c | 96.68 | ± | 0.11 | ab | 78.18 | ± | 0.25 | c |
| 5 L/s -0.4 ppm | 57.90 | ± | 0.49 | c | 96.73 | ± | 0.07 | abc | 93.45 | ± | 0.35 | e |
| 5 L/s -0.5 ppm | 57.94 | ± | 0.34 | c | 96.74 | ± | 0.06 | abc | 99.99 | ± | 0 | f |

**Note:** means followed by the same letter in columns do not differ significantly by Tukey ($p < 0.05$).

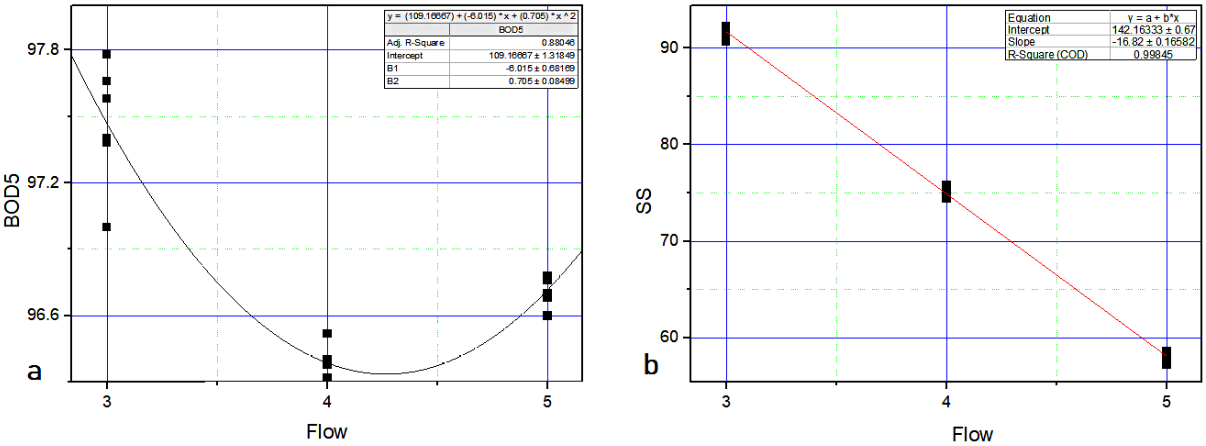

**Figure 2.** Functional analysis that relates the effects of the treatments on the $BOD_5$ (a) and SS parameters (b) with a single significant factor (flow) according to the ANOVA test

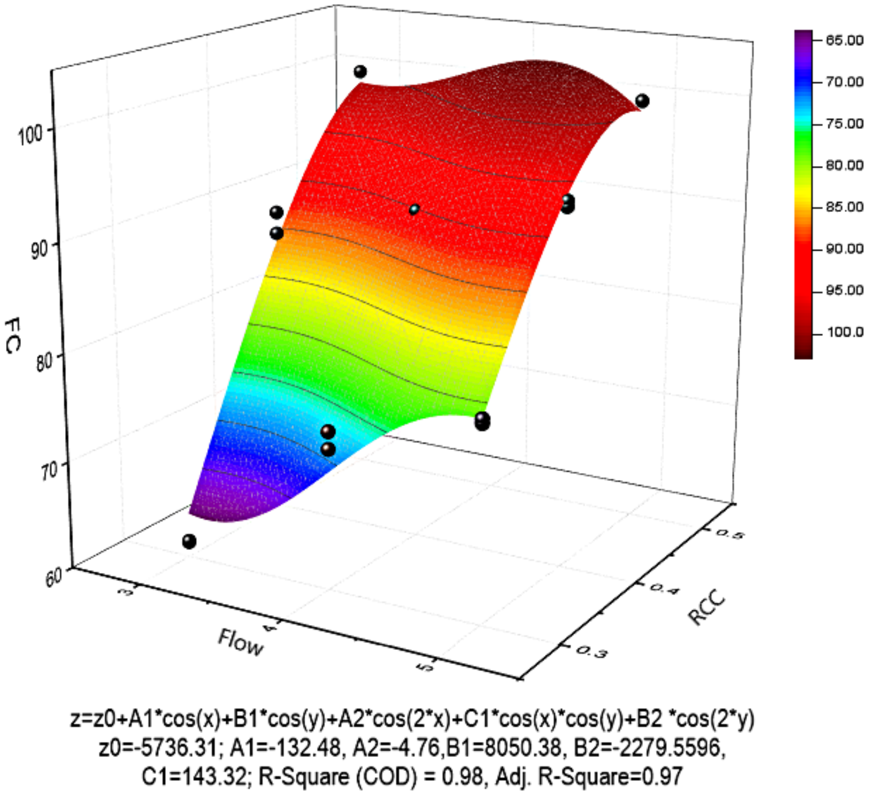

**Figure 3.** Functional analysis that relates the effects of the treatments on the FC parameter with two significant factors (flow and RCC) according to the ANOVA test

health and the environment. Principal component analysis for the efficiency of the treatments used revealed that the best alternative for removal is the flow treatment at 3 L/s and with residual chlorine treatment of 0.5 ppm. The loadings for these parameters were 0.80 for SS removal values and -0.58 for FC removal at PC1. While for PC2 the highest load was presented by the FC removal values with 0.8 followed by SS removal with a value of 0.59. The variance for PC1 had a value of 61.75%, determining that it is the SS removal that significantly determines the distribution of the treatments and that it would be determined by the flow rate. While PC2 with a variance of 38.22% indicated that there are differences in the FC removal values due to the effect of the treatments, according to the chlorine concentrations (Hassan & Hussein, 2021; Mirzaei

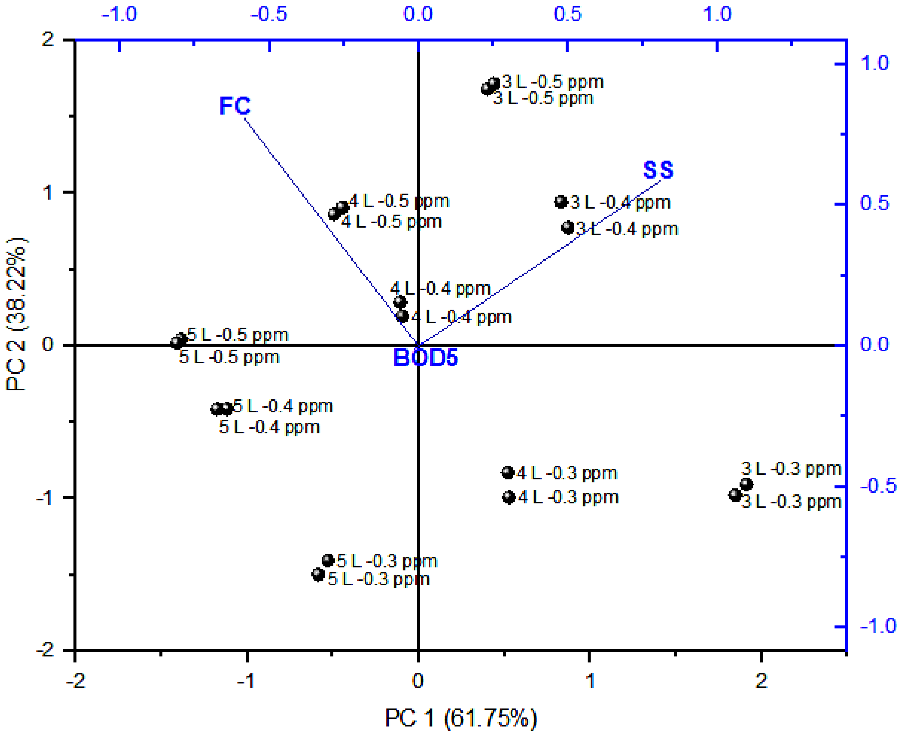

**Figure 4.** Principal component analysis biplot showing the removal efficiency of water quality parameters evaluated under different treatments

et al., 2015). In addition, it was found that any of the treatments decreased $BOD_5$, which is why the loadings were not significant in the principal component analysis. Figure 4 presents principal component analysis biplot showing the removal efficiency of water quality parameters evaluated under different treatments.

## CONCLUSIONS

In developing countries, direct chlorination or primary treatment followed by chlorination are the most commonly used methods for treating and, in particular, disinfecting hospital effluents to prevent the spread of pathogenic microorganisms. This study investigated the SS, $BOD_5$ and FC removal efficiency of hospital wastewater by the activated sludge method with flow rates 3 L/s, 4 L/s and 5 L/s in two parallel reactors and the application of sodium hypochlorite in the disinfection chamber at 0.3 ppm, 0.4 ppm and 0.5 ppm. The highest SS removal efficiency was recorded in the treatments with flow rates of 3 L/s at 0.5 ppm residual chlorine (> 90%), of $BOD_5$ in flow rates with 3 L/s at 0.4 ppm residual chlorine and of FC in the treatments with the three flow rates studied at 0.5 ppm residual chlorine. Further studies are required with a greater number of parameters to be evaluated in hospital wastewater to determine their impact on removal efficiency.

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