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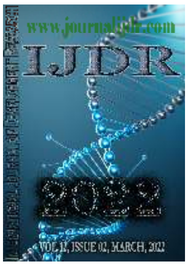

RESEARCH ARTICLE

OPEN ACCESS

GRAYWATER TURBIDITY REMOVAL BY COAGULATION/ FLOCCULATION/ DECANTATION US-ING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

The gray waters from washing machines are the ones that show the easiest treatment due to their physical, chemical, and microbiological characteristics. This study characterized the samples of gray water generated in a laundry in Palmas-TO and applied the coagulation/ flocculation/ decantation test, analyzing the removal of turbidity to determine the statistical model that represents the efficiency of the adopted process. Bench tests were carried out simulating a gray water treatment process: coagulation, flocculation, sedimentation, and filtration in a sand filter using the Jar-Test equipment with the use of aluminum sulfate coagulant, and the factorial plans were also made: fractional factorial design (FFD) and central rotational composite design (CRCD). For the characterization of the samples, the following results were obtained: pH (9.2), temperature (25ºC), turbidity (112uT), COD (200 mg / L), and alkalinity (241 mg / L). In the DFF process, turbidity responses between 7.8 uT and 28.1 uT are observed, and according to the Pareto graph, the greatest effects on the sample's turbidity result were the coagulant dosage variables (9.45) and sedimentation time (-10.70). In the CRCD process, the turbidity result between 5.2 and 26.1 uT was obtained through a regression model and according to the Pareto graph, the two variables X1 Dosage (mg / L) and X2 Sedimentation Time (min) showed considerable significance for the response. Through the analysis of variance, the R^2 coefficient reached by the regression was 0.9641, showing a good fit of the model. The results determined the statistical model that represents the removal of gray water turbidity through the coagulation/flocculation/decantation process.

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INTRODUCTION

The disorderly population growth, coupled with the advancement of living standards, has as a consequence several environmental problems that have not been adjusted, often, in a more appropriate way. Among these, the generation of Greywater and the difficulties of its reuse, due to the physical and chemical substances present, stand out (ADASA, 2018). Water is the essential condition for the life of every plant, animal or human being and without it, vegetation, climate, agriculture, etc., could not be conceived. According to Article 30 of the Universal Declaration of Human Rights in 2005, the right to water is one of the fundamental human rights: the right to life. In short, it is the most substantial natural resource for the evolution of humanity, very precious and limited. For many years there has been a stable relationship between availability in nature and human consumption, however, with population growth and globalization, this resource has become increasingly scarce. With the unbridled increase of cities due to population growth, factors such as the increase in a load of effluents discharged into springs, reduction of green areas, and the increase in water demand (UN, 2008). According to the Water, Energy and Sanitation Regulatory Agency of the Federal District - ADASA (2017), in Brazil, the commercialization of rainwater harvesting and greywater reuse systems began in the early 2000s. And even with not-yet-proven viability, we observe, every year, buildings implementing these non-drinking water building systems for the sake of sustainability. If on the one hand, the practice of water uses and reuse is stimulated by issues related to low water availability and the constant increase in demand for water, on the other hand, its investment costs can create an obstacle to its implementation (ADASA, 2017). The development of technologies and alternative solutions is extremely important since the population growth makes the demand for water resources increase more and more and the incentive for the rational use of water is a way to prevent scarcity.Alternative methods to mitigate the problem of obtaining water are being employed in several cities around the world. Techniques such as rainwater harvesting and use, the use of desalinated seawater, and the use of reused water (gray and black) are alternatives to improve the use of water resources.

Despite the lack of fiscal and economic incentives to subsidize water reuse technologies, the legislative power, and public agencies (federal, state, and municipal) have been presenting a series of laws and resolutions that stimulate, directly or indirectly, the use of rainwater and water reuse in buildings. Resolution No. 54/2005 of the National Council of Water Resources - CNRH offers legal support for the practice of greywater reuse in the built environment. In the Federal District, with District Laws that make it mandatory to capture, store and use rainwater in new urban buildings for the granting of habit-se (ADASA, 2017). According to Gewehr (2009), the environmental sanitary conditions in Brazil are far below the level designed by the National Council on the Environment - CONAMA. This work consists in carrying out the treatment of greywater from an industrial laundry to remove turbidity through coagulation/ flocculation/ decantation tests, analyzing its characteristics, and indicating the statistical model that represents the efficiency of the adopted process. During graywater treatment for reuse, different systems are proposed, from simple processes such as sand filters to more complex processes such as biological reactors. It is important to mention here that most treatments are preceded by a solid-liquid separation step (removal ofturbidity). What is the behavior of coagulants (traditionally used in water supply treatment) in removing turbidity from Graywater?

BACKGROUND

According to studies conducted by ADASA (2017), it can be concluded that with the current need for water reuse, a new model of decentralized supply is emerging in the country, which uses alternative sources of water for non-potable uses. Graywater reuse systems are prepared to promote significant reductions in building consumption and ensure a continuous supply in the main water-consuming activities in case of supply cuts. Measures such as the above, taken on a large scale, can reduce the impacts generated by the exploitation of water resources. For example, lower energy consumption and less use of chemicals for both water and sewage treatment, in addition to the reduction of waste from water and sewage treatment (ADASA, 2017). In the case of large-scale laundries, most of them use in their activities water from deep tube wells, which do not need to go through a treatment process, so they emit all the wastewater into the sewage system (MENDONÇA, 2019). In this sense, it is substantial to analyze the characteristics of the effluent from the laundries. Toverify the characteristics obtained after being submitted to coagulation/flocculation/decantation tests to define the classification in possible uses according to the norms and procedures defined by the CNRH and State Councils of Hydric Resources. Therefore, research is essential for the regulation of the practice of greywater reuse to be performed from well-defined and appropriate technical standards. Therefore, it is interesting to evaluate the possibility of reuse of greywater generated in commercial and industrial laundries in the city of Palmas-TO, so that the results can support the statistical model that represents the efficiency of the process adopted in the work.

OBJECTIVES

General Objective: Study the removal of turbidity from graywater using the coagulation/flocculation/decantation test.

Specific Goals:

Characterize the industrial laundry greywater samples through physicochemical analysis;

- Apply the coagulation/flocculation/decantation process for removing turbidity from industrial laundry greywater in a bench test format;
- Determine the statistical model that represents the removal of turbidity from graywater using the coagulation/ flocculation/ settling process.

REVIEW OF LITERATURE

Water

In the world: Water is an integral part of planet Earth. It is a fundamental element of nature's dynamics, drives all cycles, sustains life, and is the universal solvent. Without water, life on Earth would not be viable. Water is useful for human beings for their vital functions as well as for a wide range of activities, for example, food and energy production, navigation, industrial, economic and agricultural development (TUNDISI, 2003). According to the National Water Agency - ANA (2018), the land surface, upon receiving precipitation, reacts with the soil through infiltration, surface runoff, and percolation. Contributing in this way to water recharge, both in the form of feeding groundwater flows and discharges into surface reservoirs, as well as soil and atmospheric moisture. According to Figure 1, the total amount of water on Earth is considered to be 1,386 million km³, of which 97.5% of the total volume forms the oceans and seas, and only 2.5% is freshwater.

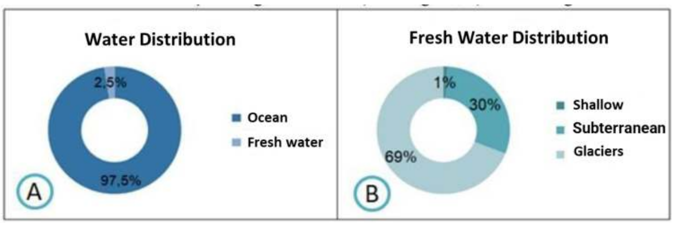


Figure 1. Distribution of water on Earth

In Brazil: According to data from the United Nations Organization - UNO (2007), in May 2007, the urban world population surpassed the rural one. The Brazilian urban population had already surpassed the rural one in 1960. Although this segmentation between urban and rural is not well defined, data from the Brazilian government indicated that in 1996 about 80% of the Brazilian population lived in urban areas and only 21.7% lived in rural areas (IBGE, 1998). It is noteworthy that this concentration of the urban population has influenced the decrease in the indices of specific water availability, a reason for concern for governments and society. According to Figure 2, the sector that consumes the most water in metropolitan regions is irrigation, with approximately 66%. The activities that consume the least are thermoelectric power plants and mining (ANA, 2018.).

Grey Waters: According to the National Council of Hydric Resources (CNRH) in its Art. 2, the following definitions (BRASIL, 2005):

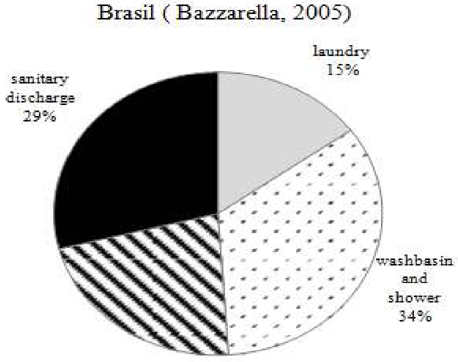
Wastewater: Sewage, discarded water, liquid effluents from buildings, industries, agribusiness, and agriculture, treated or not; II - water reuse: the use of wastewater; direct water reuse: planned use of reuse water, conducted to the place of use, without prior release or dilution in *surface* water bodies or underground. The quality of greywater can change depending on the location, lifestyle, social class, culture, and customs of the residents and due to the amount of occupancy in the dwelling. They can also present different characteristics depending on the sampling point (JOVENTINO, 2010). Among the residuary waters, the gray waters (CA) are highlighted, so-called because they present a coloration between drinking water (clear) and raw sewage (dark brown), as shown in Figure 3. In addition to the concepts of blackwater and greywater, Otterpohl (2001) adds the terms yellow-water for wastewater represented only by urine, and brown-water for wastewater represented only by feces. According to Eriksson *et al*. (2002) graywater is divided into light and dark graywater, with light graywater coming from the shower, sink, and washing machines, and dark graywater coming from the kitchen sink and dishwashers.

Figure 2. Water consumption by sector in Brazil's metropolitan regions

Source: Adapted from Mohamed (2011), Allen *et al*. (2010), and Eriksson *et al*. (2002).

Figure 3. Illustration of the transition between black water and gray water - dark and clear

Graywater Composition: Peprah *et al*. (2018) discusses that lifestyle and type and amount of chemicals used in cleaning, bathing, and laundry are reflective of the constitution of graywater that the composition of graywater. The quality of drinking water and the way it is distributed also affect the characteristics of greywater. There will be variations in the composition of the graywater linked to the variation between water consumed and greywater generated in each activity. As for the physical parameters, according to May (2008), turbidity and suspended solids are responsible for indicating the content of particles and their existence can cause clogging of the greywater collection, treatment and distribution system. By using fine grids or sieves, the removal of coarse solids is obtained; mitigating the risk of clogging. According to May (2008), the chemical parameters analyzed in graywater are distributed into four groups: nitrogen compounds; phosphorus compounds; organic compounds; and other parameters (pH, dissolved oxygen, conductivity, alkalinity, hardness, chloride, and oils and greases). The organic matter identified in gray waters comes from body waste, hair, soap, oils, grease, etc.; while the inorganic matter is the result of chemicals and detergents used for cleaning. Regarding the biological parameters, pathogenic microorganisms (protozoa, bacteria, viruses, and helminths) can be a danger of contamination for users exposed to untreated wastewater. Urine should not be found in greywater, but its presence is common in water from the shower, urine is generally sterile and harmless, but infections can be motivated by pathogens in urine (MAY, 2008). Typically, Graywater contains high concentrations of easily degradable organic matter, among them nitrates and their derivatives, phosphorus, and its derivatives, and some may include microorganisms such as fecal coliforms and salmonella. Peprah *et al*. (2018) reiterate that the composition of greywater is difficult to predict, especially when there is a chance that it may peradventure contain pharmaceuticals, aerosols, paints, and heavy metals such as lead, nickel, cadmium, copper, mercury, and chromium in reasonable amounts. Figure 4 shows the average composition of domestic wastewater generated in Brazil, according to research by Bazzarella (2005), in which 29% of domestic wastewater would be composed of black water and 71% would be composed of gray water.



Source: Mendonça (2019).

Figure 4. Average composition of domestic wastewater generated in Brazil

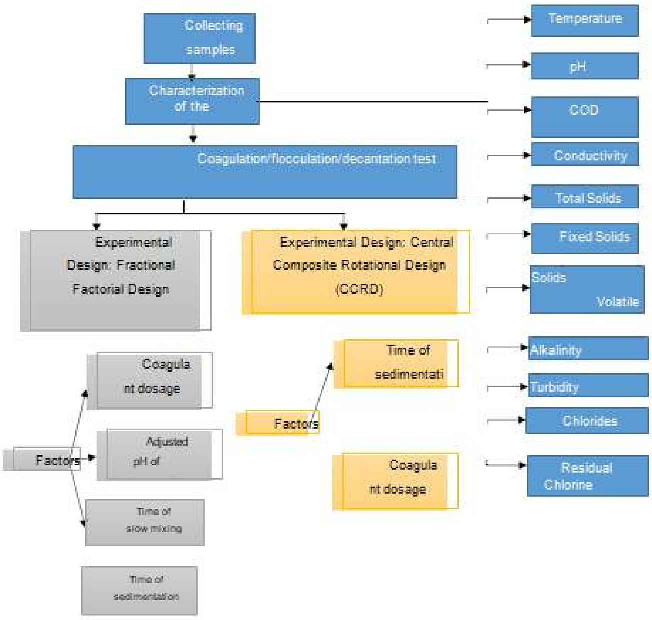
According to Gonçalves (2006), of all the drinking water consumed, around 40% is used for non-potable purposes. Shouler *et al.* (1998 *apud* Lazarova *et al*., 2003) point out that in homes, about 30% of drinking water is used for toilet flushing and 60% in commercial buildings. About graywater generated in laundries, the main characteristics of water from automatic washing machines are high hydrogen potential (pH), hotter water, presence of bleaches, nitrate, oil, and grease, oxygen demand, salinity, soaps, suspended solids, and high turbidity (MOHAMED, 2011).

A Brief History of Greywater Use: The first historical evidence of water reuse for irrigation refers to the Bronze Age in Crete, approximately 5000 years ago. In more current history, it refers to the 1500s to 1800's experiences with what was called "sewage farms". These farms were used for public health protection and pollution control, as they used sewage as a source of nutrients for agriculture (ANGELAKIS *et al*., 2015).

Advantages of Greywater Treatment: The simplest way to reuse greywater is to accumulate the water from the washing machine in a barrel, using a bucket for its extraction in floor washing. The 'barrel & bucket' practice is very common in medium to low-income households and is popularly performed on cleaning days - using the gray water from the machine on the same day, to avoid the degradation of untreated effluent (ADASA, 2017). The reuse of greywater besides reducing the consumption of potable water also reduces the volume of water discharged into the sewage system. Langergraber and Muellergger (2005) consider one of the major problems of sewage treatment to be the mixing of small amounts of potentially harmful substances with large amounts of water. Hespanhol (2008) ensures that Graywater has the potential for reuse for non-potable purposes when properly treated. And presents as relevant advantages of its treatment, the small variation of flow during the year, ease of collection, and lower concentration of organic load and thermotolerant organisms, requiring, thus, lower levels of treatment than sanitary sewage. The reuse of greywater in isolated systems in buildings makes the direct distribution to points of external use by gravity or pumping. Usually, they find two types of systems: the raw greywater detour system; and the pressurized treated greywater system (ADASA 2017). Raw greywater detour systems are responsible for subsurface irrigation, while pressurized treated greywater systems are used in sprinkler irrigation and floor washing (ADASA, 2017). Normally, the integrated systems transfer the treated water to a distribution reservoir located on the roof of the building. By gravity, internal and external points of use are supplied for non-potable use in sanitary flushing, taps for general use, and garden taps, among others. The distribution of non-potable water can be mixed. To this end, a pressurizing pump is used for direct supply to external points of use, for indirect supply utilizing a pump to the distribution reservoir (ADASA, 2017).

MATERIALS AND METHODS

Figure 5 presents the schematic drawing with all the activities developed during this research. The gray water used was collected from an industrial laundry, located in the city of Palmas, Tocantins. The water from the washing machine was collected in a plastic container with a capacity of 100 liters. The experimental tests of sample characterization were performed in the Laboratory of Water and Wastewater of the Federal Institute of Tocantins, Palmas campus. In the sample reservoir, the pH was adjusted by adding a 1:9 hydrochloric acid solution to a value close to neutral (6.5 to 7.5). pH measurements were made throughout the addition of the acid solution.



Source: The author himself

Figure 5. Schematic drawing of the activities to be performed

Coagulation/flocculation/Decantation Test: For the coagulation test, the Jartest equipment (Milan®, model JT-203/6) with six vats was used, and each sample contained 2 L of gray water with the pH adjusted (Figure 6). During the rapid mixing, a speed of 160 rpm was adopted for 10 minutes. Aluminum sulfate 1% solution was used as a coagulant. For the pH adjustment of the gray water solutions of hydrochloric acid - HCl 1 mol/L and sodium hydroxide - NaOH 1 mol/L were used.

Experimental Design: Fractional Factorial Design (2^{4-1}) - DFF $_2$ 4-1: It was verified by multivariable planning the effect of four factors in coagulation, flocculation, and sedimentation tests to obtain the best responses in turbidity removal. The Fractional Factorial Design (2^{4-1}), with 8 experiments, was used in this stage of the research, as shown in Figure 7.

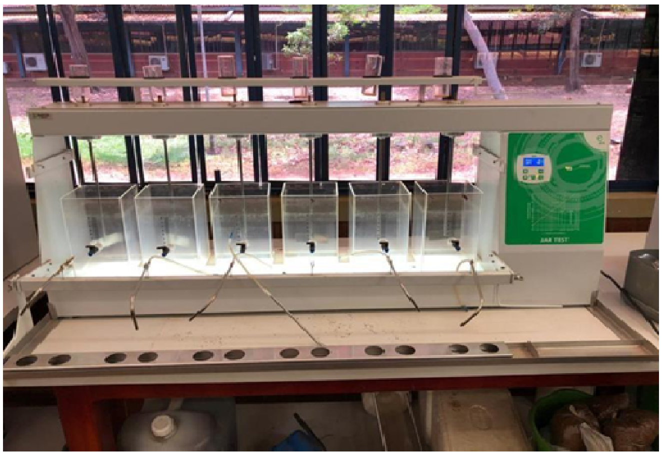


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Figure 6. Jartest equipment

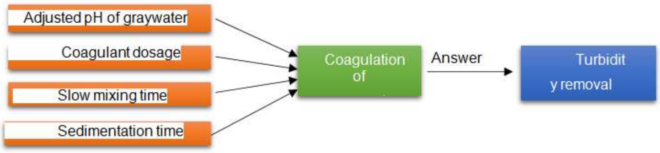


Figure 7. Representation of the experimental planning of the coagulation, flocculation, and sedimentation tests

The factors studied were: (a) adjusted pH of the gray water, (b) coagulant dosage, (c) slow mixing time, and (d) sedimentation time. The domains of the parameter ranges (minimum and maximum values for the factors) are by Rodrigues (2019). After performing the tests, samples were collected from the jugs for turbidity analysis. A Hach model 2100q turbidimeter was employed (Figure 8).

Table 1. Order of experiments employed in DFF 2 .$^{4-1}$

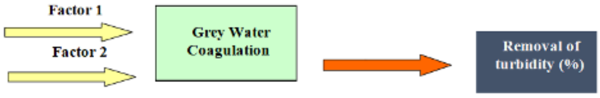
	Factors			
Order of experiments	pH (-)	Coagulant dosage (mg/L)	Slow mixing time (min)	Sedimentation time (min)
1	7	100	10	10
2	8	100	10	40
3	7	300	10	40
4	8	300	10	10
5	7	100	20	40
6	8	100	20	10
7	7	300	20	10
8	8	300	20	40

Source: The author himself

Source: The author himself

Figure 8. Turbidimeter equipment

Experimental Design: Central Composite Rotational Design (CCRD): After applying the Fractional Factorial Planning, it was verified through multivariable planning the effect of two factors in the removal of turbidity of gray water in the chemical coagulation test in the Jar Test (Figure 9). A fractional experimental planning 2^2 - Central Composite Rotational Design (DCCR) was applied, without repetitions, with 11 types of combinations among the factors. The factors studied were: coagulant dosage and sedimentation time. The domains of the ranges of the studied parameters are according to Rodrigues (2019). The minimum and maximum values are presented in Table 2. The pH of the graywater was set to 5.5 and the rapid mixing time will be 15 minutes. The experiments were performed randomly, with three repetitions at the center point according to Table 3.



Source: The author himself

Factor 1. Coagulant dosage (mg/L) and Factor 2 - sedimentation time (min)

Table 2 . Factor levels employed in the Experimental Design, during the chemical coagulation of Graywater

Factors	Levels				
	(-1,4)	(-1)	(0)	(+1)	(+1,4)
Coagulant dosage (mg/L)	129	150	200	250	271
Time of sedimentation (min)	5,9	10	20	30	34

Source: The author himself

Table 3. Order of experiments used in factorial planning DCCR 2^2

Order of experiments	Factors	
	Coagulantdosage (mg/L)	Sedimentation Time (min)
1	150	10
2	250	10
3	150	30
4	250	30
5	200	20
6	200	20
7	200	20
8	129	20
9	200	34
10	271	20
11	200	5,9

Source: The author himself

Tests employed in the characterization of raw and treated greywater samples: Raw greywater samples and after the chemical coagulation process was collected, stored, and analyzed. All samples were collected in plastic bottles. The determinations followed the recommendations of APHA/AWWA/WEF (1998), according to Table 4.

RESULTS AND DISCUSSION

Laundry Graywater Characteristics

Results of the raw greywater analysis: Table 5 presents the results of the parameters measured in the raw and coagulated CA obtained in this research as well as a comparison with other values found in the literature. The pH obtained in the graywater sample (9.2) is very close to those obtained by Edwin *et al. (*2014), Bazzarella (2005), Sostar-Turk *et al. (*2005), but is lower Christova-Boal *et al*. (1996) and higher than that of Rampelotto (2014).

Table 4. Analytical methods applied in the physical-chemical characterization of raw Graywater and after treatment by chemical coagulation

Analytical Parameter	Methodology
Temperature	Mercury thermometer
pH	Electrometric
COD	Spectrophotometric
Conductivity	Electrometric
Total Solids	Gravimetric
Fixed Solids	Gravimetric
Volatile Solids	Gravimetric
Alkalinity	Volumetric
Turbidity	Nephelometric
Chlorides	Mohr
Chlorine residual	spectrophotometric

Source: The author himself

Bazzarella (2005) states that the pH of Graywater depends on the pH of the water supply. But some chemicals can contribute to its increase, and as an example, he cites the use of soap powder and softener contributing to the alkaline pH of greywater samples from laundries. The value of the alkalinity parameter in greywater from washing machines found in this research was 241 mg/L, while Bazzarella (2005) found the value of 74.2 mg/L; Christova-Boal *et al*. (1996) defined a range between 83 to 200 mg/L, but Edwin *et al.* (2014) found a value of 721 mg/L for laundry sample alkalinity. The parameters obtained for turbidity (112 uT) and electrical conductivity (300 µS/cm) are all within the ranges found for these parameters by Christova-Boal *et al.* (1996). Chlorides (92 mg/L) are slightly above the range established by Christova-Boal *et al.* (1996). Bazzarella (2005) obtained as characteristic turbidity of gray water from the washing machine the value of 58 uT, and for electrical conductivity found the average value of 524 µS/cm. Rampelotto (2014) defined the range as 168 to 560 µS/cm, whereas the range proposed by Christova-Boal *et al.* (1996) is 190 to 1400 µS/cm. The Chlorine residual obtained in this research (0.3 mg/L) was higher than the upper limit found by Sostar-Turk *et al.* (2005). This research found a value of 200 mg/L for COD, while Rampelotto (2014) defines this value in a range between 158 and 442 mg/L. The COD found in this research was 11.1% higher than that defined by Sostar-Turk *et al.* (2005)- 180 mg/L. Average COD values for greywater from washing machines were defined by Bazzarella (2005) as in a range of 190 to 920 mg/L, the average being 521 mg/L. The differences in the values of the parameters detected between this research and the various authors reinforce the statement made by Eriksson *et al.* (2002) that the characteristics of greywater vary according to the quality of the water distributed, the type of distribution, and also the habits and culture of the water users.

Experimental Planning: Experimental planning was performed in the sequence below, seeking to optimize the interference factors in the removal of turbidity from the gray water:

- Fractional Factorial Design (FFD);
- Central Composite Rotational Design (CCRD).

Fractional Factorial Design 2^{4-1}: The values were obtained for the turbidity parameter, when the Fractional Factorial Design (FFD) 2^{4-1} was performed to verify the behavior of factors 1 (pH of the greywater), 2 (coagulant dosage in mg/L), 3 (slow mixing time in minutes) and 4 (sedimentation time in minutes) in the coagulation, flocculation and sedimentation process of the CA are presented in Table 6. Turbidity responses between 7.8 uT and 28.1 uT are observed. To analyze the strength of each of the variables, the data were launched in the Protimiza*software,* where the Pareto Graph presented in Figure 10 was obtained, considering a significance level of 5%. The largest effects were of variable X2 - coagulant dosage (9.45) and variable X4 - sedimentation time (-10.70), as shown in Table 7. These Two factors had a significant influence on turbidity indices, with the positive effect for coagulant dosage indicating that the higher the coagulant dosage, the higher the turbidity, and the negative effect for sedimentation time indicating that the longer the

Table 5. Characterization of raw and coagulated CA compared to other research on CA from washing machines

ANALYTICAL PARAMETER	RESULTS							
	Raw Sample - Author (2021)	Coagulated sample - Author (2021)	Rampelotto (2014)	Edwin *et al*. (2014)	Bazza rella (2005)	Sostar- Turk *et al.* (2005)	Siegris t *et al*. (1976 *apud* Erikss on *et al*, 2002)	Christ ova-Boal *et al.* (1996)
Temperature (° C)	25	25	25 ± 3,5	-		62	32,0	-
pH (-)	9,2	6,1	7,4 ± 1,2	9,1	9,1	9,6	-	9,3-10
COD (mg/L)	200	141	300+142	-	521	180	-	-
-Conductivity (uS/cm)	300	281	364+196	641,6	524	-	-	190-1400
Total Solids (mg/L)	2700	1050	391+215	586,0	1004,0	-	1340,0	-
Fixed Solids (mg/L)	850	800		-		-	-	-
Volatile Solids (mg/L)	1850	250		-		-	-	-
Alkalinity (mgCaCO3/L)	241	101		721,0	74,2	-	-	83-200
Turbidity (uT)	112	5,3	49+36	108,6	58,0	-	-	50-210
Chlorides (mg/L)	92	89		37,3	23,6	-	-	9-88
Chlorine residual (mg/L)	0,3	0,2		-		<0,1	-	-

Source: The author himself.

Table 6. Turbidity responses (AC after DFF 2^{4-1}).

Turbidity	Factors			
	1 (pH)	2 (Dosage)	3 (Mixing time)	4 (Settling time)
27,9	7	300	20	10
15,1	8	100	20	10
7,9	7	100	20	40
16,5	7	100	10	10
17,0	7	300	10	40
7,8	8	100	10	40
28,1	8	300	10	10
12,1	8	300	20	40

Source: The author himself.

Table 7. Effects of variables X1, X2, X3, and X4 on DFF 2^{4-1}.

Name	Effect	Standard Error	t calculated	p-value
Average	16,55	0,87	19,00	0,0003
X1	-1,55	1,74	-0,89	0,4392
X2	9,45	1,74	5,42	0,0123
X3	-1,60	1,74	-0,92	0,4261
X4	-10,70	1,74	-6,14	0,0087

Source: The author himself.

Table 8. Turbidity responses (AC after DCCR 2^2).

Testing	Factors		
	X1	X2	Turbidity
	Dosage (mg/L)	Sedimentation Time (min)	
1	150	10	16,8
2	250	10	24,4
3	150	30	5,2
4	250	30	14,7
5	200	20	11,9
6	200	20	11,8
7	200	20	12,0
8	200	5,9	26,1
9	200	34	5,3
10	129	20	14,2
11	271	20	23,5

Source: The author himself.

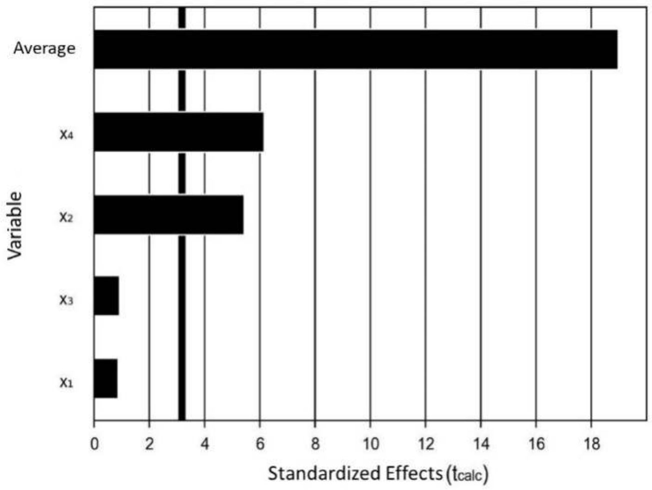
Table 10. ANOVA for turbidity test using DCCR 2 .^{2}

Source From variation	Sum of Squares	Degrees of Freedom	Square Medium	Fcalc.	p-value
Regression	488,5	5	97,7	26,8	0,00128
Waste	18,2	5	3,6		
Lack of adjust	18,2	3	6,1	606,0	0,00165
Pure error	0,0	2	0,0		
Total	506,7	10			
R2 = 96,41%					

Source: Protimiza *software.*

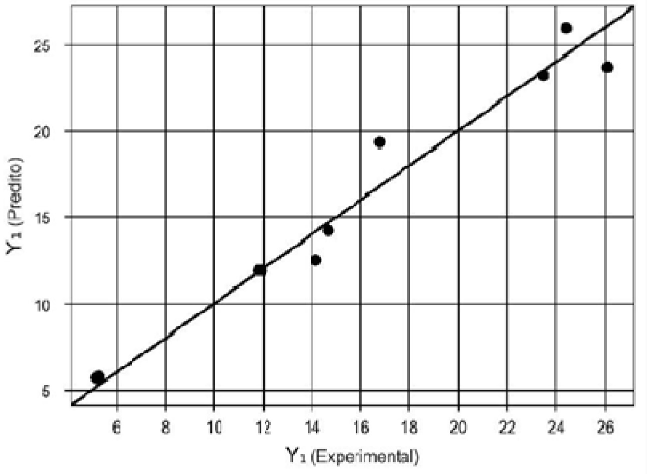
sedimentation time, the lower the turbidity. It is also observed that among these two variables, the sedimentation time is the one that presents the greatest effect on the turbidity result of the sample. The slow mixing time and pH had no significant effect on the turbidity indices.

Central Composite Rotational Design (DCCR 2^2): Seeking to optimize the best levels of the factors, coagulant dosage,and sedimentation time, new experiments were performed, now considering the Central Rotational Composite Design, and the results are presented in Table 8.



Source: Protimiza *software.*

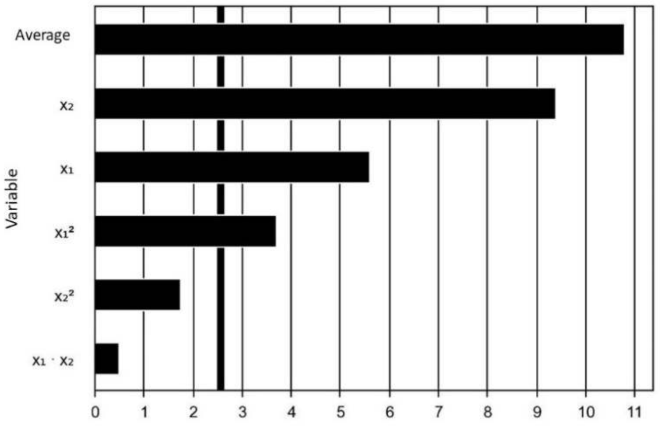
Figure 10. Pareto chart for analyzing the effects of variables X1, X2, X3, and X4 - DFF 2 .$^{4-1}$



Source: The author himself

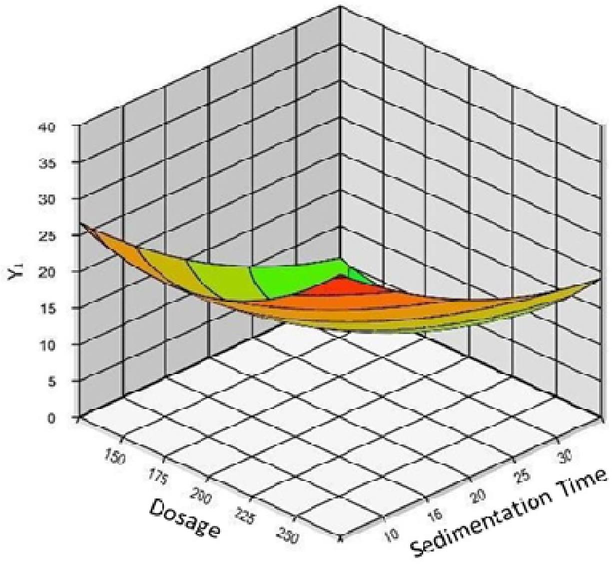
Figure 11. Observed versus predicted values for dye removal

Turbidity between 5.2 and 26.1 uT was obtained, and the regression model obtained (Table 9) also provides the expected turbidity for the model defined by this regression. Figure 11 shows the comparison between the experimentally observed values and those predicted by the fitted model. The two variables X1 and X2 showed considerable significance for the response, as presented in the Pareto Chart in Figure 12.



Source: Protimiza *software.*

Figure 12. Pareto chart for analyzing the effects of variables X1 and X2 - DCCR 22



Source: *Protimiza software.*

Figure 13. Contour surface for turbidity variation using DCCR 2.^{2}

Figure 13 shows the response surface of DCCR 2^2, where the influence of the variable'ssedimentation time varies between levels 59 minutes (-1.41) to 34 minutes (+1.4) and coagulant dosage varies between levels 129 mg/L (-1.41) to 271 mg/L (+1.41). Throughout the experimental planning, it was sought to obtain responses for a minimum consumption of coagulants because this is an item that

Table 11. CA Framework and its possible applications

Legislation	Country	Turbidity (uT)	BOD (mg/L)	COD (mg/L)	pH	Application
Code of Practice for the Reuse of Greywater (2008)	Australia	-	20	-	-	Surface sprinkler irrigation, Subsurface drip irrigation, Drip irrigation in Underground or subsoil trenches.
The Guidelines for Water Reuse - USEPA (2012).	United States of America - USA	≤2	≤10	-	6 - 9	Urban reuse –is not restricted.
Greywater for Domestic Users: An Information Guide (2011)	United Kingdom	≤10	-	-	5 - 9	Application without spray: Garden irrigation. Application without spray: Washing machine use.
Guidelines for Household Reclaimed Water for Use in Toilet and Urinal Flushing. (2010)	Canada	≤5	20	-	-	Toilet flushing.
Central Pollution Control Board - CCCP (2008)	India	20,6 -38,7	56 -100	244-284	7,3 -8,1	Application in agriculture and industrial cooling.

Source: The author himself

burdens the treatments, and the response surface shows that the minimum turbidity values occur in the values very close to the minimum tested for this consumption. Table 10 presents the Analysis of Variance (ANOVA) for the turbidity test of the CA sample using DCCR 2 experimental planning^2. The R coefficient^2 achieved was 0.9641, showing a good model fit.

Framing the treated CA to possible uses as reuse water: Table 11 brings references to legislation for the application of greywater already practiced in other countries, which can serve as a basis for the practice in Brazil. According to Table 11, when comparing the characteristics of the treated effluent of this research with the levels of acceptance of other countries, it is possible to use it for the subsurface, surface, underground, sprinkler, and drip irrigation, according to Australian regulations. According to the United States Environmental Protection Agency (USEPA), unrestricted urban reuse is possible. According to the pH and turbidity required by the UK regulations, CA is suitable for building reuse and reuse in washing machines and garden irrigation. Concerning what is established by the Central Pollution Control Board of India, the application in agriculture would be possible. One should consider some points that interfere with the practice of reuse, for example, the acceptance of society and the economic situation. Although water reuse systems can promote financial savings in terms of potable water consumption and sewage generation, the costs applied to the implementation, operation, and maintenance of these systems should be detailed and thoroughly evaluated toverify whether the proposal is economically feasible or not.

CONCLUDING REMARKS

Greywater can be an important alternative source ofwater supply in periods of scarcity. The analysis of the quality of CA indicated significant improvement in the quality of wastewater, however, there is a need for treatment to enable its non-potable reuse. When analyzing some international regulations, one can cite certain activities for reuse of CA, such as: subsoil, surface, underground, sprinkler, and drip irrigation, non-restricted urban reuse, building reuse, reuse in the washing machine, and garden irrigation, and application in agriculture. Among the analyzed properties of the CA after the coagulation process, the reductions that occurred mainly in COD (200mg/L to 141 mg/L), turbidity (112uT to 5.3uT), alkalinity (241 mgCaCO3/L to 101 mgCaCO3/L), and pH (9.2 to 6.1) stand out. The application of the Fractional Factorial Design (2^{4-1}) and followed by the Central Composite Rotational Design (DCCR2^2), were important for the optimization of the treatment, allowing that with a smaller number of data it was possible to evaluate a larger experimental space for the concentrations of coagulants employed in the treatment. Generally, it was observed that the association of chemical coagulants can result in an improvement in the quality of greywater since turbidity results were obtained between 5.2 and 26.1uT, and the variables dosage and sedimentation time showed considerable significance for the response. As for the generation of a statistical model representing the removal of turbidity from graywater through the coagulation/flocculation/ settling process, it was found that through the analysis of variance, the R^2 coefficient achieved by the regression was 0.9641, showing a good model fit.

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