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Use of activated carbon filter in infiltration well for retention of metallic contaminants present in the urban environment

Uso de filtro de carvão ativado em poço de infiltração para retenção de contaminantes metálicos presentes no ambiente urbano

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ABSTRACT

In cities, flooding negatively impacts the lives of its residents and passersby, who are unable to move during the phenomenon of heavy rain, with potential loss of human and material goods, coexisting with the risk of contamination through direct or indirect contact with the water retained in the pavement. With the premise of addressing this issue, this research brings, as a structural alternative, the use of an infiltration well, adapted to mitigate flooding, adjunct in parallel to the public rainwater drainage system, and capable of promoting the restitution of the water resource to the water table through infiltration and, notably, free from external pollutants. Thus, the use of granular activated carbon as filtering material in this structure was foreseen, for the retention of contaminants present in the impermeable urban surface. These contaminants include heavy metals such as Lead (Pb), Chromium (Cr), Cadmium (Cd) and Nickel (Ni). The efficiency of this filter was evaluated through a comparison with the results obtained in samples of runoff water, corresponding to the rainy season for an urban environment delimited in Cuiabá City. It was concluded that each gram of filtering material has a capacity to retain contaminants such as Pb and Cd, respectively of 12,05 mg and 30,58 mg, above the concentrations observed in the field. Therefore, such material has the potential for removal of even more metallic compounds, providing greater safety to human health and the environment. Regarding the elements Cr and Ni, these were not found in significant concentrations, thus not offering any risk to groundwater or requiring a filtering process.

Keywords: Flooding; Infiltration well; Filtering

RESUMO

Nas cidades, o alagamento impacta negativamente a vida de seus moradores e transeuntes, que ficam impossibilitados de se deslocarem durante o fenômeno de chuvas intensas, havendo ainda potenciais perdas humanas e bens materiais, coexistindo ao risco de contaminação através do contato direto ou indireto com a água retida na via. Com a premissa de atender essa problemática, esta pesquisa traz, como alternativa estrutural, o uso do poço de infiltração adaptado para a mitigação do alagamento, adjunto de forma paralela ao sistema de drenagem pública de águas pluviais, capaz de promover a restituição do recurso hídrico ao lençol freático através da infiltração e notadamente, livre de poluentes externos. Deste modo, foi previsto o uso nesta estrutura como material filtrante o carvão ativado granular, para a retenção de contaminantes presentes na superfície urbana impermeável, por exemplo, metais pesados como Chumbo (Pb), Cromo (Cr), Cadmio (Cd) e Níquel (Ni), sendo a eficiência desse filtro avaliada através de um comparativo com os resultados obtidos em amostras de água de escoamento superficial, correspondentes ao período chuvoso para um ambiente urbano delimitado na cidade de Cuiabá-MT. Pôde-se concluir que cada grama de material filtrante possui uma capacidade de retenção de contaminantes como Pb e Cd, respectivamente de 12,05 mg e 30,58 mg, acima das concentrações observadas em campo, de modo que tal material apresenta condição para a remoção de ainda mais compostos metálicos, conferindo maior segurança a saúde humana e ao ambiente, enquanto os elementos Cr e Ni não foram encontrados em concentrações significativas, não oferecendo, portanto, risco as águas subterrâneas ou havendo a necessidade de um processo de filtragem.

Palavras-chave: Alagamento; Poço de infiltração; Filtragem

1 INTRODUCTION

In the urban environment, the hydrological cycle suffers a strong impact. This is mainly attributable to the waterproofing of these spaces, channeling of drainage, increased pollution due to the contamination of air and surfaces, in addition to the deposition of solid material by the population (TUCCI, 2003).

According to Canholi (2014, p. 21), "chaotic urbanization and inadequate land use cause a reduction in the natural storage capacity of the runoffs and these, in turn, will demand other places to occupy". Accordingly, during a period of intense rain, some cities suffer the effects of flooding that negatively impact on the lives of residents and passersby who are unable to move normally, with potential human losses and material goods. In addition, there is also a high risk of contamination through direct or indirect contact with drained water.

The flooding can be aggravated by some factors such as the lack of maintenance in the rainwater drainage system and/or its poor dimensioning for the period of these precipitations in the region. These actions are standardized by management bodies as a guarantee against project risks to be adopted (CANHOLI, 2014).

From the 1990s onwards, human action on the urban basin came to be considered a relevant issue in the application of hydrological models. These models have been used to estimate sediment production and increase in surface runoff. The increase in sediment production, resulting from the removal of vegetation, ends up in many cases being responsible for the obstruction of storm sewers and pipes, contributing to the contamination of surface runoff (TUCCI, 2002; GOMES *et al.*, 2015).

There are two types of actions used to combat the problem of urban flooding, structural and non-structural measures. The first corresponds to works that can be implemented aiming at the correction and/or prevention of a problem, while the second is related to the creation of laws and regulatory standards (CANHOLI, 2014). With the purpose of using a structural measure with the employment of an infiltration well, it is intended to drain the excess water that promotes flooding in urban roads.

Thus, the development of this research aims to evaluate the use of activated carbon in infiltration wells to promote the retention of metallic contaminants present in the urban environment. This can be a punctual intervention alongside with the public rainwater drainage system, without intending to replace it, seeking to contribute to the resolution of a social and environmental problem.

2 GOALS

2.1 General goal

This research aims to evaluate the functioning of the proposed filtration system in the retention of metals present in urban roads, through a drainage system known as an infiltration well, adapted to the treatment of runoff and its return to the water table.

2.2 Specific goals

Evaluate the adsorption efficiency of activated carbon used as a filter, for the retention of metallic elements such as Lead (Pb), Cadmium (Cd), Chromium (Cr), and Nickel (Ni), when these present significantly as contaminants based on the CONAMA Resolution No. 396 for water samples collected in the field;

Compare the adsorption capacity of activated carbon with metal values obtained in the field with samples collected from runoff during rain in an urban environment;

Demonstrate that the concentrations of metals after filtration present values considered safe for the return to the water table, in concentrations that do not exist or close to the detection limit used in the laboratory.

3 METALLIC ELEMENTS PRESENT IN THE URBAN ENVIRONMENT

According to Silva (2014), in drainage waters and water bodies, most of the metals present are mixed with particles of smaller diameter, that is, the finer ones such as clays. Furthermore, heavy metals aggregate to suspended and dissolved particles increasing their distribution over the asphalt surface and along the hydrographic basin.

As stated by Martinez and Poleto (2011), heavy metals are part of our daily activities and many of them enter our urban environment as a by-product of economic activities considered typical of growing cities. Table 1 characterizes some of the main metals from the anthropic action present in the urban environment.

As the purpose of this research is to return a water resource to the environment, more specifically to the water table, CONAMA resolutions 396/2008 and 430/2011 establish that this type of intervention should not change its quality or portions of that, so that there is no disagreement with their water quality framing class. Table 2, also based on the same CONAMA resolution nº 396/2008, presents a list of parameters for qualitative limits, with the respective preponderant uses allowed for contaminated water.

Table 1 – Example of metals found in urban streets

Material	**Source**
Lead	Vehicle exhaust, tires, lubricating oil, grease, welded parts and paints
Cadmium	Tires, vehicle exhaust and insecticides
Chrome	Galvanized metals, engine parts and brakes
Nickel	Diesel fuel, lubricating oil, galvanized metal, brakes and asphalt pavement

Source: Adapted from Poleto and Martinez (2011)

Table 2 – Groundwater use parameters for inorganic elements in Brazil

Parameters	**Major Uses of Water**			
	Human consumption	**Animals consumption**	**Irrigation**	**Recreation**
Inorganics		$\mu g.L^{-1}$		
Lead	10	100	5000	50
Cadmium	5	50	10	5
Chrome (Cr III + Cr VI)	50	1.000	100	50
Nickel	20	1.000	200	100

Source: adapted from CONAMA Resolution 396/2008

The concentration of metallic elements in the collected sample can be measured by a type of equipment called a spectrometer, with the insertion of the material in its excitation source in the form of an aqueous solution. For this, the sediment present in the sample goes through an "opening" process in which it undergoes an acid attack, so that the metals mixed with the particles are released and dissolved in the solution, since many materials such as petroleum derivatives and minerals are not soluble directly in common solvents; therefore, a preliminary treatment is necessary to obtain the solution ready to be atomized (SKOOG *et al*., 2002; SILVA, 2014).

3.1 Infiltration well

In recent decades, the trend of adopting concepts for the development of low-impact solutions has been studied in an attempt to maintain the equilibrium conditions of the water balance (REIS and ILHA, 2014). According to Barbassa *et al*. (2014) the infiltration well is an alternative punctual compensatory technique whose function is to retain drained rainwater.

The infiltration well emerged as a compensatory microscale technique and has a wide range of dimensioning and technical characteristics. These depend on local particularities, such as rainfall, soil characteristics, depth of the water table, and availability of space (BARBASSA *et al*., 2014).

3.2 Activated carbon filter

Activated carbon (AC) is a porous carbonaceous material with a microcrystalline and non-graphitic form, which underwent processing to increase its internal porosity. It is traditionally used as an adsorbent (BÉGIN *et al*., 1990).

In the physical adsorption process, the adsorbate is maintained on the surface of the adsorbent by means of Van der Waals forces. Layers with approximate values of adsorption heat can occur, as a chemical phenomenon occurs through the binding of the adsorbate molecules with the molecules of the surface of the adsorbent with the exchange of electrons (ARNAUT *et al*., 2007).

Due to its specific characteristics, AC guarantees an efficient adsorption result, since it presents a porous volume with a high specific surface area, high affinity and selectivity, regeneration capacity, high mechanical strength and low agglomeration power (GEANKOPLIS, 1993; MARCO, 2015, PICHINELLI, 2015; SOUZA, 2015).

As a function of its porosity, AC can be classified as macro, meso and microporosity. According to the International Union of Pure and Applied Chemistry - IUPAC (1982), pores can be classified as a function of diameter, in which diameters above 50 nm are classified as macropores, 2 to 50 nm as mesopores, from 0.8 to 2 nm as secondary micropores, and finally, less than 0.8 nm as primary micropores.

The adsorption process may be more efficient when using charcoal (adsorbent particle) activation, since the activation process gives the source material greater surface area, generally ranging from 10 to 15 m^2/g for values above 800 m^2/g after charcoal activation (BÉGIN *et al*., 1990).

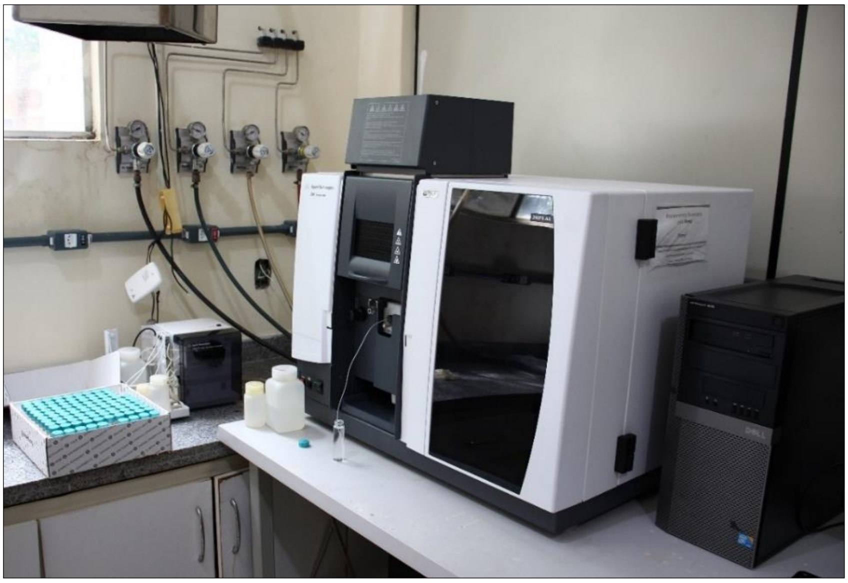
Additionally, the efficiency of adsorption still depends on the initial concentration of adsorbent, since it is capable of influencing the interaction between molecules to be adsorbed and the active sites available on the surface of the adsorbent (SALLEH *et al*., 2011).

4 MATERIAL AND METHODS

4.1 Detection of Metallic Elements

For this research, the spectrometer equipment model AA 240 FS (F-AAS) was used. Through the process of atomic absorption in flame, with the principle of absorption of ultraviolet radiation, this equipment determined the concentration of Pb and Cd metals present in samples collected in the environment of interest, urban roads. Complementary equipment such as precision electronic scales, millimeter pipettes, and vials such as Falcon tubes and borosilicate vials with Teflon bung were also used.

Figure 1 – Model AA 240 FS Atomic Absorption Spectrometer



Source: First author's personal collection

4.2 Collection of Surface Runoff

The collections of surface runoff were carried out on Marilândia Street, located in the Jardim Renascer neighborhood in Cuiabá City, Mato Grosso State, on an asphalt surface close to a ditch. The road, according to the functional classification parameters of highways of the National Department of Highways (1999) can be classified as Secondary Collector, with an average traffic of 50 vehicles per day.

The liquid samples were collected during a period of intense rain on 11/25/2020, 12/04/2020, and 01/06/2021. 10 samples were obtained containing 300mL close to the gutter through a close PVC pipe at the surface of a diameter compatible with the location in order to facilitate the collection. The pipe had a diameter of 25mm with a capped bottom and 1m in length, which later had the contents transferred to an appropriate polyethylene container with a lid as recommended by APHA (2015), in order to preserve the liquid sample, avoiding its external contamination or degradation.

It was also found that the asphalt was in a process of deterioration, due to lack of maintenance, being a major source of sediment in the environment. The recent implementation of the water supply and domestic sewage collection network is responsible for the increase in the production of waste arising from the work at the site. The environment was almost completely devoid of vegetation, with most of the surface being waterproofed, showing a rapid occupation without planning, with the exception of the interior of lots where in most cases the soil is exposed and with little or no vegetation, generally non-native of the Cerrado.

As a form of transport at the site, it can be observed that the action of the wind occurs intensely and intermittently on some days of the week, during much of the time, both in the morning and in the afternoon.

The rains cause not only the carrying of sediments, but also other materials of anthropic origin, causing the obstruction of manholes. It was found that a large amount of household waste is deposited by residents in inappropriate places along with debris from nearby buildings. Moreover, transport routes, notably paved streets, in many places show oil stains from defective vehicles.

4.2.1 Preparation of runoff samples

In order to determine the metal concentrations, the aqueous samples collected in the field were filtered through 0.1 micron Milipore® syringe filters. The liquid contents were subjected to an opening process according to the method 3030E (APHA, 2015).

The water filtrate was digested in 30ml of ultrapure hydrochloric acid for 24 hours to dissolve the solid material. When necessary, 1 ml of acrylamide sulfate was added to the mixture to lighten it before entering the flames. Once ready, the samples were analyzed in triplicate in F-AAS and the concentration values were expressed in μg.L-1 for the filtrate.

4.3 Evaluation of the Adsorptive Behavior of the Activated Carbon

With the use of F-AAS, the concentrations of the elements adsorbed in the AC were determined. The material was placed in contact with dosages at predetermined concentrations of the metals of interest for 4 minutes, reaching equilibrium in the adsorption process. For a greater reliability, the samples were kept for 24 hours, using standard solutions certified for this equipment with standards of 10, 5, 1, 0.5 ppb of the certified solution with a concentration of 1,000 mg/g provided by the National Institute for Science and United States of America Technology (NIST-USA).

From the results obtained, calibration curves were generated with the Langmuir and Freundlich isotherms models. These are mathematical equations used to describe the adsorption behavior of CA for different concentrations of heavy metals.

5 RESULTS AND DISCUSSION

The concentrations of the elements Pb, Cd, Cr and Ni were determined for the samples collected in the field (Table 3). Through the analysis of the obtained results, it was decided to carry out adsorption isotherms only for the Pb and Cd elements, since these were found in higher concentrations, even though they had low values in the urban environment.

In contrast, Cr and Ni were not detected in most results or presented values close to the detection limit of the equipment used (F-AAS), far below the contamination values considered in CONAMA resolution No. 396 (2008), as described in table 2. Therefore, there is no need to retain these same elements by the AC for the return of the water resource to the water table.

For the analysis of the adsorptive behavior of AC for Pb and Cd in the contact time, there were no significant changes in relation to the results previously observed for the concentrations adsorbed with the elements in the time of 4 minutes and 24 hours. Thus, it demonstrates that the CA reached the equilibrium, that is, its maximum adsorption capacity for the concentrations used in the contact interval of 4 minutes.

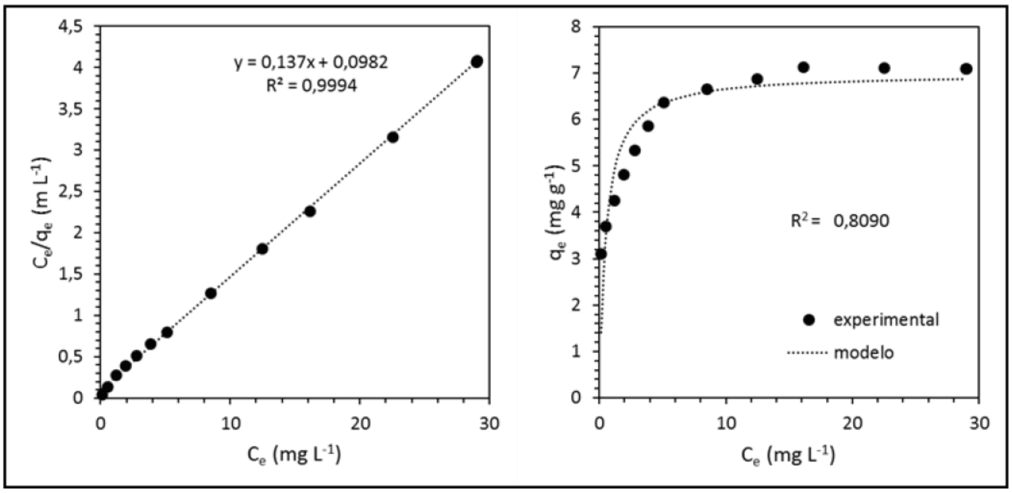
Table 3 – Concentration of metallic elements in runoff water of urban roads

Identification	Collection date	Pb	Cd	Cr	Ni
		Total metal concentration (μg/L or ppb)			
A1	25/11/2020	2.15992	0.159718	ND	ND
A2	25/11/2020	2.137309	0189036	ND	ND
A3	25/11/2020	1.848892	0.165407	ND	ND
A4	25/11/2020	2.505507	0.140464	ND	ND
A5	25/11/2020	2.051924	0.073076	ND	ND
A6	25/11/2020	2.143431	0.126024	ND	0.111867
A7	25/11/2020	1.772862	0.159718	ND	0.1409
A8	25/11/2020	0.403819	0.151841	ND	0.12765
A9	25/11/2020	2.054121	ND	ND	ND
A10	25/11/2020	2.416346	0.116835	ND	0.1109
B1	04/12/2020	1.364529	0.106212	ND	ND
B2	04/12/2020	1.410936	0.101512	ND	ND
B3	04/12/2020	1.220731	0.088823	ND	ND
B4	04/12/2020	1.594755	0.075429	ND	ND
B5	04/12/2020	1.385049	ND	ND	ND
B6	04/12/2020	1.436018	ND	ND	ND
B7	04/12/2020	1.178953	0.085769	ND	ND
B8	04/12/2020	0.280654	0.081539	ND	ND
B9	04/12/2020	1.36599	ND	ND	ND
B10	04/12/2020	1.655197	0.06274	ND	ND
C1	06/01/2021	0.92788	ND	ND	ND
C2	06/01/2021	0.95207	ND	ND	ND
C3	06/01/2021	0.800105	ND	ND	ND
C4	06/01/2021	1.052598	ND	ND	ND
C5	06/01/2021	0.921057	ND	ND	ND
C6	06/01/2021	0.990321	ND	ND	ND
C7	06/01/2021	0.784004	ND	ND	ND
C8	06/01/2021	0.181264	ND	ND	ND
C9	06/01/2021	0.915163	ND	ND	ND
C10	06/01/2021	1.124809	ND	ND	ND

(*ND: "not detected" or below detection limit)
Source: First author's personal collection

Next, the Langmuir isotherm obtained for the Pb element is presented in figure 2.

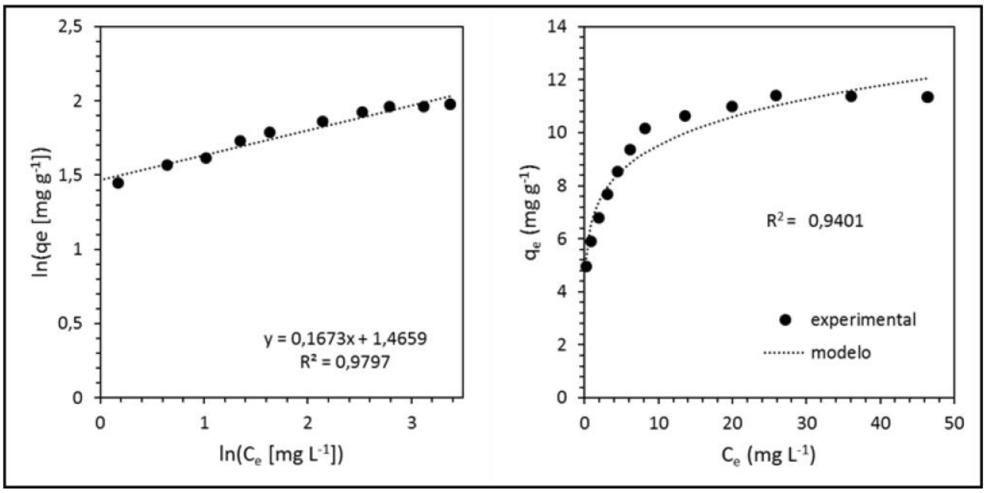
Figure 2 – Linear (Left) and non-linear (Right) Langmuir isotherm for Pb adsorption by activated carbon



Source: First author's personal collection

The Freundlich isotherm for the Pb element is presented in Figure 3.

Figure 3 – Linear (left) and non-linear (right) Freundlich isotherm for Pb adsorption by activated carbon

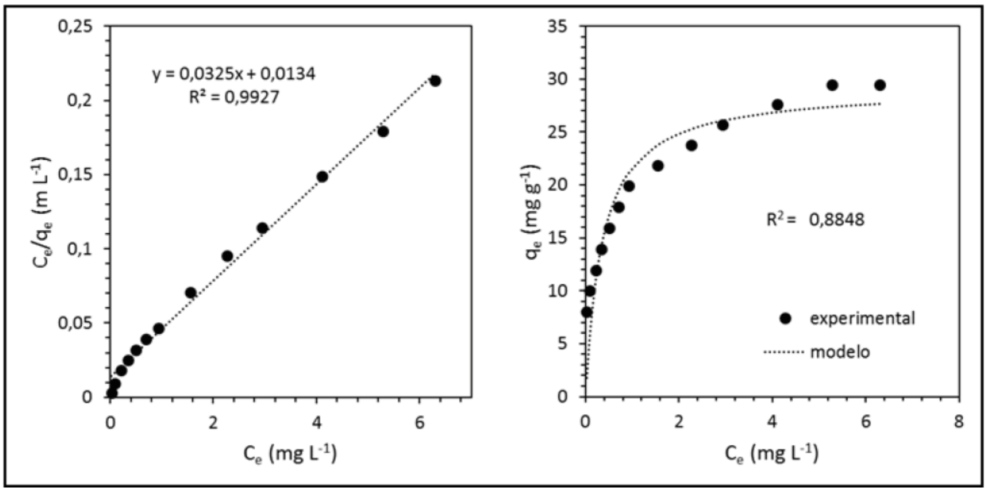


Source: First author's personal collection

The Langmuir isotherm obtained by the linear method for the Pb element can be observed in its graphic form (Figure 2) as a straight line that starts from the origin, corresponding to the trend line of the results obtained in the laboratory. This indicates that the amount adsorbed by AC is proportional to the concentration of the solution, with Ce/qe (g L^(-1) being the mass of adsorbent (AC) per liter of solution (water plus Pb) not showing its maximum capacity for adsorption. On the other hand, the non-linear method the curve was obtained and reveals an extremely favorable capacity for the adsorption of Pb by CA when using the pre-established experimental conditions, with the maximum removal achieved being 6.98 mg. g^{-1}.

As shown in Figure 3, according to the linear method, an increasing trend line can be obtained. However, it is not possible to define the maximum value of adsorption, which extends infinitely, ie the adsorption of CA increases in tandem with the concentration of Pb (Ce). The approximate value of adsorption in this case starts from 1.46 mg. g^{-1}.

Figure 4 – Linear (left) and non-linear (right) Langmuir isotherm for Cd adsorption by activated carbon



Source: First author's personal collection

Through the non-linearized method for Pb adsorption, a concave and ascending trend line which approximate starts at 5.25 mg. g^{-1} was found. This indicates a favorable adsorption situation, which tends to start to stabilize around 11.20 mg. g^{-1}), with a maximum adsorption value above 12.05 mg. g^{-1}).

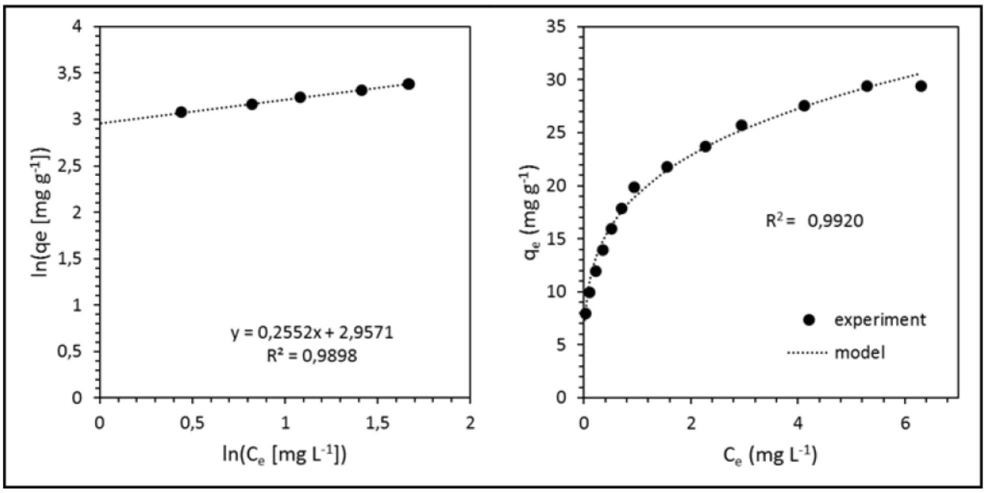
Based on the models evaluated for Pb adsorption, it appears that the Freundlich model is better fitted to the experimental data obtained, since it has a higher correlation coefficient (R^2). Therefore, the maximum adsorptive capacity for Pb is 12.05 mg. g^{-1}), when using AC as the adsorbent particle.

Through the Langmuir isotherm in its linear form for Cd, it is possible to graphically obtain, as shown in Figure 4, a trend line that starts close to the point of origin, with adsorption capacity of AC proportional to the concentration in the fluid. However, it is not possible to determine its maximum value.

As for the Langmuir isotherm in its non-linear form for Cd adsorption, a concave trend line was identified, revealing the favorable character of the adsorption process with immediate adsorption of approximately 1.80 mg. g^{-1} presenting the maximum value of 27.65 mg. g^{-1} after the required contact time.

The Cd adsorption isotherms by CA using the Freundlich model are presented in Figure 5.

Figure 5 – Linear (left) and non-linear (right) Freundlich isotherm for Cd adsorption by activated carbon



Source: First author's personal collection

As can be seen in Figure 5, when considering the Freundlich model in its linear form, a trend line is indicated. This fact is due to the adsorption behavior proportional to the concentration of the adsorbate, with an approximate value of

3 mg. g^{-1} and maximum 3.38 mg. g^{-1}. When considering the model in its non-linear form for Cd adsorption, the maximum adsorption obtained was 30.58 mg. g^{-1}.

When comparing both models with regard to Cd adsorption, the Freundlich model is also the one that presents the best fit for the obtained experimental data (R^2 equivalent to, 0.9898 and 0.9920 considering its linear and non-linear form, respectively), showing a Cd adsorption capacity of 30.58 mg. g^{-1}.

The best fit of AC for the Freundlich model in the adsorption of Pb and Cd implies a greater precision for adsorption systems in aqueous systems, taking into account the heterogeneous surface of the adsorbent as its surface becomes covered by the solute.

Considering the maximum removal capacity by AC for Pb and Cd, with the respective quantity of elements identified in the collected samples, it is observed that the concentration found for such elements in surface water runoff on urban roads is lower than the maximum adsorption AC capacity. In this way, such material presents conditions for the removal of even more metallic compounds, providing greater safety to human health and the environment.

6 FINAL CONSIDERATIONS

The proposed AC filter is characterized as a way to improve the infiltration well. Such a drainage system for the urban environment can reach the population in a practical way as an alternative tool applied to water resources management instruments, with its implementation taking place, for example, through basic sanitation agencies with regularization by state environmental agencies. This would require a study of characteristics such as the type and quality of the existing water table, allowing for greater control over the quality of water returned to the environment, through monitoring, according to the values established by CONAMA resolution Nº 396/2008. The runoff samples collected in the urban environment presented values that would fit within the strictest limits of preponderant uses in table 2, as in the case of human consumption.

However, the constant return of this resource to the water table would promote a progressive degradation over time, which would affect possible users of it. This is because the loads of heavy metals are cumulative in the environment, making the decontamination process difficult to implement.

Therefore, an infiltration well with filtering of contaminants implies a study for the region of interest, taking into account the drainage area in the contribution of surface runoff as well as the contamination loads in the urban environment, with the achievement of their respective concentrations for the correct AC sizing.

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