Residuals that originate from a higher education institution in Brazil

DOI: 10.54033/cadpedv20n7-005

Recebimento dos originais: 01/11/2023
Aceitação para publicação: 01/12/2023

Eduardo Soares de Alcantara Queiroz
Undergraduate Chemical Engineering Student
Institution: Universidade Federal do Rio de Janeiro (UFRJ)
Address: Av. Athos da Silveira Ramos, 149, Centro de Tecnologia, Rio de Janeiro – RJ, CEP: 21941-909
E-mail: eduardoalcantara@eq.ufrj.br

Monica Pertel
Doctor in Civil Engineering
Institution: Universidade Federal do Rio de Janeiro (UFRJ)
Address: Av. Athos da Silveira Ramos, 149, Centro de Tecnologia, Rio de Janeiro – RJ, CEP: 21941-909
E-mail: monicapertel@poli.ufrj.br

Alexandre Vargas Grillo
Doctor in Materials and Chemical Engineering and Environmental Process
Institution: Instituto Federal de Educação, Ciência e Tecnologia (IFRJ)
Address: R. Lúcio Tavares, 1045, Centro, Nilópolis – RJ, CEP: 26530-060
E-mail: alexandre.grillo@ifrj.edu.br

Felipe Sombra dos Santos
Doctor in Biochemistry and Chemistry Process Technologies Sciences
Institution: Environmental Engineering Program da Universidade Federal do Rio de Janeiro (PEA - UFRJ)
Address: Av. Athos da Silveira Ramos, 149, Centro de Tecnologia, Rio de Janeiro – RJ, CEP: 21941-909
E-mail: fsombra@eq.ufrj.br

ABSTRACT
In 2018, a research study was conducted at a Public University in Brazil to investigate the quantity of chemical residues produced during laboratory activities in undergraduate engineering courses. Data was collected from control documents maintained by the institution responsible for recording waste quantities. The results showed that 383.2 liters of solutions were generated with...
varying compositions. Inorganic solutions without heavy metals produced the highest volume of waste, while halogenated organic solutions produced the smallest. The study highlights the need for better waste segregation and disposal methods to reduce laboratory waste. To minimize the environmental impact of laboratory activities, implementing measures such as proper waste storage, waste exchange, recycling, reverse logistics, and life cycle assessment is essential. Educational institutions need to develop better waste management practices to reduce the amount of waste in landfills.

Keywords: hazardous wastes, segregation, waste management, final disposal, higher education institute.

RESUMO
Em 2018, foi realizada uma pesquisa em uma Universidade Pública do Brasil para investigar a quantidade de resíduos químicos produzidos durante atividades laboratoriais em cursos de graduação e engenharia. Os dados foram coletados a partir de documentos de controle mantidos pela instituição responsável pelo registro das quantidades de resíduos. Os resultados mostraram que foram gera-dos um total de 383,2 litros de soluções com composições variadas. As soluções inorgânicas sem metais pesados produziram o maior volume de resíduos, en- quanto as soluções orgânicas halogenadas produziram o menor. O estudo des-taca a necessidade de melhores métodos de segregação e eliminação de resíduos para reduzir os efluentes laboratoriais. Para minimizar o impacto ambiental das atividades laboratoriais, é essencial implementar medidas como armazenamen-to adequado de resíduos, reciclagem, logística reversa e avaliação do ciclo de vida. As instituições educacionais precisam desenvolver melhores práticas de gestão de resíduos para reduzir a quantidade de resíduos que são destinados a aterros sanitários.

Palavras-chave: resíduos perigosos, segregação, gestão de resíduos, disposição final, instituição de ensino superior.

1 INTRODUCTION
According to the GEO-6 (The Sixth Global Environment Outlook) report, there is much uncertainty around the current trajectory of global human development. One of the main reasons for this hesitation is the rising volumes of solid waste produced (Ekins et al., 2019). Despite not being the most representative parcel of the amount, chemical residues require special attention because of their hazardous properties (i.e., toxicity, corrosivity, and pathogenicity), which demand special care compared with other generated solid waste from urban and rural activities (Zhen et al., 2022).
The correct disposal of the named residues is fundamental once the impacts are related to their possible hazard characteristics, such as flammability, corrosivity, reactivity, toxicity, pathogenicity, carcinogenicity, teratogenicity, mutagenicity, or the features they can assume. Therefore, it is imperious that the emission's precursors not only provide the proper treatment for this waste, following the law's determinations, but also should search for ways to avoid them (Lara et al., 2017; D’Almeida et al., 2021).

It is important to note that several process specificities of the production chain can potentially increase the dangerousness of chemical wastes. For example, the production process employed, the feedstocks used, having high purity levels frequently, the capacity of some constituents to migrate to the environment, the high concentration of products, consequently, of the residues resulted from them, and the diversity of components in the composition (Ferreira et al., 2012; Hussain et al., 2000; Moreira et al., 2018).

Commonly, environmental impacts and damages associated with chemical residues, such as soil and water contamination and living being intoxicated, are generalized, laying the liability only because of industrial activity. However, this simplification disclaims the minor responsible for generating dangerous chemical waste. Once some generators are less exposed to accountability, they have a wider gap to be negligent with their emissions. Moreover, due to the small comparative amount generated, inspections for waste management are scarce, and Universities carry out waste management for different types of residues to comply with local legislation (Ho and Chen, 2017).

Despite being produced in fewer volumes, the rigor with the liability of correct disposal must be the same. In Brazil, Federal Law 12,305 covers all producers, i.e., everyone involved has the same liability due to shared responsibility (Brazil, 2010; Oliveira et al., 2021). However, Universities seek to comply with relevant legislation for different types of waste generated by research and other activities developed (Giloni-Lima and Lima, 2008). Although there are methodologies to be followed, the law exercises more responsibility than International Standard Organization (ISO) regulation (Ho and Chen, 2017). In fact, due to the small comparative value generated, inspections by environmental
agencies for solid waste management in public education institutions are scarce. Universities carry out waste management programs to comply with legal legislation (Balf et al., 2003; McLean et al., 2006).

According to Tauchen and Brandli (2006), higher educational institutes can be comparable with small urban centers, considering the diversity of the amount of waste from different activities developed in these institutions. They even produced at lower values when compared with industrial wastes. Chemical wastes generated by a college present a diverse composition, such as heavy metals, dyes, inorganics, halogenated organics, nonhalogenated organics, acids, and bases (Ferreira et al., 2012; Gonçalves, 2010; Zhen et al., 2022; Lara et al., 2016). Indeed, each can have a particular character besides being able to shift their composition. This varied composition makes it hard to establish a standardized system of treatment or adequate final disposal, which amplifies the environmental impact risks (Hassavand et al., 2011).

Before implementing actions that allow mitigating waste generation and highlighting the possibilities of alternative disposal, it is essential to characterize chemical wastes generated in educational institutes. In this light, the present work aims to assess the typology of chemical residues and quantify the total amount generated in a Brazilian University in 2018.

The importance and originality of this study are that it explores in detail the waste typology of the most problematic compounds found. Very little is currently known about the volumes and composition of the residues aroused from educational laboratories in Brazil, and there is a lack of them worldwide (Adeniran et al., 2017; Gallardo et al., 2016; Jacobi, 2005). Only a few studies have been published about chemical residues generated in university activities (Hussain et al., 2000; Kihampa and Kihampa, 2015; Moreria et al., 2018). Therefore, this research can provide insights into chemical waste management in higher education institutes. Thenceforth, looking to sensitize the academic community around this theme and diffuse waste management concerns among students, professors, and reports. Searching, in this way, to promote actions that lead to lower quantities of waste, as well as encourage their circulation and regeneration, decreasing the disposal amount.
2 MATERIAL AND METHODS

The local case is a higher education institute with more than 50,000 students. It is the oldest and most significant higher education institution, offering over 150 undergraduate courses. The present study proposed scanning the chemical waste (classified as hazards based on their properties) generated by Chemical Engineering, Bioprocess Engineering, Food Engineering, and Industrial Chemistry, all as undergraduate courses. Thus, six laboratories were assessed in this discussion, being used by undergraduate and graduate students. Experimental classes correspond to around 590 hours during the undergraduate period, representing nearly 18% of the total hours needed to conclude the course.

The methodology used in the data survey about the number of chemical wastes generated by different institution laboratories (Federal University of Rio de Janeiro - UFRJ) was used by consult on the waste registration between March and December 2018. These documents are delivered with the collected dangerous chemical residues when the report collect comes to transport and deliver them to their destination.

In the waste documents, it is possible to find fundamental information, both for feasible disposal and the preceding steps, as well as traceability of the wastes, such as composition, quantity, place, date, and responsibility for the generation. Based on what they registered, the data was gathered from the emissions of each analyzed lab. The chemical wastes were separated into categories for data analysis: inorganic solutions without and with heavy metals, nonhalogenated organic solutions without and with heavy metals, halogenated organic solutions, and chromium solution (Brazil, 1992). The segregation happens based on classification by pH (acid or alkaline), organic composition (halogenated or nonhalogenated), inorganic composition, and the presence or absence of heavy metals. This criterion is according to national regulations (ABNT NBR 10,004, ABNT NBR 12,235, and ABNT NBT 16,725) that classify and give legal responsibility to the waste generators. The quoted Brazilian rule considers many aspects of EPA's Resource Conservation and Recovery Act (RCRA).
3 RESULTS

Two discards that contemplated the collected volumes happened at the end of each semester during the term. The results came through the waste inventories; 383.2 liters with different typologies were totalized, all classified as hazardous, as shown in the annex. The amount of waste generated was segregated into fluxes that can be visualized in Fig. 1.

![Figure 1: Quantitative relation of segregated fluxes](image)

Fig. 1 shows that a significant percentage is constituted by inorganic solutions without heavy metals, representing 49% (190 L) of the total amount. The segment's value could catch the attention, but according to the enlistments of other higher education institutions, this segment often occupies the leading waste position (Lara et al., 2017). Fig. 2 shows the flows of Inorganic Solution without Heavy Metals and allows us to understand this number better.

Then, the second bulkiest flow, Nonhalogenated Organic Residues without Heavy Metals, is presented, totaling a volume of 115.6 L. The verified amount could be much more considerable if there were no positive effects of treatment and reuse of solvent-implemented practices, reducing disposed residues. The different kinds of organic solutions that compound this current can be seen in Fig. 3.
The hazardousness showed by the presence of heavy metals was also boarded in this research. For organic and inorganic sources, it was observed that 73.6 L represents 19% of all disposed of wastes.

The fluxes that make up the flow of an inorganic solution containing heavy metals, representing 61 L, can be analyzed in Fig. 4.
The current of the chromium solution represents a volume of 10 L. In addition, it was possible to quantify the Halogenated Organic Solution with 4 L. Finally, the minor flux, Nonhalogenated Organic Solution with heavy metals, was quantified at 2.6 L.

The graph’s behavior shows that heavy metals appear majorly in Inorganic Solutions, 82% of the amount composed by this type of solution. Focusing on found metals, Chromium, Molybdenum, Arsenic, Copper, and Tin were identified. Similar observations were shown by Hussain et al., 2000. However, during this research, we did not observe the presence of hazardous heavy metals such as Hg at the same time and any levels of Cr and Mo.

The flows that had discriminated pH presented an amount of 139 L, being 52.52% of acid nature, and between them, 86.3% have inorganic character, and 28.8% contain heavy metals in their compositions (50% of chromium). Lara et al. (2017) and Kihampa and Kihampa H. (2015) show that the most significant waste corresponds to acid-liquid wastes, presenting a certain tendency in this flow representation. On the other hand, considering the alkaline streams, all the found volume came from organic solutions without heavy metals. No mention of this category has been found in the literature. Moreover, Balf et al. (2003) concluded that waste volume is highly variable and shifts unclearly. So, it would not be surprising to notice the difference between verified data. All observed flows, listed by the technician in charge at the time of disposal, are shown in Tab. 1 in the Annex.
Therefore, it is relevant that units that generate dangerous chemical wastes implement, during the practical classes, their intern system of collection, utilization, and treatment of these residues, promoting better circulation of them. Also, the self-treatment of the residues allows the students to learn how to deal with this issue and take responsibility for it (Nakamura et al., 2015). The practicability of this initiative and positive results could be observed when evaluating a pioneer project of Chemical Laboratory Residues of Sao Paulo University (USP - São Carlos) (Alberguine et al., 2003). Students develop their abilities more effectively when they have personal contact with something (Pereira et al., 2016). Furthermore, beyond reducing the amount sent to disposal, it would happen to save resources once the company collects fewer quantities, and less virgin feedstock would have to be purchased (Santos et al., 2018).

In addition, according to Jacobi (2005), a way to mitigate the uncertainty around sound human development in a society affected by risks and grievances of environmental situation pervades the construction of a labor generation aware of their compromise with environment preservation and empowered to do so, supplying the professional capacitiation. Therefore, the implementation of sustainability actions does not aggregate only for the following of the laws; they also add on "reflexive professional" formation, educated with practical knowledge and ideals, which make them able to articulate environmentally friendly practices and construct environmental citizenship, as well as a culture of sustainability (Moreira et al., 2018; Santos et al., 2018).

Furthermore, according to Weil (2012), significant factors can compromise adopting the suggested mitigation measures, e.g., the lack of administrative support and the difficulty of different labs entering into a joint agreement. Balf et al. (2003) also presented a realistic approach, showing that culture was the most significant barrier to adopting surplus reuse. Many laboratory heads dislike using chemicals identified as waste by other persons.

Finally, suppose it expects to reduce the present volumes produced. In that case, it is fundamental to point out that the entire academic community's participation is relevant in managing waste generated at the laboratories. Community participation in coordinating the program is necessary to promote
changes in this situation (Martínez; García-Barrios, 2020; Ho and Chen, 2017). Sensitizing the community implies that fewer quantities of waste will be generated, noting that the volume found could be lower if the institution provided a system of Waste Stock, internal Circular Economy practices, or treatment of some of this waste. By adopting these practices, more waste would probably be destined for recycling instead of being directed to external therapy, such as incineration (McLean et al., 2006). In this way, there would be more remarkable preservation of the environment, rational use of natural resources, and decreased expenses with this type of service.

4 CONCLUSIONS

It is possible that other laboratories generated different chemical flows in higher education institutions. It was possible to observe the various forms of segregated hazardous chemical wastes. Even with existing local regulations, promoting the sustainable discharge of debris to avoid some accidents is complicated.

Among the measures that corroborate decreasing environmental impacts in this context, it is possible to highlight the storage and the Waste Exchange with correct waste management. This practice consists of an online system for sharing information about the type and quantity of the waste, which allows a generation unit to sell or donate its garbage and to be interested. In this scenario, the residue stock offers negotiation potential, increasing the life cycle of waste and recycling and avoiding its disposal in specific landfills through recovery and reuse actions.
REFERENCES


BRASIL. Resíduo químico — Informações sobre segurança, saúde e meio ambiente — Ficha com dados de segurança de resíduos químicos (FDSR) e rotulagem. Associação Brasileira de Normas Técnicas (ABNT). NBR 16725, 2014, Rio de Janeiro, RJ,


Santos, J. L.; Andrade, H. S.; Moreira, R. M. Monitoring solid waste generation at the Mato Grosso do Sul State University – Coxim Unit; proposed tools to mitigate the waste generation. Mato Grosso do Sul – Brazil, Realização 5(10): 77 – 82, 2018. DOI: 10.30612/re-ufgd.v5i10.8616


# ANNEX

Tab. 1 Relation between the fluxes and its volumes for 2018 year

<table>
<thead>
<tr>
<th>Different Waste Solutions</th>
<th>Volume (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inorganic Solution without Heavy Metals</strong></td>
<td></td>
</tr>
<tr>
<td>Inorganic Acid Solution with Murexide</td>
<td>40.0</td>
</tr>
<tr>
<td>Inorganic Saline Solution with Colorant</td>
<td>108.0</td>
</tr>
<tr>
<td>Inorganic Acid Solution</td>
<td>2.0</td>
</tr>
<tr>
<td>Inorganic Solution</td>
<td>40.0</td>
</tr>
<tr>
<td><strong>Partial total</strong></td>
<td><strong>190.0</strong></td>
</tr>
<tr>
<td><strong>Inorganic Solution with Heavy Metals</strong></td>
<td></td>
</tr>
<tr>
<td>Corrosive Inorganic Solution with Heavy Metals</td>
<td>40.0</td>
</tr>
<tr>
<td>Inorganic Acid Solution with Chromium</td>
<td>9.0</td>
</tr>
<tr>
<td>Inorganic Acid Solution (Mo, Cu, As)</td>
<td>8.0</td>
</tr>
<tr>
<td>Inorganic Acid Solution (Mn, I, Cu)</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Partial total</strong></td>
<td><strong>61.0</strong></td>
</tr>
<tr>
<td><strong>Nonhalogenated Organic Solution Without Heavy Metals</strong></td>
<td></td>
</tr>
<tr>
<td>Organic Base Solution</td>
<td>6.0</td>
</tr>
<tr>
<td>Organic Acid Solution</td>
<td>10.0</td>
</tr>
<tr>
<td>Nonhalogenated Organic Solution</td>
<td>39.6</td>
</tr>
<tr>
<td>Alkaline Organic Solution (NaOH + Ethyl Acetate)</td>
<td>60.0</td>
</tr>
<tr>
<td><strong>Partial total</strong></td>
<td><strong>115.6</strong></td>
</tr>
<tr>
<td><strong>Nonhalogenated Organic Solution with Heavy Metals</strong></td>
<td>2.6</td>
</tr>
<tr>
<td><strong>Halogenated Organic Solution</strong></td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Chromium Solution</strong></td>
<td>10.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>383.2</strong></td>
</tr>
</tbody>
</table>

Source: The authors