



Removal of basic violet 3 dye from aqueous media using a steel industry residue as solid phase



Camila N.R. Amaral^a, Fernanda N. Feiteira^a, Raphael C. Cruz^a, Vinícius O. Cravo^b,
Ricardo J. Cassella^a, Wagner F. Pacheco^{a,*}

^a Universidade Federal Fluminense, Niterói, Brazil

^b ThyssenKrupp CSA, Santa Cruz, Brazil

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ABSTRACT

The concern about environmental contamination resulting from industrial processes has spread worldwide in the last decades. That concern has led the scientific community to make efforts in order to help industrial processes to become less aggressive to the environment without losing their efficiency. The idea of sustainable development proposes that the amount of residues generated in production steps should decrease and/or be reused in other industrial processes in an economically viable way.

The steel industry is responsible for the emission of great amount and variety of solid residues. Nevertheless, the commercial utilization of these residues as alternative solid phases to remove metals and dyes from aqueous media is not common, what justifies alternative resolutions for this subject by the scientific community.

In this work, solid waste coming from the dedusting systems from a steel industry in Rio de Janeiro – Brazil was studied in terms of its ability to remove dyes from aqueous textile industry effluents. The dye used as model to perform this study was Basic Violet 3 (BV3).

The results show that this residue removes 90% of BV3 from aqueous media under optimized conditions: pH 4,75 and ionic strength at $0,170 \text{ mol L}^{-1}$ by acetic acid/sodium acetate buffer solution, 70 mg of solid phase, 45 °C, stirring time of 175 min at 110 rpm and particle size of 250 mesh. Studies about the kinetic and thermodynamic characteristics of the adsorption process were also realized. The kinetic profile followed the pseudo-second order and Morris-Weber models. In terms of thermodynamics, data best fitted to Freundlich isotherm.

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1. Introduction

Population growth and the development of consumerist models have generated a commercial overflow of staple products. Among industrial segments, the textile sector is highlighted, as it produces a large volume of highly pollutant waste products with high organic load, sharp color, and toxic to humans and to the environment [1,2].

As textile industries produce great amount of effluents, the treatment of liquid residues is frequently performed by these industries themselves [2,3]. Some of the most common processes used to that purpose are based on flocculation [4], coagulation [5], chemical oxidation [6], electrochemical degradation [7] and

sorption [8]. Among these treatments the sorption process is probably the most used [8,9].

The main reasons for that are simplicity, relative low cost and wide application of sorption processes. Activated carbon is one of the most common materials used to remove organic substances from effluents [8,9]. However, when the amount of material to be treated is as huge as it is in the case of industrial effluents, the high cost attached to the procedure of sorption on activated carbon should be considered. Then, studies of new materials as solid phases for sorption processes are encouraged in order to decrease costs.

Several low costs materials have been studied in the last years for this purpose, such as: agricultural solid wastes [10–12], biomass solid waste and natural clay [13–15]. Another example of applied material for solid phase sorption of pollutant residues from textile industries is the steel industry waste [16–18].

* Corresponding author.

E-mail address: wfpacheco@id.uff.br (W. F. Pacheco).

In the steelmaking process iron is obtained by the reaction of reduction of iron oxide (from its ore) with coal and carbon monoxide in a blast furnace in the presence of fluxes, that are purifying agents such as limestone, silica and dolomite. This mixture shall react to produce pig iron (the intermediate product of smelting iron ore) and some impurities as dusting powders, sludge and slag [19].

The liquid iron in the previous step (pig iron) containing high level of impurities and carbon is transferred to another reactor, a steel plant. In this reactor, oxygen injection converts carbon into CO and CO₂, turning pig iron into steel and oxidizing silicon that was soluble in iron. Silicon is then transformed into silica (SiO₂). Nevertheless, the oxygen jet drags SiO₂ together with small solid particles (spheres sometimes smaller than 400 mesh), forming a kind of dust, containing great amount of iron, SiO₂ and other particles, that is stored on the walls of the steelworks. To allow the steel production to continue, a dedusting system is needed to remove this waste, which is treated as solid residue from the steel industry [19].

The production of crude steel in the world in 2015 was 1,6 billion tons. This volume is responsible for generating approximately 30 million tons of steel production waste. In Brazil, the amount of crude steel produced in 2015 was 33,2 million tons and the generation of wastes and other by-products was about 20 million tons. From this amount, 230 000 tons are waste from dedusting system [20], which could be used in the steel production process itself, in other industrial activities, or even as a sorption solid phase for the retention of several compounds. In other words, this waste could be made a product of economical value.

In spite of the fact that the use of steel industry waste as sorption solid phase is becoming popular in the world [21–26] this application is still not common in Brazil, even though this kind of industry is very present in the country.

In this work, solid waste from a steel industry located in the state of Rio de Janeiro (ThyssenKrupp CSA) was evaluated in terms of its ability to remove dyes from textile industry effluents. The dye used as a model to perform this study was Basic Violet 3 (BV3).

2. Material and methods

2.1. Reagents and solutions

Basic Violet 3 is a dye originated from triphenylmethane. Its molecular formula is C₂₅H₃₀ClN₃, its molecular weight is 407,99 g mol⁻¹ and its pKA is 1,8. Being cationic, it is considered a basic dye [27].

The residue of the dedusting systems used as solid phase was provided by ThyssenKrupp CSA steel mill, located in the district of Santa Cruz, Brazil. No previous treatments were applied to the residue before its use.

Basic Violet 3 was purchased from Vetec (Brazil). To prepare a stock solution of the dye at the concentration of 2,50 × 10⁻³ mol L⁻¹, an amount of 510 mg of the solid dye was transferred to a 50 mL beaker, dissolved in deionized water and then transferred to a 500,0 mL volumetric flask. The volume was completed up to the mark with deionized water. This solution was wrapped with aluminium foil in order to keep it protected from light, avoiding photolytic degradation.

Acetic acid/sodium acetate buffer stock solution at concentration of 1,70 mol L⁻¹ was prepared by dissolving 13,956 g of sodium acetate (Vetec, Brazil) in deionized water, then transferring this mixture to a volumetric flask of 100,0 mL and completing the volume up to the mark with deionized water. This solution was diluted to 0,170 mol L⁻¹ to perform further experiments by

transferring an aliquot of 3,00 mL of it to a 50,0 mL polipropilene tube and completing the volume to 30,0 mL with deionized water.

Britton Robbinson buffer stock solution at concentration of 1,70 mol L⁻¹ was prepared by dissolving 13,951 g of sodium acetate (Vetec, Brazil), 20,401 g of sodium phosphate (Vetec, Brazil) and 10,517 g of boric acid (Vetec, Brazil) in deionized water. This mixture was transferred to a volumetric flask of 100,0 mL and the volume was completed up to the mark with deionized water. This solution was diluted to 0,170 mol L⁻¹ to perform further experiments by transferring an aliquot of 3,00 mL of it to a 50,0 mL polipropilene tube and completing the volume to 30,0 mL with deionized water.

2.2. Instrumentation and accessories

Solutions were prepared in deionized water by using a Milli-Q equipment (Millipore, USA), with resistivity of 18,2 MΩ cm.

Analyses were performed by using an Agilent Cary 60 UV–vis spectrophotometer (Agilent, USA). Glass cuvettes were purchased from Hellma (Germany), with optical path of 1,0 cm. Basic Violet 3 dye has its maximum absorption in the visible region at 580 nm.

Stirring processes were performed at a shaker table (Biomixer, Brazil) with rotation speed of 110 rpm. For phase separation prior to spectrophotometric analyses, the solution was centrifuged (Eppendorf Centrifuge 5804, Germany). The rotation speed was 5000 rpm for 3 min.

Particle size analyses were performed by using sieves from Bertel (Brazil) with three different mesh openings: 60, 250 and 325.

X-ray diffraction analysis was performed by using a Rigaku MiniFlex II Cu K diffractometer.

2.3. Adsorption experiments

The present methodology consists of removing the dye from aqueous solution by stirring it together with a defined mass of the steel industry residue. Experiments were conducted by transferring 120 μL of Basic Violet 3 stock solution (2,50 × 10⁻³ mol L⁻¹) to a 50,0 mL polyethylene tube, then adding an specific amount of the solid phase, the buffer solution and completing the volume up to 30,0 mL with deionized water, so that a 1,00 × 10⁻⁵ mol L⁻¹ solution was prepared.

Knowing the initial concentration of dye, the removal efficiency was stated by following the changes in the absorbance signal over time and converting it to concentration.

The removal efficiency was calculated by

$$E(\%) = \left(\frac{C_0 - C_t}{C_0} \right) \times 100 \quad (1)$$

In which E is the removal efficiency, C₀ is the initial concentration of the dye and C_t is the concentration of the dye at certain time.

The mixture was agitated on a shaker table and an aliquot of it was withdrawn at pre-determined time intervals. This aliquot was centrifuged and its absorbance was measured by using the spectrophotometer. After measuring, the aliquot was returned to the tube containing the mixture to avoid variations in volume during the extraction process.

2.4. Point of zero charge analysis

Point of Zero Charge (PZC) analyses were conducted according to the methodology proposed by Fiol and Villaescusa [28]. 50 mg of the steel industry residue were agitated together with 50,0 mL of an aqueous solution of NaCl 0,100 mol L⁻¹ (to stabilize the ionic strength of the medium) under different conditions of initial pH: 1,

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