ANALYSIS OF OPERATIONAL VARIABLES IN THE CHEMICAL SEPARATION PROCESS OF PLASTIC AND ALUMINUM IN ASEPTIC CARTON PACKAGING

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ABSTRACT

The residue composed of layers of polyethylene and aluminum (PolyAl), resulting from the first stage of the aseptic carton packaging recycling process, was subjected to a chemical separation process through a reaction with sodium hydroxide, aiming to separate the plastic and aluminum. The effects of the main variables involved in this process were studied using the Design of Experiments (DOE), in two stages: in the first, fractional factorial planning was carried out, analyzing the variables time, NaOH concentration, pre-treatment with anhydrous alcohol and stirring. A central composite design (CCD) was carried out in the second DOE. As a result, it was observed that the variables with statistically significant effects on the separation of plastic and aluminum were time and NaOH concentration, with 75 minutes and 7.5%, respectively.

Keywords: Tetra Pak packaging. Polyethylene. Aluminum. Design of Experiments. Chemical Separation.

1 INTRODUCTION

A sector that has grown is the packaging sector. However, from an environmental point of view, in addition to protecting and increasing the shelf life of food, packaging facilitates transportation and avoids unnecessary disposal [1]. Analyzing all packaging requirements at the lowest possible cost and competitively, a combination of materials has been applied, in which the properties of each component material are maximized [2]. One example of this application is carton packaging, also known as long-life packaging, composed of laminated paper, plastic, and aluminum. In this case, paper is used to provide structure and shape the container, aluminum protects the food by preventing the entry of light, air, contaminants, and the exit of aromas. In contrast, plastic is used as a waterproofing agent, as an adhesion layer between the paper and aluminum layers, and as a contact with the product [3].

Although the increasing use of packaging has contributed to a decrease in the generation of organic material waste, properly disposing of post-consumer packaging waste is important, from collection to recycling of these materials [1].

Within this context, the present study aimed to propose the use of Design of Experiments (DOE) to analyze the main variables involved in the chemical separation process, between polyethylene and aluminum, present in the resulting product (PolyAl) from the disaggregation process of aseptic carton packaging in paper industries.

2 MATERIAL & METHODS

The DOE was divided into two stages. Initially, a fractional factorial design was carried out, analyzing the following variables: time (h), NaOH concentration (%), pre-treatment with anhydrous alcohol, and stirring (rpm). A fractional factorial design is a reduced version of the full factorial design, meaning only a fraction of the runs are used. A fractional factorial design allows for more efficient use of resources as it reduces the sample size of a test, but it comes with a tradeoff in information [4]. Then, a central composite design (CCD) was carried out with only the statistically significant variables. In both analyses, the response variable for each experiment was determined based on the difference in PolyAl mass, before and after the reaction. This difference in mass was assumed to be the amount of aluminum that reacted and dissolved in the resulting solution.

PolyAl samples were separated into small squares. This format was chosen in an attempt to promote a greater contact area between the solution and the material, as in Figure 1. A population of 60 small squares was randomly chosen to characterize their measurements. The average found for the areas is 0.915 ± 0.408 cm² and presented a normal distribution.

The PolyAl samples remained immersed in 200 mL of anhydrous alcohol in a sealed beaker for 1 hour at 60°C under constant stirring with a hot plate magnetic stirrer. Finally, the alcohol was removed and the material was transferred to a beaker to carry out the reaction with NaOH solution.

In a beaker containing 200 mL of NaOH solution, the PolyAl was kept on a magnetic heating plate, under constant stirring and at an average temperature of 65°C. After removing its moisture by resting it in an oven for 48 hours with an average temperature of 38 ± 2 ^{0}C, the final mass was measured.

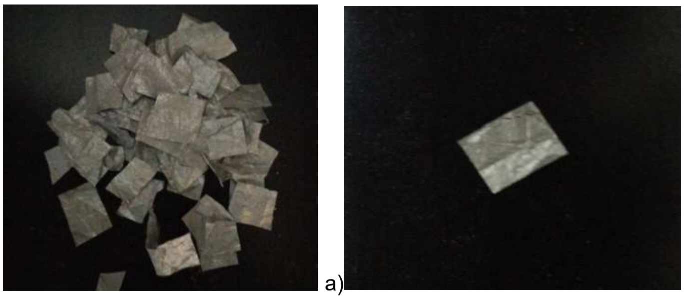


Figure 1 – a) post-preparation samples and b) individual sample

3 RESULTS & DISCUSSION

Initially, a 2^{4-1} fractional factorial design (resolution IV) was chosen instead of a complete DCC. In this option, 8 experiments were carried out to investigate four factors regarding their influence and find the optimal operational conditions for the amount of separated aluminum. The levels (+1, -1) of the factors studied, respectively, were: Pre-treatment (PT, with or without pre-treatment); Stirring (A, 100 rpm or 50 rpm); NaOH concentration (Na, 5% or 2.5%) and Time (T, 60 min or 30 min). The 8 experiments were carried out and the factors in PT, A, Na, and T levels, together with the results of Δm (g), respectively, are: Test Exp.1 (-1;-1;-1;-1; Δm=0.2280), Exp. 2 (+1;-1;-1;+1; Δm=0.7972), Exp. 3 (-1;+1;-1;+1; Δm=0.7041); Exp. 4 (+1;+1;-1;-1; Δm=0.4157); Exp. 5 (-1;-1;+1;+1; Δm=1.1204); Exp. 6 (+1;-1;+1;-1; Δm=0.7192); Exp. 7 (-1;+1;+1;-1; Δm=0.6604); Exp. 8 (+1;+1;+1;+1; Δm=1.2295).

A superior influence of time (T) and NaOH concentration (Na) to the detriment of the other two variables is observed in Figure 2, and also that they all positively modify the response, for example, follow positively towards the increase of the mass difference. It was also inferred that the pre-treatment factor (PT) has a higher effect than that of *Stirring* (A), but is still smaller than other variables studied. Comparing the F value of the model (Fcalc = 166.20) with the F value of the F distribution table ($Ftab_{(4;3;0.05)}$ = 9.12), was estimated that this is approximately 18 times higher, proving the significance of the results obtained and the model. The correlation coefficient was R^2 = 99.55%.

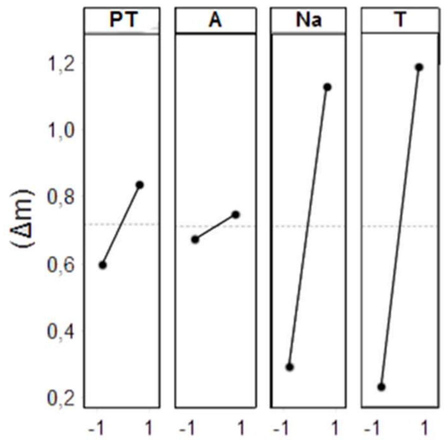


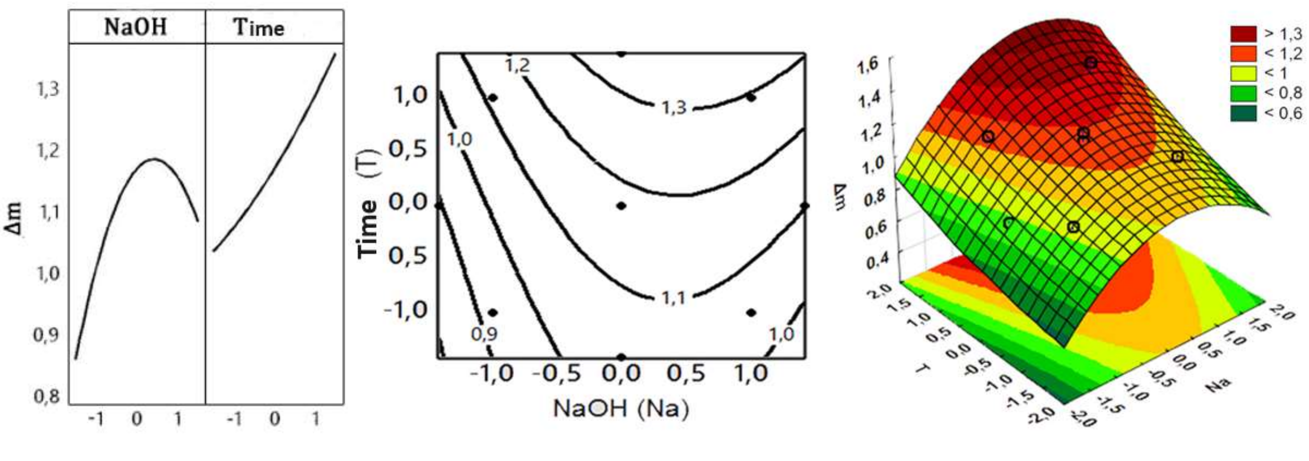
Figure 2 - Effect of factors on responses

Based on the results in the first DOE, a central composite design (CCD) with 3 central points (11 experiments) was carried out with Time (T) and NaOH concentration (Na) to determine the optimal operational conditions for the chemical separation process between the aluminum and polyethylene. Based on the previous results, levels of these variables were chosen with a larger working range, since both showed a positive effect. The levels (+α; +1; 0; -1; -α) of the factors studied, respectively, were: NaOH (in %, 11; 10; 7.5;5; 4) e Time (in min., 81; 75; 60; 45; 39).

The 11 experiments were carried out and the factors in Na and T levels, together with the results of Δm (g), respectively, are: Exp. 1 (-1;-1; Δm=0.9560), Exp. 2 (+1;-1; Δm=1.0920), Exp. 3 (-1;+1; Δm=1.1576); Exp. 4 (+1;+1; Δm=1.3461); Exp. 5 (-α;0; Δm=0,8601); Exp. 6 (+α;0; Δm=1.0541); Exp. 7 (0;-α; Δm=1.0149); Exp. 8 (0;+α; Δm=1.3005); Exp. 9 (0;0; Δm=1.2104); Exp. 10 (0;0; Δm=1.1559); Exp. 11 (0;0; Δm=1.1554).

From the analysis of the experiments, the highest value found for Δm was 1.3461, in the 4^{th} experiment, when both factors studied were at level +1.0 (time: 75 minutes and NaOH solution: 10%). In comparison, the next highest value occurred in the 8^{th} experiment (axial point) when the time was +1.4142 (81 minutes). The fact that the 6th experiment did not present a result close to these two suggested that excess NaOH could cause a negative effect, revealing a possible negative quadratic term for this factor. The two lowest values were Δm = 0.8601 in the 5th experiment when NaOH (4% solution) was an axial point (α = -1.4142) and in the 1st experiment with Δm = 0.9560 when variables had a level of -1.0 (45 min and 5%). It can be said that the model and results are valid since the value of Fcalc = 17.09 is approximately four times higher than the tabulated value of $Ftab_{(3;7;0.05)}$ = 4.35 and an R^2 = 92.43%. Cardozo et al. [5] applied fuzzy logic to simulate the performance of Microbial Energy Cells and used DOE to statistically evaluate how such parameters influence the performance of these devices. The authors concluded that after two sequential DOEs, they could identify three statistical variables, instead of 6 studied variables, and the mathematical model developed achieved an accuracy of 90% when compared with experimental results.

Figure 3a illustrates that a greater NaOH concentration (Na) had a negative effect on the response and to Time (T) variable suggested that it varies only linearly. Figures 3b-c show the results of the DCC carried out. It was observed that the optimal region for NaOH concentration was close to the 0.0 level (7.5%) and time to the level 1.0 (75 minutes), presenting an optimal region for higher values.



(a) (b) (c)

Figure 3 – (a) Main effects of factors (b) Contour Graph and (c) Response Surface

Four tests were carried out in the optimal region found to prove the method and the contour surface with 7.5% NaOH concentration and 75 minutes, resulting in an average response of 1.35 ± 0.02 g of aluminum.

4 CONCLUSION

The fractional factorial planning analysis indicated that the quantity of NaOH (Na) and time (T) were most important for the process. The optimal operating region can be found by analyzing the central composite design. The variable concentration of NaOH (Na) showed quadratic negative behavior with an optimum value of 7.5% and the Time factor (T) varied linearly, with an optimum region of around 75 minutes.

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