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DESIGN OF EXPERIMENT TO MINIMIZE FLUORIDE AND PARTICULATE EMISSIONS AT ALUMAR

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Abstract

Most of Aluminum plants have been struggling to minimize the fluoride and particulate emissions at the main source, which is the pot rooms, in order to reduce the environmental impacts. Nowadays, this challenge has been more difficult to be accomplished because of some reasons, such as: amperage increase, alumina quality deterioration and pot room expansions. Alumar, one of Alcoa's units, following a corporate vision, is continuously searching for alternatives to eliminate or reduce the environmental impact caused by operations. Many actions and studies are in place currently. This full factorial experiment 2^k was done with the aim of identifying the main factors and their impacts on fluoride and particulate emissions. The statistical model is showing that the fluoride emission has been affected mainly by Pot Draft, Pot Dressing, and the Usage of Compressed air for Housekeeping with R^2 at 82%, and for particulate at 58%. Based on the models, certain actions were recommended to minimize both of these emissions. In addition, this paper describes, step by step, how this kind of experiment can be applied to the Aluminum industry.

Introduction

Alcoa has been recognized by governmental and non-governmental agencies around the world for their accomplishments related to environmental protection and sustainable growth. Because of this, the understanding and minimization of fluoride and particulate emissions is always a subject of intense interest.

Alumar, one of Alcoa's units located in the northeastern region of Brazil, following this corporate vision, is continuously researching the root causes of fluoride and particulate in order to minimize them. Previous works were published about it, such as a study developed to map and determine the impact of each operation (anode setting, tapping, among others) in the fugitive fluoride emissions in the pot rooms [1]. It is already known that the fluoride and particulate emissions are affected by several factors inside the potroom such as bath temperature and ratio (bath chemistry), alumina quality, amperage level, operational activities, pot draft, etc. For example, it was shown the importance of the anode cover integrity to prevent gaseous and particulate fluoride evolution in another Alcoa research [2], which says that the crust integrity was capable of changing the amount of fluoride evolution by more than 1000% while the bath chemistry changes could only change the amount of evolution by 20%.

Since fluoride and particulate emissions are impacted by several variables and their effects depend on the interactions of them, it was decided to make a full factorial experiment 2^k at Alumar to find out the main factors and the size of their impacts.

The objectives of this work are to develop statistical models to predict the impacts of operational activities on fluoride and particulate emissions and recommend actions to minimize them.

Experimental

This study was started up at Alumar with a brainstorming of the possible contributors of fluoride and particulate emissions in the potroom. It was done by a very experienced team with people from several areas such as EHS, bath handling area, laboratory and potroom (operators, technicians and engineers). By using statistics and subject matter knowledge, the team hypothesized that the potential causes would be the following:

- Amperage - load creep
- Usage of compressed air for housekeeping
- Increase the number of days between pot dressing
- Analysis error - Lack of reliability at the Lab
- Sampling and preparation error - Lack of reliability at the Lab
- Stuck material and open hole in the ducts of gas
- Lack of Pot Draft
- Delays to remove the butts from potroom after anode settings
- Inefficient cleaning machines for housekeeping
- High alumina LOI
- High bath temperature
- Low bath ratio
- Excess of Burn-off (Anode failure requiring an extra set)
- Excess of anode effects
- Deficient balance of pot draft
- Pot superstructure cover is not maintained at the right position
- High amount of fines in the anode cover
- High percentage of alumina in the anode cover

Variable Definitions

The most likely causes were selected from this list, based on experience and previous work of the team. The decision was to study the effect of Pot Dressing, Usage of Compressed Air for Housekeeping and Pot Draft.

The pots at Alumar are currently dressed every 6 days by the Pot Tender Operator. This activity is really important to keep the anode cover integrity and consequently to minimize the emissions.

Housekeeping is made every shift in a group of pots at Alumar. Compressed air has been used to clean some components of the pots to guarantee the minimal TPM (Total Preventive Maintenance) requirements related to cleanliness.
Alumar uses A-398 reactors for gas treatment. Pot draft normally ranges from around 3500 to 4000 ACFM. This reactor has a very good efficiency, but the fugitive emission increases in the potroom if the pot draft is below a minimal level.

Statistical Experiment

The interaction among the variables and their effects on the fluoride and particulate emissions needed to be known for better understanding of the causes. It was decided to make a full factorial experiment 2^3, three factors with two levels for each one, as can been seen in Figure 1. By definition Factor A is the variable Usage of Compressed Air for Housekeeping, Factor B is Pot Dressing Frequency and Factor C is Pot Draft.

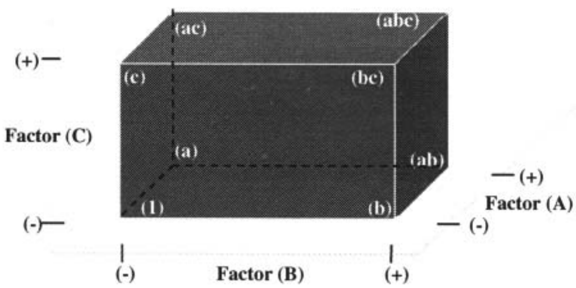

Figure 1 - Graphical depiction of full factorial DOE 2^3

Each combination was tested once in a period of 8 hours. Table 1 summarizes and gives a better understanding of how the data will be collected. The equation 1 describes the expected response model for this kind of experiment. Table 1 shows a design matrix for experiment 2^3 with all runs.

$$X_{ijkl} = \mu + A_i + B_j + AB_{ij} + C_k + AC_{ik} + BC_{jk} + ABC_{ijk} + Z_{l(ijk)} \quad (1)$$

Table 1- design matrix for experiment 2^3 with all runs

2^3	A^-		A^+	
	B^-	B^+	B^-	B^+
C^-	(1)	b	a	ab
C^+	c	bc	ac	abc

Table 2 presents the level for each variable. The experiment was run with these levels for both response variables (fluoride and particulate emissions).

Table 2- Level definition for each variable

Factor	Low level	High Level
A Compressed Air for Housekeeping	*Don't use compressed air*	*Use compressed air as usual*
B Pot Dressing Frequency	*Pot dressing every 2 days*	*Pot dressing every 5 days*
C Pot Draft	*3000 ACFM*	*4300 ACFM*

Results

The experiment was set up and run one time for each combination. Total fluoride and particulate emissions were collected for a period of 8 hours using an isokinetic test, based on US EPA Methods 13 (Determination of total fluoride emissions from stationary sources) and 14 (Determination of fluoride emissions from potroom roof monitors for primary aluminum plants). Every 8 hours the reacted solution of NaOH 0.1N was analyzed, using the ion selective electrode method and the experiment was moved to new settings. Table 3 is showing the results for fluoride emissions and Table 4 for particulate emissions. The experiment was run one time for each combination.

Table 3- Fluoride emission results for each combination

2^3	A^-		A^+	
	B^-	B^+	B^-	B^+
C^-	0.51	0.622	0.554	0.675
C^+	0.188	0.272	0.271	0.652

Table 4- Particulate emission results for each combination

2^3	A^-		A^+	
	B^-	B^+	B^-	B^+
C^-	1.043	1.592	2.282	1.620
C^+	0.404	0.434	0.916	2.454

The statistical analysis of experimental data was done using the software DOE-KISS (®-Air Academy Associates, Colorado Springs, CO, USA). The following table (Table 5) is presenting the results for fluoride emissions. The interaction among the studied factors doesn't impact the fluoride emission. F value is above the Sig F (for Alpha = 5%), which means it is a significant model. The factors Pot Draft (C) and Pot Dressing Frequency (B) are really relevant for Fluoride Emissions, while the Usage of Compressed air for Housekeeping (A) is in a "gray zone". Nevertheless, the latter was confirmed as a significant factor using others techniques such as Yates. It is recommended to maintain it as part of the final model. The model has a high strength with R^2 at 0.8 and the prediction equation for it can be seen in equation 2 (coded effects).

$$Y=0.468+0.07A+0.087B-0.122C \quad (2)$$

Table 5- Statistical analysis for the variable fluoride emission

Multiple Regression Analysis

Y-hat Model

Factor	Name	Coeff	P(2 Tail)	Tol	Active
Const		0,46800	0,0002		
A	Jateamento	0,07000	0,1371	1	X
B	Rastelamento	0,08725	0,0818	1	X
C	Pot Draft	-0,12225	0,0317	1	X

Rsq	0,8283
Adj Rsq	0,6995
Std Error	0,1067
F	6,4306
Sig F	0,0520

Source	SS	df	MS
Regression	0,2	3	0,1
Error	0,0	4	0,0
Total	0,3	7	

Factor	Name	Low	High	Exper
A	Jateamento	-1	1	0
B	Rastelamento	-1	1	0
C	Pot Draft	-1	1	0

Prediction

Y-hat	0,468
Std Error	0,1067064
99% Prediction Interval	
Lower Bound	0,1478809
Upper Bound	0,7881191

Pareto chart in Figure 2 indicates that the effects Pot Draft (C) and Pot Dressing Frequency (B) are the most important, while the usage of air for housekeeping (A) has a lower impact in the fluoride emissions.

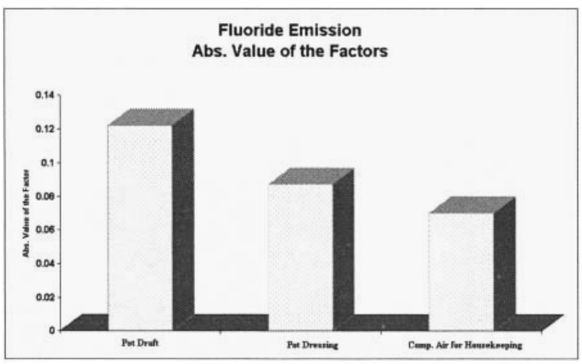

Figure 2 – Pareto chart for absolute values for each effect for fluoride emissions

The results for particulate emissions are as shown in Table 6. The interaction among the studied factors doesn't impact the particulate emissions. As in the fluoride model, the F value is above the Sig F (for Alpha = 5%), which means it is a significant model. The factor Usage of Compressed Air for Housekeeping (A) is the most relevant for this response variable. Pot Draft (C) is in a "gray zone", however, it was confirmed as a significant factor using others techniques such as Yates. Pot Dressing Frequency (B) is not a significant factor for particulate emissions. The model has a reasonable strength with R^2 at 0.5, regarding it is an industrial experiment, and the prediction equation for it can be seen in equation 3 (coded effects).

$$Y=1.34+0.47A-0.29C \tag{3}$$

Table 6- Statistical analysis for the variable particulate emission

Multiple Regression Analysis

Y-hat Model

Factor	Name	Coeff	P(2 Tail)	Tol	Active
Const		1,34313	0,0014		
A	Jateamento	0,47488	0,0726	1	X
C	Draft	-0,29113	0,2231	1	

Rsq	0,5861
Adj Rsq	0,4205
Std Error	0,5921
F	3,5397
Sig F	0,1102

Source	SS	df	MS
Regression	2,5	2	1,2
Error	1,8	5	0,4
Total	4,2	7	

Factor	Name	Low	High	Exper
A	Jateamento	-1	1	0
B	Rastelamento	-1	1	0
C	Draft	-1	1	0

Prediction

Y-hat	1,343125
Std Error	0,5921187
99% Prediction Interval	
Lower Bound	-0,433231
Upper Bound	3,119481

Pareto chart in Figure 3 indicates that the Usage of Air for Housekeeping (A) is really the most important effect. Pot Draft (C) has some impact but it is much lower than Factor A.

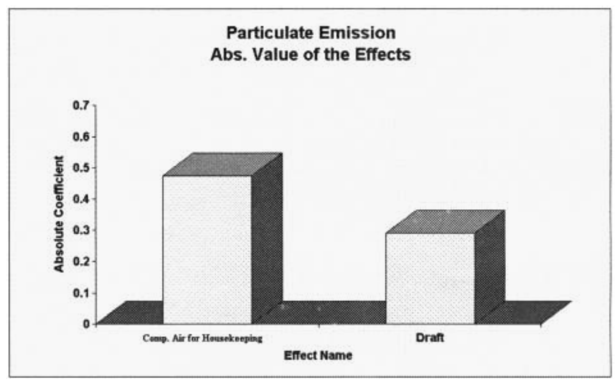

Figure 3 – Pareto chart for absolute values for each effect for particulate emissions.

Conclusions and Recommendations

According to the statistical model, fluoride emission can be significantly reduced increasing the Pot Draft (main factor) and improve Pot Dressing as much as possible. The worst condition would be to set the Pot Draft to -1 and the Usage of Compressed Air and Pot Dressing to +1. Considering this condition, the fluoride emission would be 0.74 kg/tAl; and, if the settings were the opposite values mentioned above, the result would be 0.18 kg/tAl.

Particulate emission can be significantly reduced if the Usage of Compressed air for Housekeeping is minimized or avoided. Setting the effects to maximize the particulate emission (Usage of Compressed Air to +1 and Pot Draft to -1), will make the particulate emission 2.1 kg/tAl and 0.57 kg/tAl to the opposite settings.

The team looked for alternatives to move the factors toward lower emissions.

Pot Draft

By removing the stuck material and closing the holes in the external ducts of gas, the pot draft can be improved by 500 ACMF. Figure 4 shows the current condition of the duct of gas after more than 20 years of operation and the state of it after the cleaning process.

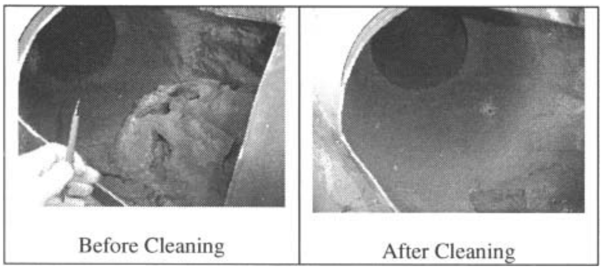

Figure 4 – External gas ducts before and after the cleaning process

Pot Dressing

It is possible to improve the pot dressing by reducing the frequency from every 5.3 to 3 days, without increasing the head count. Currently, there are four Pot Tenders by room and they are responsible for the dressing and other operational activities. Their production hours can be optimized if the dressing is done by two operators, and the additional activities are done by the others, as can been in the following figure (Figure 5).

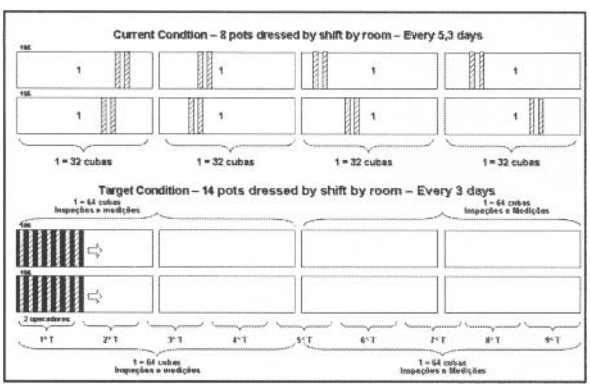

Figure 5 – Pot Dressing Frequency to reduce the emissions.

Usage of Compressed Air for Housekeeping

It can be reduced by at least 50% through the usage of cleaning machines and changes on the TPM requirements.

It was decided to set the conditions according to those recommendations and measure the emissions to check the benefits of those recommendations and to compare the results with the model's predictions. Figure 6 shows the results for fluoride emission and Figure 7 displays the results for particulate emission. The sampling time was 48 hours for both samples.

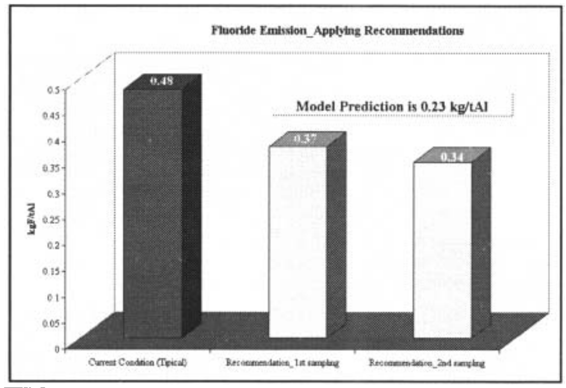

Figure 6 – Fluoride emission results under recommendation conditions for a period of 48 hours.

Although the model shows 0.23kg/tAl after applying the recommendations for a sampling period of 48 hours, the measured results were 0.34 and 0.37 kg/tAl. It is clear that the implementation of those actions will result in lower fluoride emission.

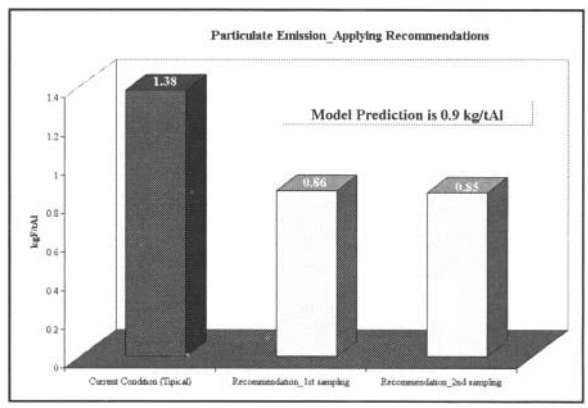

Figure 7 – Particulate emission results under recommendation conditions for a period of 48 hours.

There is a good agreement between the measured particulate emission and model predictions under the recommendation conditions for a sampling period of 48 hours. As mentioned for fluoride emissions, it is clear that the implementation of those actions will also result in lower particulate emission.

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References

1. Nagem, N., Batista, E., Silva, A., Gomes, V., Venâncio, L., Souza, L., *Understand the Fugitive Emissions at Alumar*, TMS, Light Metals 2005, pp. 289-292

2. Tarcy, G.P., *The Effect of Pot Operation and Work Practices on Gaseous and Particulate Fluoride Evolution*, TMS, Light Metals 2003, p 193-198.