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Preliminary Analysis of the Technical Feasibility of Using Spray Dryer in Gypsum Calcination

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Abstract—Gypsum's calcination is the main economic activity of the Araripe region. Its production is comparable to the greatest producing countries and its purity is the best in the world. Despite of already having a great impact in the region's economy, it has potential to grow even more. From a technological point of view, the calcination furnaces used in the region have been originated in other activities as flour production or cement calcination and, in most cases, they use indirect heating from fossil fuels combustion like firewood, coke and fuel oils. A common aspect in these furnaces is the lack of temperature control and a low thermal efficiency of the process. To answer the market challenges and difficulties which Araripe faces,regarding a non-sustainable energy matrix, new technologies of calcination need to be developed and incorporated to the process. A possibility is using direct heating, which demands a thermal fluid with lower energetic density, considering that gypsum's calcination occurs in relatively low temperatures. This would allow a reduction in fuel consumption, use of non-conventional energy sources such as thermal solar or residual energy from other processes occurring in higher temperatures. This could be achieved with fluidized bed, fixed bed or spray dryer adapted technologies. The current work contributes in this sense with a numerical study of the fluid dynamics and the heat transfer in a spray dryer based furnace that uses hot air in counter-current with a low granulometry gypsum.

Index Terms—plaster, gypsum, calcination, dryer, CFD, energy, efficiency, thermal.

1 Introduction

BRAZIL has a promising plaster industry. Most of gypsum's production comes from Araripina. It is located in the backlands of Pernambuco and concentrates many industries and mining companies. According to Brazilian's Ministry of Mines and Energy[1], the state of Pernambuco possesses 23.4% the country's gypsum reservations. Conforming to Brazilian's National Department of Mineral Production [2], in 2013 the state of Pernambuco contributed with 87.6% of all national production. Briefly comparing Brazilian and American production, it is safe to say that Brazil could explore more gypsum than it does. In 2013, Brazil explored 1.44% of its known reservations, while the United States of America explored 2.33%.

Gypsum's calcination occurs with heat transfer to itself, chemically and partially dehydrating the molecules. Depending on how the calcination is done, alpha or beta plaster may be the product. Alpha plaster has a uniform crystallographic structure. Furthermore, its production costs are greater. Beta plaster has a heterogeneous formation, making it less expensive and easily produced. Beta plaster is widely used at construction, which represents more than 95% of its market. Basically, this form of plaster is produced in simpler furnaces and conditions. This study aims at its production.

To produce beta plaster, Araripe uses some different types of furnaces, being most of them simple equipments derivative from other activities.These equipmentswere adapted to fulfill different needs.

The indirect heating coming from burning fuel is a common point in all Araripina's furnaces. Also, there is a low thermal efficiency and no precise temperature control, therefore the process is suboptimal. To overcome the market's challenges and difficulties related to a non-sustainable energetic matrix, which Araripina faces, new calcination technologies must be researched and incorporated to improve the process. A possibility is to use direct heating, which demands a heating fluid with less energetic density, considering that gypsum's calcination occurs in relatively low temperatures. This would make possible to reduce fuel consumption, utilization of non-conventional energy sources such as solar or utilizing residual energy from other processes at higher temperatures. Fluidized bed isanother, as Mujumdar [3] presents, possible technology for this, butwe'll be studying adapted technologies from spray dryers for now.

This type of equipment is used in many ways in industry and this paper will analyze it to understand how it can positively impact gyspsum's calcination. The analysis is based in a fluid dynamics model of gypsum's particles. The model was solved using the platform ANSYS-CFX and with it were accomplished parametrical studies associated to the calcination process.

2 Basic Concepts

Here some fundamental knowledge isdetailed. The basics for understanding how the whole process happens and how the study was done is here.

A basic introduction to spray dryer technology is present. Furthermore, Arrhenius law is explained. It is important to calculate the rate at which the chemical reaction takes place. Finally, changes are proposed to adapt the equipment to the process in question.

2.1 Spray Dryer

According to Mujumdar [3], spray dryers consist of using an intermediary hot gaseous fluid (usually air) to remove gaseous or liquid phase from solid particles previously atomized by special nozzles. These nozzles are installed on top of the dryer, so gravity forces down the particles, while hot fluid goes up from bottom of the furnace, permiting heat transfer in countercurrent while maximizing residence time.

Residence time is an important variable for spray dryers. The longer it takes to the reagent to leave the equipment, the best. This assures a good heat exchange and a thermal balance for its purpose. For this, they are usually large, making solid particles to receive enough thermal energy.

2.2 Arrhenius Equation

According to Levenspiel[4], to many chemical reactions, the expression of its rate can be written as the product of a temperature depending term and a composition depending term. Yet, for those reactions, the temperature dependent term and the rate constant are well represented in pratically every case by Arrhenius equation. The expression is as it follows:

$$k = A \cdot \exp[E_a / (R \cdot T)] \quad (1)$$

In this expression k stands for the rate of the reaction, A is called pre-exponential factor, which depend on every reaction, E_a represents activation energy, R is the universal gas constant and T is temperature.
This expression is applicable in great ranges of temperature and is strongly recommended by various point of views as being a good aproximation of the true dependency of temperature.
Most of its needed data are experimental. Using Santos [5] observations, it is possible to estimate at what rate the chemical reaction will occur. Using this law permits to calculate the needed time to complete the reaction.

2.3 Considerations

Even though a spray dryer is a great piece of technology, it will present some problems depending on the application. For each different usage it is put through, some changes might be needed.
Gypsum is a highly hygroscopic mineral. Because of this, to inject it in a furnace using a nozzle may be problematic, soit is going to be assumedthat it is done mechanically.
The time needed to complete gypsum's calcination is another problem. Using Arrhenius expression and Santos' [5] data, it is estimated that the whole process will take at least 28 minutes. Using a spray dryer is normally a continuous process, but it is not possible to calcinate gypsum this way.It needs more time being exposed to heat. To adapt and make it possible using this equipment, the calcination will be made in batches. To continuously receive heat from the stream of air, gypsum reaching the bottom portion of the furnace will be redirected, after all the batch is inside the furnace, to the top region. This will be repeated for 30 minutes, so the process is completed.
Concerning time, it will be considered that each batch is concluded in 1 hour: injection of all gypsum will take 10 minutes, redirection time will take 30 minutes (so all material will be heated for more than the minimum needed time) and 20 minutes will be taken to preparate a new batch.

3 Metodology

This section describes the methodology used for this study. The first section shows the model used (the spray dryer geometry), where gypsum will exchange heat with a stream of hot air, making calcination possible. The second section details how it was estimated a 28 minutes calcination time. The third section describes data used for gypsum and hot air.

3.1 Model

The adapted spray dryer features intakes and an outlet of gypsum, located at the outer top part and at the central bottom part respectively, and intakes and an outlet of air, located at the lateral bottom part and at the central top part respectively.
The mesh has 37,840 nodes and a total of 185,585 elements. It was set up with an orthogonal quality mesh metric, which had 85% average quality.

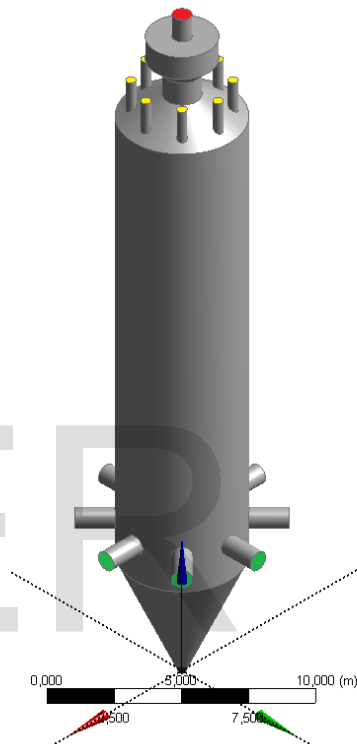


Fig. 1. Spray dryer model.

3.2 Chemical Reaction Cinetics

After an experimental study, Santos [5] observed a mean value to the pre-exponential factor and to the activation energy for gypsum's calcination reaction. Using this data and Arrhenius' law, it is estimated that the whole calcination takes 28 minutes.Therefore, the spray dryer needed the fundamental modification of not processing gypsum continuously, otherwiseit wouldn't be possible to conclude the reaction.

3.3Boundary Conditions

Here the temperature and mass flow of materials will be detailed.Starting with gypsum, the study will analyze how calcination occurs for each batch being of 5.1 Ton of gypsum. This mass corresponds to a 5 m high deposit of gypsum, starting from its outlet. The total time of a batch, as previously stated, is 1 hour, while all gypsum will have to be injected the first time in up to 10 minutes, so it is safe to assume a mass flow of 8.5 $kg \cdot s^{-1}$ for gypsum. It is also considered that this material is initially at 25 ºC and 160 ºC after receiving heat from the air.
The air boundary conditions are calculated as a function of gypsum's. An energy balance is used to estimate the needed mass flow of air, as shows (2).

$$\dot{m}_g \int_{298}^{433} c_{pg}\, dT + \dot{m}_{air} \int_{598}^{433} c_{pair}\, dT = 0 \quad (2)$$

More data is needed to solve (2) and for the simulation, such as specific heat and entalpies of gypsum, plaster, air and steam. This data was used accordingly to the work of Lange [6] and Brodkey [7]. With this data, solving (2) is possible and it yields a 9.61 $kg \cdot s^{-1}$ mass flow of air. Furthermore, air is initially at 325 ºC and, when it leaves the furnace, 160 ºC.
Boundary temperatures for gypsum are easily set because the material will always enter at ambient temperature and leave at the wanted temperature. If it's not possible to reach the wanted temperature, the results will not converge and changes will need to be made.
For air, it was set keeping two things in mind: the intake temperature should be easily attainable by any process it should not be low at a point which makes the needed mass flow too high. Its outlet temperature was defined at 160 ºC after a few tests in ANSYS.

3.4 Simulation

After defining the model and all variables, the simulation can proceed. As the main objective is to analyze if calcination temperature is reached and maintained, a steady state simulation is simpler and best suited.
A Lagrangian approach was used, for the furnace is large and gypsum greatly spreads out the further away from the injection point it is. Also, there is an interest of knowing the particles trajectory with the result of forces their weight and streaming air applies.Finally, the turbulence model used was k-Epsilon.

4 Results

In this section, the results of the study are discussed. Two important variables are mostly discussed here: temperatures and velocities. It is important to check if gypsum will reach the desired temperature, so calcination is possible, but it is also important to analyze the trajectory of the particles, and if the drag force isn't greater than the weight force. In other words, it is necessary to assure the particles don't leave the furnace with the air.

4.1 Temperatures

Fig. 2 shows temperature for gypsum in the outlet. Analyzing it, gypsum's temperature ranges from 154 ºC to 159 ºC.
In steady state simulation, gypsum's temperature is approximately equal to 160 ºC in the bottom portion of the furnace. This is important because it's the desired temperature for the process. With this achieved, calcination is possible if the min-

Fig. 3. Gypsum's temperature on top of the batch.

imum amount of time for the reaction is respected.

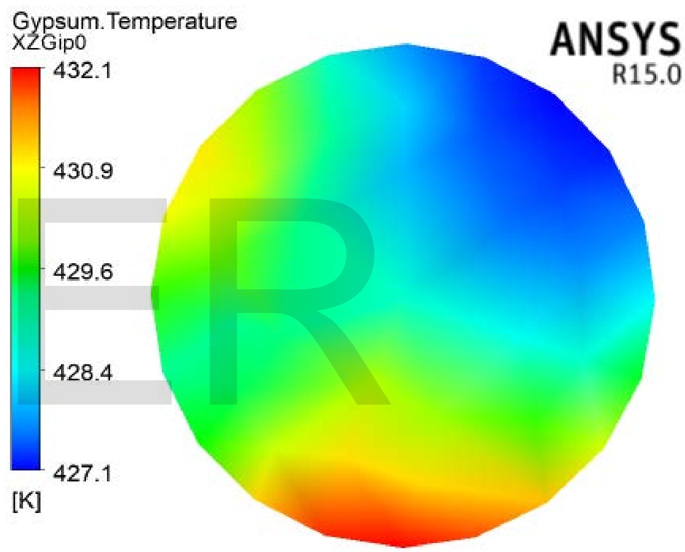
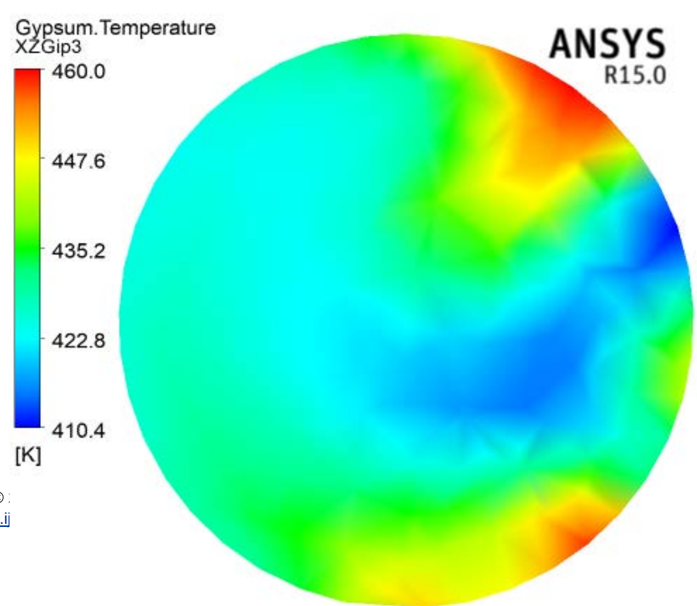
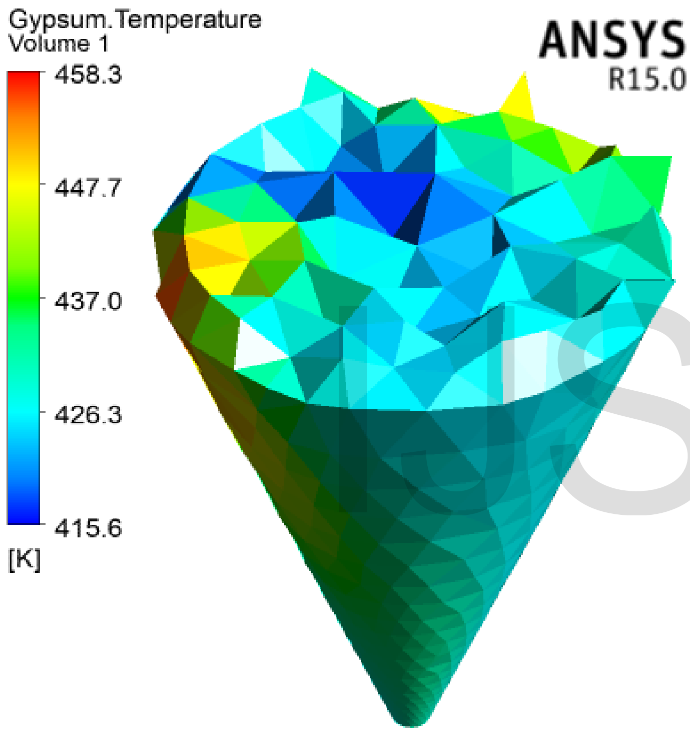


Fig. 2. Gypsum's outlet temperature.



Temperature varies greatly from the furnace's outlet from 5 m above it, where all gypsum's batch volume ends. Fig. 3 illustrates temperature in the refered section. The entire batch receives heat from the air by convection. Furthermore, when it starts depositing in the bottom of the furnace, it also conducts heat to surrounding gypsum, tending to reach a thermal balance. So, despite the top section of the batch having temperature ranging from 137 ºC to 187 ºC, it is going to continually receive heat from the air and redistribute it through conduction to surrounding gypsum.
Fig. 4 shows the bottom 5 m of the furnace, the region where gypsum deposits and keeps exchanging heat until the batch in



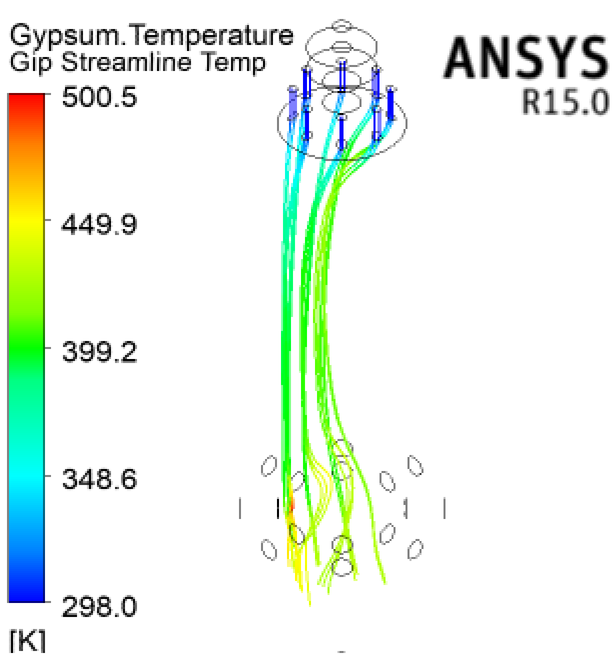


Fig. 5. Gypsum's streamline.

it completion is into the spray dryer. After this, the, previously explained, recirculation process begins. Temperature in this region varies, but its mean is approximately equal to 160 ºC as expected. Temperature tends to be closer to 160 ºC as gypsum nears its outlet.

4.2 Trajectory

Analyzingtrajectory of gypsum's particles, it is noticeable that they head towards the bottom of the furnace. No particles are dragged to top of the furnace. This is desireable to guarantee no mass of gypsum leaving the equipment. Fig. 5 shows the streamline of gypsum in the equipment. It is also possible to see temperature changing as it receives heat from the air.

5 Related Work

To evaluate how a spray dryer would work and calcinate gypsum is the main objective of this work. Initially, the biggest challenge is to acquire thermal data for gypsum to properly elaborate a model and simulate. Melo [8] deeply studied how gypsum's calcination happens and its variables. In her research, beta plaster was produced in laboratory and samples wereanalyzed. With the samples, she evaluated mechanical properties and microscopical characteristics.
Monção [9] worked similarly. In his study, many equipments and it methods of production used at Araripina are described. He proposes modifications in a sense to classify the produced plaster as recyclable. Furthermore, he proposes optimal conditions to process gypsum and produce beta plaster with good mechanical properties.

6 Conclusions and Future Work

The main goal of this study was to analyze the possibility of producing plaster using a spray dryer based technology. The results were consistent with the required conditions.Therefore, the calcination is possible, however, because of the needed adaptations for the spray dryer, it may not be economically viable. Furthermore, the adapted spray dryer function similarly to a fluid bed dryer, possibly making it a simpler and less expensive option.
ANSYS is a very powerful tool. A simulation can present reliable results when it's set properly. Data for variables are also needed, since it only has it for select materials. Therefore, we believe this study presented secure data and results.
As future work, we believe a similar study using a fluid bed dryer is industrially possible. It is also important to develop a technology which can use a sustainable energy source to heat the air.
Despite being possible, this calcination method can't be achieved with an original spray dryer. It is not possible to produce plaster in a few seconds.

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