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MODELING AND ANALYSIS OF SOLAR CONCENTRATORS FOR DRYING SUGARCANE BAGASSE USING FEM

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Abstract. To reduce the impacts of Brazilian agro-industry residues, sugarcane bagasse can be widely used as biomass, however, due to its high moisture content, this biomass has low efficiency for energy production. The conversion of sunlight into thermal energy through Concentrated Solar Energy (ESC), would bring the possibility of achieving good results in terms of sugarcane bagasse efficiency through drying, roasting and charcoal, this work was divided into two parts, initially Solar concentrators were built in different areas, 1 m² and 2.5 m², where temperature measurements were carried out and the effect of high temperatures analyzed in batch and rotating reactors. Subsequently, the modeling and reliability analysis of the reactors in the solar concentrators will be carried out through the finite element methods (FEM), using the ABAQUS software, determining the stresses and thermal fatigue resulting from the heat transfer, identifying the failure criteria, determining the more effective parameters to be assigned as random variables such as temperature gradients. Making it possible to identify solutions that can reduce thermal stresses and, if necessary, change the reactor materials.

Keywords: solar concentrator, sugar cane, finite element methods.

1 Introduction

Used mainly for the production of electricity and heating, there are several ways of generating energy from solar energy, among them are the solar energy concentrator. With a reflective surface, the concentration of solar rays directs to a focus collecting thermal energy for later use (NOWZARI, 2020) [1]. Solar energy is defined as the conversion of sunlight into electrical energy or thermal energy, which can be through photovoltaic cells, or indirectly using Concentrated Solar Energy (ESC) (NOWZARI, 2020) [1]. From clean and renewable energy, the existing solar concentrators can be classified as linear or punctual, where it will be chosen as needed. The high solar radiation in the country also provided the production of sugarcane on a large scale, this crop had a good development due to the climate and the time to which it was exposed. However, due to the high humidity, around 50%, the use of this residue has low efficiency. When using a concentrator with an inappropriate format or material, the system impairs efficiency, with low heat absorption, exchange of gases with the medium or deformations caused by temperature variations, even promoting thermal fatigue of the material.

The main objective of this work is to model and analyze voltages and displacements due to temperature variation in the receiver of solar concentrators used in the drying, roasting and charcoaling process of sugarcane. Therefore, physical models of solar concentrators with an area of 1 m² and 2.5 m² were built, in order to test the temperature variation in the focus using water to reach initial data and sugarcane bagasse to validate the operation. of model. So that later it is possible to perform modeling of different concentrators (1 m² and 2.5 m²) using the

Finite Element Method and the Abaqus software, obtain voltages from the exposure of the receiver to temperature variations; formulate thermal simulations in order to find the temperature gradients that produce the thermal stresses; to evaluate the thermal fatigue induced by the thermal stresses resulting from the transfer of heat by radiation; to compare the results obtained in the experiments of the solar concentrators, in order to find a relation of reached temperature and area.

2 Literature review

The use of solar concentrators has already been widespread, used in several areas, among them, the use of the concentrator in drying, gasification and other processes in biomass. Correia (2017) [2], used a solar concentrator, in a pulp production unit, to increase the temperature of the condensed water, taking it to its state of saturated steam to be delivered to the boiler, as this type of industry demands high consumption. of steam and electricity. This project resulted in savings in fuel consumption and increased steam power generation (CORREIA, 2017)[2]. According to FAOSTAT (2020)[3], Brazil is the country with the largest production of sugarcane in the world, about 760 million tons per year, and for each ton of this, 276 kg are represented by bagasse with 50 % moisture. Making bagasse the biggest residue of the Brazilian agroindustry. As an alternative to minimize the impacts caused by the large amount of waste, sugarcane bagasse can be used as biomass, however, due to high humidity, this material has low efficiency (CHIEPPE, 2011)[4] (SOARES and ROSSELL, 2006)[5]. Santos et al (2020) [6]performed the drying of sugarcane bagasse by a focal solar concentrator, with the aid of gas flow, generating agro-industrial biomass, increasing the efficiency of cogeneration, obtaining the removal of 82% of the initial moisture of 100 grams of bagasse in 45 minutes of sun exposure (SANTOS, CARVALHO, et al., 2020)[6].

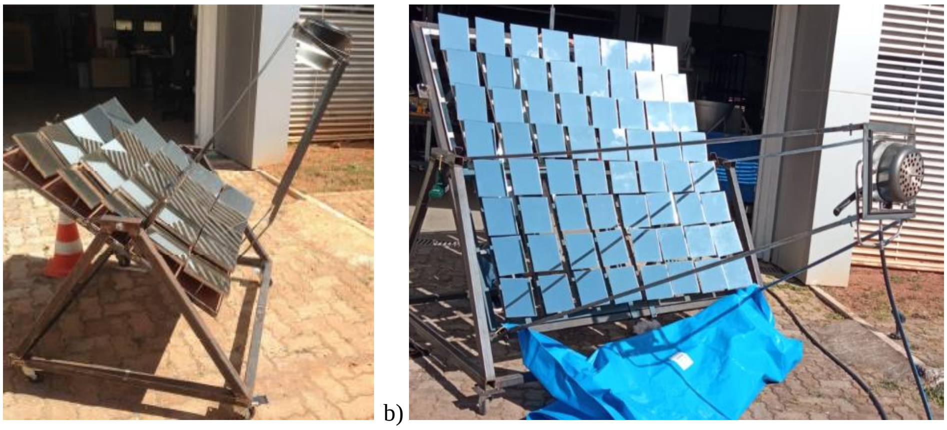
The behavior of the reactors is extremely important for the optimization of the systems, they must be analyzed regarding their shape, material, among other factors, evaluating the temperature variation, thermal fatigue caused, fatigue life and structural reliability, to achieve maximum efficiency. of the system. Through the Abaqus software, it is possible to simulate loads to obtain equivalent displacements, deformations and stresses, this software uses the mechanism of dividing the problems into elements of simpler geometry, known as the Finite Element Method, which when used in structural problems, seek to find tensions, displacements and deformations of the body subjected to external factors and displacements, with static, dynamic and modal analyzes (MARANHÃO, 2016)[7].

The Finite Element Method (FEM) was developed to determine the state of stress and deformation of a solid subject to external actions (AZEVEDO, 2003)[8]. The FEM is an approximate numerical method to analyze various physical phenomena that occur in continuous media, through partial differential equations, boundary conditions and initial conditions (SOUZA, 2003)[9]. The greater the number of elements and nodes, the more exact the solution, however, computational time and cost also increase. Linearity in heat conduction requires temperature independence. The software is able to determine the temperature at each node and flow through each element, generating results in contour graphics (FISH and BELYTSCHKO, 2009)[10]. Abaqus is a versatile software, with several modules, to be applied in engineering problems, it allows an efficient geometry definition, it simulates problems with complex geometries, large deformations, as well as transient loads and interactions between materials, making it a highly complex software, which must be operated by users with good physical knowledge (CONCER, 2011)[11].

3 Methodology

3.1 Experimental

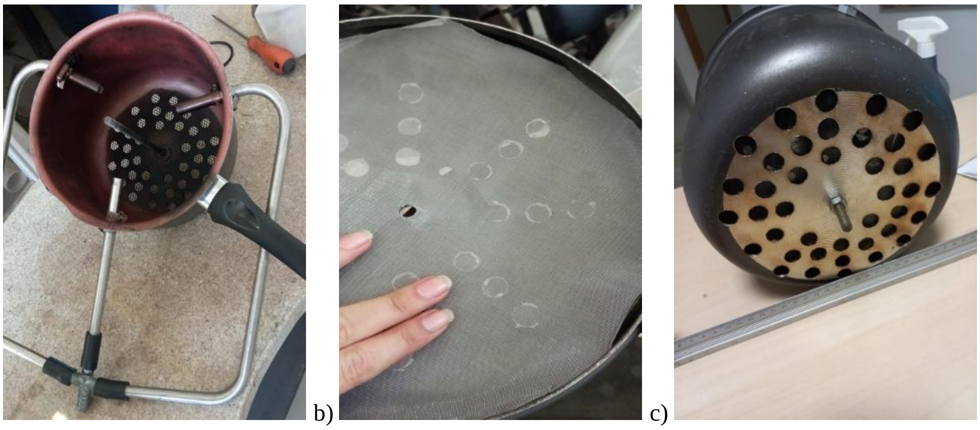
Solar concentrators of 1 m² and 2.5 m² were used. The movement for solar tracking is done manually, from the solar calibration pin and a tarpaulin was used to interrupt the sun rays incident on the panel. The 1m² concentrator (figure 1a) was built with 25 mirrors measuring 0.2x0.2m, while the concentrator measuring 2.5 m² and 64 square mirrors measuring 0.2 m on a side (figure 1b), its movement was also carried out manually, as well as the concentrator with an area of one square meter.



a) b)

Figure 1 – a)1m² solar concentrator and 25 mirrors b) 2.5 m² solar concentrator and 64 mirrors

The first oven, to receive all radiation from the focus, a circular-shaped container is used as an oven (figure 2a), used for air circulation inside the oven, providing a more uniform drying, by means of compressed air. To combat the condensation of the water in the upper part of the oven, there are 40 holes where the water evaporated during drying, can leave the circuit, making it an open system. For the second reactor, a container of the same diameter and lid was used, differing only in the mesh used and the closing of the holes for the passage of compressed air. Tested with 1.7 mm mesh and right after mesh with 0.5 mm spacing (figure 2b). In this second reactor, the air circulation took place through the rotating system of the reactor, and therefore, without the need for additional equipment. This rotation during the tests was done every one minute, with the reactor rotating around its own axis. The finalization of the experiments was carried out with a third reactor, where holes were drilled at the bottom, further speeding up the biomass drying process (figure 2c).



a) b) c)

Figure 2 – a) Reactor 01, b) reactor 02, c) reactor 03

The sugarcane bagasse is evenly distributed in the container and the temperature is measured every one minute and the material is weighed every 15 minutes to check the loss of moisture in the 1m² concentrator, in the larger area concentrators, the measurement Temperature measurement is performed every minute and verification of the mass of the material is performed at the end of the test due to the short time to achieve drying, roasting or charcoaling.

In sequence, the second stage will take place, where the FEM modeling was carried out, using ABAQUS, in the two initially tested models, obtaining tensions and displacements due to temperature variation. Modeling will be done from reactor 02 and 03, with cylindrical geometry, holes at the top and bottom, with a composition of about 82% aluminum, protected by a 0.5 mm mesh screen so there is no loss of biomass. It will also verify the relationship between the temperatures obtained in the focus and the area of each solar concentrator, in the process of drying, roasting and charcoaling of sugarcane. Finally, it will analyze the fatigue life and structural reliability of the tank in focus. The thermal simulation, object of the second stage, is carried out in order to find the temperature gradients that produce the thermal stress. The temperature gradients found will be used as loads for the voltage simulation, which will be done at various points within the transient phase. At each point the thermal stress is calculated, determining the maximum stress value.

4 Modeling

For experimental modeling, 24 experiments were carried out, 10 tests with water and 14 for drying the sugarcane bagasse, where 16 experiments were carried out in the 1 m² concentrator, 08 experiments in the 2.5 m² concentrator. For tests with a bag of 100 g of biomass, tests were also carried out using water, to assess the time and temperature relationship, with 500 g and 1000 g of mass. During the biomass drying tests, measurements were taken such as temperatures at the focus, bottom of the reactor and on the side of the reactor, in addition to carrying out weighings to verify the progress of drying. Non-concentrator with 1 m² as temperatures measured at the bottom of the reactor reached 180.2 °C, while concentrators of 2.5 m² as temperatures measured at 180.3 °C.
However, in the experiments that the water is concentrated, because the temperatures will not be used the mark 9 °C in the reactor for the concentrator with 98 °C in the reactor for 2.98 °C in the reactor for 2.98 m². Low temperatures occur during the water during the boiling point, where the reactor system is open, which reaches about 98.3°C evaporates, keeping the internal temperature in this margin, so the external temperature of the reactor cannot Due to heat transfer by conduction. As gauged foci do not depend on radiation in mirrors, the point of mirrors that are reflected in mirrors only for essential focus. The first test was carried out on the 2.5 square meter solar concentrator, when temperatures reached 170.5°C, due to misalignment of the mirrors.
After the experiments, it was observed that in the 1m² concentrator the temperatures 2m were efficient at 180 °C, during a period of around 2 hours, there was a drying, reaching relatively low temperatures when exposed to high radiation. There is no solar concentration of 2.5 m² as temperatures can reach the level of 34.2°C, the high torrefaction of the biomass before an efficient drying, for that, the rotating reactor was necessary, so that the temperatures do not reach peaks so high in a short period of time, making drying more efficient (table 01).

Table 1 - Summary of experiment results

N° do exp.	Time	Moisture (%)	Temp. Max	Radiation	Comments
4	02:00	5,25	163,2	High	-
5	01:59	7,47	180,2	High	-
6	01:54	12,84	150,7	Some variations	-
7	01:48	47,55	170,5	High	Misaligned concentrator
8	00:20	7,9	320	High	Roasting
9	00:12	29,02	295,6	High	Partial roasting
13	00:09	27,4	342,2	High	Smoke 4 min
14	00:18	16	365,3	High	Smoke 4 min
15	00:05	23,06	282,6	High	Smoke 4 min
16	00:03	37,97	298,9	High	-
21	00:05	20,5	234,7	Cloudy	-
22	00:05	20,97	153,4	Cloudy	-
23	00:04	22,75	268,4	Cloudy	Mirrored
24	00:05	15	193	Cloudy	-

After drying the biomass samples, the calorific value, the quantification of CHN (carbon, nitrogen and hydrogen) were tested, table 02, as well as the calorimetric value, to determine the calorimetry, using the calorimeter equipment with refrigeration bath, brand IKA, model C-2000. In a sample of dry biomass in a solar concentrator with 1 m², the calorimetric power is around 17.57 Mj/Kg and standard deviation of 0.1727. However, in a sample tested in a 2.5 m² concentrator, mean around 17.94 Mj/Kg and standard deviation of 0.9182. Demonstrating that the larger the area of the concentrator, the greater the standard deviation of the calorific value of the sample, explaining its characteristic of homogeneous drying.

Table 2 - Resultados ensaios CHN

Concentrator	C%	H%	N%

1 m²	44,63	5,98	0,287
2,5 m²	40	2,23	0,54

However, the amount of carbon for a 2.5 m² concentrator contains a standard deviation of 2.94, while for a 1 m² concentrator the standard deviation is 0.97. Finally, the humidity, volatility, fixed carbon, ash and dry ash were determined for the same samples of the CHN, as follows table 03, with the average of the results for each area of the concentrator.

Table 3 - Experimento TGA

Concentrator	Moisture %	Volatile %	Fixed carbon %	Ash %	Dry Ash %
1 m²	3,78	79,44	12,74	4,05	4,21
2,5 m²	2,80	75,71	17,685	3,8	3,91

After the experimental modeling, we will start modeling in ABAQUS (figure 3) to analyze what high temperatures cause to reactors, the fatigue caused by high temperature peaks, finding the temperature gradients and the service life, as well as thermal simulations to analyze the limit of the material, relating to the sizes of solar concentrators, finding the ideal relationship between size, maximum temperature reached and efficiency.

a) b)

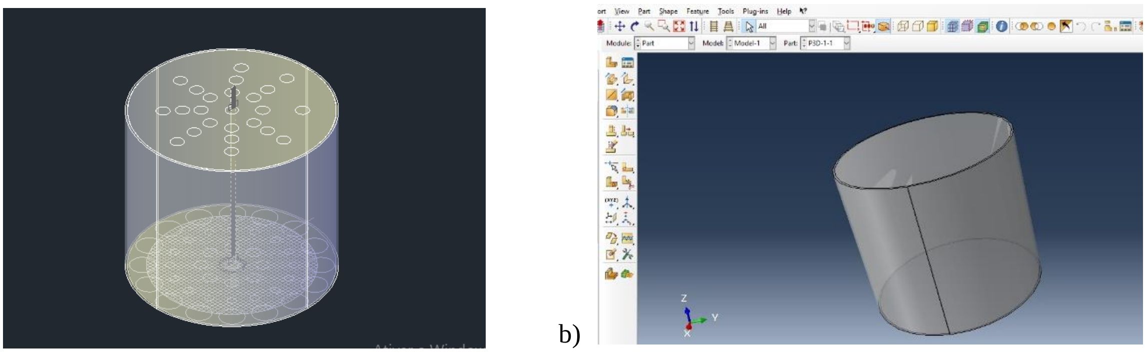


Figure 3 - Initial 3D modeling using a) Autocad and b) Abaqus

5 Conclusions

Analyzing on industrial scales, due to the high content of residues of this biomass in the agroindustry, the drying of bagasse quickly and in large quantities will bring the need to use large reactors at high temperatures in a rotating regime, where with the tests carried out it is already possible to say that the radiation reached in the reactor is the primordial factor to reach the necessary efficiency of drying the sugarcane bagasse. Thermal simulation finds the temperature gradients that produce thermal stresses. It becomes essential to evaluate the fatigue of the material for a safe use and reliability of the structure, estimating the fatigue life and the maximum capacity that the reactor supports, defining the ideal time and the amount of material to use the process, according to the parameters found.

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