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MAPPING AND DEFINITION OF OPERATIONAL PARAMETERS OF AN INNOVATIVE VIBRATING THERMAL SYSTEM FOR PRODUCTION OF TORREFACTED BIOMASS

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Abstract
The search for renewable energy source is growing on a large scale over the past few years. In all industry segments, the market competitiveness encourages investments in new researches to improve the efficiency of energy obtaining processes. Within this scenario arises an alternative source of renewable energy, the use of torrefacted biomass as solid fuel in cofiring with coal or charcoal, currently employed on large scale. This paper aims to study a method for mapping and definition of operational parameters of an innovative electrical vibrating thermal system, in order to provide the residence time to continuous process. Due to system versatility it is necessary to make a study of the combination parameters: motor angle, counter weight balance and frequency, in order to achieve the desired residence time. By the use of homogeneous sets of biomass samples, was possible to map the range of residence time available to complete a circulation cycle of biomass in the system (0:54 – 2:42 min). It can be concluded according to the methodology adopted was possible to determine the range of residence times and their settings for this new reactor concept.
Keywords: *Torrefaction, Torrefacted Biomass, Torrefaction Parameters*

1. INTRODUCTION

The torrefaction objective is to concentrate the carbon present in the biomass, through the low rates of heating and moderated temperatures, allowing the highest heating value volatiles to be retained in its own product (DOAT, 1985). It is a heat treatment with low temperatures that aims to produce a higher energy density fuel by the decomposition of hemicellulose (Prins, 2006).

Over the possibility of improvement on the energy properties, it is expected that the wood torrefaction product be more easily fragmentable, in due to its physical-mechanical resistance decrease, which is desirable, in the hypothesis of the material changing for the pulverized way, as in the pellets and briquettes production.

The process of torrefaction is done in the atmospheric pressure, so the machines employed aren't, in general, complex. The technologies for the torrefaction may be classified by the heat transfer (direct or indirect) and by the type of process (batch or continued) (Oliveira e Rousset, 2009).

The batch process is characterized by the heat transfer by convection of the combustion gas through the wood load. The system developed by the enterprise PILLARD is constituted by two furnaces, one for the drying and other for the torrefaction (Girard & Shah, 1991). In this kind of process, the main disadvantage is about the time of production, because in general the process needs to be interrupted so that there is the removal of roasted biomass, thus, growing the adjustment time of the machine to receive the new batch.

The continued process was developed by PECHINEY electrometallurgy, in which the heat transfer takes place by conduction by contact between biomass and the reactor heated surfaces (Girard & Shah, 1991), in this process, the wood is previously dried and crushed in 10mm maximum size and the torrefaction gas is recirculated to the drying boiler, the main advantage is the not interruption of the process, but very often it is noted that not renewable energy sources are used to the heat generation.

Some examples of torrefaction technologies developed nowadays are: Rotating drum, is a reactor robust and well-established for drying, but it has low heat transfer efficiency and his product is heterogeneity; Screw reactor, indirect heating by hot gas circulation inside the walls and the screw, it has low mixing of the bed, cleaning difficult; Multiple Hearth Furnace, which has a large range of biomass, independent heating for each floor, but his temperature is heterogeneity and no re-use torrefaction gas.

The roaster described in this article has the advantages of performing the heat transfer by conduction through the Joule effect and have a continued production process, over a flexibility as the adjustment parameters for the residence time of torrefaction, the objective of this article is to show a method to define the best configuration among the operation parameters of the roaster.

2. DESCRIPTION OF THE ROASTER AND ITS OPERATIONAL PARAMETERS

2.1. Description of the operation

This device is constituted by an octagonal metallic matrix, wrapped by 4 spiral tubes, size 21m and external diameter 88,9mm, where the chips will circulate, being roasted by the heat changed by direct contact with the tubes, heated by passage of electric current (heat by Joule effect) (Carrère, 2014). To the heat there are two possibilities, the first one is keeping the temperature constant and the second one is keeping the rate of heat transfer constant (fig. 1).

How it is about a laboratory level equipment, the supply of chips is done manually, however for a process in large scale it may be used devices as the pneumatic transport or silos for the automation of the supply.

The chips move into the tubes, being high through the vibration impressed by motors localized under the machine, whose operational parameters are cited in the item 2.2. The exhaustion of the gases is done by an outlet duct connected to an exhaust which removes the gases and volatiles, producing a slight depression on the system.

After complete the residence time defined for the process, the biomass roasted is discharged, may be refrigerated and stored to posterior utilization.

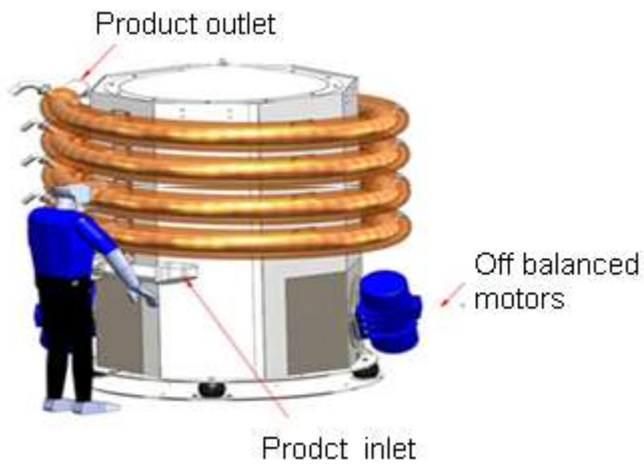

Figure 1. Roaster (Doassans, 2014)

2.2. Operational parameters

The product is transported and mixed in a stainless steel spiral tube using vibrations induced by two off-balanced shaker motors (Carrère, 2014). An off-balance shaker motor is a rotating motor equipped with eccentric weights. As these masses rotate they generate vibrations along a plane at right angles to the motor axis, whose frequency is determined by the speed of rotation and whose amplitude is proportional to the mass of the off-balance weights. To modify the residence time of the particles inside the spiral, three parameters can be changed: angle of attack of the motor, the position of the eccentric weights and the frequency of rotation of the motors.

The main operational parameters that affect directly the move and define the residence time of biomass in the system are: the frequency of activation of the motors, unbalance and motor angle of attack. For each there is an operation range shown in Tab. 1.

Table 1. Parameters of the torrefaction unity.

Parameter	Range
Temp Setpoint	0 – 400°C
Motor Angle	12 – 45°
Counter Weight Balance	60 – 95 %
Frequency	40 – 50 Hz

3. METHODS

3.1. Definition of parameters and data collection

To begin the mapping process methodology, the first step was to define the combination of setup parameters (motor angle, counter weight, frequency) will be used for each test, showed in Tab. 2. The parameters value were choose according with the range of operation, it means that for each parameter was choose a value in the lower limit, in the middle and in the upper limit. To the first test, the setup was: motor angle 45°, counter weight 95% and frequency 50Hz, respectively.

Table 2. Test settings

Test	Setup	Test	Setup	Test	Setup
1	45° 95% 50Hz	10	30° 95% 40Hz	19	12° 95% 40Hz
2	45° 95% 45Hz	11	45° 80% 40Hz	20	12° 95% 50Hz
3	45° 80% 50Hz	12	30° 80% 45Hz	21	12° 95% 45Hz
4	45° 95% 40Hz	13	30° 65% 50Hz	22	12° 80% 45Hz
5	45° 80% 45Hz	14	45° 65% 45Hz	23	12° 80% 50Hz
6	30° 95% 50Hz	15	30° 80% 40Hz	24	12° 80% 40Hz
7	30° 95% 45Hz	16	30° 65% 45Hz	25	12° 65% 50Hz
8	45° 65% 50Hz	17	45° 65% 40Hz	26	12° 65% 45Hz
9	30° 80% 50Hz	18	30° 65% 40Hz	27	12° 65% 40Hz

Once that the parameters were defined, the next step is feed the reactor spirals with the biomass that will be used in the torrefaction process, for these tests was used 8.9 kg of pieces of wood with the size between 0.001 mm and 30 mm. Then is turned on the reactor vibration system without turn on the heating system. After 5 minutes of stabilization, begins a video to record the inspection window. Different wood colored cubes (Blue, Green, White, Yellow and Red) with the same dimensions are inserted in the reactor one by one on each 10 seconds, totalizing 5 colored cubes. For each test the camera records the movimentation inside the reactor by 20 minutes. For this method, the reactor has the outlet connected to the inlet in order to recirculate the biomass within the system.

3.2. Data acquisition

Each recorded video was watched frame by frame with the intention to identify the time that each colored cube has passed in front of the inspection window, a table was filled up with this information. The test is considered valid if at least one cube passes at least three times by the inspection window.

4. MATHEMATICAL EQUATIONS

4.1. Behavior of the product subjected to vibration

To describe the movement inside the reactor, these equations and correlations can be used.

- Relation between poles, speed and frequency.
  In the case of three-phase induction motor:

$$N = \frac{60 \times f}{p}$$

Where:

N = the speed of rotation of the motor in revolutions per minute;
f = the frequency in Hertz or cycles per second of the power supply;
P = the number of pairs of poles.

- Relation between centrifugal force, the speed of rotation and the off-balance weights.
  The centrifugal force developed by an eccentric mass during rotation is given by the following equation:

$$F_c = M_1\omega^2 R$$

Where:
F_c = centrifugal force in daN (1 daN=0.981);
M_1 = the total mass of the off-balance weights, excluding the shaft, in kg;
ω = the angular velocity in radians per second, and also:
$\omega = \frac{2\pi N}{60}$;
N = the rotation speed in rpm;
R = the distance of the axis from the center of gravity of the off-balance weights in meters.

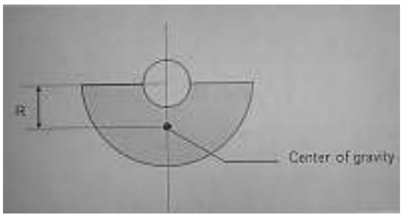

Figure 2. REVTECH Process Systems maintenance and commissioning manual.

- Working moment of the vibrating motors.

The working moment is the work developed by the motor to turn its off-balance weights. It is expressed as follows:

$$C = M_1 R$$

C = working moment in kg/cm;
M1 = the total mass of the off balance weights, in kg.

It is possible to determine the amplitude (peak to peak) of a vibrating device based on the holding torque of its vibrator, by means of the following equation:

$$2A = \frac{2 \times (10C)}{M_2}$$

Where:
$2A$ = double the amplitude in mm, this value allowing of measurement on the vibrating device;
M_2 = total vibrating mass including the vibrators. In kg;
C = holding torque of the motor in kg/cm.

- The relation between centrifugal force and double the vibration amplitude and the acceleration.
  It is also possible to determine the total amplitude of a vibrating device from the total centrifugal force of its vibrators by means of the following equation:

$$2A = 2 \times \frac{\mathrm{F_c} g}{M_2\omega^2}$$

Where:
$2A$ = double the amplitude in mm, this value allowing of measurement on the vibrating device;
M_2 = total vibrating mass including the vibrators. In kg;
$\mathrm{F_c}$ = the total centrifugal force of the vibrators, in daN;
ω = the angular velocity in radians per second.

Second REVTECH manual, these equations allows us to predict the centrifugal force necessary to communicate a vibration of specified double amplitude to a structure of a given mass.

4.2. Data processing

The loop duration was calculated by difference of time between the pass of the cube with same color, using the equation 1. This was repeated for each cube.

$$t_{cube} = t_{final} - t_{initial} \quad (1)$$

The average time per loop for each cube was calculated applying the equation 2. Where N are the number of time samples.

$$t_a = \frac{\sum t_{cube}}{\sum N} \quad (2)$$

The equation 2 was applied again on the results of each color to obtain the residence time.

5. RESULTS AND DISCUSSIONS

The residence time results were organized in a graphic presented in the figure 2 showing the residence time for each test.

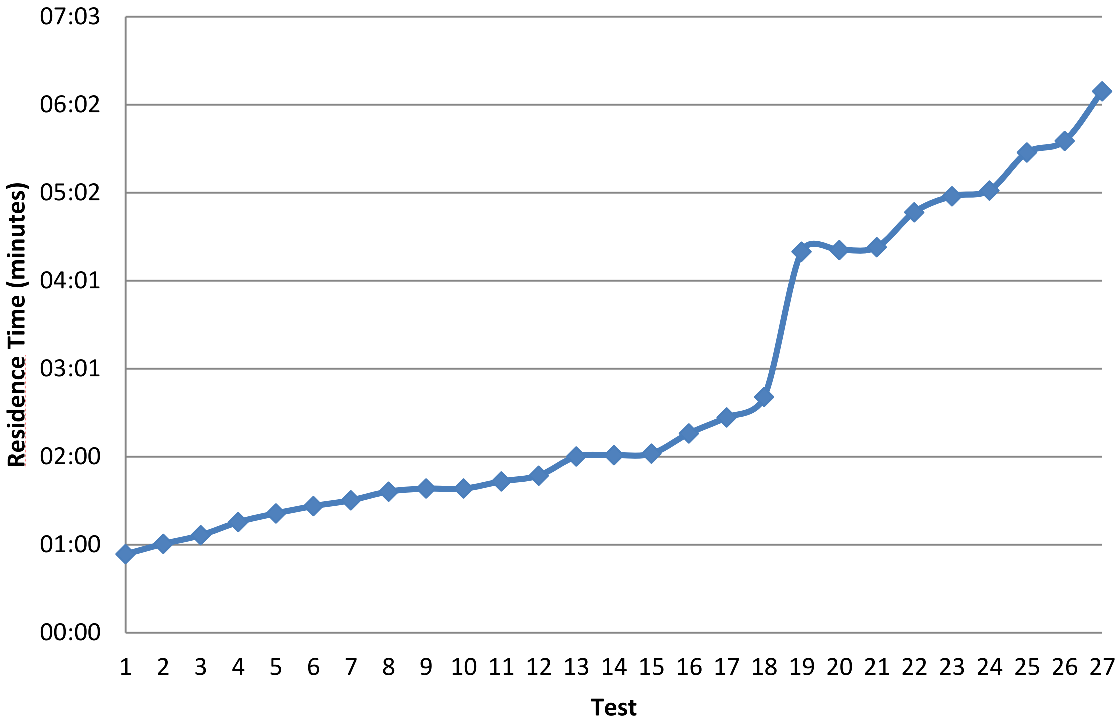

Figure 2. Residence time obtained for each test.

The figure 2 shows that the residence time with angle of the motors in the position 45° has the more fast residence times, followed by motors with angle 30° and finally the motor angle 12°. The Tab 1. shows the results in ascending order of time. The results with motor angle in position 12° has a longer residence time, that can be explained by the move characteristics where the impulse in this angle generate a greater vertical movement in comparison to the forward movement. According with the Tab. 1, the residence time more quickly has the setup: motor angle 45°, counter weight 95% and frequency 50Hz, and the more slowly was the setup: motor angle 12°, counter weight 65% and frequency 40Hz.

6. CONCLUSIONS

The results shows that the motor angle has more impact on the residence time, for this case was possible identify that the motor angle in the position 45° results in a faster biomass move, the second parameter more impactful was the counter weight balance and finally the frequency. According to the results obtained lower motor angles have an unstable behavior it's can harm the torrefaction process. So, for this case the lowest recommended motor angle is around 30°, where the behavior is stable, according to impact order previously established. The balance of the counter weights impact in the impulses generated by the motor, making the vibration effects stronger or softer. The frequency is responsible in the excitation rate that the biomass is subjected.

The previous study of the biomass behavior in reactor is important for to discover which parameter has more impact in the particles movement. Changing the parameters is possible modify the time per loop, making the biomass move faster or slower, this will impact on the residence time of the torrefaction process. Also, the residence time can change with the biomass used (Doassans et al, 2014). In a continuous process the residence time is critical to the performance of torrefaction process. Besides the residence time, another important factor in roasting is the temperature at which the biomass will be subject, once known the residence time and their parameters, an appropriate temperature can be selected to perform the torrefaction to improve the production rate and the biomass roasting level, for choose an ideal roasting point (Wannapeera et al, 2011). Finally, this new torrefaction technology proved be very versatile with parameters that can be adjust according the biomass used. But the better characteristic of this new technology is the operate capability in process continuous.

7. ACKNOWLEDGMENTS

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