TECHNICAL NOTE:

TEST OF FAST PYROLYSIS AT BED REACTOR FLUIDIZED WITH THREE AIR FLOW RATES

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ABSTRACT

Test of fast pyrolysis at bed reactor fluidized were carried out with sugar cane using air as fluidizing agent, where three bands were used to adjust the valve opening to control air flow to the reactor. The objective was to evaluate the yields of bio-oil and fine charcoal depending on the flow of air, in which it was measured with an orifice plate. The temperature profiles and pressure inside the reactor were also monitored. The pyrolysis plant where the tests were conducted belongs to the School of Agricultural Engineering at the University of Campinas (UNICAMP), being installed at the Laboratory of Thermodynamics and Energy. The reactor has a nominal capacity of 200 kg.h^{-1} of biomass and operates on auto-thermal regime, consuming between 10% and 15% of the biomass to supply heat to the process. The values of temperature and pressure increased, as well the amount of biomass burned to supply heat. It was observed that the total biomass fed into the reactor presented decreased in relation to increased air flow, as well as the gravimetric income of fines charcoal and bio-oil.

Keywords: Fast pyrolysis, Fluidized bed, Air flow.

RESUMO

TESTES DE PIRÓLISE RÁPIDA EM REATOR DE LEITO FLUIDIZADO COM TRÊS VAZÕES DE AR

Foram realizados ensaios de pirólise rápida em reator de leito fluidizado com palha de cana-de-açúcar utilizando ar como agente de fluidização, onde foram utilizadas 3 faixas de ajuste para a abertura da válvula de controle de fluxo de ar para o reator. O objetivo foi avaliar os rendimentos de bio-óleo e finos de carvão em função das vazões de ar, que foram medidas com uma placa de orifício. Também foram monitorados os perfis de temperatura e pressão no interior do reator. A planta de pirólise onde foram realizados os testes pertence a Faculdade de Engenharia Agrícola da Universidade Estadual de Campinas (Unicamp), estando instalada no Laboratório de Termodinâmica e Energia. O reator possui uma capacidade nominal de 200 kg.h^{-1} de biomassa e opera em regime auto-térmico, consumindo entre 10 e 15% da biomassa para fornecimento de calor ao processo. Enquanto os valores de temperatura e pressão sofreram elevação, assim como a quantidade de biomassa queimada para fornecimento de calor, observou-se que a quantidade total biomassa alimentada no reator apresentou comportamento decrescente em relação ao aumento da vazão de ar, assim como os rendimentos gravimétricos de finos de carvão e bio-óleo.

Palavras-chaves: Pirólise rápida, leito fluidizado, vazão de ar.

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INTRODUCTION

In Brazil, fast pyrolysis is presented as a promising technology in the production chain of second generation biofuels by the thermochemical route (JORDAN et al., 2010). It works through the gasification and production of synthesis gas to obtain synthetic fuels, with characteristics similar to gasoline and diesel. In this case, bio-oil presents advantages over natural biomass in the gasification process, as the transport logistics (CORTEZ et al., 2010).

The fast pyrolysis is a process of thermochemical conversion of biomass. It is characterized by the thermal degradation of solid fuel with restriction of oxygen in a short reaction time, of few seconds. The main product of interest is the bio-oil, but there is also the production of charcoal powder, pyroligneous acid and gases (MESA PEREZ et al., 2010).

Fast pyrolysis, gasification and carbonization are variants of the same process. What distinguishes one from another is the residence time in the reactor, the reaction temperature and the heating rate. In auto thermal reactors, the air supply will affect the reaction temperature and the retention time of the particle. These parameters influence the amounts of solids, liquids and gases (BRIDGWATER, 2002).

The yields of products from fast pyrolysis in a laboratory scale using highly efficient bio-oil recovery equipment can reach 75% by weight (BRIDGWATER, 2001, quoted by OLIVAREZ GOMES et al., 2008). This yield considers the total recovered mass of liquid such as water, acids, extracts, and bio-oil.

In general, we can say that the yield of pyrolysis products of organic solids is a function of operating variables such as the input heating rate; temperature and pressure of the process, heating and residence times of the phases in the reactor; type technology used ; the physico-chemical and geometric characteristics of the input; among other variables (MARCOS MARTIN, 1989; FELFLI F. F., 2003; MEZERETTE C. & GIRARD P., 1991; ANTAL JR. et al., 1992a and 1992b; LUENGO et al., 2008).

The increased pressure in the pyrolytic reactor favors high yields of solid and reduces considerably gaseous fractions. However, high temperatures and high heating rates favor high yields of the gaseous fraction (Bridgwater, 2006). Vacuum pyrolysis reduces the residence time of the vapor phase by increasing the yields of the liquid phase.

According to BRIDGWATER (2001), the fluidized bed technology is interesting because of the versatility of the technique, its relative simplicity when compared with other options (such as vacuum pyrolysis, rotary cone, vortex ablative, etc.), and attractive cost of establishment. The bio-oil obtained by biomass pyrolysis can be used as a renewable fuel to replace diesel and fuel oil at stationary power generation in thermoelectric systems.

The bio-oil is the biomass in its liquid form, which gives advantages in terms of transportation, pumping, storage, and handling, characteristics that the solid biomass, with its high moisture content, does not have. Thus the bio-oil can benefit the entire structure currently used for liquid fuels. The transport of the biomass in the liquid state, i.e., in the form of bio-oil, is much more convenient and feasible at long distance due to its high energy concentration (MESA PEREZ *et al*., 2010).

The reactors for catalytic conversion of synthesis gas, in general, are pressurized (50 to 100 bar), what reduces operating costs in the gas compression step with the increase in production capacity of gasifiers. In contrast, pressurization hinders the operation of biomass power systems, especially those with low density (SEABRA, 2008).

Thus, the gasification of bio-oil is more interesting because the gasification system can be easily pressurized and the pure oxygen can be used instead of using atmospheric air. This method allows the production of high quality synthesis gas since it avoids its dilution in nitrogen from the atmospheric air and results in high concentrations of two components of the synthesis gas, hydrogen and carbon monoxide (HAMELINCK *et al*., 2001; HAMELINCK *et al*., 2003; LARSON *et al*., 2005).

Pyrolysis needs to be further developed for large-scale application, especially with regard to increased efficiency in the conversion of biomass into bio-oil. There are other issues, such as those related to the quality and stability of bio-oil. But

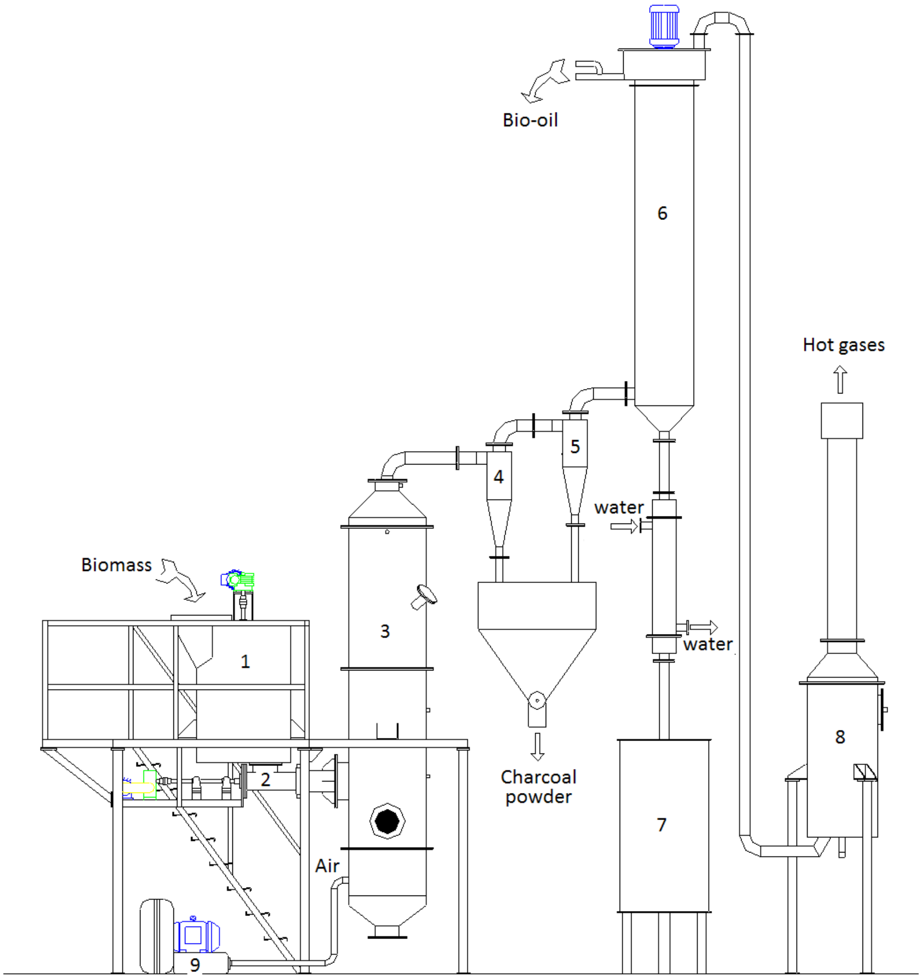


Figure 1. Schematic plan of the fast pyrolysis plant of the School of Agricultural Engineering at UNICAMP.

there is no doubt that the increase in yield and scale are the key points to achieve a thermochemical route based on the use of bio-oil instead of in natura biomass (CORTEZ e*t al*., 2010).

This paper presents results of tests carried out in the fast pyrolysis plant belonging to the School of Agricultural Engineering at Unicamp, using sugarcane trash, where the objective was to evaluate the transformation yield of this biomass into charcoal and bio-oil as a function of air flow rate of fluidization reactor.

MATERIAL AND METHODS

Figure 1 shows a schematic plan of the fast pyrolysis plant of the School of Agricultural Engineering at UNICAMP with its major equipment components.

Figure 1 shows the following operations: biomass contained in the silo (1), through the feeding screw (2), is injected into the fast pyrolysis fluidized bed reactor (3). The biomass, when it comes into contact with the bed reactor, is volatilized, thus becoming solid (coal), vapors (bio-oil and pyroligneous acid), and gases. Coal is separated in the battery of cyclones (4 and 5); the pyroligneous acid and bio-oil are separated in the recovery system (6) independently. In the reservoir (7), pyroligneous acid is obtained, and bio-oil is removed from the top side exit of the separator through a rotating mechanical system. The remaining gases are burned in the combustion chamber (8). These gases could be used as an agent of the fluidization bed in the reactor. However, the tests were carried out with atmospheric air injected directly into the reactor by an air blower (9).

The reactor is cylindrical and built of carbon steel with an internal diameter of 417 mm, and internally lined with refractory insulation. The feed nominal capacity is 200 $kg.h^{-1}$ of polydisperse dry biomass, and it utilizes a bed of inert material during its operation. Table 1 provides the main design characteristics of the reactor. The inert material utilized in the bed is silica sand (silicon dioxide = SiO_2) with a particle diameter of 0.164 mm and 0.6 of average sphericity.

The reactor is auto-thermal, thus a portion of the injected biomass (10-15%) is consumed to supply heat to the bed of inert material. Therefore, air is used as fluidizing agent, which is injected into the reactor by the air blower through its base. It goes through holes in the distribution board, which is the bed of inert material. Figure 2 shows the detail of the reactor and the biomass supply system, which consists of the silo and feeding screw.

The rotation of the electric motor of the feeding screw is controlled by a frequency inverter. The adjusting of the feed rate of biomass in the reactor is given by the frequency adjustment of the feeding screw motor. During normal operation of this plant, this adjustment is done to ensure a feed rate that maintains the temperature of the bed in a condition suitable for the process, i.e., between 450 and 500 ° C.

The centrifugal air blower used is triggered by a three-phase electric motor directly coupled and with a nominal power of 5.5 kW. According to the data plate, a pressure of 3.1 m.c.a. provides a flow of 360 $m^3.h^{-1}$. The air flow to the reactor is adjusted by a valve located before the orifice plate utilized to measure the flow (Figure 3). A second valve is used for pressure relief, directing the excess air to the atmosphere. Both valves are spherical.

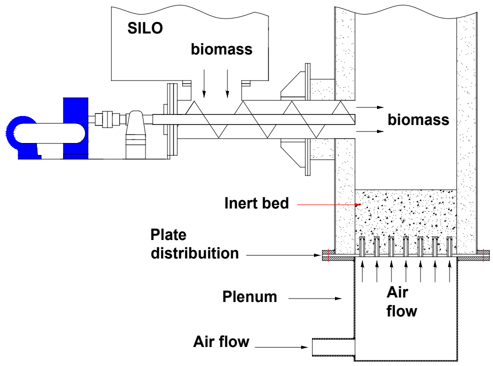
The biomass utilized was sugarcane trash, which, after being dried and crushed to obtain a particle size between 1 and 5 mm, suitable for the fluidized bed process, was wrapped in plastic bags. They were then weighed to enable the monitoring of the amount of biomass fed into the reactor. The weight of biomass in the plastic bags ranged from 6 to 9 kg.

Two markings were used in the biomass silo, one upper and one lower. The level of biomass was in the top mark at the beginning of the operation. Feeding occurred every time that the level of biomass reached the lower mark, then completing up to the upper mark, continuing during the tests.

The profiles of temperature and pressure in the reactor were monitored during the tests through pressure transmitters and K type thermocouples, which were connected to acquisition modules of FieldLogger model, manufactured by Novus. Then, they were connected to a microcomputer, where the reading and writing of data was made through FieldChart software.

Table 1. Technical characteristics of the reactor

Reactor type	Fluidized bed
Material of construction	Carbon steel
Diameter (internal)	417 mm
Height	2600 mm
Bed height	400 mm
Type of insulation	Refractory
Insulation thickness	80 mm
Plate distribution material	Carbon steel
Minimum fluidization velocity	0.025 m/s at 25 ºC
Retention time of particles	2 to 3 seconds
Operating temperature	400-500 ºC
Pressure	300 mmH_20



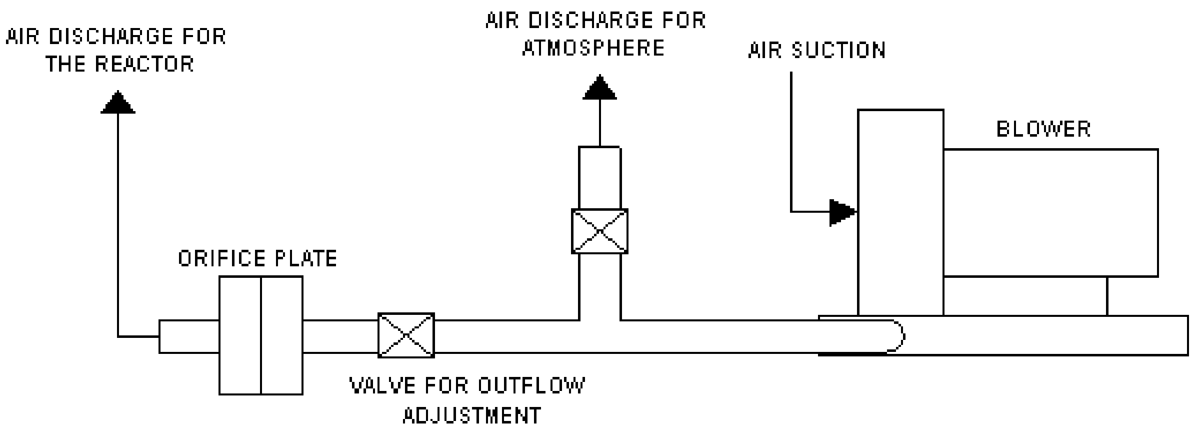


Figure 3. Air blower, system, and valves to adjust the air flow.

The air flow values were calculated utilizing equation 1, the data from the orifice plate, and pressure values measured in the differential manometer tube (Figure 4).

$$\dot{m} = C_d \cdot \frac{A_2}{\sqrt{1 - â^4}} \cdot \sqrt{2.ñ.ÄP} \quad (1)$$

$$â = \frac{d}{D} \quad (2)$$

where
$\dot{m}$ -mass flow of air [kg/s];
C_d - discharge coefficient [dimensionless];
A_2 - area of the orifice plate [m^2];
$ñ$ - density of air [kg/m^3];
$ÄP$ - differential pressure measured at the orifice plate [kPa];
d - diameter of the orifice plate [m];
D - pipe diameter [m].

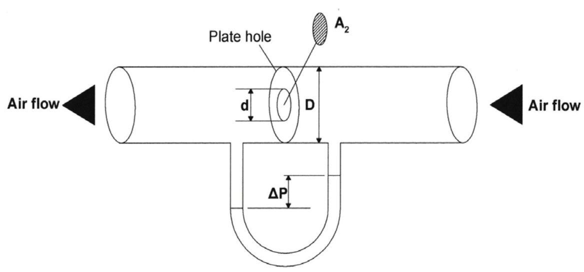


Figure 4. Data collection scheme to calculate air flow.

The discharge coefficient is a correction factor for the orifice plate when dealing with compressible fluids, such as air. This was determined by the Reynolds number and the relationship between the diameter of the orifice plate and pipe diameter, which was equal to 0.8 in this case.

The volumetric air flow (m^3/s) was obtained by multiplying the result obtained from equation 1 by the specific volume of air. It was obtained by the inverse value of the density determined as a function of air temperature.

The duration of each experiment was approximately 30 minutes. In all experiments, the rotation of the feeding screw that feeds the reactor was fixed through the frequency set by the inverter, which was 31 Hz.

There were two replicates for each flow rate, i.e., for each position of the control valve opening of the air flow to the reactor. After each test, the amount of fine coal and bio-oil produced were weighed on a digital scale, Toledo brand, with a maximum capacity of 30 kg and precision of 10 grams.

The burned amount of biomass to supply heat to the process was estimated based on the values of air flow for each test, considering a stoichiometric condition.

The yields of bio-oil and coal fines were determined based on the mass of useful biomass, which is the mass of pyrolyzed organic liquid. It was determined by subtracting, from the total mass fed in the reactor, the amount burned for heat supply, the mass of ashes and the mass of water present in the biomass. The mass of ashes and the mass of water were estimated utilizing data from the proximate analysis performed for a sample of the sugarcane trash.

RESULTS AND DISCUSSIONS

Table 2 shows the data of the proximate analysis of sugarcane trash utilized in the tests, which allowed the calculation of the mass of water and ashes that were utilized in the calculation of the mass of useful biomass.

Table 2. Data of the proximate analysis of the sugarcane trash utilized in the tests

Composition	**Levels [%]**
Ashes (CZ)	11.70
Volatile materials (MV)	81.55
Humidity (U)	9.92
Fixed carbon (CF)	6.90

Table 3 presents average values of operating parameters of the fast pyrolysis plant for tests with sugarcane trash as a function of the point of the air flow control valve opening, increasing from position 1 to position 3.

It can be noted that in position 3, despite the greater openness of the control valve, there was a reduction in air flow compared to position 2. It was caused by the loss of load imposed by the reactor and the equipment connected to it, which caused increased pressure in the reactor. Thus, it causes the direction of airflow to the atmosphere through the relief outlet. This demonstrates a failure of the flow control system adopted, which should be done by controlling the blower motor speed, avoiding this problem.

Table 4 presents the mean values related to the consumption of biomass and the production and yield of bio-oil and coal fines as a function of the operating conditions imposed by the position of the air flow to the reactor control valve.

Table 3. Average values of operating parameters of the fast pyrolysis plant as a function of the point of the air flow control valve opening

Data	**Position 1**	**Position 2**	**Position 3**
Air flow [kg/h]	85.47	94.71	87.69
Air flow [m^3/h]	77.59	85.99	79.61
Reactor temperature [ºC]	460	553	600
Reactor pressure [mm.c.a](*)	154	182	166

(*) Pressure measured just above the bed of the reactor.

Table 4. Mean values of biomass consumption, production, and gravimetric yield of bio-oil and coal fines

Data	Position 1	Position 2	Position 3
Consumption of raw biomass [kg/h]	147.27	128.16	93.19
Burned biomass [kg/h]	18.66	20.68	19.15
Pyrolysed useful biomass [kg/h]	100.8	84.24	58.04
Bio-oil production [kg/h]	22.43	17.33	8.84
Charcoal production [kg/h]	30.00	24.21	12.19
Bio-oil yield [%]	22.25	20.57	15.23
Charcoal yield [%]	29.76	28.74	21.00

As can be verified by the data from biomass consumption, increased interior pressure in the reactor also affected the feed supply of biomass, which caused reduction in the amount fed, even maintaining constant the rotation of the feeding screw. The rise in pressure caused a reduction in the occupation rate of the screw, which was also affected by the escape of gases through it. It also explains the reduction of pressure in the reactor between positions 2 and 3. However, the amount of biomass burned to supply heat to the reactor did not follow such behavior because of the amount of air, favorable to the combustion, which explains the growing behavior of the reactor temperature.

Therefore, from the total fed into the reactor, the percentage of biomass burned to supply heat for positions 1, 2 and 3 of the flow control valve were, respectively, 12.7%, 16.1%, and 20.5%. From position 1 to position 2, there was an increase of 7.8 percentage points, which explains the rise in reactor temperature.

From position 1 to position 3, the products of gravimetric yield (fine coal and bio-oil) increased 52.01% to 36.23%, i.e., a decrease of 15.78 percentage points. This shows that the increase of the percentage of biomass consumed for heat generation affected the yield, and, also, pressure and temperature conditions.

According to Olivarez Gómez *et al.* (2008), the increase of the pyrolytic reactor pressure should favor higher yields of solid fraction. However, the pressure was not the only factor to change;there was also the increase of reactor temperature, from 460 ºC in position 1 to 600 ºC in position 3. The combined high pressure and temperature caused increased at residence time of pyrolysis products in the reactor. Thus, promoting a more extensive gasification. There was a reduction in the yield of solid fraction (fine coal) as well as in the liquid fraction (bio-oil). This has been verified in tests where the amount of biomass burned in process was above 15% (position 1 and position 2) showing air supply rates exceeding 15% of stoichiometric.

CONCLUSIONS

- It was found that the amount of air injected into the reactor not only changes the amount of biomass consumed for heat generation and temperature of the process, but also affects the amount of total biomass fed and the reactor pressure, considering the type of control adopted for air flow and features of the feed system utilized in the fast pyrolysis plant where the tests were performed;
- The lower air flow rate utilized in the tests provided conditions more suitable for the fast pyrolysis process, thus favoring higher gravimetric yields of fine coal and bio-oil;
- The use of flow rates greater than 15% of stoichiometric air provided favorable conditions for a more extensive gasification, thus reducing the yield of fine coal and bio-oil;
- The flow adjustment system utilized, through valves, proved itself to be ineffective.

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