Comparative study of the rheological behavior of palm shell, peanut shell and cashew shell in rotating drum

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Abstract— **This paper presents an experimental study of the determination of the dynamic angle of repose (β) of peanut shell, cashew shell, palm shell and mixture of these residues, an important macroscopic parameter for the characterization of flow granular materials. The study of the residence time and the determination of active and passive layers thicknesses were also performed by using empirical formulas. The dynamic angles of repose of peanut shell, cashew shell and palm shell were experimentally studied in rotating drums (drum diameters are 400 mm, 560 mm and the lengths are 1000 mm) for filling rate of 15 % and 25 % with rotational speeds (n) from 2 to 11.66 rev/min and inclination angles from 0 to 3°. First, the results show that the flow properties are depending to the physical properties of the material such as density and roughness. The results are strongly influenced by operating conditions such as rotational speed, inclination angle, drum diameter and filling rate. Thus, the increase of rotational speed involves the decrease of the dynamic angle of repose (β) of the solid while an increase of the inclination angle (θ) would increase this dynamic angle of repose. Concerning the drum diameter, the results show that the decrease of the dynamic angle of repose would increase it, depending to the material type. About the study of residence time, we found that the cashew shells presents the shortest residence time followed by peanut shells and finally palm shells. For the determination of active and passive layers thicknesses, we noted that the height of the active and passive layers decrease with the decrease of the filling rate and with the increase of the rotational speed. Peanut shells have the higher active and passive layers followed by cashew shells and finally palm shells.**

Keywords— dynamic angle; drum; cashew, peanut and palm shells

I. INTRODUCTION

In a context of sustainable development and the fight against climate change, reducing energy costs and the use of renewable energies based on processes that maximize energy efficiency and protecting the environment are the main challenges for developing countries. With the depletion of fossil fuel resources, countries must turn to renewable energy for the development of their economy. To this end, the control of waste treatment technologies is a necessity. Our study is moving in the case of using rotary kilns. The use of rotary kilns appeared most recently for applications such as waste and biomass treatment and valorization. All these applications are costly in energy and some can cause harmful emissions and greenhouse gases. Therefore, the search for optimal operating conditions of the rotary kiln remains a priority. Thus, a study on the determination of the dynamic angles of repose of peanut, cashew and palm shells within rotating drum was conducted in order to achieve better design of treatment equipment of these materials. The dynamic angle of repose a macroscopic parameter, influencing the flow profile and the residence time of the material, corresponds to the slope at which a granular material, given by avalanche, will stabilize and come to rest. It is determined numerically or experimentally. Several studies measuring the dynamic angle of repose were conducted on materials of different sizes and forms [1-4]. For the study conducted by [3], a new method was used for simultaneously measuring the angle of repose and friction coefficient of wheat grains. The method was based on the motion of the grains in a partially-filled horizontal rotating drum at the slumping and rolling modes of motion. The results obtained by Khazaei and Ghanbari, [3] confirmed that rotating drum method at filling degree of 0.222 and rotation speed of 3 rev/min can be used for simultaneously measuring the dynamic angle of repose and friction coefficient of wheat grains. For the studies carried out by [1], the image processing method is used. Digital images were taken through a transparent plastic plate attached to the drum at the same time as the rotation of the system to measure the dynamic angle of repose for all operating conditions. The dynamic angle obtained during the simulations is estimated through the mean surface of the flat bed.

Note also in the literature that we have not found any studies which determine the dynamic angle of repose of these kind of residues by using the image processing method or the experimental method.

In this paper, comparative study of the rheological behavior of palm, peanut and cashew shells in a rotating drum was performed in order to determine their dynamic angles of repose, their residence time and their active and passive layers thicknesses.

II. MATERIALS AND METHODS

A. *Experimental setup*

The experimental setup shown schematically in Fig. 1 corresponds to a rotating drum arranged horizontally on a rectangular support. On one of the drum extremities, a circular transparent plate containing a circular opening of 10.5 cm diameter is fixed in order to observe the movement of the material inside the drum. On the other extremity of the drum, an electric motor of 0.25 kW rotating at a maximum speed of 1380 rev/min at a frequency of 50 Hz with a converter connected to the drum by a drive shaft. The speed reduction ratio of the motor/drum is equal to 71. The motor is powered with 220 V. The rotation of the motor drives the drum in its rotational movement with a maximum rotational speed of 19.44 rev/min. The drum can be inclined at an angle varying from 0° to 3°. This variation of the inclination angle is adjustable using the handle, which is located just behind the electric motor. To avoid sliding motion, the drum is covered with sandpaper. Two drums with dimensions of DxL = 400 mm x1000 mm and 560 mm x1000 mm were used.

D represents the drum diameter and L the length. A digital camera (canon type) is use to visualize the residue inside the drum through the transparent plate. The images taken by this camera are scanned image by image using image processing software to deduce the dynamic characteristic of the rotating residue bed.

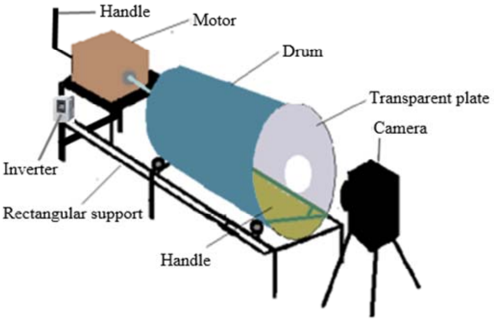

Fig. 1. Drum rotating scheme used in the experiments.

B. *Materials*

The experiments were conducted on peanut, cashew and palm shells. The physical and physico-chemical characteristics of these three residues are determined. The shells have different sizes, different bulk densities and different thermal properties. The results show that the shells have significant lower heating values. However, the peanut shell has a low energy density and low bulk density. The elementary and immediate analyzes of the three residues are also performed. We noted that the cashew residues have high rates of volatile elements, high carbon content, low ash content, nitrogen and also elements traces such as chlorine and sulfur.

1) *Elementary and ultimate analysis:*

The use of biomass for energy and industrial purposes cannot be achieved only if the requirements (features, changes, etc.), resources (nature, available quantity, quality, location, etc.) and associated technology resources are well identified. Therefore, knowledge of the composition of the fuel and its related energy properties are required. The elemental compositions of our different residues were determined by using an elemental analyzer of Perkin-Elmer (2400 series II CHNS/O) following the protocol described by [5]. A thermogravimetric analyzer (TGA, SDTQ-600) was used for the rough analysis to determine the fixed carbon content, volatile matter content and ash content. We used the protocol described by [5] to perform the immediate analysis of samples. The results of elementary and immediate analyzes are given in table 2.

2) *Physical and physico-chemical properties:*

Water content (E) is measured by weighing the samples before and after drying at 105 °C for 24 hours in an oven. The moisture content is calculated from this average value of three measurements per sample. The bulk density (ρ) is determined using the formula given by:

$$\rho = \frac{m}{V} \tag{1}$$

where m is the mass of sample and V the box volume. We used a box of known volume (v), which is filled with a mass (m) of sample.

The palm shells particle sizes were determined by screening and those of the peanut and cashew shells by measurement using the ruler method in a representative sample. Based on the elemental analysis, we determined theoretically the high heating value (HHV) and low heating value (LHV) of our residues using the formulas of DULONG given by:

$$HHV = 81.3C + 345.5\left(H - \frac{O}{8}\right) + 22.2S \tag{2}$$

$$LHV = HHV - 6(9H + E) \tag{3}$$

where C, H, O and S are the percentages of carbon, hydrogen, oxygen, and sulfur, respectively and E the water content.

The energy density (ED) is calculated using the following formula:

$$ED = \rho \times LHV \tag{4}$$

We used an empirical formula estimating the transverse thermal conductivity for our biomass residues expressed in terms of the bulk density (d) and its moisture in dry base (E_s).

$$\lambda = d(0.200 + 0.0052E_S) + 0.024 \tag{5}$$

The specific heat capacity C_p is determined using a Dewar calorimeter. Firstly, the water value of the calorimeter is determined by mixing two water masses at different temperatures (hot water + cold water). Then, a mixture of water heated at 40 °C and a sample mass is performed in order to determine the specific heat capacity.

The results of the determination of the physical and physicochemical properties of the samples are given in table 1.

C. *Methods*

In incineration plants, the rolling motion is most often encountered. It is sometimes coupled to the avalanche and cascade modes. The rolling motion provides a good cross mixing of the bed and allows obtaining good conditions of heat transfer. In this study, we focused on the rolling and cascading motions. Based on the work of [6], the flow mode of one set of particles is characterized by parameters such as the Froude number (F_r), the filling degree (f) and the friction coefficient (μ). Thus, according to Mellmann's work, filling degrees of 0.15 and 0.25, which correspond to the values permitted by the rolling and cascade motion (f > 0.1) were used. The value of the Froude number for rolling and cascading motions is between 10^{-4} and 10^{-1}. The knowledge of the range of the Froude number allowed us to determine the drum rotation speed ranges to be respected to stay in rolling and cascading flow modes. The determination of the latter is done by using the following equation.

$$n = \frac{30}{\pi}\sqrt{\frac{g \times F_r}{R}} \qquad (6)$$

F_r is the Froude number, g the gravitational acceleration and R the radius of the drum.

The speeds used in these experiments vary between 2 and 11.66 rev/min. Using a digital camera, the sample within the drum is visualized through the transparent plate (see fig. 1). Images taken by this camera are digitized frame by frame using image processing software to determine the dynamic characteristic (β) of the rotating bed residue.

III. RESULTS AND DISCUSSION

A. *Shells sample characteristics*

Before the determination of the dynamic angle of repose, samples of peanut, cashew and palm shells were characterized at first. This characterization is necessary as it was noted that the dynamic angle of repose is an intrinsic property of the material; it therefore depends on the material properties. Tables 1 and 2 summarize the results of this characterization. Table 1 shows the physical and physic-chemical characteristics of the studied residues. We note that the shells do not have a spherical shape. The determination of the bulk density (apparent density) shows that the palm shell has the higher apparent density compared to those of the other shells. The values of the apparent densities found are comparable to those reported in the literature [7, 8]. We also noted that the cashew shell has the most high moisture content; this can be explained by the release of CNSL substance during its drying in the oven. The studied shells have good lower heating values compared to other biomass residues. The lower heating values found are close to those given by [9-10] equal to 16 400 kJ/kg, 21 300 kJ/kg and 19 942 kJ/kg, respectively for peanut shell, cashew shell and palm shell. Peanut shell has the lowest energy density and bulk density; therefore its valorization will require densification step.

TABLE I. PHYSICAL AND PHYSICOCHEMICAL CHARACTERISTICS OF THE STUDIED RESIDUES

Residues (shells)	**Size (mm)**	**ρ (kg.m^{-3})**	**E (%)**	**LHV (kJ/kg)**	**ED (MJ.m^{-3})**	**λ (W.m^{-1}.K^{-1})**	**C_p (J.kg^{-1}.K^{-1})**
Peanut	23.00	102	9.33	20 643	2.70	0.049	878.19
Cashew	31.64	346	13.25	22 095	7.64	0.155	1916.66
Palm	≥4.00	560	8.90	16 298	9.63	0.164	2734.14

For immediate and elemental analysis, the shells have high contents of volatile matter, fixed carbon and low ash contents. More than 50 % of the shell material consists of hydrocarbon elements that give the shell significant energy content. Low content of nitrogen are obtained, also with trace elements in the form of chlorine and sulfur; so when treating these shells, emissions of NOx and SOx can be reduced. The elemental and immediate compositions of studied shells are consistent of those found by [11; 12].

TABLE II. ULTIMATE AND PROXIMATE ANALYZES OF THE STUDIED RESIDUES

Residues (shells)	**Immediate analysis on dry basis (%)**			**Elementary analysis on dry basis (%)**					
	VM	FC	Ash	C	H	O	N	Cl	S
Peanut	65.42	23.79	5.74	56.49	6.62	35.38	1.51	---	---
Cashew	81.6	15.8	2.6	58.1	7.3	34.4	0.62	<0.1	0.01
Palm	84.2	13.5	1.2	49.3	6.2	43.2	1.2	---	---

B. *Effect of the drum rotational speed*

Fig. 2 shows the influences of the rotational speed of the drum on dynamic angles of repose of peanut, cashew and palm shells. The rotation speed is varied between 2 and 11.66 rev/min in order to stay in rolling and cascading motions. The experiment is carried on a drum diameter (D = 400 mm) and length (L = 1000 mm) for a filling degree of f = 0.25.

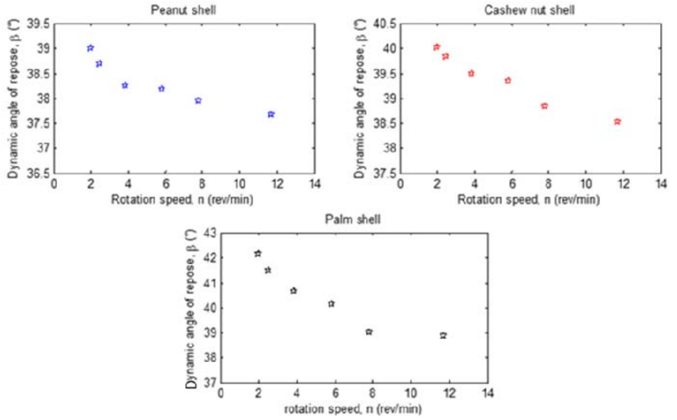

Fig. 2. Effect of rotational speed on the dynamic angle of repose of the three residues.

Thus, for rotational speeds of the drum ranging from 2 to 11.66 rev/min, the dynamic angle of repose of peanut, cashew and palm shells decrease respectively from 38.995° to 37.670°; from 40.026° to 38.531° and from 42.137° to 38.872°. These dynamic angles of repose are in consistence to those found by [4], for cement raw materials in the rolling motion, measured between 30° and 50°. Moreover, the work of [1] on shredded tire shows that the dynamic angle of repose decreases with increasing rotation speed. This study shows that the dynamic angle of repose is influenced by the drum rotational speed.

C. Effect of drum diameter and filling degree

The effect of the drum diameter was studied for two filling rates (15 % and 25 %). The drum rotation speed is varied from 2 to 11.66 rev/min. Table 3 shows the effects of drum diameter and filling degree on the dynamic angles of repose of the samples.

TABLE III. EFFECT OF DRUM DIAMETER AND FILLING DEGREE ON DYNAMIC ANGLE OF REPOSE OF RESIDUES

n (rev/min)	***f*=0,25**		***f*=0,15**		**Residues**
	β(°)_D=400 mm	β(°)_D=560 mm	β(°)_D=400 mm	β(°)_D=560 mm	
2	38.995	42.134	41.112	43.530	Peanut shells
2.5	38.688	41.888	39.878	43.354	
3.88	38.251	41.423	39.743	43.209	
5.83	38.186	40.623	39.808	42.911	
7.77	37.949	40.474	38.967	42.550	
11.66	37.670	40.239	38.162	42.137	
2	40.026	39.704	40.732	40.600	Cashew nut shells
2.5	39.836	39.485	40.529	40.078	
3.88	39.488	39.079	39.510	40.078	
5.83	39.337	38.583	39.495	38.796	
7.77	38.836	37.483	39.557	38.574	
11.66	38.531	36.151	38.689	37.476	
3.11	42.137	41.075	43.329	42.886	Palm shells
3.88	41.490	40.923	42.528	41.993	
5.83	40.656	40.153	41.601	41.325	
7.77	40.160	39.776	41.450	41.317	
9.72	39.023	39.775	40.975	41.000	
11.66	38.872	39.373	40.572	40.229	

In table 3, we note that for speeds ranging from 2 to 11.66 rev/min and filling rate of 15 % and 25 %, the dynamic angle of repose of peanut shells increases with the increase of the drum diameter. However, the dynamic angle of repose of cashew shells tends to decrease with increasing drum diameter. For the palm shells, we noted more or less important variations of the dynamic angle of repose when we increase the drum diameter. The results in Table 3 show that the drum diameter has an influence on the dynamic angle of repose of the three studied residues. It was also shown that for the 400 mm drum diameter, average values of the dynamic angles of repose, for the filling rate of 15 % and 25 %, were found to be equal to around 40° and 38°; 40° and 39°; 42° and 40°, respectively for the peanut shells, cashew shells and palm shells. Therefore, we can conclude that the filling degree has an influence on the dynamic angles of repose of these residues. The interaction of the drum diameter and the filling degree has no significant effect on the dynamic angle of repose ($\Delta\beta=\pm3°$). These results agree with those of [2] who have shown that the interaction of the drum diameter and the filling degree on the dynamic angle of repose of corn seeds is not significant. This more or less important variation of the dynamic angle of repose can be explained by the influence of control parameters (rotation speed, drum diameter and filling rate) and the flow mode.

D. Effect of the drum inclination

The angle of the kiln or drum is an important parameter particularly in relation to the residence time of the material in the rotary kiln or drum. In fact, the residence time and the filling rate decrease when increasing the inclination of the drum. Thus, to study the influence of the drum inclination on the dynamic angle of repose, we conducted tests with inclinations of the drum ranging from 0.5° to 3°. To stay in the rolling mode, we fixed the speed to 3.88 rev/min and the filling degree at 15 %. Fig. 3 and fig. 4 show the influence of the drum inclination on dynamic angle of repose of peanut shells, cashew shells and palm shells in two drums having the following characteristics (D=400 mm_L=1,000 mm et D=560 mm_L=1,000 mm). Fig. 3 and 4 indicate that more the drum is inclined, more the dynamic angle of repose increases and this, for all studied residues.

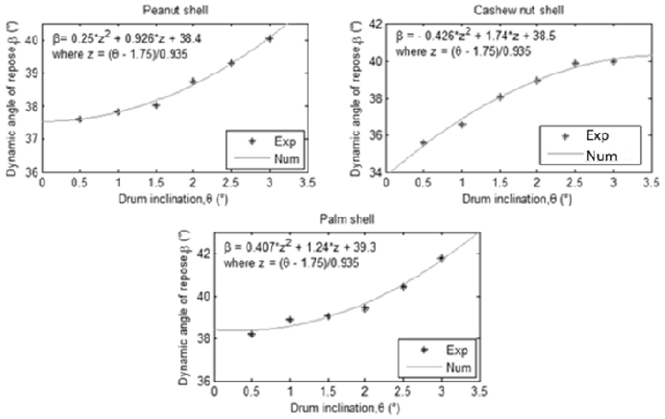

Fig. 3. Effect of drum inclination on dynamic angles of repose of the residues studied in the lower diameter drum.

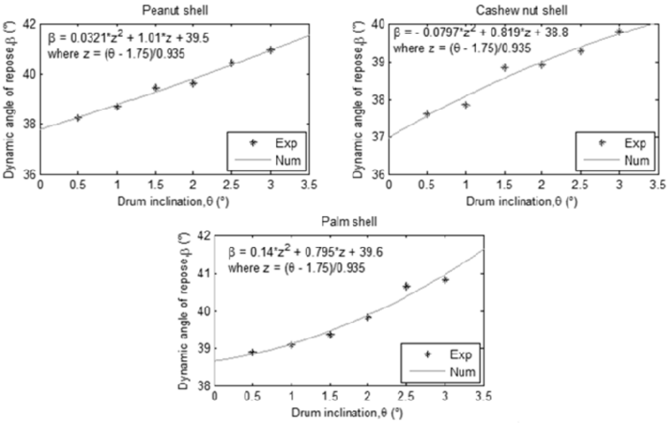

Fig. 4. Effect of drum inclination on dynamic angles of repose of the residues studied in the higher drum diameter.

Relation between the dynamic angle of repose and the drum inclination angle follows a quadratic correlation ($R^2 > 0.9$). However, in the literature, we found no studies dealing directly the influence of the drum inclination on the dynamic angle of repose. It will be noted that the increase of the drum inclination means a reduction of the residence time, an increase of the particles axial velocity, which would correspond to an increase of the dynamic angle of repose and therefore, better will be the transfer. Indeed, more a material is small, more it flows quickly and greater will be the dynamic angle of repose. Therefore, by increasing the inclination of the drum, we increase mass and heat transfers during incineration process. Table 4 shows the values of the dynamic angle of repose for inclinations of 0° and 0.5° for the three residues in the lower diameter drum.

TABLE IV. VALUES OF THE DYNAMIC ANGLE OF REPOSE FOR TWO DIFFERENT INCLINATIONS

Inclination, θ (°)	**Dynamic angle of repose, β (°)**	**Residues**
0	39.743	Peanut shells
0.5	38.187	
0	39.510	Cashew shells
0.5	35.595	
0	42.528	Palm shells
0.5	37.827	

Knowing that the dynamic angle of repose is always determined when the bed is horizontal (zero inclination), the idea is to have a glimpse of what transfers can be when the drum is tilted because in reality the rotary kilns operate for angles between 0 and 1 °.

Although there are no studies dealing directly with the influence of the inclination of the drum on the dynamic angle of repose, there are nevertheless empirical formulas relating the dynamic angle of repose (β) to the rotational speed (n) and the inclination angle of the drum (θ) as well as the others parameters such as the residence time (τ) or the speed of the solid (V_s), the length and the diameter of the drum. Reference [13] was the first in 1927 to propose a residence time formula in a rotary cylindrical kiln. This formula is as follows:

$$\tau = \frac{1.77L\beta^{0.5}}{Dn\theta} \tag{7}$$

E. Study the dynamic angle determination in the case of mixing

In this section we have defined the parameters given in the table below in order to study the variation in the dynamic angle of a mixture of residues consisting of 40 % of cashew shells, 40 % of peanut shells and 20 % of palm shells.

TABLE V. PARAMETERS AND VALUES FOR THE DETERMINATION OF THE DYNAMIC ANGLE OF REPOSE IN THE CASE OF MIXTURE RESIDUES

Parameters	**Values**
θ (°)	0.5
n (rev/min)	3.88, 7.77, 11.66
f (%)	15, 25
R (m)	0.2
L (m)	1

Fig.5 shows the effect of the mixing on the dynamic angle of repose. In this case, one mixture constituted of 100 % of peanut shells (PTS) and one another mixture consisting of 40 % of peanut shells, 40 % of cashew shells (CWS) and 20 % of palm sells (PMS) are studied for filling rates of 15 % and 25 % and rotational speeds of 3.88, 7.77 and 11.66 rev/min. We note that whatever the filling rate, it is observed an inconsiderable difference between the different dynamic angles of repose of the two cases of mixture studied. The maximum deviations found between the two mixtures are 3.20° and 3.65° respectively for filling rates of 15 % and 25 %. Analysis of the two graphs shows also the more the filling rate is lower, the more the dynamic angle of repose is higher.

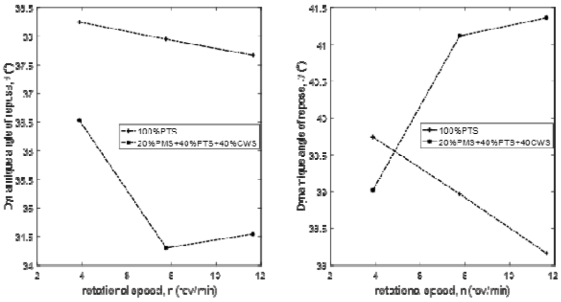

Fig. 5. Effect of the mixing on the dynamic angle of repose: to the left for 25 % and to the right for 15 %.

$$\beta_m^f = \kappa_{n,f} \sum_{i=1}^{3} \frac{\rho_i}{\rho_m} \beta_i^f \tag{8}$$

Where β_m^f is the dynamic angle of repose of the mixing, $\kappa_{n,f}$ constant depending to the rotational speed and the filling rate, ρ_i the residue bulk density, ρ_m the mixing bulk density and β_i^f is the dynamic angle of repose of the residue for a given filling rate.

In order to prove the agreement of this relation, we plotted the profile of this correlation with the experimental values (see fig. 6).

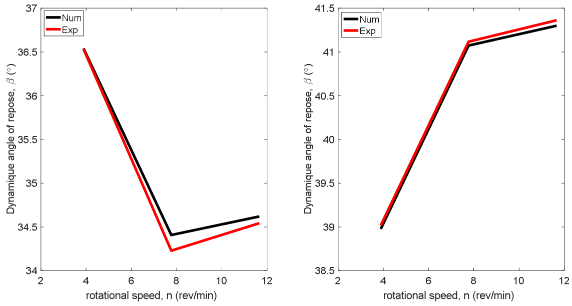

Fig. 6. Correlation between the experimental and numerical values of the dynamic angle of repose of the mixture: to the left for 25 % and to the right for 15 %

The analysis of fig. 6 shows that the numerical values can be correlated with the experimental values and we have estimated the relative deviations of the numerical values compared to the experimental values. The maximum relative deviations are evaluated at 0.52% for the 25% loading and 0.15% for the loading of 15%.

F. *Time residence determination*

The mean residence time through rotary reactor (kiln, drum, dryer, etc.) is an important parameter which directly influences heat and mass transfers and also determines chemical reaction degree of solid and gas phase. It is therefore an important parameter in the design and operation of rotary reactors. In the approach of prediction, [14] proposed also a formula of the axial velocity V_s of the solid bed by basing to the correlation of residence time (ζ) given by [15].

$$\zeta = \frac{0.19L}{Dn\theta} \tag{9}$$

$$V_s = 0.061\frac{Dn\theta}{\beta} \tag{10}$$

The residence time as given in the Lee and Shun correlation does not allow us to conclude directly which of the three residues studied are moving faster. The rheological parameter (dynamic angle of repose) plays an important role on passage time of particles through the rotary reactor as indicated in equation (7). As a result, we have investigated the axial velocity of the solid which depends on the control parameters (n and θ), geometric parameters (D) and the rheological parameter (β). Prediction of the axial velocities of three residues beds was made on the basis of equation (10) (see fig. 7). The rotation speed of the drum is fixed at 3.88 for a filling ratio corresponding to 15 % and angles of inclination varying from 0.5 to 3 and by using two drum diameters, 400 mm and 560 mm.

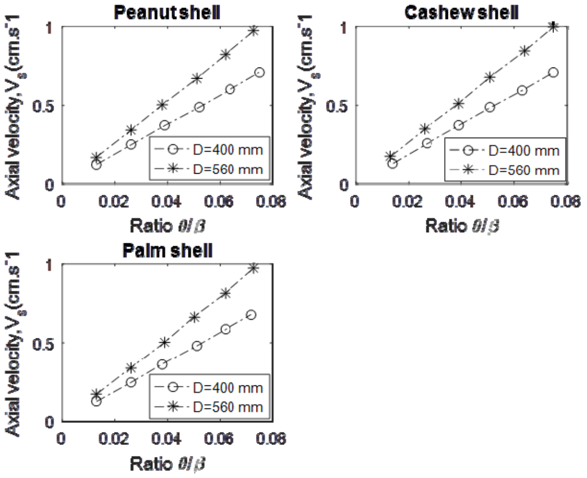

Fig. 7. Axial velocity prediction with different inclinations and diameters of the drum

Fig. 7 shows the more the inclination and the drum diameter increase, more the axial velocities of these residues bed increase. The rheological parameter β contributes also to this increase because it is influenced by the command parameters (n and θ).

Furthermore, an increase of the axial velocity of solid bed in rotary reactors means an increase of passage frequency of particles through the active layer. A solid material which has a higher axial velocity in a rotating reactor therefore has a shorter residence time. In the case of the small diameter drum (D = 400 mm), we have calculated the axial velocity of each of the residues to see which residue is moving faster. We found that the three residues studied have very close axial velocities. Nevertheless, cashew shells roll with a slightly higher mean axial velocity (V_s=0.426 cm/s), followed by peanut shells (Vs=0.425 cm/s) and finally the palm shells (V_s=0.413 cm/s), in this order, cashew shells bed will have the shortest residence time. Using Sullivan's empirical formula (7), we have also found that for a drum inclination varying from 0.5 ° to 3 °, the residence times vary from 13.61 to 2.40 min, from 13.99 to 2.41 min and from 14.10 to 2.46 min respectively for cashew shell, peanut shell and palm shell.

G. *Active and passive layers determination*

During the rotation of the drum, the structure of the bed comprises two layers [4]: the active layer and the passive layer. In the passive zone, the particles are actuated by the rotation of the drum and there is practically no interactions between the particles. On the other hand, the active layer is a dilated layer where the particles are in motion relative to each other and it is accepted that this is where all the mixing occurs. Thus each particle in the solid bed is found in situations of transverse and axial motion. Knowing the thicknesses of the active and passive layers is therefore to learn how to control its mixture. According to [1], the higher the rotation speed, the more the heights (h) of the active and passive layers roll and become weaker at the same time. It is therefore essential to operate at low rotation speeds in order to increase the mixture and thus increase the active layer. In order to estimate the thicknesses of the active (δ_0) and passive (h- δ_0) layers of our residues, we used the empirical equation [16] given by:

$$\delta_0 = 0.277\left({n}/{n_c}\right)^{0.36}(2R)^{-0.19} f^{-0.34} \times h \tag{11}$$

The thicknesses of the active and passive layers of peanut shells, cashew shells and palm shells that recap the filling rate used in cold tests are given in table 5. We note that the heights of the active and passive layers decrease with the decrease of the filling rate and with the increase of the rotational speed. In addition, when the rotational speed is fixed, we remark that the active layer thickness of peanut shells increase with the decrease of the filling rate. However, the active layers thicknesses of cashew shells and palm shells decrease. This difference could be due to the morphology of the residues (form, size).

TABLE VI. ACTIVE AND PASSIVE LAYERS THICKNESSES

Residues	**f (%)**	**n (rev/min)**	**h (mm)**	**Active layer thickness, δ0 (mm)**	**Passive layer thickness, h- δ0 (mm)**
Peanut Shells	25	3.88	170.00	13.43	156.57
	25	7.77	162.0	17.25	144.75
	25	11.66	160.0	19.96	140.04
	15	3.88	129.0	15.98	113.02
	15	7.77	123.0	20.52	102.48
	15	11.66	120.0	23.74	96.26

Cashew Shells	25	3.88	145.0	11.46	133.54
	25	7.77	140.0	14.20	125.80
	25	11.66	127.0	14.91	112.09
	15	3.88	101.0	9.49	91.51
	15	7.77	95.0	11.47	83.53
	15	11.66	91.0	12.72	78.29
Palm Shells	25	3.88	137.0	10.82	126.18
	25	7.77	129.0	13.09	115.91
	25	11.66	121.0	14.21	106.79
	15	3.88	90.0	8.46	81.54
	15	7.77	81.0	9.78	71.22
	15	11.66	79.0	11.03	67.97

The active layer is responsible for nearly all the mixing in the transverse direction of the drum. Mixing in a rotating drum is an important process in the particulate industries and is often accountable for the rate of heat transfer between the solids. This rate directly affects the yield and efficiency of the process. As the active layer thickness increases, more material would be in the active layer and thus more mixing would be able to occur. Thus, for filling rate of 25 % and rotational speed of 3.88 rev/min, the transfers would be better for peanut shells than cashew shells and finally palm shells.

IV. CONCLUSION

During cold experiences rotating drum, samples of peanut shells, cashew shells and palm shells were studied. Dynamic angles of repose of these three residues and the mixture of these residues were determined according to the rotational speed of the rotating drum and for two shells filling rates (15 % and 25 %). The determination of active and passive layers thicknesses and the study of residence time were also performed. The effects of the drum diameter and the drum inclination on the dynamic angles of repose of these shells have also been studied. It has been shown that by working with zero tilt of the drum, the dynamic angle of repose decreases with increasing drum rotation speed and that, for all the residues samples. It was also shown that the dynamic angle of repose of peanut shells increases with the increase of the drum diameter. However, the dynamic angle of repose of cashew shells tends to decrease with increasing drum diameter. In terms of the palm shells, we noted more or less important variations of the dynamic angle of repose when we increase the diameter of the drum. This study also found that the filling degree influences the dynamic angles of repose of peanut shells, cashew shells and palm shells. It has been found that the dynamic angle of repose is higher for a smaller filling rate. The study of the effect of the inclination of the drum showed that by increasing drum inclination, the dynamic angle of repose increases although that dynamic angle of repose was determine at zero degree inclination. In addition, the dynamic angle of repose is also influenced by the mixture depending on the filling rate.

The determination of the dynamic angle of repose of peanut shells, cashew shells and palm shells is important for the simulation of solid flow within the drum (for example, load profile and residence time of solid) particularly during heat and mass transfer processes under industrial applications. The study of the mean residence time allowed us to conclude that cashew shells has the shortest residence time followed by peanut shells and finally palm shells.

About the determination of active and passive layers thicknesses, we note that the heights of the active and passive layers decrease with the decrease of the filling rate and with the increase of the rotational speed. Furthermore, when the rotational speed is fixed, the active layer thickness can increase or decrease depending to the type of residue with the decrease of the filling rate.

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