Drying of Oil Palm Frond via Swirling Fluidization Technique

Mohd Faizal Mohideen, Mohd Faiz , Hamidon Salleh, Hanis Zakaria, Vijay R. Raghavan

***Abstract*—Oil palm frond (OPF) is one of the largest available resources of biomass from oil palm plantations. Previous research works reported the high potentials of using the OPF as the main component for cattle feed. The production of cattle feed however, depends strongly on the drying efficiency of freshly pruned OPF. The current study proposes the swirling fluidization technique as a method for drying the OPF. A laboratory scale swirling fluidized bed dryer (SFBD) was constructed to carry out investigation on hydrodynamics and drying characteristics of chopped OPF in hot air stream at temperatures of 45ºC and 60ºC. OPF which consists of leaves (57% moisture content – wet basis) and stem (70% moisture content – wet basis) are dried separately in the SFBD. The average time taken to reduce moisture to 15% (as per required in cattle feed production) is about 60 minutes for leaves and 90 minutes for stems. It was found that the hydrodynamics and drying kinetics of both leaves and stems differ greatly. The leaves dry faster with large amount of moisture loss in early stages of drying before slowing down, in contrast with stems. This leads to a conclusion that the leaves are kinetic controlled while the stems are diffusion controlled and thus justifies the drying to be conducted separately. In conclusion, drying of OPF using swirling fluidized bed is effective for both continuous and batch drying. The ability to fluidize the highly irregular shapes of OPF at relatively low energy consumption is another strong advantage to use the swirling fluidization technique in comparison with other methods of fluidized bed drying as reported in the literature.**

***Index Terms* — Oil palm frond (OPF), Drying characteristics, Swirling fluidized bed dryer (SFBD), moisture content.**

I. INTRODUCTION

Malaysia is currently the second largest exporter of palm oil in the world after Indonesia. Also known as the ‘tree of life’, all parts of the tree can be effectively utilized for various uses. Compared to other types of biomass, palm oil industry leaves a very huge amount of biomass from its plantation and milling activities.

In the year 2005 alone, about 55.75 million tonnes of oil palm biomass was recorded, comprising of empty fruit bunch (EFB), palm pressed fiber (PPF), oil palm shell (OPS), oil palm kernel (OPK), oil palm trunk (OPT) and oil palm frond (OPF). [1]. Figure 1 shows the anatomy of an oil palm tree and oil palm frond.

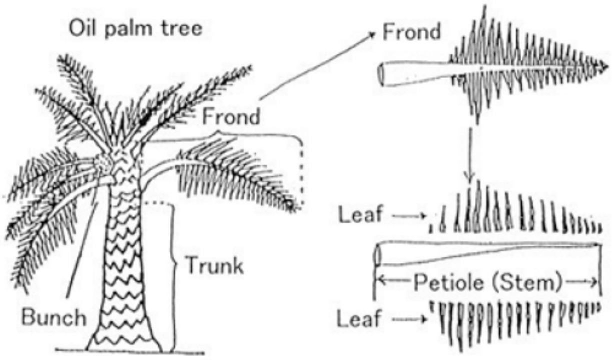

Fig.1. Anatomy of an oil palm tree and oil palm frond (OPF) [2]

Oil palm frond (OPF) on the other hand, is the least attractive part of the tree and usually left rotting between the rows of palm trees, mainly for soil conservation, erosion control and ultimately the long-term benefit of nutrient recycling. The large quantities of fronds produced by a plantation each year make these a very promising source of roughage feed for ruminants [2,3]. It is estimated about 36 million tonnes of OPF is produced on dry matter basis annually during the pruning and replanting operations in the plantations [4].

However, in OPF processing for production of ruminants feed, drying is one of the pre-cursory process in which the moisture content has to brought down to about 15% for about 60% to 70% wet basis, w.b. The current technology proposed and developed by [4] uses 2-stages of drying, namely the *pre-drying* (solar energy) followed by *secondary drying* (artificial dryer). The OPF are first chopped into small pieces of 10 – 30 mm using a cutting-chopping machine prior drying. According to [4], the cost of drying process alone accounts about 30% of the total production cost, thus pre-drying of the chopped OPF using solar is necessary for cost reduction purpose. Unfortunately, solar drying is highly dependent on daily weather which affects significantly the production of ruminant feed, while the artificial heater which produces hot air from fossil fuel combustion is costly.

This paper proposes a new technique in drying the OPF for ruminant feed production – the swirling fluidization technique. The technique involves the usage of the swirling fluidized bed dryer (SFBD) to reduce the moisture content

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of the chopped OPF in a single stage operation. In general, this technique offers ease in operation and maintenance of the dryer, high rate of moisture removal, adaptability to automation and for combining several process such as mixing, classification, drying and cooling.

Unlike typical fluidized bed systems which are unsuitable to fluidize fibrous materials like the chopped OPF which are highly irregular in geometry, the SFBD was had shown excellent hydrodynamic characteristics from preliminary investigations. Figure 2 shows the basic configuration of a SFBD.

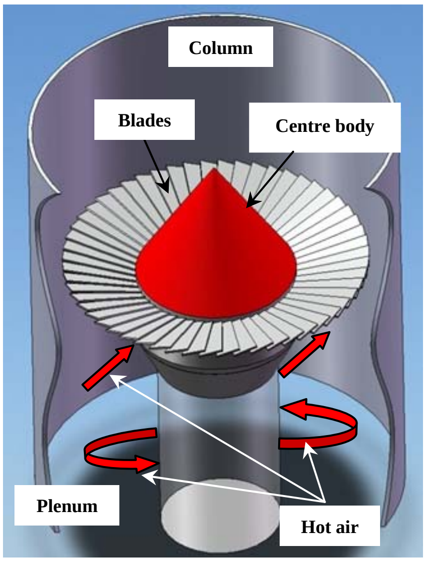

Fig.2. Basic configuration of a SFBD

The bed is annular type, made by an array of blades at the bottom with centre body at the middle and enclosed by a column. These blades were inclined to the horizontal plane in which the blades form trapezoidal openings. This results in angular injection hot air, similar to that reported by [5,6,7]. The bed material, in this case - chopped OPF which was loaded on the top of the distributor will swirl due to angular momentum by the hot air. Since the angular momentum is zero at the middle of the bed, a centre body is required in a SFBD to avoid the possible presence of dead zone. This centre body is preferably extended straight to the bottom of the distributor because the hot air enters the plenum tangentially (not shown in the figure). The extension of the centre body will minimize flow expansion inside the plenum (as a result of volume occupied by the centre body) while aiding the flow to swirl even before entering the distributor. Hence, energy loss due to flow expansion can be minimized.

Apart from the ability to fluidize the chopped OPF, the advantage of using the SFBD with annular blade distributor is the relatively low pressure drop imposed by the distributor for fluidization [8]. This significantly reduces total energy consumption by the system.

In this preliminary study to investigate the hydrodynamics and drying characteristics of chopped OPF using the SFBD, batch experiments were conducted by varying the superficial velocity of hot air (1.25 & 2.0 m/s), temperature of hot air (45 ºC & 60 ºC) and three bed loadings (100g, 120g, 140g). The OPF leaves and stems are dried separately as they posses different moisture content and drying behavior.

II. MATERIALS & METHOD

This section discusses the details of the experimental set-up, preparation of the chopped OPF for batch experiments, measurement and data collection.

A. *Preparation of chopped OPF (leaves and stem)*

UTHM, which is located in the Batu Pahat district is surrounded by huge oil palm plantation. However, it should be noted that the quality and yield of products from one oil palm plantation to other in a same province may vary depending on soil condition, irrigation, fertilization and many more. In the current, the OPF are collected from a same plantation nearby the university to the reduce variation of OPF characteristics, particularly the moisture content.

Fresh OPF are collected in the morning soon after pruning for sample preparation. The sample preparation must also be done quickly because increase in temperature during daytime may affect the moisture content of the OPF, particularly in the leaves. Initial investigation from direct drying method in oven as per suggested by [9], found that the OPF leaves contain moisture about 57% w.b. while the OPF stems (petiole) has moisture about 70% w.b. Therefore, drying both OPF leaves and stems together should be avoided not only because of different initial moisture contents, but because the different geometry. Leaves which are slender in shape have very small moisture diffusion depth and hence loose moisture fast, in contrast to the stems which are thick and with larger moisture diffusion depth. As a result, if dried together, the remaining moisture in the stems will migrate to the already dried leaves and wet them again.

Therefore batch experiments are conducted separately for both OPF leaves and OPF stems. Figure 3 shows the chopped OPF leaves and stems which is approximately 10 – 12 mm in size. The chopped OPF falls in between type-B and type-D in Geldart’s classification of particles.

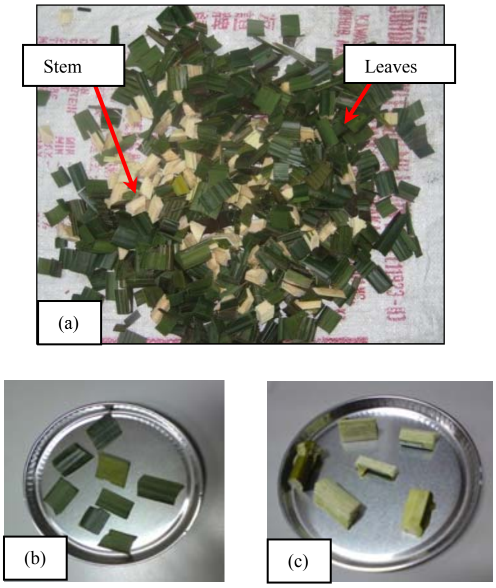

Fig.3. (a) Chopped OPF leaves and stems, (b) OPF leave samples and (c) OPF stem samples

B. *Experimental set-up*

Figure 4 shows the actual experimental set-up which consists of blower (not shown), air heater, plenum chamber, distributor and column. The distributor in the present study was made by 60 blades which accounts for a total open area of 17.2%. A close up on the actual swirling fluidized bed dryer is as in Figure 5.

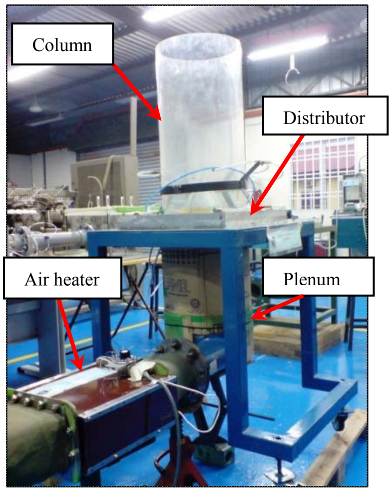

Fig.4. SFBD experimental set-up

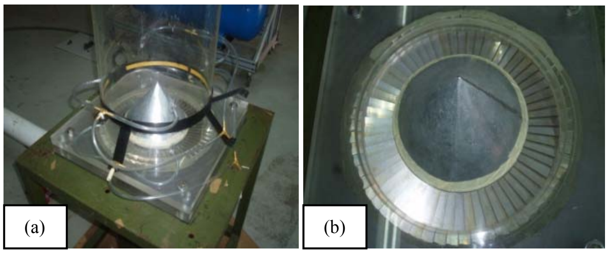

Fig.5. (a) Swirling fluidized bed dryer, (b) Annular distributor

C. *Data measurement & acquisition*

The blower used in the study is a 25 hp (model Cowdray). The flow rate of supply air was controlled by regulating its motor's speed using an inverter (model Holip -HL PA07543B). Superficial velocity of supply air was measured using a pitot-static probe which was mounted at the downstream of the blower just before the air enters the heater. The flow is assumed to be incompressible, fully developed turbulent flow and average velocities were calculated using the 1/7th power law equation [10].

Surrounding temperature, dry bulb and wet bulb temperatures before and after the SFBD were measured using the K-type thermocouple with an accuracy of ± 0.1 ºC together PicoLog datalogger. As for the distributor and bed pressure drop measurement, digital manometers (model Infiltech) with 0.1 Pa resolutions and accuracy of ± 2% were used. For determining the moisture content, industrial oven (model Memmert) is used at 105 ºC together with an electronic weight balance (model Perkin-Elmer) which has an accuracy of ± 10 mg where samples were removed at each nominated interval in the drying process. To vary the hot air temperature, a 3 kW electrical heater is used in the study.

D. *Experimental procedure*

For hydrodynamics study, the flow rate of supply air is varied to obtain increasing superficial velocity while recording the bed pressure drop for both OPF leaves and stems. The regimes of operation are observed carefully and minimum fluidization velocity, U_{mf} and minimum swirling velocity, U_{ms} were recorded until elutriation starts occurring in the bed.

As for drying studies, experiments were performed at fixed drying temperatures of 60 ºC for the OPF leaves and 45 ºC for the OPF stems with respective fluidizing velocity of 1.25 m/s and 2.0 m/s for all three bed loadings (100 g, 120 g and 140 g). The temperatures are fixed due to the limitation of the electrical heater capacity while the velocities are the best to generate swirling motion of OPF samples inside the bed. Lower velocities resulted unstable and clogging in the bed while higher velocities resulted excessive bypassing of hot air, as well as elutriation. The dryer operated without product for about 30 minutes to obtain steady drying conditions.

Experiments were conducted for about 90 minutes. This duration is found to be sufficient to reduce the initial moisture content to about 15% as per required for further processing of OPF in actual production of ruminant feed. To trace changes in moisture content during the drying process random samples of both OPF leaves and stems were taken using a small cup inserted from the top of the bed at sampling intervals (every 15 minutes). This is relatively easy because the samples are in swirling motion. The OPF samples withdrawn at each interval was cooled down and handled carefully to avoid handling error. To minimize measurement uncertainties, experiments were replicated at 2 times and average values are taken for analysis. The oven drying is only limited to 4 hours because from the preliminary works, it was found that there is no variation in sample weight beyond 4 hours.

E. *Determination of moisture content, M.C.*

Moisture content is the quantity of water contained in a material such as soil, ceramics or any organic materials like biomass. Moisture content is used in a wide range of technical areas, which can range from 0 (completely dry) to the value of the materials' porosity at saturation. It can be given on a volumetric or mass (gravimetric) basis. Gravimetric moisture content percentage, M.C., based on w.b. is defined mathematically as:

$$M.C. = \frac{w_1 - w_2}{w_1} \times 100 \qquad (1)$$

where:
w_1 = initial weight of sample (before inserted into oven)
w_2 = final weight of sample (after dried in the oven)

III. RESULTS AND DISCUSSION

It is not the objective of this paper to investigate the effect of various parameters on the drying kinetics of chopped OPF. The experiments are carried out just to have an insight on drying of chopped OPF using the SFBD. Therefore, feasibility of using the SFBD was investigated first through the hydrodynamics study in which system's resistance and regimes of operation were obtained. Due to the distinct hydrodynamic behavior of chopped OPF leaves and stems, both are separated before batch experiments of drying were carried out. Findings from both studies are discussed with possible reasoning being addressed.

A. *Hydrodynamics*

Figure 6 depicts the bed pressure drop, ΔP_b against superficial velocity for both chopped OPF leaves and stem for a bed loading of 140 g. Only this bed loading is presented here since other bed loading were found to produce similar findings. As reported by [5], the minimum swirling velocity, U_{ms} commences soon after the minimum fluidization velocity, U_{mf}. From careful observations on the operating regimes, it was found that the bed starts from packed regime, attaining U_{mf} and followed by U_{ms} before completely swirling. The swirling regime is the desired regime of operation in the drying process because both OPF leaves and stem were excellently fluidized and vigorous interaction with fluidizing air occurs. Hence moisture removal is optimum.

Steady increase in superficial velocity resulted faster swirling motion and further increase causes elutriation of particles. As can be seen in the figure, the leaves can only withstand superficial velocity up to 1.6 m/s while the denser stem is capable to withstand superficial velocity beyond 2 m/s (up to 2.3 m/s).

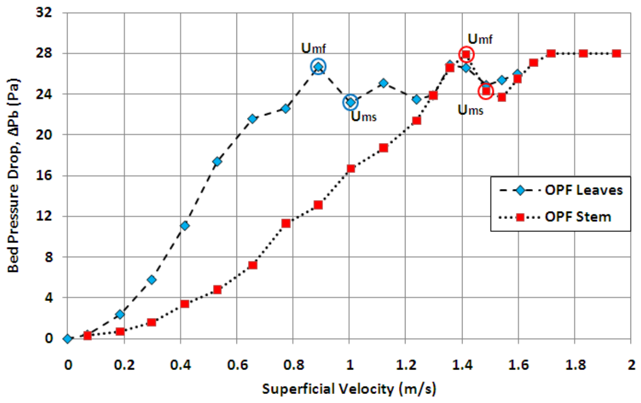

Fig. 6. Moisture content (w.b.) against drying time

The leaves had higher ΔP_b in the packed regime due to the relatively larger surface area in comparison to the stems. Being very thin and light, the amount of leaves, thus the total surface area was naturally larger in comparison with heavier, cubic-shaped stems. The stems only started swirling beyond 1.4 m/s of superficial velocity. A slight drop in bed pressure drop after minimum fluidization velocity is due to the OPF samples rearranging themselves to allow better flow of air through the interstices. Unlike findings by [5,6,7], the swirling regime in the present study is relatively shorter due to elutriation of OPF samples.

It was also found that operating the bed at higher swirling velocities was not really practical because the residence time of hot air inside the bed becomes shorter. Thus the shearing action and removal of saturated moisture from the chopped OPF surfaces becomes lower, affecting the overall efficiency of the system. Apart from that, as reported by [5, 7], a SFB has increasing ΔP_b upon U_{mf} as a result of increasing centrifugal bed weight due to swirling motion. This eventually increases the system's resistance, resulting loss of substantial amount of energy.

It was observed that during drying in SFBD, the swirling velocity of OPF samples increased though the superficial velocity of hot air was kept constant. This was due to the continuous weight (moisture) loss. The swirling velocity of the OPF samples was the fastest at the end of experiment since the samples had become lightest and easiest to fluidize.

B. *Drying of OPF Leaves*

Figure 7 presents the dependence of moisture (w.b.) against time for chopped OPF leaves, dried at 60 ºC with superficial velocity of air about 1.25 m/s. Batch experiments conducted with three different bed weights (100 g, 120 g and 140 g) produced typical exponential-decay drying curves. The slight difference in initial moisture content of the samples, as can be seen in the figure is due to the fact that OPF were taken from the oil palm plantation on different day of experiment from different tree. This is because pruning of OPF is only about 24 fronds / per tree annually [4] and hence variation in initial moisture content presents.

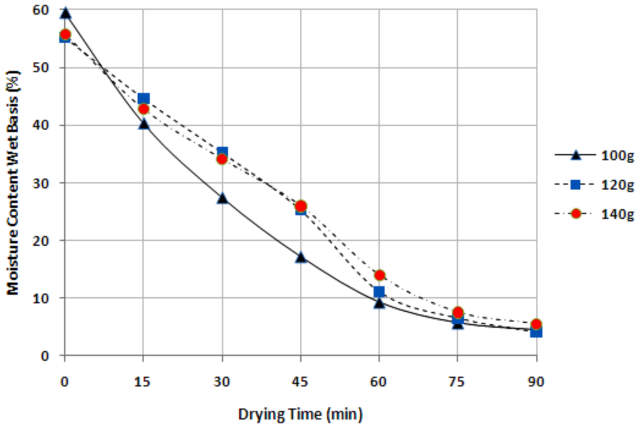

Fig. 7. Moisture content (w.b.) against drying time for OPF leaves

From the experiment, it was found that all bed loading achieved the desired final moisture content of 15% (w.b.) in about one hour with samples from the smaller bed weights (100 g and 120 g) dries faster owing to the smaller amount in total moisture. It was also found that the drying rate was fastest for the lowest bed weight, particularly for the first 30 minutes before decreasing. The other two bed loadings (120 g and 140 g) showed fairly consistent rate of drying throughout the first 60 minutes of drying.

This high moisture removal rate is due to the high concentration difference between hot air and OPF samples in the initial stages of drying. Apart from that, large quantity of moisture on the OPF leaves' surface contributed to easier moisture discharge. After 1 hour, the moisture content inside OPF leaves became low, resulting difficulty in moisture discharge. At this stage, the OPF leaves curled and their effective surface area that was exposed to air became substantially smaller. Hence, in the later stages of drying, the moisture removal rate became very low.

The whole drying process was found to have only falling-rate drying, which is typical for most agricultural products. Therefore, the OPF leaves can be classified as kinetic-controlled particles when operating in a SFBD. Although not proven experimentally here, it is predicted that increase of superficial velocities for a given hot air temperature will result in some increase in drying rate although it may not be favorable as discussed in the previous section. For the range of bed weight studied, it can be seen that operating with higher bed loading is advantageous due to similar drying behavior. Hence, with equal amount of energy spent, higher throughput is possible with current configuration.

C. *Drying of OPF Stem*

About 70% of dry matter weight ratio of an OPF is stem while the rest are leaves. The leaves contain higher percentage of crude protein and ether extract [4] which makes the leaves more valuable than the stem but since it only make about 30% of dry matter weight; it's more economical to process the whole frond. In the present work, the stems were cut at 1cm x 1cm as per recommended by [4] and since the stems are thick, they become cubes. The OPF stems had to be prepared manually due to unavailability of chopping machine in the required range of sample size.

Figure 8 shows the moisture content (w.b.) of OPF stems against drying time for superficial velocity 2 m/s and drying temperature of 46 ºC. Unlike the OPF leaves, the OPF stems' drying curve differs substantially. The drying rate is somewhat linear, particularly in the first 30 minutes of drying for all three bed loadings. Upon 30 minutes, the drying rate remained almost linear for 100 g bed loading while for 120 g, a constant rate drying is evident. However the duration was limited to 15 minutes only. On the other hand, for 140 g bed loading, the constant rate drying period only occurred after 1 hour of drying.

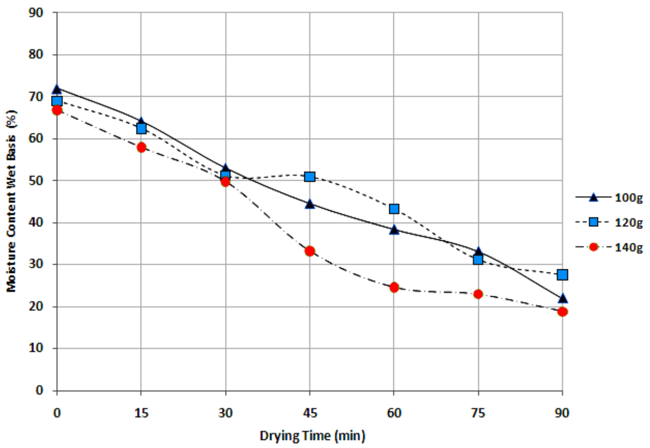

Fig. 8. Moisture content (w.b.) against drying time (OPF stems)

The linear and constant rate drying periods for OPF stem as shown in Figure 8 was attributed to the physical characteristics of the OPF stems. Upon chopping, the stems became large cubical chunks. These chunks naturally have larger moisture diffusion path, which can be interpreted as resistance for moisture to migrate to the surface. After surface moisture has been removed by the fluidizing air, the OPF stem became diffusion controlled. Any increase in superficial velocity will not contribute in moisture removal because the moisture from the inside of the stem has to first migrate to the surface.

After 1 hour of drying, change in physical characteristic of the OPF stems was seen. The stems started to shrink and their surface became harder. This change reduced the drying rate of the stem at the later stages, similar to OPF leaves. Due to slower moisture removal rate and higher initial moisture content in the OPF stems, longer drying period is required to achieve final moisture content of 15% (w.b.). For a period of 90 minutes, the SFBD was only capable in achieving about 20 – 27% (w.b.) final moisture content.

IV. CONCLUSION

From both experiments conducted, the most important finding is that the SFBD is able to provide good fluidization characteristic and almost uniform moisture removal rate from both OPF leaves and stem. The different hydrodynamic characteristic is a proof that both OPF leaves and stems cannot be fluidized together if any fluidized bed drying of OPF is attempted. On the other hand, the unique drying characteristics and different moisture content of both products suggests that drying should be done separately for OPF leaves and stems, unlike the current practice in the industry now.

The hydrodynamic investigation revealed that the OPF leaves have higher ΔP_b in the packed regime in comparison to the OPF stems due to higher surface area. The OPF stems reach U_{ms} and U_{mf} at much higher superficial velocity. Both products however, has limited swirling regime due to elutriation. It was also found that higher superficial may not really provide much benefit though the products swirl faster.

From the drying experiments, it was found that the OPF leaves are kinetic-controlled particles where the whole drying process is strictly falling-rate type. On the other hand, the OPF stems were found to have somewhat linear drying rate before achieving constant rate drying period after sometime. Hence, the OPF stem may be attributed as diffusion-controlled particles.

In conclusion, the SFBD was found to be a viable technique in drying OPF. Though the present study is only a preliminary investigation, the results are promising towards development of actual drying system of OPF based on SFBD technique. Further investigation on drying kinetics by studying other parameters, especially the temperature effect is imperative towards obtaining a better understanding.

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