Flowing performance and drying characteristics of paddy in a triangular spouted-bed

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Abstract

Flowing patterns of paddy at two moisture contents, 13% wb and 26% wb, were observed in a triangular spouted bed. With the help of a suitable insert, a plug-flow pattern could be obtained leading to an efficient drying process.

Paddy of high moisture content was dried in a triangular spouted bed with different levels of air temperature It was observed that the reduction of moisture with time was following a linear trend. Drying tests showed that air temperature up to 160℃ in the first stage and 80℃ in the following stage can be used to dry paddy from 26% wb down to around 16% wb without significantly changing grain quality in term of head rice recovery Even higher temperature-up to 190℃ – could be applied without affecting head rice recovery notably in the first period of drying, as long as the grain moisture content remained above 17% wb. However, a temperature of 100℃ was found to reduce the head rice rapidly when the grain moisture content reached around 17% wb.

Introduction

Spouted bed (SB) technology offers an appealing way to dry grains thanks to its ability to produce grain circulation and its role in facilitating transport phenomena by producing excellent solid-gas contact. A further advantage is the possibility of using high temperatures. The concept has potential for high energy efficiency, fast drying rates and uniform drying (Becker and Sallans, 1960). Although first application of this technology was for drying wheat, its commercial applications in drying grains have not been successful The difficulty mainly comes from scale-up procedures (Nemeth et al., 1983)

Conventional cylindrical-conical SB was modified later on by inserting a draft tube to have better grain circulation, to reduce pressure drops and to increase bed heights (Buchanan and Wilson, 1965; Khoe and Van Brakel, 1980 and 1983; Claflin and Fane, 1984). A slight variation is the use of a slotted draft tube in order to gain more air flowing to the downcomer (Viswanathan et al , 1986) These authors strongly recommended the use of a draft tube thanks to its obvious benefits.

Kalwar et al. (1991), and Kalwar and Raghavan (1992 and 1993) investigated a drafted two-dimensional SB which had a rectangular chamber with a slanted base and draft plates. This configuration partially avoids the scale-up problem by designing a single small-scale cell, and then combining several cells until sufficient capacity is achieved.

The concept of a triangular spouted bed (TSB) with spouting air being introduced in one corner was suggested by Mujumdar in his 1984 review. The advantage of lower pressure drop could be foreseen, since air would be confined within smooth walls. Its construction is simple and suitable for instrumentation in lab experiments.

A TSB comprises three plane walls and a slanted base at the bottom A moveable draft plate is installed in one corner to separate the downcomer containing grains and the spout guiding airflow coming from a triangular air entry. The draft plate is used to control the separation distance (He) which determine the amount of grains entering the spout and travelling upwards. He also provides some portions of airflow moving through the grains in the downcomer. The scale-up problem can be partially avoided by combining triangular units to form a hexagonal dryer (Figure 1), and multiple units of hexagonal dryers can be arranged in a honeycomb pattern.

Flowing patterns of grains inside a SB significantly affect drying characteristics of the process. Normally, a plug-flow behaviour is desirable, since this pattern can result in a uniform heat treatment for the entire grain mass in a SB. Dead zones must be avoid, otherwise some portions of the grain mass would be overdried and the drying process could be destroyed seriously. Therefore, the main objectives of the research presented in this paper were to observe flowing patterns of paddy grains inside a TSB and to investigate some drying characteristics likely to affect grain quality.

Materials and Methods

The layout (Figure 2) using a lab-scale TSB was the same as described by Hung Nguyen et al. (in press). The notation of the drying chamber is given in Figure 3. The TSB has two

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sides of galvanised sheet and one side of heat-resistant glass wall so that grain flow patterns can be easily observed. Paddy grains move down by gravity in the downcomer and are picked up by inlet air moving through the spout. At the top of the drying chamber, due to a volume expansion, the grain velocity decreases, which make grains fall down into the downcomer. The exhausted air is discharged into a cyclone, throwing some husks, immature grains and light foreign materials into a collecting bin. In the downcomer there is also some portions of the inlet air moving counter-currently against the paddy movement.

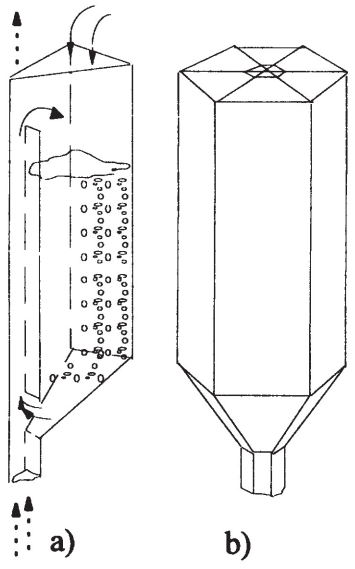

Fig.1. a) Triangular spouted bed with a draft plate on the left
(------→ : air movement; → : grain movement)
b) A hexagonal spouted bed formed by triangular units

Tests of flowing performance

Preliminary tests showed that without an insert, plug flows of grains can hardly be achieved. Using slanted angle of 60° of the bottom plate, a large dead zone was still noticed. This dead zone next to the outside wall stretched from the bottom to the top of the grain column inside the SB. To improve grain flowability, three sizes of inserts with notation showed in Figure 4 and dimensions listed in Table 1 were used. Flowing performance of grains at two moisture contents, 13% wb and 26% wb, were investigated. High moisture content grains was obtained by soaking paddy in water for 5 hours, drained and spread in 7 – 10 cm layers in shade to remove surface water.

Inserts were positioned at three levels of the *He* coded 1, 2, and 3, which are 70mm, 140mm, and 210mm, respectively, from the inlet. Airflow rate was adjusted so that it was just sufficient for the grains to spout in a stable condition. Airflow rate range was within 0.026 – 0.028 kg/s in these experiments.

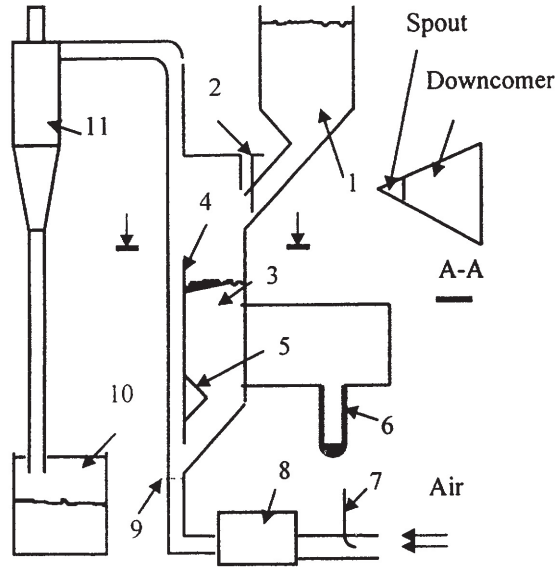

Fig.2. Schematic diagram of the triangular SB
1) container, 2) slide plate, 3) drying chamber, 4) draft plate, 5) insert, 6) manometer, 7) annubar, 8) heater, 9) screen, 10) collecting bin, 11) cyclone

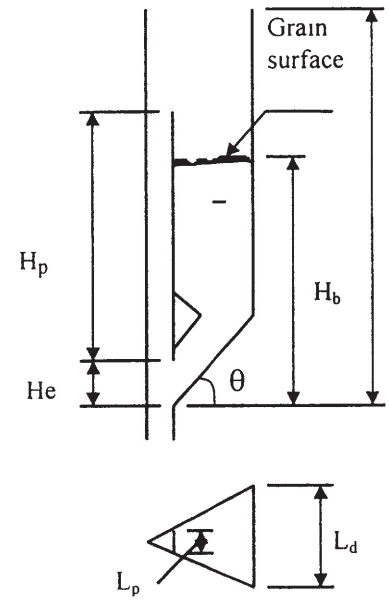

Fig.3. Notation of the drying chamber.

Prior to the test runs, a portion of paddy was dyed with methylene blue and spread to make parallel horizontal layers on top of a bed which is 1.1 m high in total. A video camera

was used to record the changes in shapes of these blue layers during the operation of the SB. Sketches were then drawn from the video films to show the shapes of these layers evolving in time.

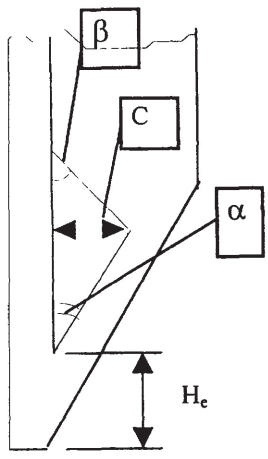

Fig. 4. Schematic presentation of main features of the insert (details shown in Table 1).

Table 1. Dimensions of experimental inserts.

Insert no.	Angle α(°)	Angle β(°)	Dimension C (mm)
1	30	45	75
2	30	45	100
3	30	45	125

Drying tests

Long paddy grains (Langi variety) were rewetted using the procedure described by Hung Nguyen et al. (in press). Duplicates of samples were taken for moisture content measurement and head rice recovery determination. Through a fitting mounted in the drying chamber, grains flowed into a plastic bag where the grain temperature was determined by taking the maximum value using a digital thermometer. Moisture contents were determined by the air oven (whole grain, at 130℃ and 10 hours). The results were calibrated using a regression equation suggested by Jindal and Siebenmorgen (1987). Grain samples withdrawn at 10min intervals during a drying process were spread in thin layers and allowed to reach the equilibrium moisture content at room temperature before milling tests. Milling quality was assessed by a Satake test kit, including a dehusker, a whitener and a cylindrical grader. The draft plate width was held constant at 63mm for all tests

Results and Discussions

Flowing performance of paddy

Tests with dry paddy

The test runs were carried out with paddy at 13% wb initial moisture content

Good plug-flow patterns were seen at level 1 with the help of insert no. 1 (Figure 5) At level 2, plug-flow behaviour was also observed. However, when the insert was positioned at level 3, good plug-flow was only achieved at the beginning After 5 minutes a faster zone at the centre was gradually formed and also occupied nearly half the grain column (Figure 6).

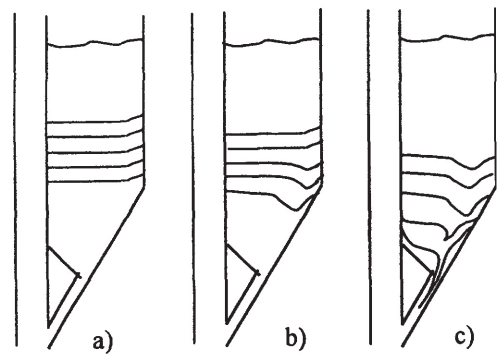

Fig. 5. Shapes of dyed layers in a TSB (Insert no 1, H_e = 70mm) after: a) 40sec, b) 2min and c) 3.5min.

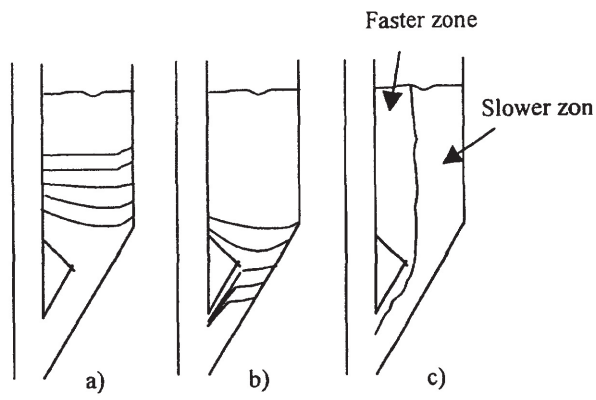

Fig. 6. Shapes of dyed layers in a TSB (Insert no 1, H_e = 210mm) after: a) 1min, b) 2min and c) 5min.

Replacement of insert no. 1 by inserts no. 2 and no. 3 resulted in excellent plug-flow patterns at all levels. Although in the conical part and at level 3, grains next to the outside wall moved somewhat slower than those inside, the grain mass flowed uniformly (Figures 7 & 8)

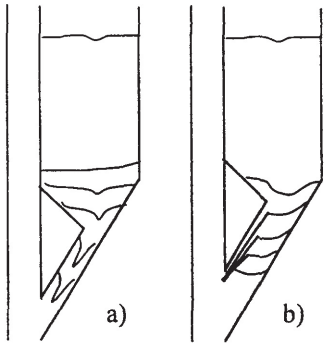

Fig.7. Shapes of dyed layers in a TSB (Insert no 2) after 2min: a) $H_e = 140$mm, b) $H_e = 210$mm.

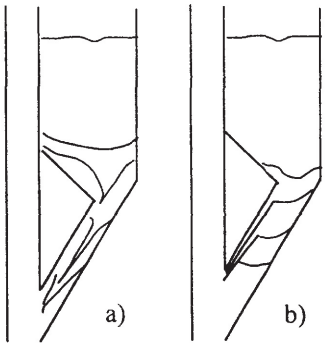

Fig.8. Shapes of dyed layers in a TSB (Insert no 3) after 2min: a) $H_e = 140$mm, b) $H_e = 210$mm.

Tests with wet paddy

The test runs were carried out with paddy at 26% wb initial moisture content.

Insert no. 1: At level 1, grains against the outer side of the bin moved faster than those near the draft plate at the beginning (Figures 9a & b). After about 4 minutes, slow moving zones developed above the insert and at the bin-to-hopper transition, which made the grains flow slower. At level 2, the initial flow was similar to that in level 1 (Figure 10a). However, at the conical part, the stagnant layer formed sooner and developed upwards along the outside wall

After about 4.5min a reverse trend of grain movement took place: grains near the draft plate moved faster and a clear faster/slower front appeared from bottom to top layers of the whole bed (Figure 10b). At level 3 the inverse trend happened from the beginning as inside grains flowed faster than outside grains (Figure 11a). The outside, slow moving grain column was about two-third of the total column and gradually formed an almost dead zone after about 4 minutes (Figure 11b)

Insert no 2: An excellent plug-flow was noticed at level 1 However, at level 2 a small stagnant zones appeared above the insert and the bin-to-hopper transition (Figure 12) At level 3, good plug-flow was still recognised. The stagnant zones, however, were less clear than when the insert was at level 2.

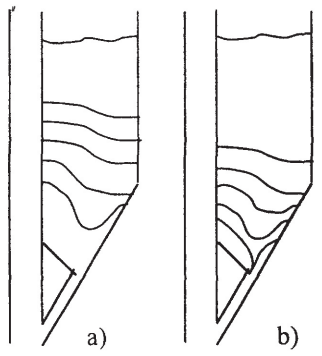

Fig.9. Shapes of dyed layers in a TSB (Insert no 1, $H_e =$ 70mm) after: a) 2min, b) 3.5min.

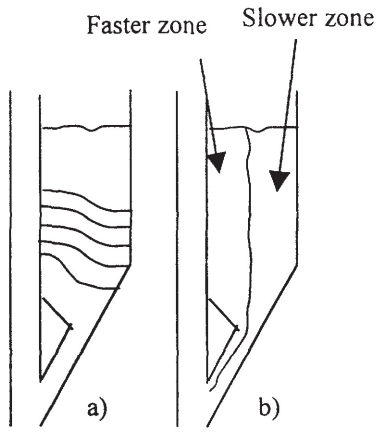

Fig.10. Shapes of dyed layers in a TSB (Insert no 1, $H_e =$ 140mm) after: a) 1.5min, b) 4.5min.

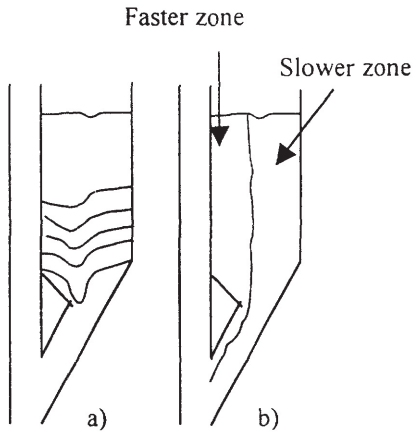

Fig.11. Shapes of dyed layers in a TSB (Insert no 1, $H_e =$ 210mm) after: a) 1.5min, b) 4min.

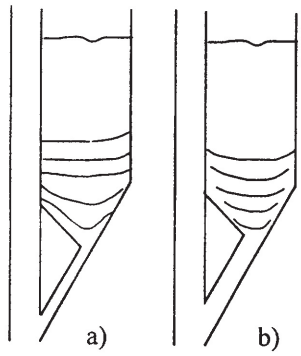

Fig. 12. Shapes of dyed layers in a TSB (Insert no. 2): a) H_e = 70mm, after 3min, b) H_e = 140mm, after 2.5min.

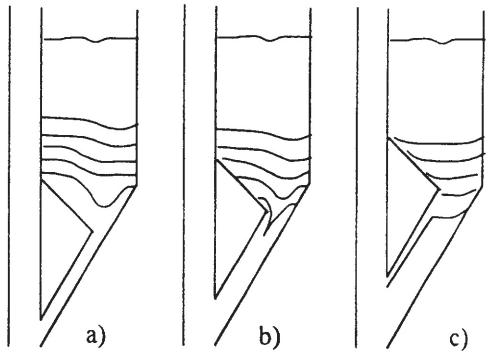

Fig. 13. Shapes of dyed layers in a TSB (Insert no. 3) after 2min: a) H_e = 70mm, b) H_e = 140mm, c) H_e = 210mm.

Insert no. 3: Although a good plug-flow was still detected at level 1, a small stagnant zone was seen above the insert A better plug flow was obtained when the insert was positioned at levels 2 and 3 (Figure 13). The stagnant zone above the insert was insignificant.

These figures showed that grains flow in a TSB in different patterns depending on their moisture contents, the separation distance, and the size of an insert. Plug-flow behaviour of high moisture content grains was difficult to achieve without the help of a suitable insert In these experiments, insert no 3 appeared to be most suitable for movement of grains with moisture contents as high as 26% wb. Therefore, insert no. 3 was used in all further drying experiments.

Temperature distribution in the downcomer

Hung Nguyen et al. (in press) reported that a narrow band of temperatures was observed in the downcomer of a TSB. Figures 14 & 15 show the grain and air temperatures in the downcomer. The details of drying steps are listed in Table 2. Even when a high inlet temperature of 190℃ was used, the difference in temperature between top and lower layers was within 10℃

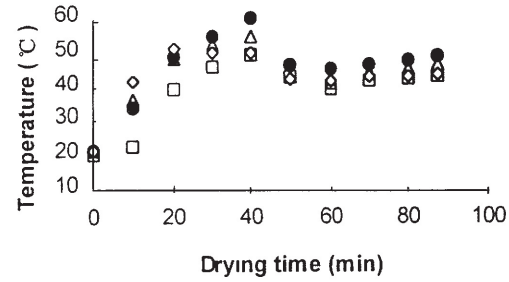

Fig. 14. Top surface grain and air temperatures at different bed heights in the downcomer (T_i = 160℃ & 80℃, H_b = 1.4m, Q_m = 0.034 kg/s)

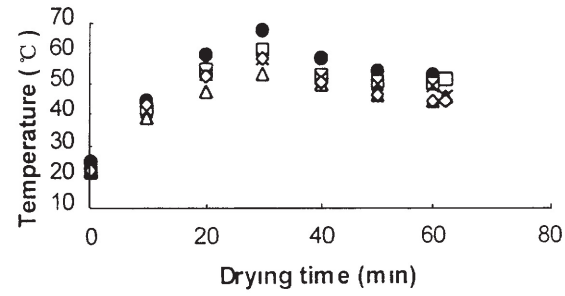

Fig. 15. Top surface grain and air temperatures at different bed heights in the downcomer (T_i = 190℃ & 100℃, H_b = 1.1m, Q_m = 0.033 kg/s)

Table 2. Levels of temperature used for drying experiments.

Figure	Stage	Inlet temperature setting (℃)	Duration (min)
17	1	140	80
	2	Stop the burner	until end
14 & 18	1	160	40
	2	Stop the burner	20
	3	80	until end
15 & 19	1	190	30
	2	100	until end

The grain temperature of the top layer was observed to be higher than air temperature of the layers below The grain temperature decreases as it moves from the top layer to the bottom layer of the downcomer Thus, after a high temperature pulse is given to the grains in the spout, they are tempered during their resident time in the downcomer,

which facilitates the moisture distribution within the grain kernels and mass transfer during the drying process

Drying characteristics

Plots of moisture reduction with time are showed in Figure 16 Generally, slow drying rates were noticed at the beginning as grain temperatures increased gradually This period lasts around 15 – 20 min depending on the bed height. Bed heights appeared to affect drying rates significantly. In batch drying, high beds provide longer residence time in the downcomer for moisture redistribution but fewer cycles for grains to be exposed in high temperature pulses. Although, grains spend a very short time in the spout, the heat received in this part of a SB will favour the moisture transfer in the downcomer.

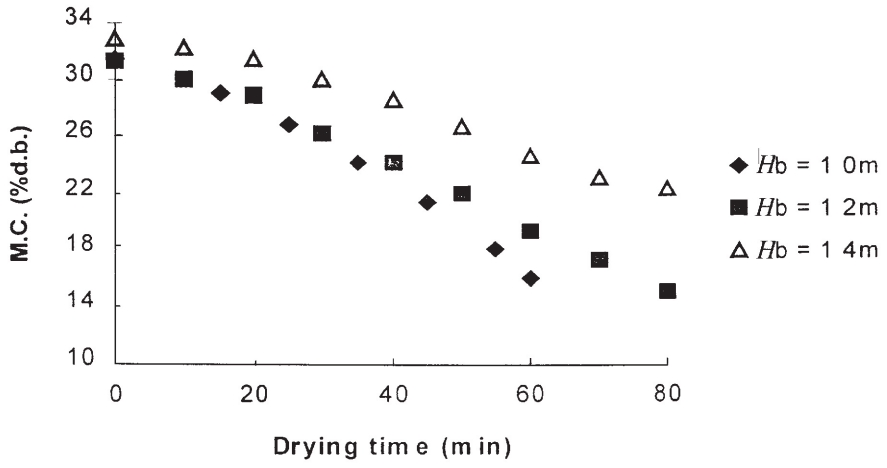

Fig. 16. Moisture reduction with time at different bed heights (T_i = 140℃, H_e = 170mm, Q_m = 0.028 kg/s).

The reduction of moisture content with time in a TSB using different levels of temperature is plotted in Figures 17, 18, & 19 The different heat treatment regimes were listed in Table 2. In Figures 17 & 18, although the burner was turned off after 80 min and 40 min, respectively, during the drying run; the moisture content of grains continued to decrease by 2.5 – 3 % db This can be explained by the fact that the heat accumulated during the first stage of drying helped to evaporate some moisture in the grain mass.

After some warming-up periods of about 15 – 20 min, Figures 17, 18, & 19 suggest a linear trend in the moisture reduction with time The surface moisture of the grains that had received a high temperature pulse in the spout could be easily removed. And the fact that they rested for a some time in the downcomer contributed to redistribution of moisture within grain kernels, leading to a drying process with constant drying rates

Very limited information about the reduction of moisture with time was given when paddy was dried using a conventional SB in the works of Zuritz and Singh (1980 & 1982); their figures, however, appeared to have a linear trend. This linear relationship was also observed by Khoe and Van Brakel (1980 & 1983) when paddy was dried in a conventional SB with a draft tube. Their observation of a constant drying rate lead them to suggest following mechanism: outer layer or the thin hull is dried in the draft tube and the zone next to the air entrance. The hull is then rewetted in the annulus (or the downcomer) by the moisture transfer from the interior of the grain.

It is noteworthy that deviations from the linear relationship could be observed with different flowing patterns of grains inside a SB If a plug-flow pattern is not achieved, non-uniform movement of grain layers could result in a wide range of moisture distribution within the same layer. For example, when a dead or slower zone develops along the outside wall, grains near the outside wall would have higher moisture contents than those inside near the draft plate

Milling quality

In a TSB, if paddy was dried continuously from a high moisture content (>24% wb) down to a low one (around 14% wb), the head rice recovery was seen to reduce seriously when the grain moisture content reached around 18% wb (Hung Nguyen et al , in press). These authors suggested that in a batch mode, different levels of temperature should be applied to preserve grain quality

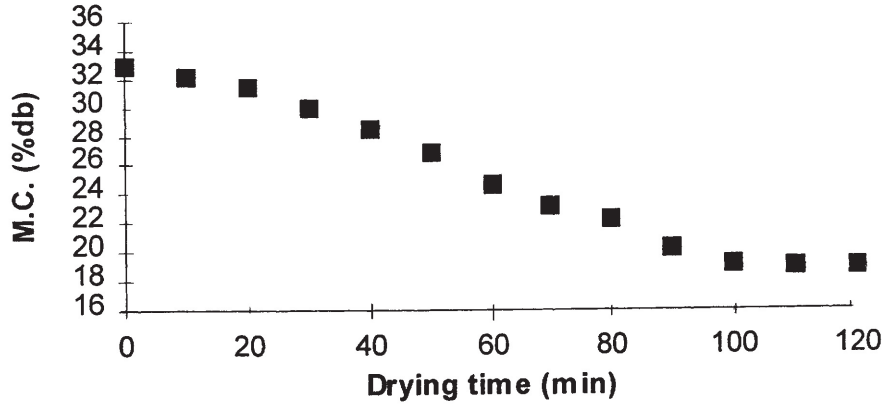

Fig. 17. Moisture reduction with time(H_b=1.4m, H_e=170mm, Q_m=0.028 kg/s, T_1 = 140℃ & stop the burner)

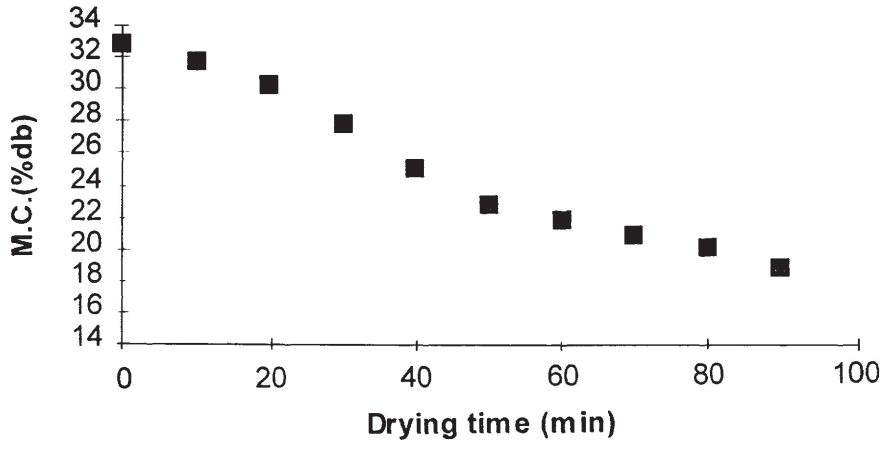

Fig. 18. Moisture reduction with time(H_b=1.4m, H_e=210mm, Q_m=0.034 kg/s, T_1=160℃ & 80℃)

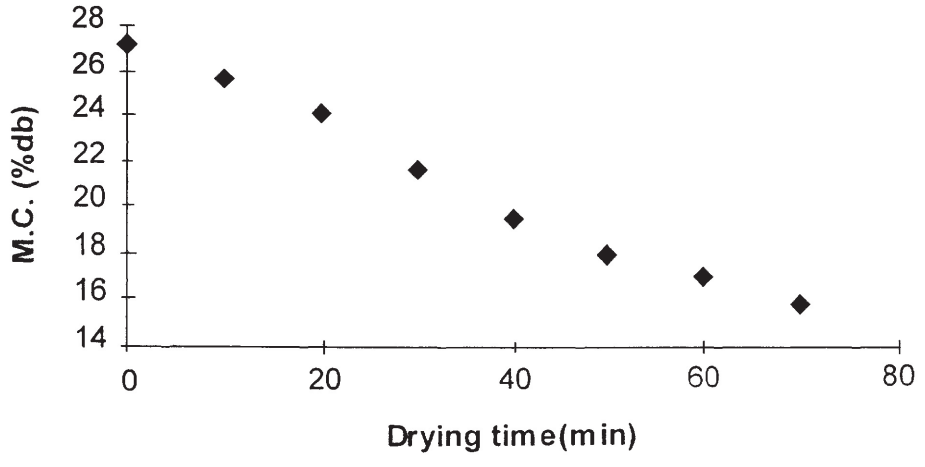

Fig. 19. Moisture reduction with time(H_b=1.1m, H_e=210mm, Q_m=0.033 kg/s, T_1=190℃ & 100℃)

Moisture contents, brokens and head rice recovery during drying period were listed in Tables 3 & 4. Using different levels of temperatures, high temperature up to 160℃ for the first drying period, followed by a cooling period and a lower temperature treatment of 80℃ (see Table 2), resulted in an acceptable milling yield (Table 3). In comparison with the shade dried control, only about 2% points of head rice were lost when moisture content reduced from around 25% wb down to 17% wb However, a significant increase of brokens was recorded when the moisture content was reduced lower than below 16% wb. If higher temperatures were applied, i. e 190℃ for the first stage and 100℃ for the last stage (see Table 2), a rapid loss of head rice was noticed when moisture content reached about 17% (Table 4). Further reduction of moisture content resulted in more serious loss These results suggested that heating procedures should be carefully selected and monitored to preserve grain quality.

Table 3. Evolution of grain quality and moisture content during drying process (T_1 = 160℃ & 80℃, H_b = 1.2m)

Drying time (min)	Broken (%)	Head rice (%)	Total yield (%)	Moisture content (%wb)
0	17.4	51 3	68.7	24.7
10	–	–	–	24.1
20	–	–	–	23.2
30	17.3	51 4	68.6	21.8
40	17.8	51.2	69.0	19.9
50	17.8	50.1	67.9	18.5
60	17.4	50.0	67.4	17.8
70	18.1	49.0	67.1	17.1
80	18.5	48.8	67.3	16.5
90	22.2	44.8	67.0	15.6

Table 4. Evolution of grain quality and moisture content during drying process (T_1 = 190℃ & 100℃, H_b = 1.1m).

Drying time (min)	Broken (%)	Head rice (%)	Total yield (%)	Moisture content (%wb)
0	7.9	60.6	68.6	21.3
10	–	–	–	20.7
20	8.5	59.5	68.1	18.9
30	9.5	58.1	67.5	16.9
40	11.3	55.7	67.0	15.5
50	18.4	48.2	66.6	14.1
60	25.9	40.9	66.8	13.4

Conclusions

The help of an insert installed in a TSB improves the flowing performance of paddy grains significantly Flowing patterns of paddy grains were found to be dependent on grain moisture contents, positions of the insert and as well as its size Suitable inserts should be selected and installed in a TSB to achieve a plug-flow behaviour of grains which effectively determine the drying process.

Drying tests revealed that bed height affects the drying rate in a TSB. The reduction of grain moisture with time was found to follow a linear trend which was also observed by previous research works with conventional cylindrical-conical SB with a draft tube The trend, however, could be affected by flowing patterns of grains In a SB with a draft tube, a plug-flow movement of grains is always expected to obtain a uniform heat treatment for the grain mass.

While fast drying aiming at achieving a high capacity for the drying system is always expected, different levels of drying temperature should be used to preserve paddy quality in term of head rice recovery. Towards the lower end of the 14 – 18% wb bracket, lower temperature should be applied. At the end of the drying process, i. e. around a moisture content of 16% wb, temperature higher than 80℃ is not recommended

Acknowledgements

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Notation

H_d	Maximum height of the drying chamber (= 2.4m)
H_b	Bed height, m
H_p	Draft plate height, m
H_e	Separation distance from draft plate to the slanted bottom, mm
L_d	Side length of the triangular cross section of the drying chamber (=0.314m)
L_p	Draft plate width (=0.063m in these experiments)
Q_m	Mass flow rate of air, kg/s
T_1	Inlet air temperature, ℃
θ	Slanted angle (= 60°)
α, β	Angles of an insert, °
C	Dimension of an insert, mm

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