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# Determination of designing and operating parameters of circulating concurrent-flow rapeseed dryer

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*Abstract*—This study aimed to investigate the designing and operating parameters of the circulating concurrent-flow dryer for rapeseed drying, such as drying section height, airflow rate, grain flow velocity, and drying air temperature, to meet the dryer performance in the best performance conditions, minimum cost, and the quality of seed. The simulation program which exhibited good fitness with experimental data performing on a pilot scale concurrent-flow dryer 200 kg a batch was used in this study. The results showed that the optimal parameters of drying section height, air flow rate, grain flow velocity and drying air temperature were found at 0.52 m, 30 cmm m–2, 5.5 m h–1, and 115oC, respectively. At these conditions, corresponding drying rate reached 3.01 %,w.b., fuel energy consumption was 4977 kJ kg–1 water, and germination rate was 94.5%.

***Keywords*—rapeseed, drying section height, airflow rate, grain flow velocity, drying air temperature.**

## INTRODUCTION

Rapeseed contains over 40% oil and 20% protein, the rapeseed oil is extracted from the seeds for production of edible oil and biological fuel [3]. Because of its high oil content, rapeseed is susceptible to spoilage if not properly drying.

Concurrent-flow dryer was developed for drying many kind of grains. However, it can be concluded that no unique operating parameters has the ability to apply accurately for various types of grain. Therefore, it is necessary to determine specific operating parameters for a specific grain. A considerable amount of work has been done on designing and operating parameters of different agricultural products, a literature review revealed that most of the previously studies have been conducted on products such as corn, rice, soybean, peanuts [5],[6],[10]. However, studies on rapeseed are scarce.

A simulation program of rapeseed drying in circulating concurrent-flow dryer (RCDSim-2009 simulation program) was developed by Duc and Keum (2009), the results showed that the simulation program had good fitness with experimental data on a pilot scale concurrent-flow dryer 200 kg a batch. The simulation program was proved its reliability and was showed to be a convenient tool for predicting rapeseed drying in circulating concurrent-flow dryer [7].

To ensure that the dryer operates in the best performance, the proper design and operating parameters of the dryer should be determined. In addition, to scale-up from pilot scale dryer to commercial scale dryer, these proper parameters are also required [6]. Therefore, the objective of this study was to use the simulation program that has been developed to determine the optimal design and operating parameters of circulating concurrent-flow rapeseed dryer, such as drying section height, airflow rate, grain flow velocity, and drying air temperature in order to meet the dryer performance in the best performance conditions, minimum cost (minimum fuel energy consumption), and ensure the germination rate, this is also considered to be very important parameter for assessment quality of seed [2].

## MATERIALS AND METHODS

In this study, there are two components: a set of variables that can control (designing and operating parameters), and a set of requirements to satisfy (drying performance parameters). The proper designing and operating conditions of the concurrent-flow dryer for rapeseed in this study were determined based on the Complex method using graph [4], [9].

The operating principle of the circulating concurrent-flow rapeseed dryer is showed in Fig. 1. The main structure of the dryer includes grain inlet section, burner, plenum section, drying section, tempering section, suction centrifugal fan, variable speed discharge augers and bucket elevator. The hot air is supplied by a direct combustion kerosene jet-burner (including burner, control and air filter), after going through the mixed chamber the drying air will enter the dryer through plenum section. Rapeseed and drying air are moving the same direction until drying air out by forced of suction centrifugal fan through five exhaust air ducts. Rapeseed flow rate is controlled by two variable speed discharge augers. Rapeseed is out the dryer by discharge auger and by bucket elevator or circulated by bucket elevator from the top of the dryer and flows down the vertical drying chamber.

The simulation program was validated by comparison results of program with experimental data of the pilot scale concurrent-flow dryer 200 kg a batch [8]. The input data of simulation program were entered in accordance with data of actual experiment, such as initial rapeseed conditions, dryer specification, and drying air and ambient air conditions.

The germination tests were conducted according to protocols described for the standard germination test [1].

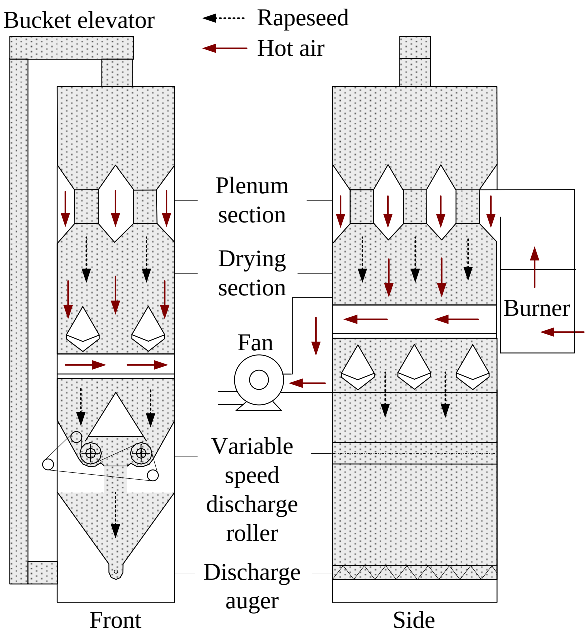


Fig. 1. Schematic diagram of pilot circulating concurrent-flow rapeseed dryer

RESULTS AND DISCUSSION

Designing and operating parameters

Design factors and target performances: the main factors that effect on drying performance include: drying section height (m), air flow rate (Cubic Meter per Minute: cmm) (cmm m–2), grain flow velocity (m h–1), and drying air temperature (oC). The target factors include drying rate (%,w.b. h–1), fuel energy consumption (kJ kg–1 water), germination rate (%). In addition, power of fan (kW m–2) was also considered to select the proper designing and operating factors.

The constraint for designing and operating parameters and required target performance showed in table 1. The drying section height varied from 0.2 ~ 1.0 m, air flow rate varied from 20 ~ 40 cmm m–2, grain flow velocity varied from 2.5 ~ 7.5 m h–1, and drying air temperature varied from 80 ~ 125oC.

Hypothetical initial drying conditions for analysis were presented in table 2. The ambient air conditions were selected follow Suwon (Korea) weather condition in June and July. The average initial moisture content of Korean rapeseed (crop harvested in June) is 23 %,w.b.

a) Drying section height:

The effects of drying section height on the drying performance were illustrated in Fig. 2. The height of drying chamber increases from 0.1 ~ 1 m. It is showed that more fuel energy decreased when the height of drying chamber increases. However, when the height of drying chamber increased, drying time increased and drying rate decreased continuously. A larger reduction of fuel energy and drying rate were observed when the height of drying chamber less than 0.5 m.

If the drying section height was higher than 0.55 m, drying rate lower than 3.0 %,w.b. h–1. In addition, fan power was fairly high. With the increase of drying section height the fan power is increase, this is caused by the resistance of grain layer.

In general, the lower value of drying section height, the better value of fan power, drying time, drying rate, however it caused low germination rate and high fuel energy consumption. For optimal designing and operating parameters, the ideal height of drying section is 0.52 m. At this drying section height, drying rate reaches 3.01 %,w.b. h–1, fuel energy is 5700 kJ kg–1 water, germination rate is about 91.4%.

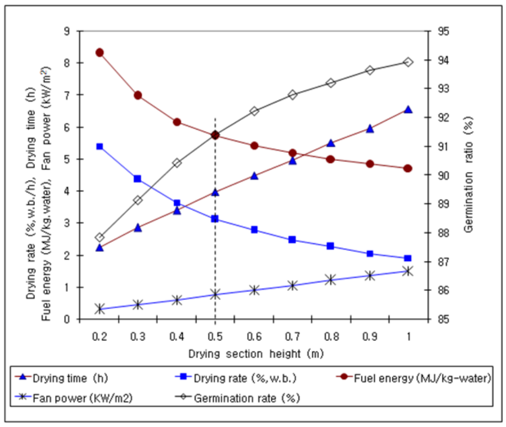


Fig. 2. The effects of drying section height on drying rate, drying time, fuel energy consumption, fan power and germination rate.

b) Air flow rate:

Higher air flow rate will increase the drying rate, fan power and fuel energy consumption, whereas the drying time decreases. Therefore, the level of air flow rate must be selected considering all of them.

The effects of air flow rate on drying rate, drying time, fuel energy consumption, fan power and germination rate were showed in Fig. 3. The variation of air flow rate from 20 ~ 40 cmm m–2.

Drying rate increased with increasing air flow rate, however, drying process takes more fuel energy consumption.

The largest germination rate at air flow rate of 26 cm m–2, which is equivalent to 95.9% of germination rate and decreases rapidly when air flow rate higher than 30 cmm m–2. When the air flow rate increases, the fan power light increases whereas drying time decreases. At air flow rate increased above 30 cmm m–2, fuel energy exceeded the allowed level.

At 30 cmm m–2 level, fuel energy consumption is 5000 kJ kg–1 water, fan power is 0.393 kW m–2, germination rate is 95.1% and drying rate is 2.76 %,w.b. h–1.

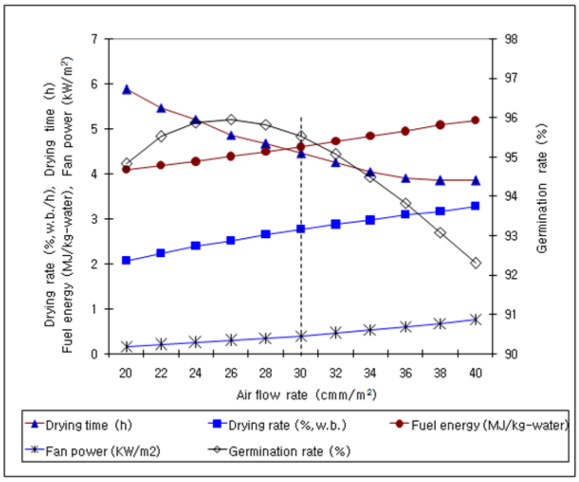


Fig. 3. The effects of air flow rate on drying rate, drying time, fuel energy consumption, fan power and germination rate.

c) Grain flow velocity:

The grain flow velocity depends on the drying section height and drying air temperature to ensure rapeseed temperature does not exceed the allowable value. The effects of grain flow velocity on drying rate, drying time, fuel energy consumption, fan power and germination rate were showed in Fig. 4. The grain flow velocity increases from 2.5 ~ 7.5 m h–1.

Grain flow velocity increases does not affect the fan power. With the increase of grain flow velocity the germination rate is increase, this is caused by the decreased residence time of grain in the drying section. When grain flow velocity increases, from 2.5 ~ 5.5 m h–1, drying rate and germination rate increased whereas fuel energy decreased. However, when grain flow velocity is higher than 5.5 m h–1, drying rate and germination rate virtually no increased and fuel energy increased.

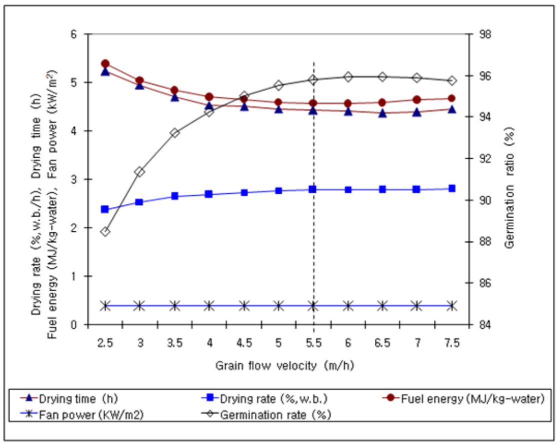


Fig. 4. The effects of grain flow velocity on drying rate, drying time, fuel energy consumption, fan power and germination rate.

At the grain flow velocity of 5.5 m h–1, fuel energy consumption is 4600 kJ kg–1 water, germination rate is 95.62%, and drying rate is 2.73 %,w.b. h–1.

d) Drying air temperature:

Drying air temperature is one of the most important parameters in concurrent flow dryer [5]. Fig. 5 shows the variation of drying air temperature from 80 ~ 125oC. It showed that with higher drying air temperature faster amount of moisture will be removed, therefore drying time decrease and drying rate increases.

Drying air temperature does not affect the fan power. Although the drying air temperature increases, fuel energy consumption decreased due to the increase of drying rate, the corresponding decrease in fuel energy was insignificant. A minimum of fuel energy at drying air temperature of 115oC. Drying air temperature increases will causes germination rate decreases.

The drying air temperature can be selected from 110 ~ 115oC. However, when the drying air temperature was higher than 115oC, fuel energy increased (about 100 kJ kg–1 water), and germination rate decreased rapidly to 92.8%.

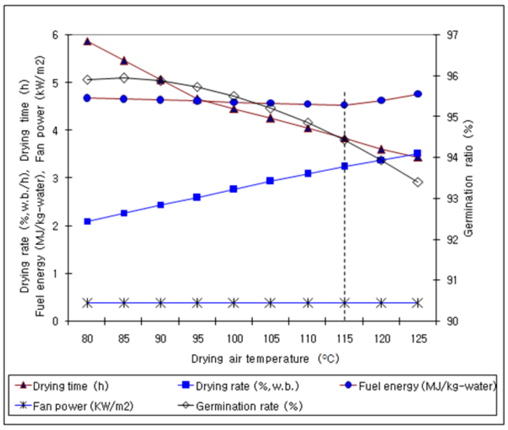


Fig. 5. The effects of drying air temperature on drying rate, drying time, fuel energy consumption, fan power and germination rate.

At the drying air temperature of 115oC, fuel energy consumption is 4536 kJ kg–1 water, germination rate is 94.7%, and drying rate is 3.24 %,w.b. h–1.

3.2. Selection of designing and operating parameters

From the results as shown in the previous section, the designing and operating parameters for dryer were obtained in table 3, along with performance parameters of dryer by using simulation program.

When the dryer operates at the optimal parameters, namely drying section height 0.52 m, air flow rate 30 cmm m–2, grain flow velocity 5.5 m h–1, and drying air temperature 115oC with initial ambient air and initial grain conditions (table 2), predicted parameters were higher than the measured values (Pvalue < 0.01): predicted drying rate reaches 3.01 %,w.b. h–1, higher than 5.79% compared to the measured value; predicted germination rate reaches 94.5%, higher than 5.25% compared to the measured value; predicted total energy consumption reaches 5090.3 kJ kg–1 water, higher than 6.59% compared to the measured value of experiment at optimal operation.

The value of drying air temperature is very important for rapeseed quality. At the drying air temperature of 115oC, the maximum temperature of rapeseed in drying chamber at the end of drying process is 44.6oC. This was due to the contact between hot drying air and rapeseed in the short time inside drying chamber. The maximum temperature of grain is very important to determine quality of grain after drying. The germination rate of rapeseed after drying reaches fairly high (94.5%).

Specific energy consumption or the energy required to remove a quantity of water from the rapeseed is 4977 kJ kg–1 water, which is in the limited energy and lower level of average energy for conventional grain dryers (4000 ~ 6000 kJ kg–1 water), meaning that energy can be saved. Fuel energy consumption for rapeseed drying was 4977 kJ kg–1 water, slightly higher compared to 4700 kJ kg–1 water of the continuous multi-flow grain dryer [10], patent Vertec VT-5600R.

TABLE 3. SELECTED PARAMETERS AND PERFORMANCE OF THE DRYER.

| | |
|---|---|
| Designing and operating parameters | |
| Drying section height (m) | 0.52 |
| Air flow rate (cmm $m^{-2}$) | 30 |
| Grain flow velocity (m $h^{-1}$) | 5.5 |
| Drying air temperature ($^{o}$C) | 115 |
| Drying rate (%,w.b. $h^{-1}$) | 3.01 |
| Number of circulation | 20 |
| Final moisture content (%,w.b.) | 10.7 |
| Rapeseed temperature at the end of drying ($^{o}$C) | 44.6 |
| Germination rate (%) | 94.5 |
| Fan power (kW $m^{-2}$) | 0.40 |
| Fuel energy consumption (kJ $kg^{-1}$ water) | 4977.4 |
| Total energy consumption (kJ $kg^{-1}$ water) | 5090.3 |

CONCLUSIONS

The designing and operating parameters of the circulating concurrent-flow dryer for rapeseed drying were investigated by using a validated simulation program and the pilot scale circulating concurrent-flow with capacity of 200 kg a batch. The drying systems were optimized by considering these factors include drying rate, fuel energy consumption, power of fan and germination rate.

The optimal designing and operating parameters were found, namely are drying section height is 0.52 m, air flow rate is 30 cmm m–2, grain flow velocity is 5.5 m h–1, and drying air temperature is 115oC. At these conditions, corresponding maximum grain temperature in drying is 44.6oC, drying rate is 3.01 %,w.b. h–1, total energy consumption is 5090 kJ kg–1 water, fan power is 0.4 kW m–2 and germination rate is 94.5%.

The pilot scale circulating concurrent-flow rapeseed dryer with capacity of 200 kg a batch was used to verify the optimal operation. It is concluded that the results of this study can be employed as a basis to scale-up for commercial scale dryer and it can be utilized for predicting the performance of concurrent-flow rapeseed dryer.

TABLE 1. CONSTRAINT CONDITIONS AND REQUIRED TARGET PERFORMANCES.

| Constraint for designing and operating factors | Target performances |
|---|---|
| $0.2 \leq$ Drying section height $\leq 1.0$ m<br>$20 \leq$ Air flow rate $\leq 40$ cmm $m^{-2}$<br>$2.5 \leq$ Grain flow velocity $\leq 7.5$ m $h^{-1}$<br>$80 \leq$ Drying temperature $\leq 125^{o}C$ | Drying rate $\geq 2.5$ %,w.b. $h^{-1}$<br>Energy consumption $\leq 5000$ kJ $kg^{-1}$ water<br>Germination rate $\geq 94\%$ |

TABLE 2. HYPOTHETICAL INITIAL CONDITIONS.

| | |
|---|---|
| *Ambient air conditions* | |
| Temperature ($^{o}C$) | 25.4 |
| Relative humidity (%) | 63.4 |
| *Grain conditions* | |
| Initial moisture content (%,w.b.) | 23.0 |
| Initial grain temperature ($^{o}C$) | 22.8 |
| *Dryer specifications* | |
| Drying air temperature ($^{o}C$) | 100 |
| Drying section dimension (L×W×H) (m) | 0.5 × 0.7 × 0.5 |
| Tempering section height (m) | 0.5 |
| Air flow rate (cmm $m^{-2}$) | 30 |
| Grain flow velocity (m $h^{-1}$) | 5 |

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