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Drying a Bean-Curd Refuse in a Mixed-Flow Dryer

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Drying characteristics of bean-curd refuse were measured in a mixed-flow dryer, which was a conductive indirect-heating dryer using steam as a heating medium and had an agitated solid bed. Effects of agitating speed and solid inventory were discussed on drying characteristics of bean-curd refuse. Height of a solid bed increased with increasing agitation speed. The evaporation rate and the overall heat transfer coefficient increased on the heating surface as bed mass of the drier or agitation speed increased. Water content of dried solid decreased with increasing bed mass of the drier or agitation speed.

1. Introduction

Recently the price of live stock feed is getting more expensive because the corn price, which is controlling the price of livestock feed, dramatically grows. Food waste such as bean-curd refuse contains lots of useful nutrients, and can be recycled to make livestock feed (Kim, 1989). However, food waste usually contains a lot of moisture and has to be dried first before next treatment. In this case, drying is a necessary process not only for reducing the handling and transportation cost (Park, 1994) but for sanitation. The bean-curd refuse is reused to make health food (Lee, 2001; Hirose et al., 2007; Yoo, 2007; Tanno, 2008) and livestock feed. It needs to be dried at a thermal death point for sterilization before reuse.

Drying is a relatively simple process but selecting a proper type of drier depends on physical and chemical characteristics of dried material. There have been developed many types of driers for various properties of material (Choi and Yoon, 1990). A conductive indirect-heating dryer with agitation can be used for drying organic waste material like bean-curd refuse which is sticky and disintegrated to small pieces or particles during being dried. A solid bed formed of dried material in the drier also plays an important role for taking a fed wet and sticky material smoothly.

The purpose of this study is to investigate drying characteristics of a bean-curd refuse in a mixed-flow dryer, which is a conductive indirect-heating dryer using steam as a heating medium and has an agitated solid bed. Drying characteristics are discussed in

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terms of evaporation capacity per heating surface, overall heat transfer coefficient across the heating surface, and moisture content of dried solid with variations of agitation speed and bed mass of the drier.

2. Experimental

Figure 1 shows schematic diagram of mixed-flow dryer system used for experiment (Kim, 1997). The dryer system consisted of a steam boiler, a dryer with an insulated single steam jacket and an agitator, a steam trap, a condenser, an induced draft fan, and two sets of a screw conveyer and a hopper system for feeding wet bean curd refuse and discharging dried solid each. An automatically controlled boiler supplied saturated steam (414 K, 371 kPa-abs) into the jacket outside the dryer. Condensation of steam in pipeline between the boiler and the jacket was prevented at most by placing the boiler close to the dryer together with good configuration and insulation of the pipeline. Temperature and pressure at the steam inlet of the jacket were very close to those of the boiler at normal operation. The steam trap kept steam and only allowed condensate to be discharged out of the steam jacket. The amount of steam used as heating medium was determined by means of measuring the amount of condensate. Temperature of heating medium was considered as an arithmetic mean of inlet steam and condensate temperatures.

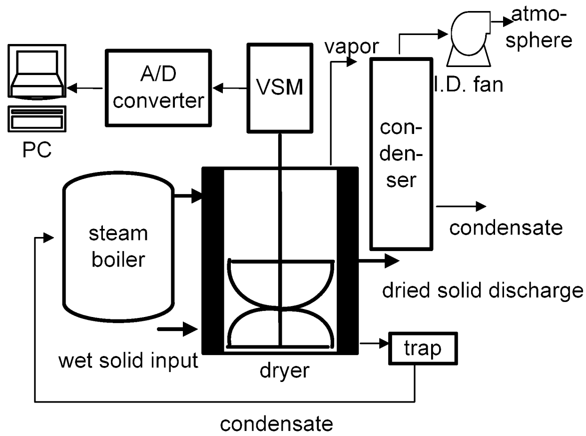

Figure 1 Schematic diagram of the present experimental setup.

The dryer (SUS 304) is a cylindrical shape having inside diameter 0.396 m and height 0.605 m. The side wall of the dryer is surrounded by a steam jacket with good insulation outside. The dryer had an axial agitator driven by a dc variable speed motor. The axis of the agitator was supported at both centers of top cover and bottom plate of the dryer. The shape of the agitator blades is shown in Figure 2. The bottom of the blade was placed 10 mm close to the bottom of the dryer. There was formed a 10 mm thick static bed of solid at the bottom of the dryer, which played an important role in thermal insulation during the normal operation. Both top cover and bottom plate of the dryer were also insulated as good as possible. A sight glass and a gas exit were installed in the top cover of the dryer.

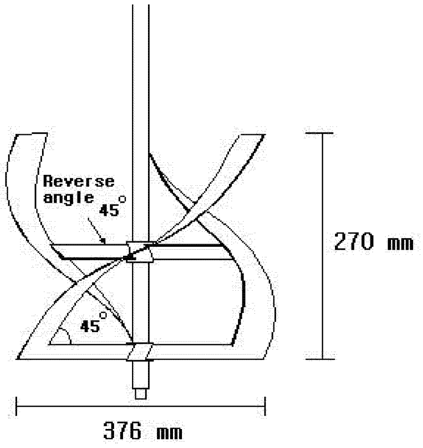

Figure 2 Shape of agitator blades.

The wet bean curd refuse was stored in a hopper and fed by a screw conveyer installed at a height 80 mm from the bottom of the dryer. A screw conveyer for discharge of dried solid was installed at a height 0.25 m from the bottom of the dryer. The discharge rate of dried solid was controlled to maintain the bed mass constant at a feed rate of wet bean curd refuse. A known amount of dried bean curd refuse was placed in the drier as bed materials in the beginning. The constant bed mass could be achieved by keeping power consumption of the agitator constant. Mass flow rate and moisture content of fed and discharged solid were measured for mass and heat balance in the dryer. The evaporated moisture was drawn at the top of the dryer via a condenser by an induced draft fan. Negligible amount of solid was entrained out of the dryer by evaporated moisture. Pressure at the gas exit was kept about 98 Pa vacuum. Thermocouples (K-type) were installed in the feed hoper, at the inlet and outlet of the steam jacket, and at gas exit and solid bed of the dryer. Temperature of discharged solids was considered as a bed temperature. The moisture content of bean curd waste ranged from 79% to 82%. Drying characteristics were measured with variation of bed mass and agitation speed at the steady state.

3. Result And Discussion

This dryer had a dry bed of particles which was stirred by an agitator. Sometimes, it seemed that evaporated moisture, which was flowing up, promoted the agitation better and easier. Solid particles were moved upwards by the agitator and fell down. The inside wall, heat transfer area, was always rubbed by moving particles and kept clean with no sticking particles. Wet lump of feed seemed to be disintegrated, surrounded by dry particles of the bed, and spread away throughout the bed soon after it came into the bed. This seemed to prevent wet particles from sticking to the heat transfer surface and keep heat transfer superior on the surface of the inside wall contacting the emulsion phase like a gas fluidized bed. The agitation brought bed expansion together with well mixing. The bed height increased due to an increase of upward momentum transferred from the agitator to solid particles as the agitating speed increased. The heat transfer on the surface immersed in the bed was actually much higher than on the bare surface, and governed the drying capacity of this dryer. Therefore, an increase of bed height means an increase of drying capacity of the dryer.

Figure 3 shows effects of agitation speed and bed mass of the dryer on the evaporation rate of moisture in solids in the dryer, based on whole heat transfer area. The evaporation rate of moisture was determined through mass balance of moisture in solids. The evaporation rate increases with an increase of agitation speed or bed mass of the dryer (Schlunder and Mollekopf, 1984). This trend is associated with an increase of heat transfer resulting from bed height increasing as agitation speed or bed mass of the dryer increases. However, the effect of bed mass of the dryer appears relatively small at a bed mass greater than 7.8 kg, which seems to have a heat transfer rate approaching a saturated value. The evaporation rate of this study ranged as much as that of the agitated pan type dryer (Backhurst and Harker, 1973).

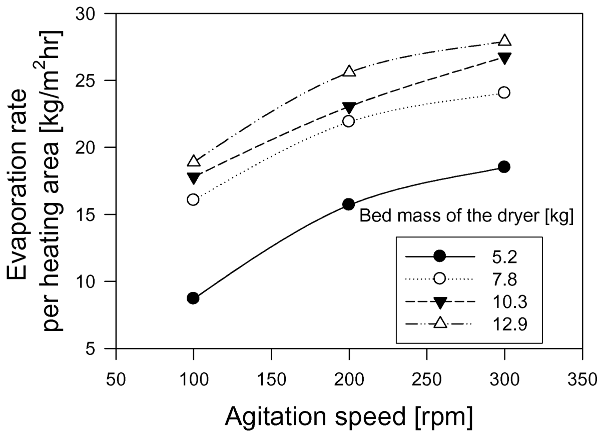

Figure 3 Effects of agitation speed and bed mass of the dryer on evaporation rate of moisture per heating area based on whole heat transfer area.

Figure 4 shows an overall heat transfer coefficient at the heating surface, based on the whole heat transfer area. Temperature of heating medium was considered as an arithmetic mean of inlet steam and condensate temperatures. Temperature of discharged solid was considered as a bed temperature. Saturated steam entered the heating jacket and the amount of consumed steam was determined by means of measuring the amount of condensate. An overall heat transfer rate was determined an enthalpy change from condensate to steam multiplied by consumed steam flow rate. Heat loss on the outside wall of the heating jacket was negligible. The overall heat transfer coefficient based on the whole heat transfer area increased with increasing bed mass or agitation speed due to an increase of bed height i.e. effective heat transfer area. Bed height i.e. effective heat transfer area increased with increasing bed mass or agitation speed. However, the effect of bed mass appears relatively small at a bed mass greater than 7.8 kg, which seems to have an overall heat transfer coefficient approaching a saturated value.

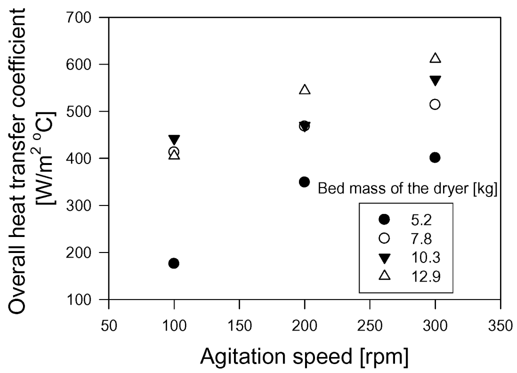

Figure 4 Effects of agitation speed and bed mass of the dryer on overall heat transfer coefficient.

Figure 5 shows effects of solid inventory of the dryer and agitation speed on moisture content of discharged solids. Moisture content of dried solids almost decreases with increasing solid inventory of the dryer or agitation speed. Generally, the residence time of solids increased with increasing solid inventory of the dryer. A long retention time of solids means a long drying time of solids, which results in the low moisture content of discharged solids. The higher speed of agitation seems to give the solids bed better mixing resulting in better radial heat transfer in the bed, the evaporated moisture releasing out of the bed more easily, and the gas phase of the bed a lower humidity, which seem to be responsible for lowering the moisture content of discharged solids.

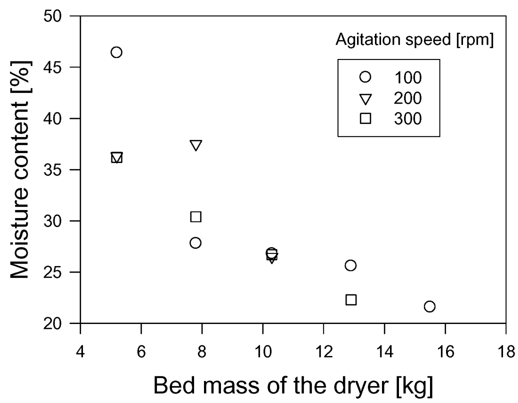

Figure 5 Effects of bed mass of the dryer and agitation speed on moisture content of discharged solids.

4. Conclusion

Drying characteristics of a bean-curd refuse were measured in a mixed-flow dryer, which was a conductive indirect-heating dryer using steam as a heating medium and had an agitated solids bed. Effects of agitating speed and bed mass were investigated on drying characteristics of bean-curd refuse. Expanded height of the solids bed increased with increasing agitation speed. The evaporation rate and the overall heat transfer coefficient increased on the heating surface as the agitation speed or the bed mass increased. Water content of dried solids decreased with increasing bed mass of the drier or the agitation speed.

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