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Variability of bulk density of distillers dried grains with solubles (DDGS) during gravity-driven discharge

C.L. Clementson, K.E. Ileleji *

Department of Agricultural and Biological Engineering, Purdue University, 225 S University Street, West Lafayette, IN 47907, USA

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ABSTRACT

Loading railcars with consistent tonnage has immense cost implications for the shipping of distillers' dried grains with soluble (DDGS) product. Therefore, this study was designed to investigate the bulk density variability of DDGS during filling of railcar hoppers. An apparatus was developed similar to a spinning riffler sampler in order to simulate the filling of railcars at an ethanol plant. There was significant difference ($P < 0.05$) between the initial and final measures of bulk density and particle size as the hoppers were emptied in both mass and funnel flow patterns. Particle segregation that takes place during filling of hoppers contributed to the bulk density variation and was explained by particle size variation. This phenomenon is most likely the same throughout the industry and an appropriate sampling procedure should be adopted for measuring the bulk density of DDGS stored silos or transported in railcar hoppers.

1. Introduction

Distillers dried grains with solubles (DDGS) is the main co-product of fuel ethanol production from corn by the dry grind process. The marketability of DDGS has significant implications for the success of the ethanol industry. From its market value and the quantity produced, DDGS revenue can be as much as 20% of the total revenue from an ethanol plant. The fiber, oil and relatively high protein content in DDGS makes it suitable for animal feed (Rosentrater and Muthukumarappan, 2006). With the increase of fuel ethanol production, the production of DDGS has increased significantly in the last few years and reached 23 million metric tons in the 2008 marketing year (Renewable Fuel Association, 2010). Most of the DDGS is produced in the Mid-west region and is usually shipped primarily by rails or trucks to feedlots and ports throughout the US; hence handling and logistics are essential.

Maintaining a consistent bulk density of DDGS during handling and shipping is essential to minimizing shipping costs. Ileleji and Rosentrater (2008) pointed out the cost saving when DDGS of consistent bulk density is shipped. Ethanol plants have expressed concern about the inability to sequentially load railcars with consistent freight tonnage, even when the product was all from the same batch (Personal communication with The Anderson Clymers Ethanol in Indiana, 2007). Several researchers have highlighted the bulk density variability of DDGS. Rosentrater (2006) showed that the bulk density of DDGS produced at six ethanol plants in South Dakota ranged from 391 to 496 kg/m^3. Bhadra et al. (2009) found ranges of 490–590 kg/m^3 from five plants in South Dakota. In another study using DDGS from 69 sources in 2004 and 2005, it was found that the bulk density ranged from 365 to 561 kg/m^3 (US Grains Council, 2008). Some of these variations could be caused by differences in process conditions as pointed out by Kingsly et al. (2010). They showed that by varying the solubles content of a particular plant, the bulk density changed from 420.47 to 458.05 kg/m^3. However, all the above variations in bulk density referred to are the bulk density of DDGS sampled from the plant for physical and chemical property characterization. No study has been published investigating bulk density variation of DDGS during loading by gravity-driven discharge.

Of greatest concern to DDGS handlers is the inconsistency that exists when transporting DDGS from the same batch. The inability to achieve a consistent maximum tonnage increases the cost of shipping this product and underutilizes resources. Particle segregation takes place during handling operations of discharging from a hopper or silo (Ketterhager et al., 2007) and would similarly impact filling and emptying railcars transporting bulk DDGS. This could occur when different sized particles are lodged in segregated regions in a vessel causing the particle size distribution of a heterogeneous bulk to change with time during discharge (Shinohara et al., 1968; Fowler and Glastonbury, 1959). Shinohara et al. (1972) studied the size segregation of particles in filling a hopper and proposed the screen model for segregation of particles in filling a hopper. In this model, they suggested that when a bulk is poured and flows down the heap formed, small particles tend to be

* Corresponding author. Tel.: +1 765 494 1198; fax: +1 765 496 1115.
E-mail addresses: ileleji@purdue.edu, ileleji@pasture.ecn.purdue.edu (K.E. Ileleji).

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separated from the mixture by passing through the interspaces of large particles forming a flowing layer. These smaller particles drop into the gaps formed by the stationery layer of large particles under the flowing layer. A V-shaped zone in the hopper where the smaller particles are concentrated is formed. Shinohara and Miyata (1984) used this model to advance a mechanism of density segregation of particles in filling vessels. They deduced that denser particles behave like smaller particles in size segregation by settling near the feed line and forming a V-shaped narrow zone within the bed of lighter components.

Standish (1985) studied size segregation during filling and emptying of a hopper. He confirmed that during filling the hopper, smaller particles segregate in the center, large particles segregate towards the wall and the concentration of medium-size particles remain uniform throughout the hopper. He further determined in-bin segregation influences size segregation in the discharging of the material with concentration of small particles high in the discharge stream initially and low at the final stages. Salter et al. (2000) used a two-dimensional representation of a hopper to study the segregation of binary mixtures during filling; they expressed that segregation when forming a heap is influenced by different mechanisms within different regions of the heap. Bagster (1983) used mixtures of controlled size distribution and moisture content to investigate the effect on the segregation process, and concluded that the cohesivity of the material forming the heap influences the segregation process. The principles of these models have been validated using relatively homogeneous solids like glass beads, sand or similar materials but not thoroughly studied for heterogeneous bulk solids.

DDGS is a heterogeneous granular bulk solid (Ileleji et al., 2007) having particles of various sizes, morphological features and particle densities which are characteristic of the structural components of a corn kernel (germ, fiber, endosperm and tipcap). Shinohara (1979) studied the segregation of differently shaped particles in filling of storage vessels and found that angular particles behaves like smaller particles in size segregation being deposited near the feed point forming a V-shaped zone; therefore the heterogeneity of DDGS may exacerbate segregation during handling. Particle segregation during handling of DDGS was investigated by Ileleji et al. (2007) and Clementson et al. (2009), and found to occur during gravity-driven discharge. It is most likely that the bulk density variation observed during the filling of railcar hoppers might be caused by particle segregation. Therefore, the primary objective of this study was to investigate the bulk density variation of DDGS from a discharge vessel that simulated the filling of railcar hoppers, and determine the effect of particle segregation on the bulk density variation.

2. Methods

2.1. Materials and equipment

DDGS production involved the blending of condensed distillers soluble (CDS) and wet distillers grains (WDG), then drying the composite material using rotary drum dryers. Samples of DDGS for this study were prepared at a 416 million liters per year commercial fuel ethanol plant (The Andersons Clymers Ethanol plant in Clymers, Indiana) by varying the CDS and WDG composition. The process used incorporated two dryers in series where the total quantity input of CDS was split into the two dryers with the quantity of WDG remaining constant. Three distinct samples of DDGS produced by varying the CDS levels from the maximum amount routinely added at the plant to zero level (no CDS addition) were used in this study. The three CDS levels were: (i) about 7.39 percent volumetric basis (% v.b.), (ii) reduced to half of this amount, 3.69% v.b. and (iii) no CDS, 0% v.b. These samples were prepared in sequential order from 7.39%, 3.69% to 0% v.b. CDS respectively. Refer to Kingsly et al. (2010) for a detailed analysis of the physical and chemical variability in DDGS due to CDS levels.

To simulate the handling operation of filling and emptying of railcars at an ethanol plant; an equipment was assembled to sequentially sample bulk product being discharged from hoppers. The assembly (Fig. 1) consisted of a conveyor system (Model 2100-32A, C.W. Brabender Instrument Inc., NY), and a filling station similar to a spinning riffler sampler (Charlier and Goossens, 1971). The simulation was designed to accommodate mass (MF) or funnel (FF) flow, from hoppers mounted on a frame which empties into sixteen (16) cups that sit on a rotating table (turn-table) driven by an electric right angle gear motor (Model 1XFY8, Dayton, Burton, MI). The advantages and disadvantages of each flow mode are well documented (Marinelli and Carson, 2001) along with the impact of hopper design, material characteristics and operating conditions (Carson et al., 2008). Each cup was 550 cm^3 in volume and holds about 250 g of DDGS on average. The hoppers were composed of perplex glass cylinder of 30.5 cm diameter that fit into aluminum cones of half angles 36° and 65° for the mass flow and funnel flow hoppers, respectively and discharge diameter of 5.1 cm.

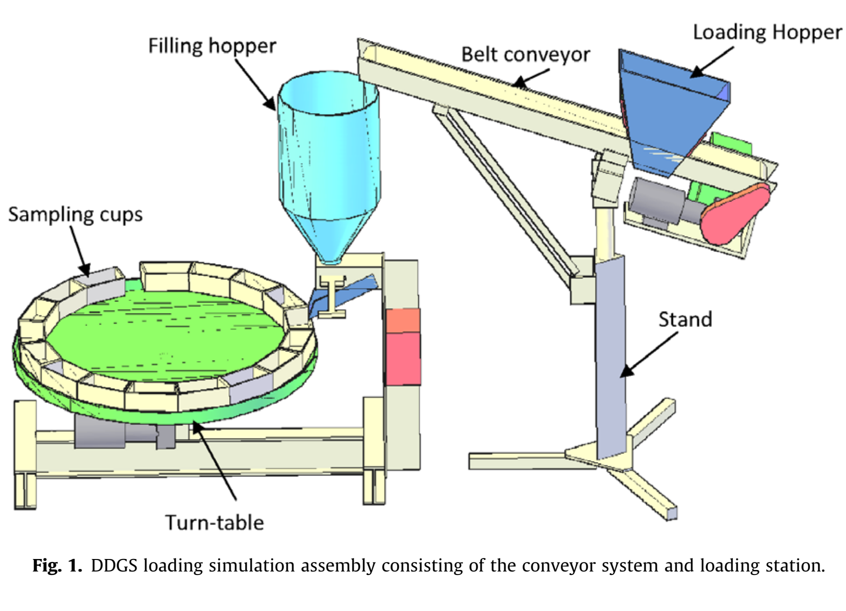

Fig. 1. DDGS loading simulation assembly consisting of the conveyor system and loading station.