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ORIGINAL PAPER

A Laboratory Decanting Procedure to Simulate Whole Stillage Separation in Dry-Grind Corn Ethanol Process

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Abstract In the dry-grind corn ethanol industry, horizontal decanter centrifuges are used to separate the whole stillage into wet grains and thin stillage. The wet grains mixed with condensed thin stillage are dried to form dried distiller's grains with solubles (DDGS). In order to investigate the effect of different corn breaking treatments on increasing oil partitioning in thin stillage, a laboratory method is needed to simulate industrial decanting where a typical thin stillage is produced. The thin stillage obtained using a conventional laboratory centrifuge had much lower solids content and less than one-half of the dry-matter yield compared to the industry counterpart because the conventional laboratory centrifuge and industry decanter centrifuge have different separation mechanisms. By evaluating the properties of industrial thin stillage and the mechanism of industrial decanter centrifugation, a laboratory decanting device was designed and a decanting procedure, the multiple-wash centrifugal filtration (MWCF) method, was developed. This method involves multiple steps of filtration under centrifugal force after washing the solids with the liquid generated from the same mash. Four cycles of MWCF produced a thin stillage with similar solids content (7.3 vs. 7.2%), dry-matter yield (54.2 vs. 54.7%), and wet yield (83.3 vs. 80.6%) compared to industrial thin stillage. The presence of ethanol did not influence the laboratory decanting results, which indicates the application robustness of this laboratory thin stillage preparation method.

Keywords Centrifuge · Corn oil · Decanter · Dry-grind · Filtration · Fuel ethanol · Thin stillage

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Introduction

The corn fuel ethanol industry in the United States has expanded rapidly over the past 8 years. In 2007, about 28 billion L (7.2 billion gal) of corn fuel ethanol was produced, which was more than four times the production in 2000 [1]. Corn fuel ethanol is produced by two processes, the dry-grind process and the wet-milling process. The dry-grind process is the dominant process as about 82% of corn-derived fuel ethanol is produced using this process [1]. In the dry-grind process, the corn kernel is ground, and the resulting ground meal is slurried, cooked, liquefied, and saccharified using enzymes, and then fermented with *Saccharomyces cerevisiae*. After distilling the ethanol from the fermented mash, referred to as finished beer in industry, the residual ethanol-free slurry, called whole stillage, is separated into two fractions by horizontal decanter centrifuge: a solid phase usually referred to as wet grains (or wet distiller's grains) and a liquid fraction with solid content of 7% referred to as thin stillage [2]. While part of the thin stillage is recycled to slurry the corn meal at the beginning of the dry-grind corn ethanol process (it is referred to as backset in industry), the rest is sent to the evaporator to be concentrated into a syrup-like paste called thick stillage, which has about 35% solid content (data from our laboratory). The thick stillage is usually combined with the wet grains and dried to form distiller's dried grains with solubles (DDGS). DDGS is primarily used as cattle feed.

Conversion of starch to ethanol during fermentation concentrates oil content from about 4% (w/w) in original corn to 11–14% (w/w) in the DDGS ([3] and data compiled from our laboratory, communications with industry). The relatively high residual oil in DDGS may interfere with normal milk production in dairy cattle [4] and also lead to pork bellies (bacon) from swine with an undesirably soft texture [Keisei, Suga, Japan Scientific Feeds Association (Japan), personal communication]. Therefore, removal of oil from DDGS will improve its feed quality. More importantly, the recovered oil may be used to produce biodiesel, biolubricants, and other biorenewable materials. It can also be potentially refined to produce edible oil. Assuming 70% of the oil contained in corn can be recovered from all dry-grind corn ethanol plants in the United States, about 2 billion L (440 million gal) of corn oil could be produced annually. Such production is nearly equivalent to the current annual biodiesel production in the United States (production from October 1, 2006 to September 30, 2007, data from the National Biodiesel Board [5]).

It is believed by some industry professionals that recovering oil from post-fermentation (at the tail-end) is more practical and cost-effective because there is no additional germ separation step after initial grinding so no loss of endosperm into the germ fraction, and the oil level is elevated in the final co-product due to the disappearance of starch, making it easier to separate. The oil may be easily recovered by centrifugation or decanting of the liquid phase. Evidence and experience related to front-end and tail-end oil recovery will continue to be gathered as the industry evolves.

In the current industrial operation, about 50% of the total oil goes to the liquid phase (thin stillage) and the remainder to the solids (wet grains or wet distiller's grains) (data from our own laboratory). One strategy to improve the oil recovery from the dry-grind process is to shift oil distribution in the thin stillage by using different methods to break corn kernels (such as grinding, flaking, extrusion, etc.) before fermentation and using enzymatic treatments during or after fermentation. The decanting step is one of the key control points in industry because it determines the amount and the properties of thin stillage and wet grains. In order to accurately quantify corn pretreatment effects on oil partition, a laboratory-scale method that can simulate the industrial decanting process is needed. Accurate simulation of the industrial process is critical in transferring laboratory discoveries to industrial operation.

Limited information is available in the literature on how to produce thin stillage and wet grains on a bench scale as done in the dry-grind corn ethanol fermentation industry. One method involves using a US No. 200 sieve to filter the whole stillage under gravity ([6, 7], and personal communications with the authors). The solids content of such resulting thin stillage was only 2.4–3.6%, and the overall yield was low compared to industry thin stillage. In addition, the results and thin stillage quality were highly variable. No reference was found on how to simulate industry decanting for dry-grind ethanol process. Communications with major dry-grind ethanol production companies confirmed that such a laboratory method is not available and would be highly desirable.

This study was designed to investigate the possibility of developing a bench-scale decanting procedure to simulate industry horizontal decanter centrifuge operation. Such a procedure is critical for investigating the distributions of corn ingredients or contaminants, such as oil, protein, fiber, mycotoxin, mineral elements [8], between thin stillage and wet grains.

Experimental Procedures

Industry Operation Characteristics and Sample Analysis

The decanting parameters, such as temperature, decanter residence time, centrifugal force, and flow rates of whole stillage were collected in a local corn dry-grind fuel ethanol plant with an annual ethanol production capacity of 185 million L (50 million gal). This is considered a typical dry-grind corn ethanol plant [Riley, Joseph P., FEC Solutions (Des Moines, IA), personal communication], so the conditions should be representative of the industry. One sample of ground corn meal was obtained in December 2007, and four batches of finished whole beer, wet grains, and thin stillage were collected at different times from October 2007 to March 2008 when the production was stable. About 100 ppm sodium azide (Sigma Chemical, St. Louis, MO) was added to the liquid samples to prevent microbial spoilage. All samples were kept in a cooler at 5 °C until analysis, and all samples were analyzed within weeks.

Other industry decanting parameters, such as the yields of thin stillage and wet grains, had to be calculated based on the mass balance of the two fractions. Two sets of estimates were calculated. The first one was derived by measuring the solids contents of wet grains, thin stillage, and the original whole stillage. The whole stillage, thin stillage, and wet grains were collected at the same time, i.e., the whole stillage from the inlet and the thin stillage and wet grains from the outlets of the same horizontal decanter within minutes. The three fractions were considered to belong to the same batch of material, and they should follow these relationships:

$$Y_{wg} + Y_{ts} = 100 \quad (1)$$

$$S_{wg} + S_{ts} = S_{ws}, \text{ i.e.,} \quad (2)$$

$$Y_{wg} \times \% \text{ solids}_{wg} + Y_{ts} \times \% \text{ solids}_{ts} = 100 \times \% \text{ solids}_{ws} \quad (3)$$

where $Y = \%$ yield on wet-weight basis, $S =$ solids on dry-weight basis, and the subscripts wg, ts, and ws refer to wet grain, thin stillage, and whole stillage, respectively. The term % solids was the solid content in the material.

The second set of estimates was derived by measuring the flow rates of the whole stillage at the inlet of the decanting units and that of the thin stillage at the outlet of the same decanting units.

The particle size distribution (as volume-weighed diameters of particles in the slurries) was measured using a laser light scattering particle size analyzer (Mastersizer 2000 S, Malvern Instruments, Chicago, IL). A few drops of samples were added to 1,000 mL of deionized water, and the sample was vortexed for 30 s before analysis. The refractive index used for the dispersant was 1.34, chosen according to the instrument manual.

Yields and Compositions of Wet Grains and Thin Stillage

The wet- and dry-matter yields of thin stillage and wet grains were quantified by measuring the wet- and dry-matter weights relative to the original whole stillage. Dry-matter content was obtained by drying an aliquot of sample at 80 °C overnight; oil content was measured using a modified acid-hydrolysis method based on AOAC Official Method 922.06 with the samples digested in the Mojonnier flasks [9]. The oil partition in the thin stillage was calculated from the difference between the oil in the original mash and the oil in the wet grains. Attempts were made to extract oil directly from the thin stillage using both acid hydrolysis and chloroform–methanol methods. It was found that the low oil level (1% or less in the thin stillage) and interference from the thin stillage components (such as soluble acids, sugars, and proteins) prevented accurate quantification (data not shown).

Laboratory Decanting Using a Traditional Centrifuge

This experiment was intended for the identification of an appropriate centrifugal force to produce a thin stillage similar to that from the industry. Since the centrifugal force of industry decanters ranges from 3,000 to 3,5000×g, with an average of about 3,310×g, a series of centrifugation tests with g forces from 400 to 12,500 under the same centrifuge time (1 min) as in industry decanting were carried out. Twenty grams of industrial whole stillage was placed in a 50-mL centrifuge tube at 88 °C (as in typical industry operation), and different centrifugation speeds were applied using a IEC Centra MP4 centrifuge with a fixed-angle rotor 854 (International Equipment, Needham Heights, MA, USA). The wet and dry matter yields, and solids contents of the supernatants (simulated thin stillage) were compared with the industrial thin stillage produced from the same whole stillage.

Construction of the Multiple-Wash Centrifugal Filtration (MWCF) Laboratory Decanting Device

This work was the continuation of the aforementioned experiment after it was found that conventional laboratory centrifuge cannot closely simulate industry decanting (data shown in the "Results and Discussion" section). The MWCF laboratory decanting device is shown in the schematic drawings in Fig. 1. This device has three major parts, a 400-mL wide-mouth centrifuge bottle, a filtration pouch, and a plastic filtration pouch holder (as in A of Fig. 1). The cap was omitted in all the drawings. The filtration pouch was made from one piece of Ombre Rainbow Sheer fabric material (60% nylon and 40% polyester; Spring Creative Products Group, Rock Hill, SC, USA). Two sides of the fabric were sewed together then sealed with flexible glue (Amazing Goop All Purpose Contact Adhesive & Sealant, Eclectic Products, Eugene, OR, USA) to prevent the seams from being torn. The fabric has a pore size of 250 × 280 μm. It was chosen based on our preliminary filtration tests. Because of the flexibility of the fabric, the pouch takes the shape of the holder when samples are added. The dimension of the pouch was 100 × 90 mm (L × W) with an opening on top.

The filtration pouch holder was made of a plastic cup tightly fitted in the mouth of the centrifuge bottle. The bottom section of the holder (designated as the drain chamber) was perforated with 1-mm diameter holes. Two additional rows of holes, which formed a washing liquid drainage channel (Fig. 1a), were drilled near the center of the filtration holder. Detailed dimensions of the centrifuge bottle, filtration pouch holder, and their assembly are shown in Fig. 1b. Figure 1c shows the upside-down orientation of the MWCF decanting device during the "washing" step and the seal between the filtration pouch holder and the centrifuge bottle. When turned upside down after one centrifugation, the washing liquid (supernatant) drains into the washing chamber through the washing liquid drain channel and re-disperses the wet grains that remained in the filtration pouch by mixing.

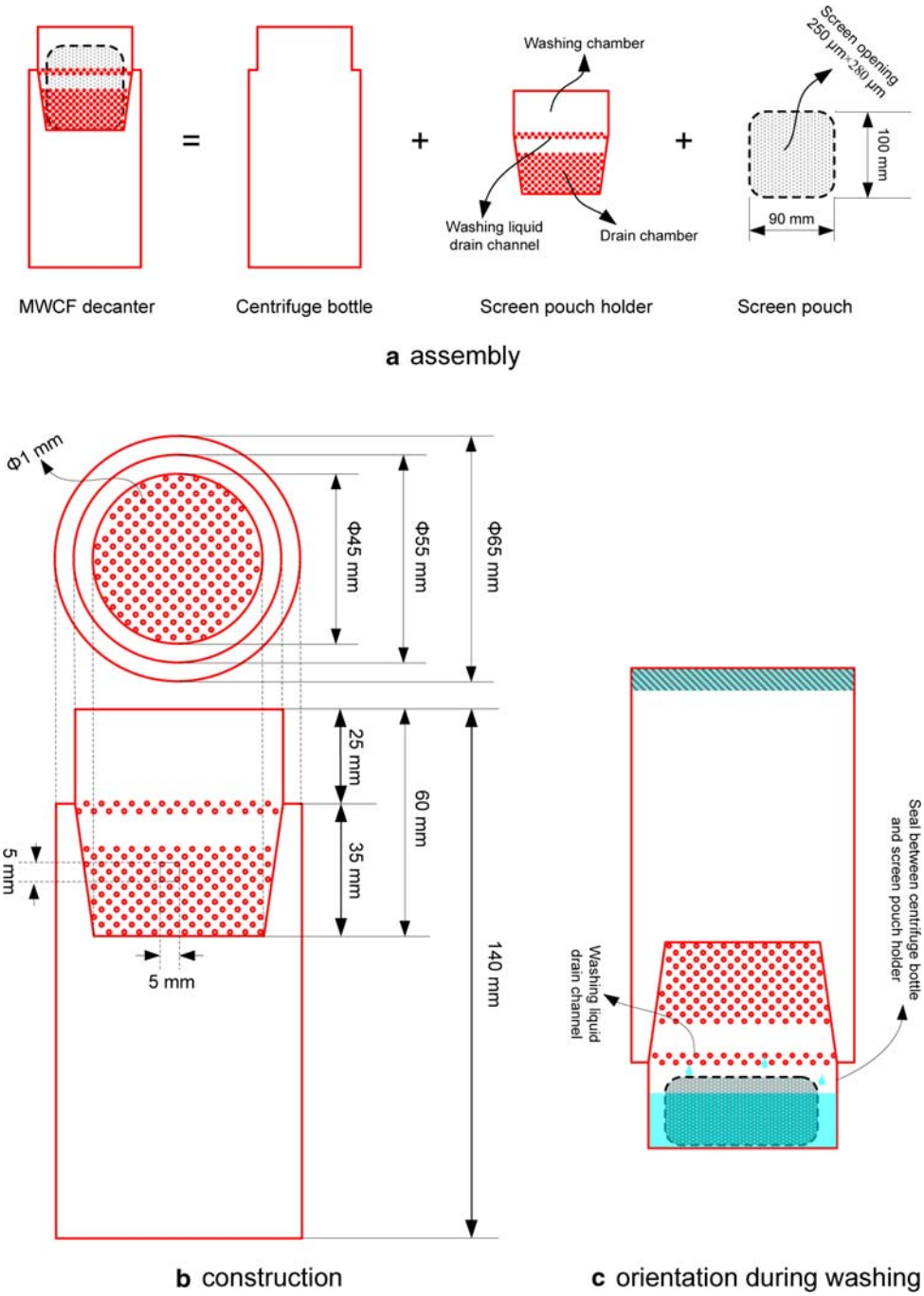

Fig. 1 Assembly and construction of the multiple-wash centrifugal filtration (MWCF) laboratory decanting device

MWCF Laboratory Decanting Procedure

Two identical MWCF laboratory decanting devices were made to be used as a pair with a loading of the same material in a swing-bucket laboratory centrifuge (Avanti J-20 XPI, Beckman Coulter, Fullerton, CA, USA). After the MWCF laboratory decanting device was assembled, about 100 g whole stillage was put into the filtration pouch (Fig. 2). The pouch was closed with a wire tie. The device was centrifuged at 3,000 × *g* at ambient temperature (25 °C) for 2 min. During centrifugation, the liquid, which consisted of water and water-soluble components along with fine solid particles, passed through the filtration pouch fabric and the holes in the filtration pouch holder and accumulated at the bottom of the centrifuge bottle. This fraction was considered "thin stillage," and the dewatered solids remaining inside the filtration pouch were considered "wet grains." After one centrifugal filtration, the wet grains still had a significant amount of fine particles that should have been washed into thin stillage according to the

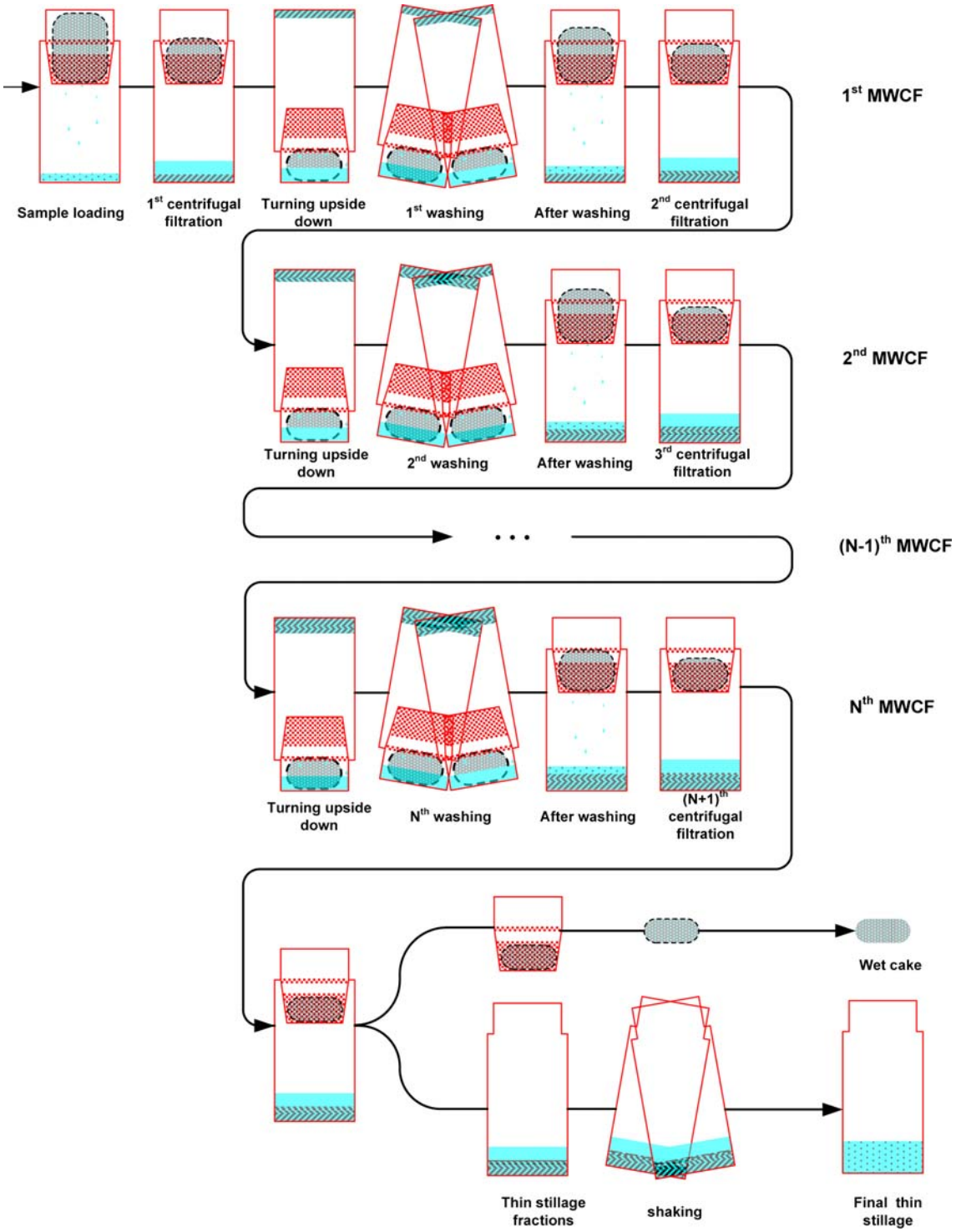

Fig. 2 Illustration of laboratory decanting procedure by the MWCF device

industry decanting mechanism. This is because while centrifugation removed water, it made the wet grains become compact quickly thus trapping a considerable amount of fine particles inside the wet grains. The net result was underestimation of solids in the thin stillage.

In order to release more fine particles, a step of re-dispersing and washing was added. This step was possible without adding additional water because a relatively clear supernatant was generated during the same centrifugal-filtration process after much of the fine solids in "thin

stillage" fraction precipitated and packed at the bottom of the centrifuge bottle. Only the "thin stillage supernatant" was used to wash the wet grains. This was done by turning the MWCF decanting device upside down and letting the thin stillage supernatant flow into the washing chamber to re-disperse the wet grains (Fig. 1c). In order to achieve thorough washing, 1 min of vigorous shaking was applied. Care was taken to shake with same force and frequency for all treatments, and to avoid washing off the thin stillage precipitate at the bottom of the centrifuge bottle although there was 90 mm of clearance between them. After washing, the sample in the device was centrifuged again, and a new layer of fine precipitate formed on top of the first thin stillage precipitate. This process was repeated for multiple cycles until thin stillage with the desired composition was produced. The residual solids in the filtration pouch were the final wet grains and the supernatant and multiple precipitate layers at the bottom of the bottle were mixed thoroughly until a uniform dispersion was formed, which was the final thin stillage (Fig. 2). In this study four cycles of MWCF (4MWCF) were carried out in order to produce similar decanting results as those in industry.

Effect of Ethanol Distillation on Laboratory Decanting

An industrial whole beer was used to test the effect of ethanol distillation on laboratory decanting performance. The ethanol distillation was done with a rotary evaporator (Büchi Rotavapor R-124, Flawil, Switzerland) at 85 °C under vacuum. After ethanol was removed, water was added to bring the solids content of the whole stillage to that of the original beer. The thin stillages from both the ethanol-free whole stillage and the original beer were produced using the 4MWCF laboratory decanting procedure. The wet- and dry-matter yields of each thin stillage, the solids content and the oil partitioning in the thin stillage were quantified as previously described.

Experimental Design and Statistical Analysis

All treatments were randomized and replicated two times except the laboratory MWCF experiment, which was replicated three times. Statistical analysis was performed using the general linear model procedures of SAS 9.1 [10].

Results and Discussion

Industry Operation Characteristics and Sample Analysis

From the first estimation method, i.e., mass balance calculation, the wet yields of thin stillage and wet grains in industrial decanting were 81 and 19%, respectively (Table 1). The values were 80 and 20% using the second estimation method, i.e. flow rate calculation. These two sets of results were very similar; however, since the flow rate measurement was not as accurate as the mass balance method (due to the fluctuations in pumping and decanting), we chose the first set of estimates as the industry decanting parameters.

Other industry operation conditions were either measured directly (such as decanting temperature of 88 °C) or obtained from the production plant, such as the decanting centrifugal force of 3,000–3,500×g and residence time of 1 min.

Laboratory Decanting Using Conventional Centrifuge

No apparent liquid–solid separation was observed when the centrifugal force was below 400×g. When the centrifuge force was increased from 400 to 2,500×g, the mass yield of thin stillage increased from 39 to 60%. However, above the 3,000×g force, the increase in slope reached a plateau. For example, when centrifugal force increased from 2,500 to

Table 1 Comparison of decanting results among the industrial and two laboratory decanting methods

	Solids (%)			Wet-matter yield (%)		Dry-matter yield (%)	
	Thin stillage	Wet grains	Whole stillage	Thin stillage	Wet grains	Thin stillage	Wet grains
Industrial decanting[a]	7.19a	36.19b	12.83a	80.62a	19.38b	45.27a	54.73a
Lab decanting (conventional centrifugation)[b]	5.08b	23.63c	12.63a	59.31b	40.69a	23.17b	76.83a
Laboratory decanting with 4MWCF[c]	7.31a	40.80a	12.59a	83.26a	16.74b	48.35a	54.22a
$LSD_{0.05}$	0.79	1.66	0.56	3.27	3.27	7.12	43.79

LSD Least significant difference

Values with *different letters* in the *same column* are significantly different at $P = 0.05$

[a] Average of four industrial samples collected each month between December 2007 and March 2008 ($n = 4$)

[b] Derived from the conventional laboratory centrifugation regression functions (see Fig. 3.) at the typical industrial centrifuging force of 3,310×g ($n = 1$)

[c] From one batch of industrial whole stillage ($n = 3$)

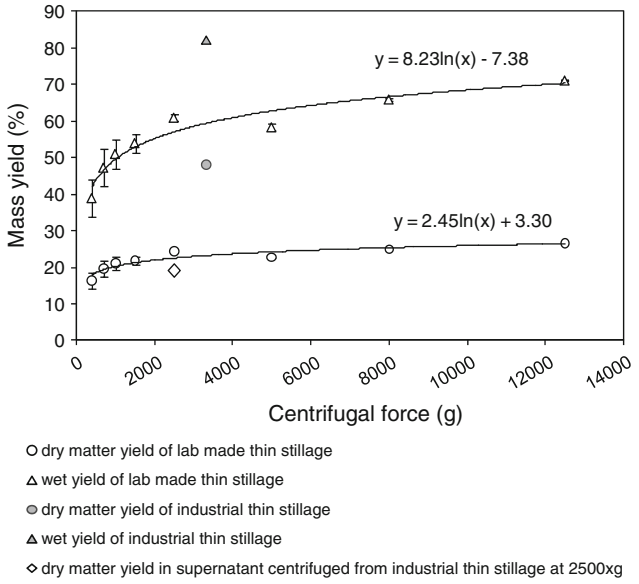

Fig. 3 Wet- and dry-matter yields (%) of thin stillage made by conventional laboratory centrifugation. The *symbols* with *solid fill* are thin stillage yields by industrial decanting with the same whole stillage. The *error bars* represent standard deviation ($n = 2$). *Open circles* dry matter yield of lab made thin stillage, *open triangles* wet yield of lab made thin stillage, *filled circle* dry matter yield of industrial thin stillage, *filled triangle* wet yield of industrial thin stillage, *open diamond* dry matter yield in supernatant centrifuged from industrial thin stillage at 2,500×*g*

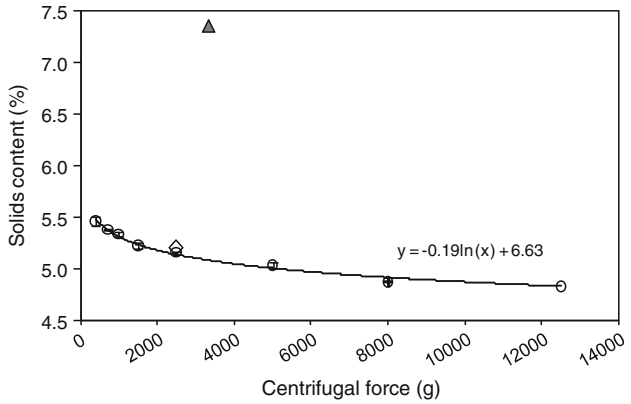

Fig. 4 Solids content of thin stillage produced by laboratory conventional centrifuge. The *filled symbol* is thin stillage solids by industrial decanting with the same whole stillage. *Open circles* solids % of lab thin stillage, *filled triangle* solids % of industrial thin stillage, *open diamond* solids % of supernatant centrifuged from industrial thin stillage at 2,500×*g*

12,500×*g*, the thin stillage wet yield increased only by 10% to about 71% (Fig. 3). The solids content in the thin stillage decreased with increasing centrifugal force. For example, the solids contents in the thin stillage were 5.5, 5.2, and 4.8% at 400, 2,500, and 12,500×*g*, respectively (Fig. 4). These data showed that the solid particles precipitated instantly, even at the low centrifuge force. With increasing centrifugal force, more water with solubles was expelled from the wet grains, and solids content in the "thin stillage" (supernatant) decreased (Fig. 4). The reduction in solids content of thin stillage was apparently due to the settling of fine particles. In order to verify this observation, the industrial thin stillage was centrifuged using the same conventional laboratory centrifuge (Figs. 3, 4). About 60% of the dry matter in the industrial thin stillage was removed using the laboratory centrifuge at 2,500×*g*, and the solids content in the liquid phase was reduced to 5.2 from the original 7.4% (Fig. 4), which was very similar to the sample prepared at the same speed in the lab. This centrifuge speed was chosen simply as a check point. Additional comparisons are presented in Table 1.

To predict properties of thin stillage produced by laboratory centrifuge under the industrial typical *g* force of 3,310, regression was made for the three relationships presented in Figs. 3 and 4. The data fit logarithmic regression the best as shown, and the regression R^2 values were 0.9344 for wet yield, 0.8710 for dry-matter yield, and 0.9885 for solids content. Using these equations, the wet yield, dry-matter yield, and solids content of a thin stillage produced by a 3,310×*g* force would be 59.3, 23.2, and 5.1% as reported in Table 1, which are very different from industry decanting.

Typical industrial thin stillage contains about 7.0–7.5% solids and the wet yield of thin stillage is about 81% (data from our sampling, calculation, and communications with industry personnel). In order to produce thin stillage with similar wet mass yield, higher centrifugal force had to be employed. High centrifugal force, however, removed fine particles that should have remained in thin stillage (Fig. 4). Reducing the sample temperature or increasing the centrifugation time made the discrepancy even worse (data not shown), indicating that conventional laboratory centrifugation cannot simulate industrial decanting.

Further investigations showed that the centrifuge used in industrial decanting is mechanistically different from the conventional laboratory centrifuges. Most dry-grind ethanol plants use a continuous horizontal decanter centrifuge, which consists of a horizontal rotating bowl and a conveyor screw inside. Both the bowl and screw rotate in the same direction but with differential speeds. The wet grains and thin stillage are discharged at the opposite ends of the decanter. According to Keller [11], there are three types of action in a decanting process: sedimentation of the solid particles, conveying of the precipitated solids toward the solids discharge end (beach zone), and dewatering of the solids by the screw.

For a conventional laboratory centrifuge, the dewatering of the precipitate solely relies on centrifugal force. Another difference is that centrifugation by a decanter is a

continuous process in which the liquid and solids fractions move in opposite directions inside the decanter. During the conveying, liquid and solids are blended by the screw-conveyor at high speed, which may act as a mixing and washing process, where more fine particles are released from the wet grains and dispersed into the liquids, and eventually become part of the thin stillage. In a conventional laboratory centrifuge, in contrast, the large solid particles precipitate instantly and pack tightly, trapping the fine particles inside. Therefore, the laboratory centrifuge is not suitable to simulate industrial decanting because of the different separation mechanisms. A new method has to be developed for laboratory simulation.

Development of a New Laboratory Decanting Device and Procedure

The particle size distribution profile shows that the majority of fine particles remaining in industrial thin stillage had particle sizes ranging from 1 to 100 μm with the highest concentration at about 9 μm, while the majority of the larger particles remained in wet grains (Fig. 5). Efforts were made to find a screen material with proper openings that could produce a filtrate similar to the industrial thin stillage. A fabric, Ombre Rainbow Sheer (with rectangular openings of 250 × 280 μm), was eventually chosen. Through this fabric, the majority of the particles in thin stillage passed, but particles larger than 400 μm did not, as shown by the particle size distribution of filtrate of thin stillage (Fig. 6). When filtered through this fabric, the filtrate from an industrial whole stillage had a similar particle size profile as the industry thin stillage produced from the same whole stillage, except that the filtrate had a higher concentration of particles with a diameter of 100 μm than that of industry thin stillage. Nevertheless, these particles seem only to account for a small portion of the total particles in thin stillage.

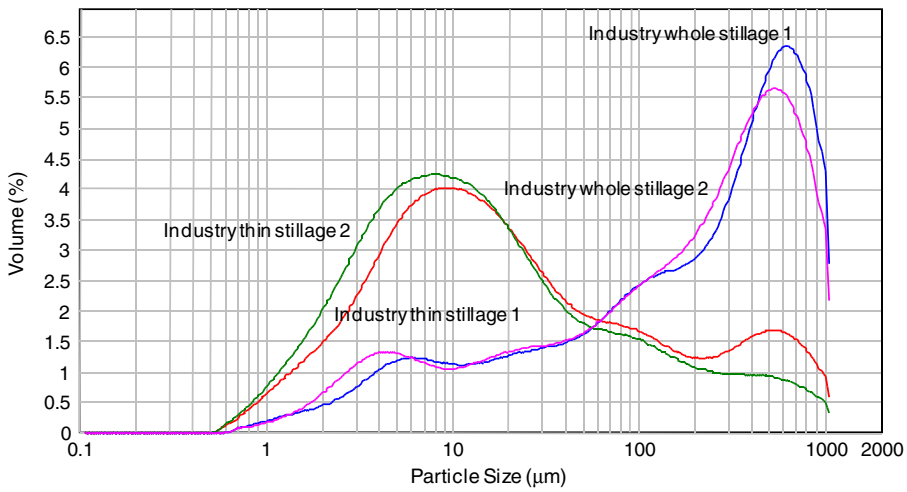

Fig. 5 Particle size distribution profiles of industrial thin stillage and whole stillage (industry thin stillages 1 and 2 were produced from industry whole stillages 1 and 2, respectively)

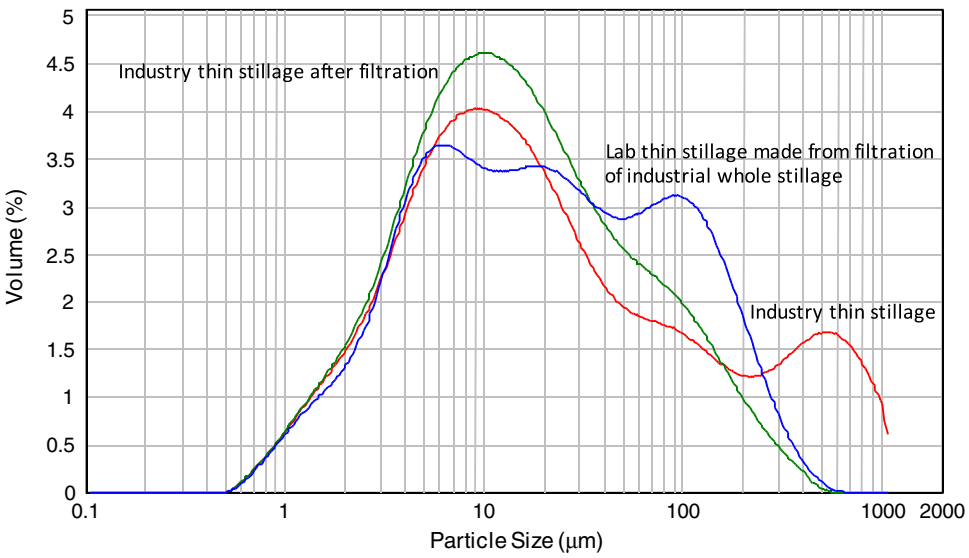

Fig. 6 Particle size distribution of the filtrates of industrial thin stillage and whole stillage filtered through the fabric used to construct the filtration pouch for the MWCF device

Although filtering with this fabric can produce an acceptable thin stillage compared to industrial practice, its wet mass yield was only a fraction of that of industrial practice if the filtration was done under gravity or manual squeezing because the wet grains still held a considerable amount of liquid. Vacuum was applied but the results were not acceptable. Filtration under centrifugal force with this screen, on the other hand, showed promising results, thus a centrifugal-filtration device was designed. With this device the mass yield of thin stillage was dramatically increased. After centrifugal filtration, the whole stillage was separated into three fractions: the wet grains in the filtration pouch, the precipitate at the bottom of centrifuge bottle, and the supernatant above the precipitate. After vigorous shaking, the supernatant and precipitate formed a slurry with a uniform appearance similar to the industry thin stillage. However, the solids content in this thin stillage and mass yield were still lower than those of industry thin stillage if the procedure was done just once. Since the whole stillage was under constant mixing inside the spinning bowl of the industry decanter centrifuge during decanting process, we used the supernatant of the thin stillage to wash the wet grains inside the filtration pouch and then ran another centrifugal filtration. The net result was that more fine particles were washed into the thin stillage fraction (Figs. 1, 2). Multiple washes were used until the thin stillage yield and solids content were similar to those of industry process. Thus, the process was referred to as multiple-wash centrifugal filtration (MWCF).

Figure 7 shows the effect of wash cycle on the solids content and wet- and dry-matter yields of the thin stillage. After four washings, a thin stillage with a solids content of 7.3%, a wet yield of 83.3%, and a dry-matter yield of 48.4% was produced from an industry whole stillage. It is comparable to the industry thin stillage from the same whole stillage (7.2, 80.6, and 45.3%, respectively).

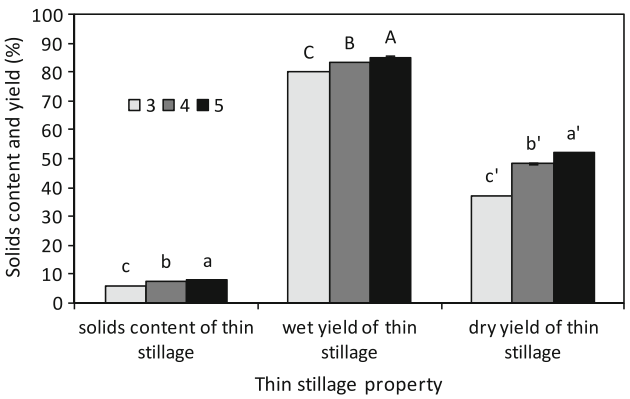

Fig. 7 The effect of MWCF washing cycle (3, 4, 5 cycles) on wet and dry matter yields and solids contents of the thin stillage ($n = 2$). *Bars* followed by *different letters* are significantly different at $P = 0.05$. The *error bars* represent standard deviations

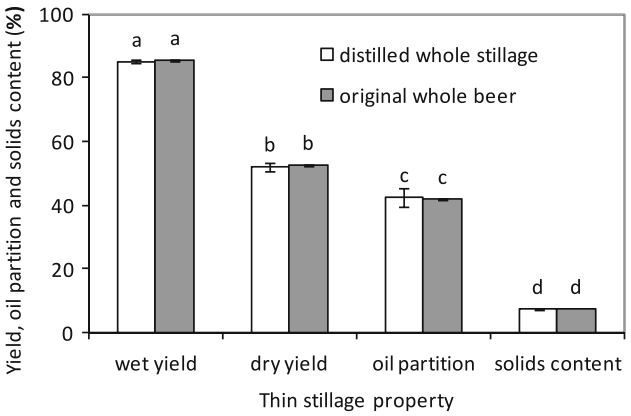

Fig. 8 Effect of ethanol distillation on laboratory decanting ($n = 2$) performance. *Bars* followed by *same letters* are not significantly different at $P = 0.05$. The *error bars* represent standard deviations

Therefore, we have demonstrated that laboratory MWCF decanting can produce thin stillage similar to industry decanting.

Effect of Ethanol Distillation on Laboratory Decanting

In industry, the decanting is applied after ethanol is removed from the whole beer by distillation. Inside a distillation column, the whole beer descends through a stack of trays from the top to the bottom of the column, while the ethanol vapor rises from the bottom to top. A temperature gradient forms inside the distillation column with 88 °C at the top and 34 °C at the bottom. Ethanol distillation simulation with great accuracy on a bench scale with a small amount of materials (such as 1.5 L of fermented beer) is difficult. Some researchers have heated the whole beer in a fume hood at 85–90 °C for 2–3 h to evaporate ethanol [6, 7, 12], but it is difficult to produce a whole stillage with the same solids content as in industry. Since the overall goal of our research was to investigate oil distribution in thin stillage after fermentation, the distillation step may be omitted if it does not affect the decanting and oil distribution with the laboratory procedures. The results (Fig. 8) show that ethanol in the whole beer did not influence the yields, solids contents, and oil distribution of the thin stillage. Thus, we chose not to remove ethanol before laboratory decanting. It saves time and potentially reduces the data variations. The good reproducibility of the decanting results in another study [1, 13] using the same device and procedure developed in this study demonstrates the robustness of this method.

Conclusion

In summary, we have designed a device and developed a laboratory procedure to produce wet grains and thin stillage similar to those from industrial corn dry-grind fuel ethanol

process. Using this device and procedure, we have produced a thin stillage with similar solids content (7.3 vs. 7.2%), dry-matter yield (54.2 vs. 54.7%), and wet yield (83.3 vs. 80.6%) compared to industrial thin stillage. This device and procedure successfully simulated the industry decanting using a horizontal decanter centrifuge. Although this method was designed for research projects related to the corn dry-grind fuel ethanol fermentation process, it has the potential to be used in other applications where there is a need to separate solids and liquid. By using a filtration pouch with different opening sizes and by increasing the washing cycles, separation and exhaustive fractionation of the solids based on the particle size are possible. Therefore, the concept of MWCF may have other significant applications.

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