December, 2009

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Bioresource Technology 100 (2009) 6550–6558

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Modeling the effects of pelleting on the logistics of distillers grains shipping

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ARTICLE INFO

Article history:
Received 27 March 2009
Received in revised form 16 July 2009
Accepted 18 July 2009
Available online 14 August 2009

Keywords:
Biofuels
DDGS
Distillers grains
Logistics
Simulation

ABSTRACT

The energy security needs of energy importing nations continue to escalate. It is clear that biofuels can help meet some of the increasing need for energy. Theoretically, these can be produced from a variety of biological materials, including agricultural residues (such as corn stover and wheat straw), perennial grasses, legumes, algae, and other biological materials. Currently, however, the most heavily utilized material is corn starch. Industrial fuel ethanol production in the US primarily uses corn, because it is readily converted into fuel at a relatively low cost compared to other biomass sources. The production of corn-based ethanol in the US is dramatically increasing. As the industry continues to grow, the amount of byproducts and coproducts also increases. At the moment, the nonfermentable residues (which are dried and sold as distillers dried grains with solubles – DDGS) are utilized only as livestock feed. The sale of coproducts provides ethanol processors with a substantial revenue source and significantly increases the profitability of the production process. Even though these materials are used to feed animals in local markets, as the size and scope of the industry continues to grow, the need to ship large quantities of coproducts grows as well. This includes both domestic as well as international transportation. Value-added processing options offer the potential to increase the sustainability of each ethanol plant, and thus the industry overall. However, implementation of new technologies will be dependent upon how their costs interact with current processing costs and the logistics of coproduct deliveries. The objective of this study was to examine some of these issues by developing a computer model to determine potential cost ramifications of using various alternative technologies during ethanol processing. This paper focuses specifically on adding a densification unit operation (i.e., pelleting) to produce value-added DDGS at a fuel ethanol manufacturing plant. We have examined the economic implications of pelleting DDGS for varying DDGS production rates (100–1000 tons/d) and pelleting rates (0–100%), for a series of DDGS sales prices ($50–$200/ton). As the proportion of pelleting increases, the cost of transporting DDGS to distant markets drastically declines, because the rail cars can be filled to capacity. For example, at a DDGS sales price of $50/ton, 100% pelleting will reduce shipping costs (both direct and indirect) by 89% compared to shipping the DDGS in bulk form (i.e., no pelleting), whereas at a DDGS sales price of $200/ton, it will reduce costs by over 96%. It is clear that the sustainability of the ethanol industry can be improved by implementing pelleting technology for the coproducts, especially at those plants that ship their DDGS via rail.

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1. Introduction

The increasing cost of nonrenewable fossil fuels and the potential decline in their supply in coming years have been an increasing focus for many energy-dependent nations in recent years, including the US. There are two primary ways to approach these challenges: reducing energy dependency, and/or developing alternative methods of energy production (RFA, 2008).

Utilizing biofuels, which are renewable sources of energy, is a promising alternative for producing energy, and can be done in a relatively efficient manner, depending upon the conversion technologies that are employed. There is a variety of biomass materials that may be used to produce biofuels (i.e., residue straw, corn stover, perennial grasses, legumes, MSW, biological wastes, and other agricultural and biological materials). Currently, the most heavily utilized material in the US is corn starch, since fuel ethanol production from corn can be accomplished very efficiently and at a relatively low cost compared to other biomass sources. In fact, corn starch is currently the only biological material that can be economically converted into ethanol on an industrial scale.

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0960-8524/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.biortech.2009.07.051

The number of corn ethanol plants has been markedly increasing in recent years. For example, in 2005, 87 manufacturing plants in the US had an aggregate production capacity of 13.46 billion L/y (3.56 billion gal/y). At the beginning of 2009, however, that number had risen to over 193 plants with a production capacity of nearly 46.86 billion L/y (12.38 billion gal/y) (RFA, 2009), which is an increase of nearly 350% in just four years. As the ethanol market segment continues to grow, so have the quantities of processing residues, or coproducts, which are generated from this industry. In 2008, approximately 23 million metric tons of coproducts were produced.

In-depth details on ethanol manufacturing, which are beyond the scope of this paper, can be found in (Bothast and Schlicher, 2005; Dien et al., 2003; Jaques et al., 2003; Maisch, 2003; Tibelius, 1996; Weigel et al., 2005). Briefly, there are mainly two techniques for producing fuel ethanol using corn grain: (1) wet mill processing and (2) dry grind processing. Wet mill processing tends to be highly capital and resource intensive, whereas dry grind processing has significantly lower capital and operational requirements. Therefore, dry grind processing has rapidly gained prevalence in the industry; in fact, in 2007 it accounted for 82% of the entire industry (RFA, 2008).

The dry grind production process (Fig. 1) consists of several key steps, including grinding, cooking, liquefying, saccharifying, fermenting, and distilling. Typically ethanol is the primary end product of this process along with two byproducts: residual nonfermentable corn kernel components and carbon dioxide. The nonfermentable kernel components (i.e., corn protein, fiber, and oil) are usually further processed (Fig. 2) and then marketed in the form of distillers dried grains with solubles (DDGS), and to a lesser degree in the form of distillers dried grains (DDG), which do not contain added solubles, distillers wet grains (DWG), and condensed distillers solubles (CDS). Hereafter "distillers grains" will be used in a generic sense to refer to all of these byproduct materials.

Residue streams are separated from the ethanol during distillation. They are often dried to approximately 10% moisture content, to ensure a long shelf life and facilitate transportation, and are then sold as distillers grains (most often DDGS or DDG) to local livestock producers or shipped via rail to livestock feed markets throughout North America, and they are increasingly being exported to overseas destinations as well.

Feeding distillers grains to animals is a viable method for utilizing these coproducts because they contain high nutrient levels. Over the years, numerous research studies have investigated use as livestock feed, including beef (Al-Suwaiegh et al., 2002; Firkins et al., 1985; Ham et al., 1994; Lodge et al., 1997; Peter et al., 2000), dairy (Hippen et al., 2004; Kalscheur et al., 2004; Nichols et al., 1998; Powers et al., 1995; Schingoethe et al., 1999), swine (Cromwell et al., 1993; Gralapp et al., 2002; Noblet et al., 1994; Shurson et al., 2004; Whitney and Shurson, 2004), and poultry diets (Ergul et al., 2003; Lumpkins et al., 2003; Noll et al., 2002; Parsons et al., 1983; Roberson, 2003), to name a few. Aines et al. (1986) and UMN (2009) provide comprehensive reviews of much of this research.

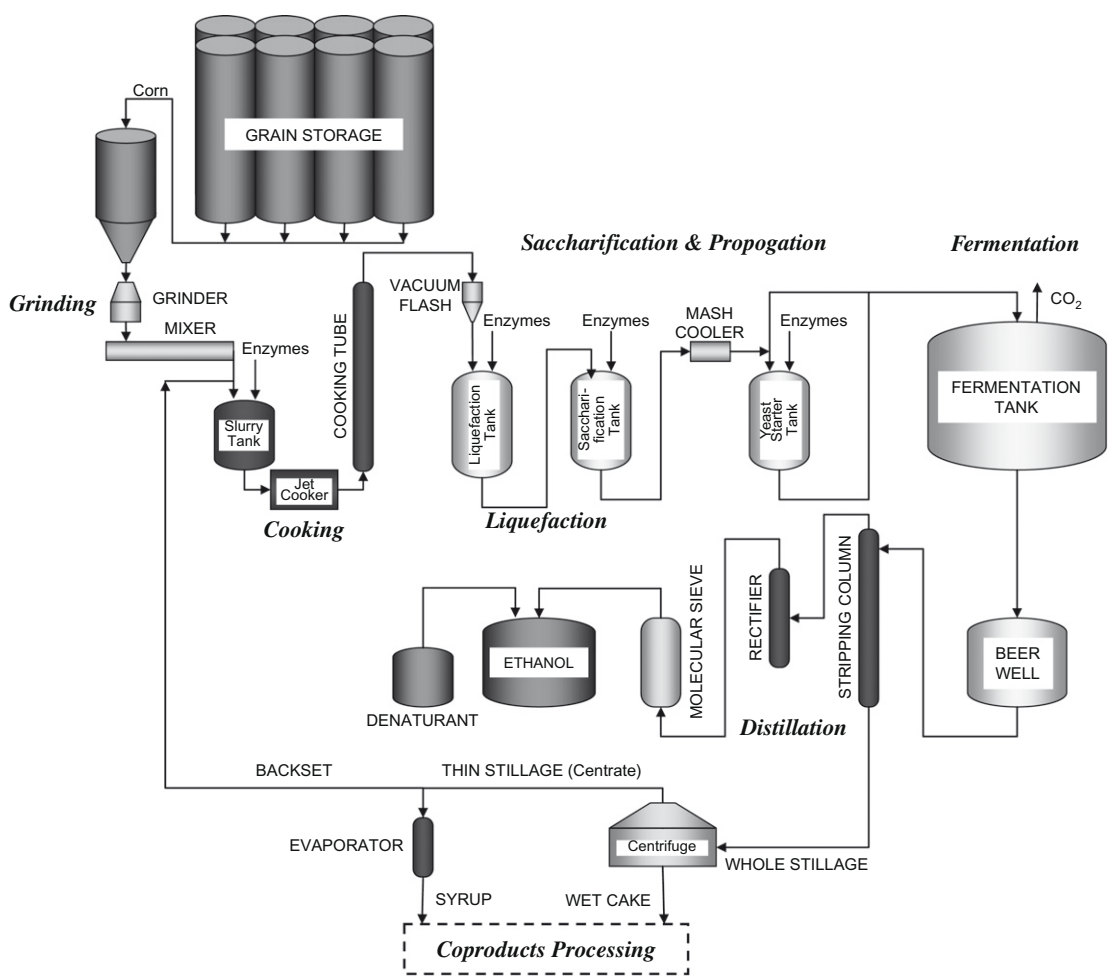

Fig. 1. Process flowchart for typical corn dry grind fuel ethanol production steps.

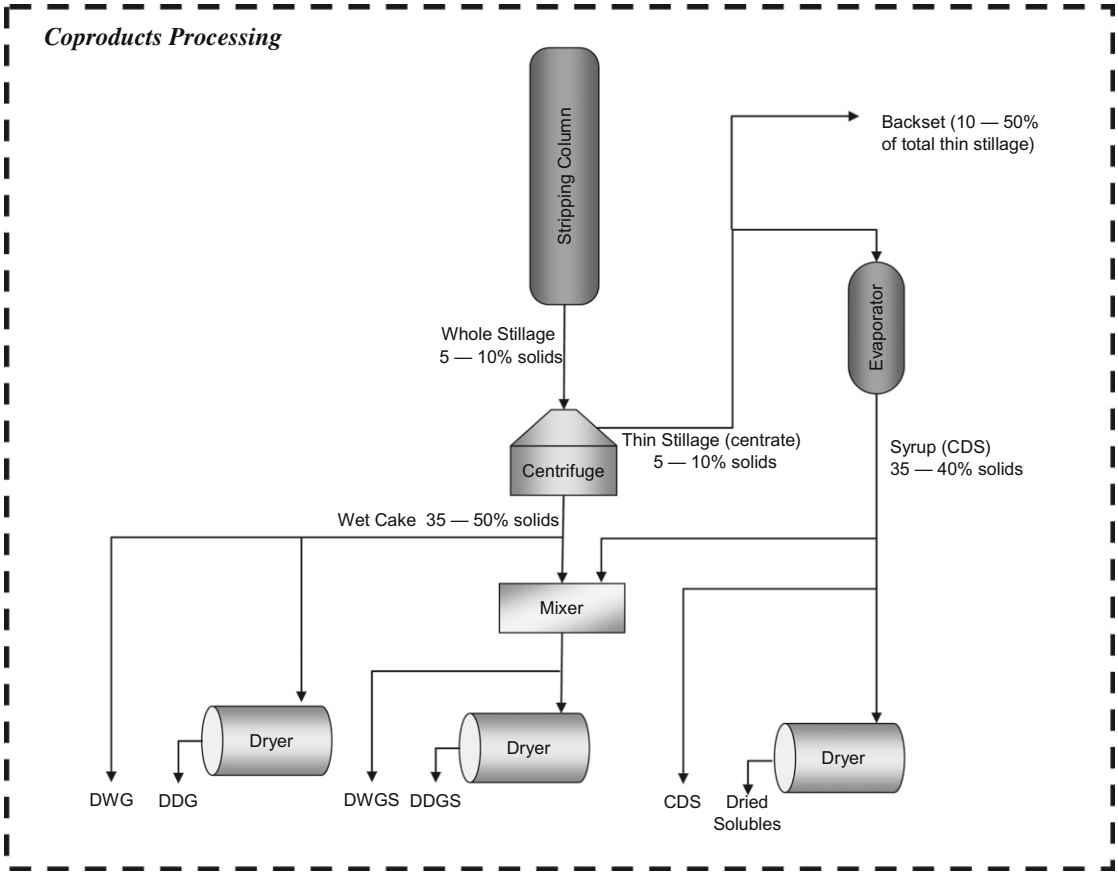

Fig. 2. Process flowchart for typical corn ethanol coproducts processing steps.

The sale of distillers grains contributes substantially to the economic viability of ethanol manufacturing (generally between 10% and 40% of an ethanol plant's entire revenue stream, depending upon DDGS sales price (Fig. 3) – which historically has been bracketed between $50/ton and $200/ton, corn feedstock price, natural gas price, and other market conditions), and is thus a vital component to each plant's operations. Because of the dynamics of the free market economy under which this industry operates, the quantity of processing residues that will be produced as this industry continues to grow (and the ability to sell and utilize them) will significantly impact the future of the industry.

DDGS is a dry, granular bulk material, often with particle sizes less than 1.0 mm in diameter. Water activity values are often below 0.5, thermal conductivity is near 0.7 W/m °C, and angle of repose can range from nearly 25° to 35° (Rosentrater, 2006b). Protein content of DDGS often varies between 26% and 34% (db), fat can

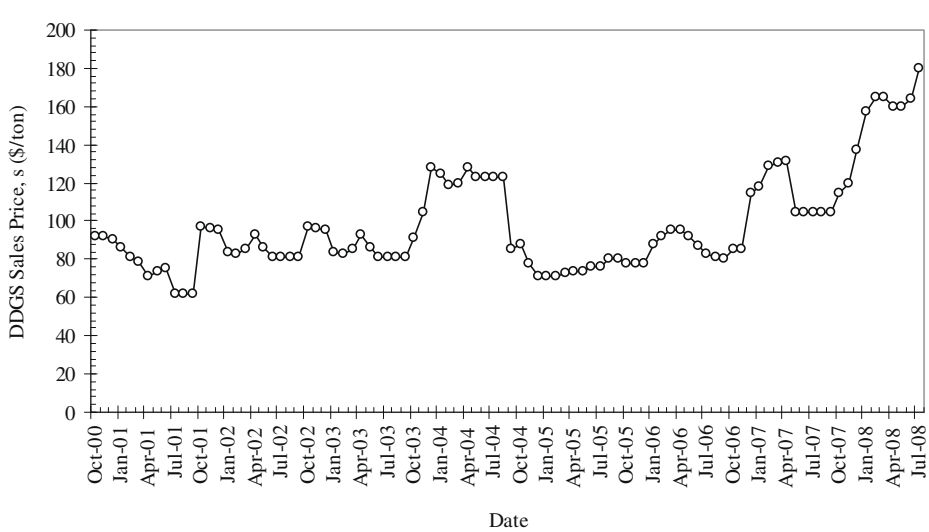

Fig. 3. Monthly DDGS sales price between October 2002 and July 2008 (based on USDA ERS, 2008).

range from 3% to 13% (db), neutral detergent fiber (NDF) can vary between 25% and 50% (db), and ash can range from 2% to 10% (db) (Rosentrater and Muthukumarappan, 2006).

There are a host of issues surrounding the value and utilization of distillers grains, both from the ethanol production standpoint, and from a livestock feeding perspective (Rosentrater, 2007b; Saunders and Rosentrater, 2009). Some of the most pressing include the large quantities of energy required to remove water, coupled with the high cost of energy; moving DDGS to diverse and distant markets (i.e., shipping via rail) when there are fluctuations in supply and demand; variability in nutrient content, quality, and associated quality management programs – all of which ultimately impact the end users; how to avoid mycotoxin contamination; inconsistent product identity and nomenclature; and international marketing and export challenges. These are discussed in more depth by (Rausch and Belyea, 2006; Rosentrater and Giglio, 2005; Rosentrater, 2006a; UMN, 2009).

Over the years, a persistent barrier to effective utilization of distillers grains is product storability and flowability, because it directly impacts the ability to ship DDGS (Ganesan et al., 2008c; Rosentrater, 2007b). This coproduct is a granular, powder-like material that consists of a range of particle sizes and shapes. DDGS is typically shipped in trains and trucks throughout the US to be used for animal feed. However, DDGS is often difficult to unload once the vessel reaches destination, because the particles lock together and have flowability problems. This necessitates manual unloading processes, which create substantial financial burdens for the ethanol manufacturer. This flowability problem is resulting in serious economic implications for ethanol plants (e.g., sledgehammers, shovels, and pick axes must be used to get the DDGS to discharge). These economic losses include rail car repairs (due to damage), and labor expenses. Remediating this flowability problem has been the subject of considerable research (Ganesan et al., 2007, 2008a,b,c,d, 2009).

Another issue with the transportation of DDGS revolves around capacity (i.e., weight vs. volume) of each car. Railcars or trucks containing DDGS are filled to volumetric capacity for shipping, but are often not at maximum allowable weight, due to the low bulk density of the granular material itself (approximately 30 lb/ft^3 [480 kg/m^3]) – this wasted capacity thus causes additional potential economic loss to the ethanol manufacturer.

Consequently, there exists a critical need to modify the DDGS that is currently produced in the industry (and inherently the processes which are used to produce the DDGS), or to alter the storage and transportation systems for these products in order to alleviate DDGS flowability problems. One way to do this is by altering the physical form of the DDGS itself. Pelleting is a manufacturing process that is commonly used to densify and improve the value of granular materials (Rosentrater, 2005). Rosentrater (2007a) has proven that this process is both feasible and appropriate for DDGS, and can be accomplished using conventional feed milling equipment. In fact, pelleting of DDGS (Fig. 4) could be readily implemented in existing ethanol plants, and would simultaneously overcome the flowability problem, as well as allow shipping vessels to be filled to both weight and volumetric capacity simultaneously. Ultimately, however, the adoption of this technology is contingent upon price ramifications to the ethanol plant. Costs associated with pelleting of DDGS have not yet been thoroughly explored. Indeed, the cost-effectiveness of pelleting DDGS versus current industrial practice, which is to ship DDGS as-is (i.e., in granular bulk form) must be investigated.

In order to help answer these questions, a computer model was developed and implemented to examine the economic implications of pelleting DDGS for varying DDGS production and pelleting rates, for a series of DDGS sales prices. The rest of this paper is organized as follows: After the Introduction, the Materials and Methods section will present the industrial processing scenario which has been modeled, the algorithm used to develop the model, specific independent and dependent variables used in the model, and implementation of the algorithm; the Results and Discussion

Table 1
Equipment listing for proposed pelleting option.

Item	Description	Item	Description
001	Conveyor	008	Pellet mill
002	Bucket elevator	009	Cooler
003	Scale/surge bin	010	Conveyor
004	Vibrator	011	Bucket elevator
005	Gate	012	Scale/surge bin
006	Conveyor	013	Gate
007	Conditioner		

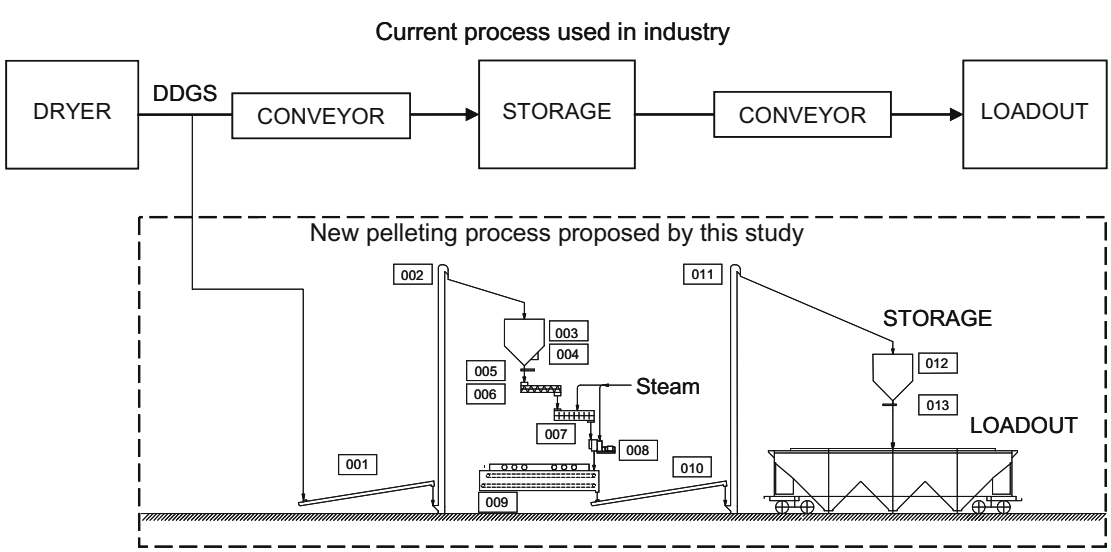

Fig. 4. Proposed flowchart for DDGS processing augmented by pelleting.

Table 2
Total annualized capital and operational costs of pellet processing.

g (tons)	Co_p (\$/ton)	g (tons)	Co_p (\$/ton)
100	1.4700	600	1.1025
200	1.3965	700	1.0290
300	1.3230	800	0.9555
400	1.2495	900	0.8820
500	1.1760	1000	0.8085

Table 3
Shipping cost data.

Variable	Description	Value
x	DDGS shipping cost per rail car	\$4,800/car
y	Maximum volumetric capacity per rail car	6,350 ft^3/car
wt	Maximum theoretical weight per rail car	109 ton/car
s	DDGS sales price	Variable, \$/ton
t	Train capacity	10,464 tons
rt	Maximum cars/unit train	96-cars

section will present the impacts of pelleting rate, DDGS generation rate, and DDGS sales price on the wasted space for each rail car, and thus each unit train, as well as the pelleting levels which result in breakeven points; finally, the Conclusions section will summarize the key findings of the study and discuss potential future work.

2. Methods

2.1. Processing scenario

Typically, ethanol production facilities directly store DDGS after it is discharged from the dryer, and then load it onto train cars for shipping after the product has cooled sufficiently. Our contention is that value-added processing, such as pelleting, could be added as an additional step prior to loading out the DDGS (Fig. 4; Table 1). The best location for this would probably be either immediately after exiting the dryers, or after storage, which would give the DDGS time to cool (i.e., cure).

2.2. Algorithm development

When developing the algorithms, relevant independent variables were selected to model each step of the process; the values for each of these were based upon data available for a range of current ethanol processing facilities. Both dependent and independent variables were embedded into the computer model as follows.

2.2.1. Independent variables

Daily DDGS generation rate, g (tons/day), was selected to be:

$$g = 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 \quad (1)$$

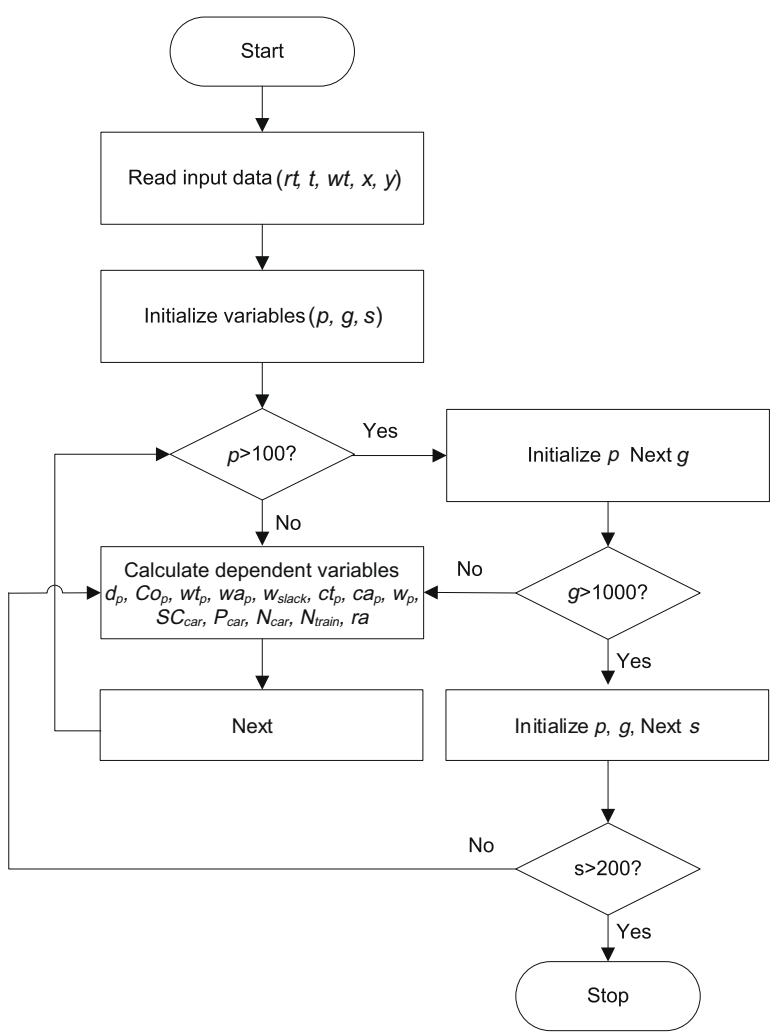

Fig. 5. Flow chart of algorithm used to develop model.

Roughly speaking, these rates are appropriate estimates for fuel ethanol plants of processing capacities up to 150 million gallon per year.

Data for the percentage of DDGS pelleted, p (%), are given as:

$$p = 0, 25, 50, 75, 100 \tag{2}$$

These percentages accommodate no pelleting up to completely pelleted DDGS at the ethanol plant.

2.2.2. Dependent variables

Based on data gathered by previous work (Rosentrater, 2007a), it can be assumed that bulk density of p percent pelleted DDGS, d_p (tons/ft^3), can be defined as:

$$\begin{aligned} d_0 &= 30\ \text{lb/ft}^3 = 0.0134\ \text{tons/ft}^3 \\ d_{25} &= 32.5\ \text{lb/ft}^3 = 0.0145\ \text{tons/ft}^3 \\ d_{50} &= 35\ \text{lb/ft}^3 = 0.0156\ \text{tons/ft}^3 \\ d_{75} &= 37.5\ \text{lb/ft}^3 = 0.0167\ \text{tons/ft}^3 \\ d_{100} &= 40\ \text{lb/ft}^3 = 0.0179\ \text{tons/ft}^3 \end{aligned} \tag{3}$$

Daily pelleted quantity, pq (ton/day), can thus be calculated as:

$$pq = g * p \tag{4}$$

Based on information provided by a commercial pellet mill manufacturer (data unpublished), the total cost of pellet processing can be assumed to follow Table 2.

Relevant transportation variables along with their corresponding descriptions and values are provided in Table 3. This information was based on actual data provided by a commercial fuel ethanol plant (data unpublished). According to the data provided in Table 2, the actual rail car weight when filled according to *per percent* pelleted DDGS (wa_p) can be expressed mathematically as (ton/car):

$$Wa_p = y * d_p \tag{5}$$

Theoretical shipping cost of *per percent* pelleted DDGS (Ct_p) can be given as ($/ton):

$$Ct_p = x/wt_p \tag{6}$$

while actual shipping cost of *per percent* pelleted DDGS (Ca_p) ($/ton) is:

$$Ca_p = x/wa_p \tag{7}$$

Hence, slack (i.e., unused) capacity (w_p) can be calculated as ($/ton):

$$W_p = Ca_p - Ct_p \tag{8}$$

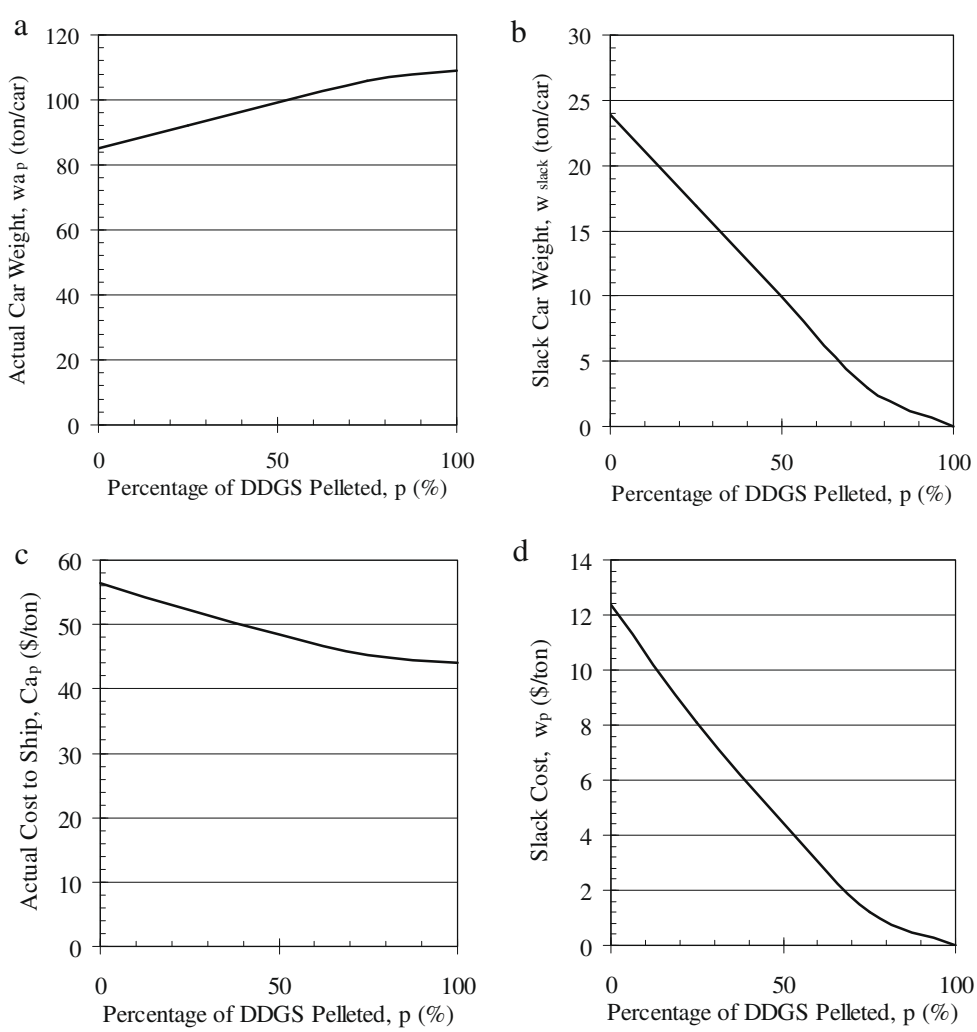

Fig. 6. The amount of DDGS that is pelleted influences the economics of shipping. As the percentage increases, (a) actual car weight (tons/car) increases because (b) slack car weight (tons/car) (i.e., wasted capacity) decreases, which leads to (c) a decrease in actual cost to ship ($/ton) and thus (d) the slack cost of shipping ($/ton) (i.e., cost of wasted space) decreases. In fact, when all of the DDGS is pelleted, there will be no wasted capacity, and thus minimized shipping costs.

Depending on Eq. (8), the total slack cost per car (SC_{car}) can be calculated as ($/car):

$$SC_{car} = s(wt - wa_p) + w_p(wt - wa_p) \quad (9)$$

where w_p is the shipping expense for unused space in the rail car ($/ton).

Pelleting cost per car (P_{car}) and net cost per car (N_{car}) be calculated as ($/car):

$$P_{car} = (Co_p - wa_p.p/100) \quad (10)$$

$$N_{car} = SC_{car} + P_{car} \quad (11)$$

The theoretical number of cars required for a given daily DDGS production rate (rt) can be given as (cars):

$$rt = |t/wt| \quad (12)$$

where function $|\cdot|$ returns the nearest larger integer, as partially-filled cars cannot be shipped in reality. The actual number of cars (ra) can be expressed mathematically as (cars):

$$ra = |t/wa_p| \quad (13)$$

2.3. Algorithm Implementation

Fig. 5 shows a flow chart which depicts all of the steps of the proposed algorithm. All of the algorithm's equations were programmed into an electronic spreadsheet (Excel v. 2003, Microsoft Corporation, Redmond, WA). Then the model was run to simulate the effects of pelleting, reflecting actual market conditions, for DDGS sales price between 50 and 200 $/ton.

3. Results and discussions

The impacts of pelleting on the logistics of each rail car are depicted in Fig. 6. As indicated, compared to the baseline case (i.e., shipping DDGS as-is, with 0% pelleting), all scenarios that involve pelleting have improved shipping performance. And, as the percentage of DDGS which is pelleted increases, each performance indicator improves as well. For example, actual rail car weights (Fig. 6a) increase (and thus the slack weights (Fig. 6b) decrease) as the percentage of DDGS which is pelleted increases. At 0% pelleted, each actual car weight was determined to be 85.09 ton/car; at 100% pelleted, however, each car weight was determined to be 109 ton/car (this was a 28.1% increase). Thus the slack weight for each car was 23.91 ton/car at 0% pelleted, whereas it was 0 ton/car at 100% pelleted (which is a 100% decrease). This behavior arises due to the increase in bulk density as the fraction of the DDGS which is pelleted increases, and large decreases in shipping costs are observed (due to weight versus capacity for each car). And, the least shipping costs are produced (Fig. 6c) when 100% of the DDGS is pelleted. Thus, slack cost (Fig. 6d) is minimized when 100% of the DDGS is pelleted. At 0% pelleted, the actual cost to ship

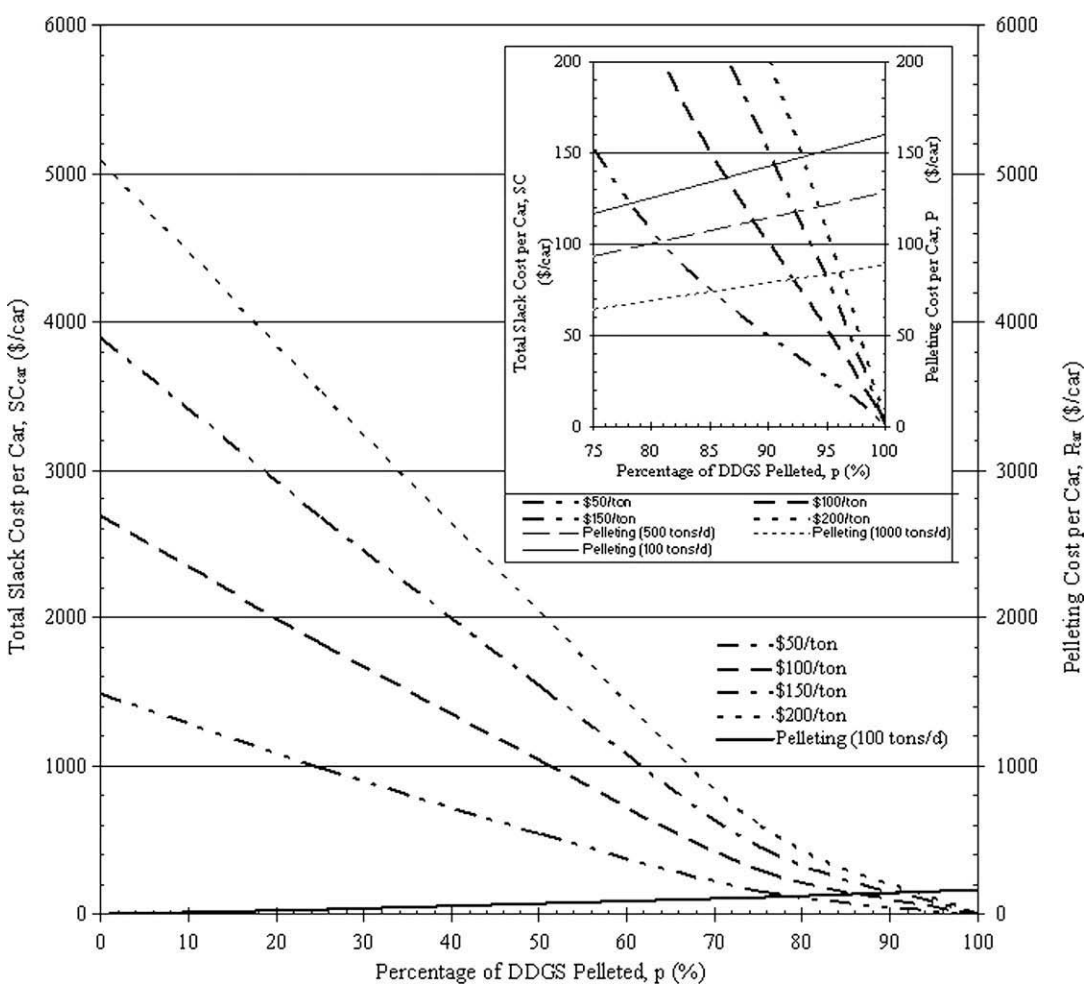

Fig. 7. Pelleting of DDGS improves product flowability, and it is also economically feasible. For all DDGS sales prices, as the quantity of DDGS pelleted increases, the slack cost for each car decreases, but the cost of pelleting increases. Breakeven points are where these lines intersect. Breakeven points exist for all production scales. The inset shows the breakeven points more clearly. The economies of scale (due to DDGS generation rate) have a strong influence on what level of pelleting is best. Note that for a given DDGS generation rate, as the DDGS sales prices increases, the optimal level of pelleting increases as well.

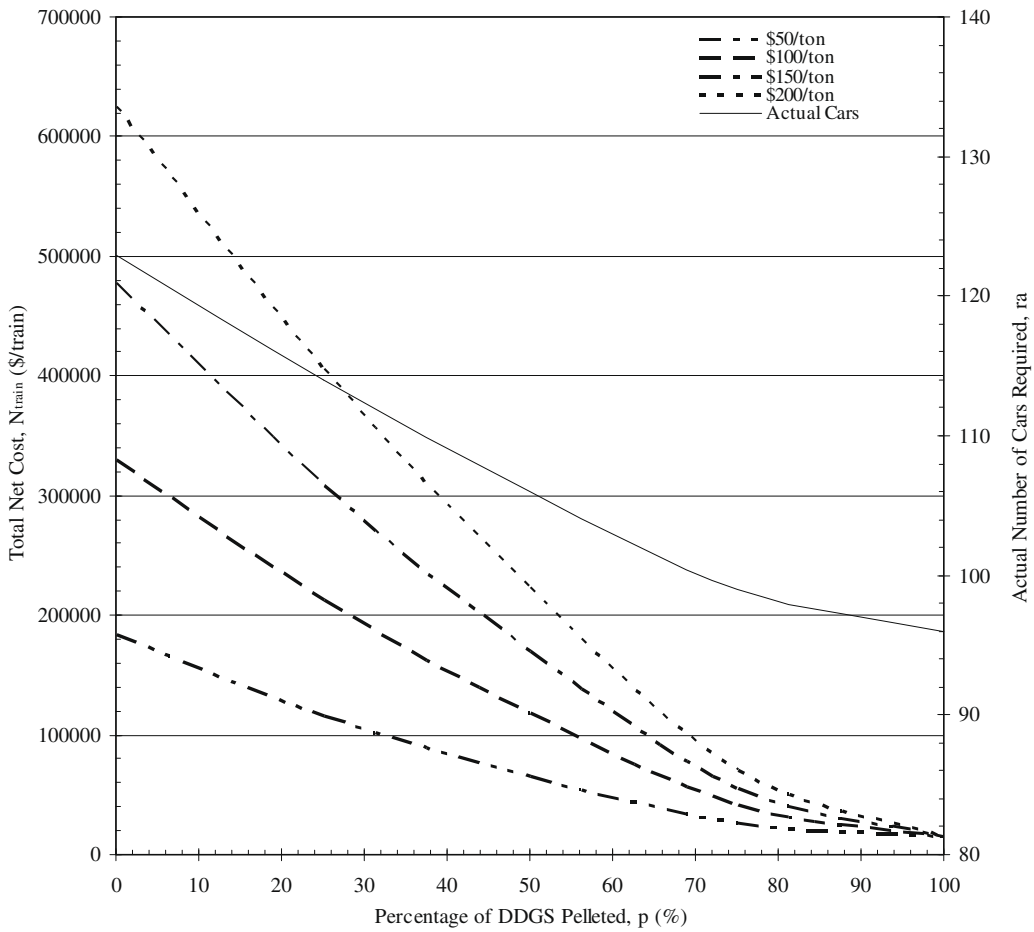

Fig. 8. For all DDGS sales prices, as the quantity of DDGS pelleted increases, the total cost to ship a 96-car unit train decreases, as does the number of rail cars required for a given daily DDGS production rate, due to minimizing of wasted capacity in each car.

each rail car is 56.41 $/ton; at 100% pelleted, however, the actual cost is 44.04 $/ton (which is a 21.9% decrease). Thus, the slack cost for each car reduces from 12.37 $/ton to 0 $/ton (which is a 100% decrease). The values depicted in Fig. 6 are valid for all rates of DDGS generation (i.e., economies of scale) – in other words, the data in Fig. 6 are not dependent upon the size of the ethanol plant. Nor do these results vary when the DDGS sales price varies.

When considering the slack cost per car (Fig. 7), the impact of pelleting becomes readily apparent when both the sales price of the DDGS and the daily DDGS generation rates are considered. When the fraction of DDGS which is pelleted increases, the slack cost per car decreases, no matter what sales price is considered, or which economy of scale is examined. As shown, at 0% pelleting, the total slack cost is 1491.37, 2686.87, 3882.37, and 5077.87 $/car for a DDGS sales price of 50, 100, 150, and 200 $/ton, respectively. Total slack cost for each car decreases to 0 $/car at 100% pelleting. When considering the cost of the pelleting unit operation itself, then breakeven points can be observed at the intersection of these curves, as shown in Fig. 7. The cost of pelleting was 160.23, 128.18, and 88.13 $/car for DDGS generation rates of 100, 500, and 1000 ton/day, respectively, at a pelleting rate of 100%.

Consequently, because the wasted space in each car is minimized as the rate of pelleting increases to 100%, as are the associated slack costs for each car, the overall cost for each train which is shipped out of the ethanol plant is also minimized (Fig. 8). At 0% pelleting, the cost to ship each 96-car unit train was 183438.04, 330454.54, 477531.04, and 624577.54 $/train at a DDGS sales price of 50, 100, 150, and 200 $/ton; at 100% pelleting, however, the cost was minimized at 15382.08 $/train (for all DDGS sales prices). Thus, substantial reductions in train costs are achieved as the rate of pelleting increases.

4. Conclusions and future work

We have attempted to answer the question posed regarding the cost-effectiveness of pelleting DDGS versus current industrial practice, which is to ship DDGS as-is (i.e., in granular bulk form). It appears that, overall, pelleting is extremely cost-effective for these manufacturing coproducts. In terms of cost/car and cost/train, pelleting has been shown to reduce costs for shipping DDGS for all production rates studied – the greater the fraction pelleted, the greater the cost savings, because slack (i.e., unused capacity) is reduced in each car. This is especially true as the sales price of DDGS increases, because the greater the unused capacity, the greater the lost revenue for each car. Both production rate and fraction pelleted results point toward a greater cost savings when the DDGS is completely pelleted. A logical follow-up for this study would be to verify capital and operational costs for each of the production rates (i.e., economies of scale) involved, to examine the effects of car leasing fees, as well as train sizes and car capacities.

Disclaimer

Mention of a trade name, propriety product or specific equipment does not constitute a guarantee or warranty by the United

States Department of Agriculture and does not imply approval of a product to the exclusion of others that may be suitable.

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