ADDING VALUE TO DISTILLERS GRAINS BY PELLETING

Kurt A. Rosentrater *
Agricultural and Bioprocess Engineer
USDA-ARS, North Central Agricultural Research Laboratory
2923 Medary Ave., Brookings, SD, 57006, USA
Phone: (605) 693-3241; Fax: (605) 693-5240; Email: kurt.rosentrater@ars.usda.gov

Disclaimer

ABSTRACT
As the ethanol industry continues to expand, it is imperative to augment markets for coproducts. Toward that end, pelleting holds much promise. This densification process can convert DDGS into physical forms that will expand the potential sales base. To date, even though there is much interest, very little work has actually been conducted on pelleting of DDGS. The goals of this presentation are to examine the pelleting process, discuss parameters which influence pelleting performance, and to share insights gained by investigations into pelleting DDGS from a commercial fuel ethanol plant, both on a laboratory scale as well as a commercial scale. DDGS pellets have been produced with excellent quality, as evidenced by high Pellet Durability Index (PDI) values, and exhibited minimal nutrient degradation. Further studies are necessary to quantify the effects of various processing conditions (including die length/diameter ratios), other DDGS sources, and the efficacy of binders.

INTRODUCTION
Over the last several years the fuel ethanol industry has experienced tremendous growth, and consequently so has its major coproduct, DDGS. This has spurred the continued quest for increasing the use of, and market value for DDGS. Densifying, or pelleting, may be one of the easiest ways to increase the market potential for DDGS, but to date has seen limited use.

Pelleting of feed ingredients is not a new technology – it has been used by the formula feed industry for many years. Pelleted feed offers several advantages over granular feed, including increased bulk density and flowability (because the altered physical form changes the inter-particle friction, the angle of repose, and typically produces less bridging between particles), and thus improved handling and storage. Additionally, pelleting can increase nutrient density and palatability, and reduce feed waste, generated dust, and ingredient segregation. There are several potential disadvantages to pelleting, though, including increased space requirements for the equipment, the need for steam, increased electricity consumption, and ultimately capital and operational costs, which can often range between 1 and 10 $/ton. Although pelleting systems are not typically inherent to a fuel ethanol plant, pellet manufacturing components are already in place at many feed mills.

Feed pelleting is far more an art than a hard science. It is common to see pellets with durability values (i.e., a measure of quality) between 25 and 90%. Pelleting works for many feed ingredients, although it may not work for all. For each ingredient stream, pelleting studies must be conducted, often on a trial-and-error basis, before quality pellets can be produced. Such is the case with DDGS.

The major parameters that influence pelleting include feed conditioning, feed composition, and pellet mill die geometry. Feed conditioning is one of the most important aspects to producing quality pellets. Processing goals for conditioning include heating the feed particles, adding moisture, and mixing. In a conditioner, temperature is relatively easy to control with steam – typically added at levels of 4 to 5%. Conditioner discharge temperatures between 185 to 200°F are common. Temperatures have to be controlled carefully to prevent harm to heat-sensitive vitamins and amino acids. Moisture is also essential. Steam addition is usually sufficient, but sometimes direct injection of water must occur. When conditioning, target moisture contents at conditioner discharge between 15 and 17% are most common; 18% is often the highest recommended moisture, as too much moisture can plug the pellet mill. Thoroughly mixing the moisture into the feed particles and providing a consistent heat distribution throughout the feed mass is another major goal of conditioning. To achieve this mixing, retention times between 30 seconds to 5 minutes are common. Proper conditioning prior to pelleting has several potential benefits, including increased PDI, increased starch gelatinization, altered protein structures (which can improve the binding of the ingredients), and potential pasteurization.

The feed ingredients themselves are also important. Materials with high starch, high protein, or high fiber tend to pellet fairly easily, but products with high fat or high sugar typically are more difficult. Composition of a single ingredient can vary in terms of protein, fat, fiber, and starch contents, especially in DDGS. These changes will impact the ability to produce optimal pellets. Added to this is the physical nature of the feed itself – the particle size of the ingredient is important. In general, the finer the particle size, the better the resulting pellets, because moisture and heat have the ability to penetrate more thoroughly during conditioning. Recommended particle size is often between 500 and 650 μm.

Another key consideration is the die of the pellet mill. It is in this area where the feed mash is compressed (by rollers) into the die openings and compacted to form pellets. The die geometry includes the number of openings in the die, opening length (i.e., die thickness), opening diameter, and the resulting die length/diameter ratio (L/D) for each opening. Geometry is important, not just because of compaction, but because as the feed passes through the die, friction produces heat, which leads to particle binding. Often, thicker dies with smaller openings produce better pellets. Unfortunately, the tradeoff for this can be lower throughput of the pellet mill.

When discussing pellet quality, PDI is the criteria most frequently used in the feed industry. It is a measure of how resistant pellets are to abrasion and breakage. To determine this, a 500 g sample of pellets is placed in a rotating container for 10 minutes, and then the mass of pellets remaining on a wire screen (with a mesh size slightly smaller than the pellet diameter) is determined. Pellet Durability Index is calculated as:

$$\text{PDI (\%)} = M_{after}/M_{before} * 100$$

where M_{after} is the mass of the pellets remaining on the screen after tumbling, and M_{before} is the initial mass of pellets prior to tumbling (i.e., 500g). PDI represents relative hardness and is also a measure of the resistance to mass loss through abrasion. Ideally, the goal is to produce PDI values near 100%; in reality, though, PDI values greater than 80% are often considered “good enough” in the feed industry.

Conditioning, composition, and die size – all of these parameters are important when pelleting feed ingredients. But pelleting is a dynamic process, and settings will need to be modified when using different feed materials. In other words, one size does not fit all. That is certainly the case with DDGS.

PELLETING EXPERIMENTS

To illustrate this, three DDGS pelleting experiments have been undertaken and will be discussed. The first was conducted on a laboratory scale; the second and third using commercial milling equipment.

<u>Laboratory Scale</u>

Using a variety of processing conditions (Table 1), we were able to produce pellets for both unmodified and deoiled DDGS. There were, however, some differences in performance due to the types of DDGS as well as the processing conditions used. For example, there were drastic differences in pellet mill throughput and in resulting fines – L/D definitely had an important effect for both types of DDGS.

Physical properties are provided in Table 2. Color alterations were observed (Table 4): the pellets were somewhat darker than the original DDGS samples. Additionally, we observed some very promising results from a physical standpoint. When pelleted, bulk density increased by 20.4% to 44.1%, and angle of repose changed between 2.7 to 27.3%. These results indicate that pelleting of DDGS could yield substantial benefits from a storage, transport, and flowability standpoint. Thus pelleting may be one solution to the DDGS flowability problem. However, PDI values varied considerably, and must be improved in order for this processing option to become viable on a commercial scale.

Proximate composition remained mostly unchanged (Table 3) before and after the pelleting process, which was anticipated because we did not operate at extreme temperatures. And, heat damaged protein was negligible – which has been a concern by many who have inquired about the possibility of pelleting DDGS, because feed quality must not be compromised. It appears that it was not.

It is important to bear in mind that these results were on a laboratory scale only. The next two experiments were conducted in order to see if we could successfully scale up to commercial operations.

Commercial Scale

Using two commercial pellet mills, we found that unmodified DDGS can indeed be pelleted on a large scale. We did note some slight performance differences between the two pellet mills, however (Table 5). But, both processing lines were able to produce high quality pelleted DDGS (PDI values ranged from 88.9 to 93.9%). As with the previous study, physical changes were observed (Table 6). Color was altered when the DDGS was pelleted (Table 8) – the pellets were somewhat darker. Also, bulk density increased (9.1 to 20.1%), and angle of repose decreased substantially (18.3 to 19.2%). Proximate composition remained mostly unchanged before and after the pelleting process (Table 7), which was anticipated. Heat damaged protein was negligible, as were changes in amino acid profiles. Overall, this study resulted in high quality DDGS pellets – with no binders necessary.

As a follow-up study, using a single commercial pellet mill, we found that deoiled DDGS can also be pelleted on a large scale, but the settings used did not produce high quality pellets (PDI values ranged from 62 to 72%). We did note some slight performance differences between the settings, however (Table 9). As with the previous study, physical changes were observed (Table 10). Color was altered when the DDGS was pelleted (Table 12) – the pellets were somewhat darker. Also, bulk density increased (4.1 to 14.1%), and angle of repose changed (19.2 to 32.2%). Proximate composition remained mostly unchanged before and after the pelleting process (Table 11), which was, once again, anticipated. Overall, this study illustrated the need for additional work into determining optimal process settings when attempting to produce pelleted DDGS.

CONCLUSIONS AND FUTURE WORK

The DDGS used in these trials (both unmodified and deoiled, from a single fuel ethanol plant) were able to be pelleted (without binders), but with varying degrees of quality, as shown by PDI values. And no detrimental effects were found on the resulting nutrient compositions. These findings provide a reference point for follow-up studies, and should provide a basis for further discussions. But this is only the beginning of the research on pelleting of DDGS; there is much room for additional research in this area. For example, there is a need to quantify the effects of various die L/D ratios; to examine the pelletability of various sources of DDGS from a variety of ethanol plants; to quantify how differences between plants influence DDGS composition and physical properties and how these impact pelletability; and to examine whether pelleting hot vs. cold DDGS has an effect (e.g., pelleting at the ethanol plant vs. pelleting at a feed mill). Furthermore, feeding trials need to be conducted to determine the efficacy of pelleted DDGS in livestock diets. And, as DDGS varies from plant to plant, optimal processing conditions must vary accordingly, and thus must be experimentally determined for each source of DDGS.

Table 1. Processing conditions used for laboratory-scale pelleting of DDGS and deoiled DDGS.

	Run 1	Run 2	Run 3	Run 4
Product	DDGS	DDGS	Deoiled DDGS	Deoiled DDGS
Pellet Mill	CPM CL3	CPM CL3	CPM CL3	CPM CL3
Die Length (in) / Die Diameter (in) (L/D)	1.75/0.19 (9.35)	2.25/0.25 (9.0)	1.75/0.19 (9.35)	1.5/0.25 (6.0)
Water Addition (%)	0.0	0.0	4.0	4.0
Mill discharge temp (^{o}F)	220	105	118	129
Throughput (lb/hr)	72	226	262	122
Fines Generation (%)	1.0	5.8	17.0	9.0

Table 2. Physical properties of DDGS, deoiled DDGS, and laboratory-scale pellets.

			Pellets			
Property	DDGS	Deoiled DDGS	Run 1	Run 2	Run 3	Run 4
Moisture content (%, db)	9.11	5.88	5.30	7.65	9.35	9.06
Water activity (-)	0.393	0.251	0.241	0.338	0.387	0.387
Particle size-GMD (mm)	0.65	0.72	--	--	--	--
Particle size-GSD (mm)	1.84	1.81	--	--	--	--
Thermal –conductivity (W/mC)	0.07	0.07	--	--	--	--
Thermal – diffusivity (mm^2/s)	0.14	0.14	--	--	--	--
Color – L (-)	46.16	49.45	34.94	40.94	36.40	36.88
Color – a (-)	10.25	8.35	6.44	7.16	7.90	7.63
Color – b (-)	23.42	19.98	15.04	18.72	14.91	14.89
Pellet Durability Index (%)	--	--	88.34	21.04	88.20	80.20
Bulk density (lb/ft^3)	29.54	28.56	35.56	38.12	39.58	41.17
Angle of repose (^{o})	13.28	13.10	16.05	16.90	13.46	14.84
Unit density(kg/m^3)	--	--	1017.82	994.76	1041.69	1096.86

Table 3. Nutritional properties of DDGS, deoiled DDGS, and laboratory-scale pellets.

			Pellets			
Property	DDGS	Deoiled DDGS	Run 1	Run 2	Run 3	Run 4
Moisture content (%, db)	9.11	5.88	5.30	7.65	9.35	9.06
Protein (%, db)	30.70	33.55	30.10	30.60	33.20	32.55
Fiber - NDF (%, db)	32.85	39.05	28.15	28.20	36.10	36.15
Fat (%, db)	11.10	2.60	11.85	11.75	3.45	3.45
Ash (%, db)	4.28	4.71	4.24	4.31	4.59	4.65

Table 4. DDGS, deoiled DDGS, and laboratory-scale pellets.

DDGS	Deoiled DDGS	Pellets			
		Run 1	Run 2	Run 3	Run 4
					

Table 5. Processing conditions used for commercial-scale pelleting of DDGS.

	Run 1	Run 2
Pelleting Equipment	Sprout	CPM
Die Length (in) / Die Diameter (in) (L/D)	1.75/0.17 (10.2)	2.625/0.17 (15.3)
Ambient Temperature (^{o}F)	49	49
Conditioner Discharge		
Mash Temperature (^{o}F)	175	155
Mash Moisture (%, db)	17.73	16.08
Pellet Mill Discharge		
Pellet Temperature (^{o}F)	190	160
Pellet Moisture (%, db)	17.57	16.62
Cooler Discharge		
Pellet Temperature (^{o}F)	56	55
Pellet Moisture (%, db)	13.49	12.80

Table 6. Physical properties of DDGS and commercial-scale pelleted DDGS.

			Pellets			
	DDGS		Run 1		Run 2	
Property	Mean	St Dev	Mean	St Dev	Mean	St Dev
Moisture content (%, db)	11.3	0.07	13.5	0.08	12.8	0.18
Water activity (-)	0.474	0.005	0.538	0.003	0.534	0.002
Particle size-GMD (mm)	0.93	--	--	--	--	--
Particle size-GSD (mm)	1.61	--	--	--	--	--
Thermal –conductivity (W/mC)	0.07	0.005	--	--	--	--
Thermal – diffusivity (mm^2/s)	15.35	1.27	--	--	--	--
Color – L (-)	40.66	0.28	33.26	0.19	34.19	0.61
Color – a (-)	9.48	0.11	5.15	0.05	6.01	0.11
Color – b (-)	20.00	0.06	13.64	0.13	15.17	0.33
Pellet Durability Index (%)	--	--	93.93	0.01	88.87	0.01
Bulk density (lb/ft^3)	29.72	0.26	35.70	0.14	32.43	0.17
Angle of repose (^{o})	20.06	0.64	16.39	1.00	16.21	0.10
Unit density(kg/m^3)	--	--	1035.25	66.24	938.44	49.28

Table 7. Nutritional properties of DDGS and commercial-scale pelleted DDGS.

			Pellets			
	DDGS		Run 1		Run 2	
Property	Mean	St Dev	Mean	St Dev	Mean	St Dev
Moisture content (%, db)	11.3	0.07	13.5	0.08	12.8	0.18
Protein (%, db)	28.8	0.01	28.1	0.10	28.6	0.20
Fiber – NDF (%, db)	31.4	0.60	30.3	1.00	28.9	0.80
Fat (%, db)	11.0	0.30	11.1	0.01	11.5	0.10
Ash (%, db)	3.84	0.10	3.98	0.10	4.00	0.11

Table 8. DDGS and commercial-scale pelleted DDGS.

DDGS	Pellets	
	Run 1	Run 2
		

Table 9. Processing conditions used for commercial-scale pelleting of deoiled DDGS.

	Run 1		Run 2	
Pellet Mill	CPM # 3016		CPM # 3016	
Die Length (in) / Die Diameter (in) (L/D)	2.25/0.19 (12.0)		2.25/0.19 (12.0)	
	Mean	St Dev	Mean	St Dev
Mill discharge temp (^oF)	170.22	3.87	172.90	3.32
System motor load (kW)	39.39	7.81	29.82	1.91
Throughput (tons/hr)	1.91	0.39	1.13	0.04

Table 10. Physical properties of deoiled DDGS and commercial-scale pelleted deoiled DDGS.

			Pellets			
	Deoiled DDGS		Run 1		Run 2	
Property	Mean	St Dev	Mean	St Dev	Mean	St Dev
Moisture content (%, wb)	10.89	0.25	7.64	0.35	7.52	0.27
Water activity (-)	0.48	0.00	0.36	0.00	0.35	0.00
Particle size-GMD (mm)	0.65	--	--	--	--	--
Particle size-GSD (mm)	1.87	--	--	--	--	--
Thermal –conductivity (W/mC)	0.08	0.00	--	--	--	--
Thermal – diffusivity (mm^2/s)	0.12	0.00	--	--	--	--
Color – L (-)	45.10	0.99	35.45	0.49	34.62	0.84
Color – a (-)	9.00	0.21	7.05	0.42	7.03	0.28
Color – b (-)	19.37	0.40	14.05	0.63	13.74	0.46
Fines (%)	--	--	10.00	3.00	3.00	0.00
Pellet Durability Index (%)	--	--	61.97	1.82	71.98	2.22
Bulk density (lb/ft^3)	30.71	0.06	31.96	0.35	35.04	0.12
Angle of repose (^{o})	14.99	0.51	19.82	1.66	17.87	0.49
Unit density(kg/m^3)	--	--	727.17	97.21	605.70	98.64

Table 11. Nutritional properties of deoiled DDGS and commercial-scale pelleted deoiled DDGS.

			Pellets			
	Deoiled DDGS		Run 1		Run 2	
Property	Mean	St Dev	Mean	St Dev	Mean	St Dev
Moisture content (%, wb)	10.89	0.25	7.64	0.35	7.52	0.27
Protein (%, db)	34.35	0.07	34.15	0.07	33.50	0.14
Fiber (%, db)	8.20	0.14	8.20	0.28	8.00	0.28
Fat (%, db)	2.65	0.07	4.95	0.07	5.10	0.14
Ash (%, db)	5.01	0.03	4.97	0.09	4.98	0.01

Table 12. Deoiled DDGS and commercial-scale pelleted deoiled DDGS.

Deoiled DDGS	Pellets	
	Run 1	Run 2