

(21) Utilizing the National Corn-to-Ethanol Pilot Plant to Develop a Predictive Model for Distillers Dried Grain for the Fuel Ethanol and Animal Feed Industries

The objective of this two-year effort is to develop and validate a neural network predictive plant model for the composition of Distillers Dried Grain with Solubles (DDGS), a coproduct resulting from the dry grind fuel ethanol process.

Total project cost: \$807,221

Funding request: \$633,149

Project Lead: Southern Illinois University Edwardsville: National Corn-to Ethanol Research Center

Project Participants: Washington University, St. Louis, Missouri-Department of Chemical Engineering; Emerson Process Management; Illinois Department of Commerce and Economic Opportunity.

Start Date: May 23, 2005

End Date: May 23, 2007

Presentations/Publications

None.

Patents

None.

Progress in Past Quarter and Current Status

5.1 Plant Trial for Determining Effect of Post-Distillation Processes on DDGS.

In May the NCERC conducted a trial to determine the effects of drying on Distiller's Dried Grains with Solubles (DDGS). Once distillation of beer began, whole stillage was dewatered using a decanter centrifuge and the wet cake collected. The liquid stream from the decanter centrifuge was concentrated in an evaporator to syrup at 30% solids content. Once 200 gallons of syrup and 1000 lbs. of wet cake were available, the Dupps pilot dryer was operated on a 24 hour basis from May 16th to 18th to create 9 samples of DDGS.

Wet cake, syrup, and dried DDGS were combined to create a dryer feed with a moisture content of 30%. Although the moisture content was fixed, the ratio of syrup to wet cake was varied in the experiment. Values chosen for this ratio represents the upper and lower limits of syrup to wet cake ratios used in the ethanol industry, and are shown in Table 2. Initially, the dryer must be primed with DDGS from a previous run. However, 65% of the product from the dryer is recycled into the next batch of feed and eventually replaces all of the primed material.

The different feeds were dried at temperatures from 600° F to 700° F and air flows corresponding to 60% and 85% the capacity of the blower. These values represent the upper and lower limits for these values in the ethanol industry. The plant digital control system (DCS) recorded trends on the dryer inlet and outlet temperatures as well as the percentage of oxygen in the dryer.

Temperature was measured using J-type thermocouples, while oxygen percentage was measured using a Yokogawa Zirconia Oxygen Analyzer (ZR202G). The gaseous composition inside the dryer consists of air and steam; thus, the measurement of oxygen allows one to determine the humidity inside the dryer. Other relevant data, such as feed moisture, product moisture, and dryer

pressure were measured and logged by operators. A diagram showing the sample points and locations of the dryer measurements is shown in Figure 2.

Samples from the dryer were taken after 3 hours of continuous operation at a particular condition. Dryer residence time is approximately 30 minutes, which means 6 dryer turnovers were used before product collected. This was necessary due to the large percentage of recycled material used to reduce the moisture content of the incoming feed. Five gallon buckets of product were collected and stored in the cold room. Tests on the chemical properties of these samples provided values for protein, fat, fiber, fatty acid, and amino acid content. Tests on the physical properties provided values for bulk density and color. Samples were also provided to the Dupps dryer company for analysis.

5.2 Color Contrast and Drying Conditions

Hunter Labs donated a colorimeter for the purposes of testing DDGS color from the dryer outlet for this trial. The test is performed quickly (< 1 min.) and provided immediate results for this trial. The outputs of the colorimeter are variables designated L, a, and b. L represents a range of lightness to darkness of the material, with 0 being black and 100 being white. The values for a and b represent ranges from red to green and yellow to blue respectively. Initially, it is expected that the L value will correlate most to DDGS nutritional value. The data for color and the dryer operating conditions are shown in Table 1.

Table 1: Color data for Dupps dryer trial with DDGS.

#	Inlet Temperature (°F)	Blower VFD Frequency (Hz)	Syrup Addition Rate (%)	Percent Oxygen in Dryer (%) [± 0.2]	Moisture Content (%) [± 0.3]	Outlet Temperature (°F) [± 1]	L Value [± 0.2]	a Value [± 0.2]	b Value [± 0.2]
1	650	40	75	0.64	9.25	251.4	55.73	15.93	44.01
2	700	50	50	2.84	6.64	267	56.01	15.92	44.31
3	700	35	100	0.34	14.91	228.8	57.85	15.37	46.87
4	600	50	100	1.57	9.08	249.8	60.46	14.88	48.59
5	600	35	50	1.53	11.82	229.8	55.41	15.14	43.27
6	600	35	100	21.03	14.76	138.9	62.42	13.44	49.56
7	600	50	50	21.03	10.1	159.5	61.75	12.95	45.98
8	700	35	50	20.72	11.43	150.8	61.78	12.87	46.16
9	700	50	100	21.01	9.05	174.1	63.48	12.15	48.3

Three controlled variables were varied in the dryer: inlet temperature, blower speed, and the amount of syrup addition. In addition, the dryer was operated with either air or steam as the drying medium, as shown by the oxygen content being either low (< 3%) or high (> 20%). The effect of the inlet temperature is to change the gradient in temperature across the drum, while the change of blower speed affects the residence time of the material in the dryer. Syrup addition affects the composition of the incoming feed. The amount of syrup added to the dryer feed is based on the amount of thin stillage that is recycled into the process water. A syrup addition of 50% represents the composition of dryer feed that would exist in a plant which recycles 50% of its thin stillage, while a syrup addition of 100% represents no recycling of the thin stillage. The dryer inlet feed composition for the different recycle ratios is shown in Table 2.

Table 2: Masses of various components in a 100 lb. batch fed to the Dupps dryer. Each column represents the composition corresponding to the proportion of thin stillage used to make syrup. All formulations have a 30% moisture content.

Thin Stillage Converted to Syrup	Syrup Addition Amounts		
	50%	75%	100%
Syrup	8 lbs.	11 lbs.	13 lbs.
Wet Cake	26 lbs.	23 lbs.	22 lbs.
DDGS	66 lbs.	66 lbs.	65 lbs.
<i>Total</i>	<i>100 lbs.</i>	<i>100 lbs.</i>	<i>100 lbs.</i>

Using the data generated, multiple linear regression was performed to determine the significant parameters which affect DDGS color. Factors, such as inlet temperature, feed moisture, product moisture, and drum humidity were not statistically significant at a 95% confidence as determined by the t-statistic and were discarded. Outlet temperature, blower speed, and the amount of syrup contributed significantly to a regression model and were able to predict 94% of the variance in the data ($R^2=0.94$). A parity plot of the predicted and actual L values is shown in Figure 1. The actual model parameters are shown in Table 3. Increases in outlet temperature darken DDGS, while increasing blower speed and syrup addition tend to lighten the color.

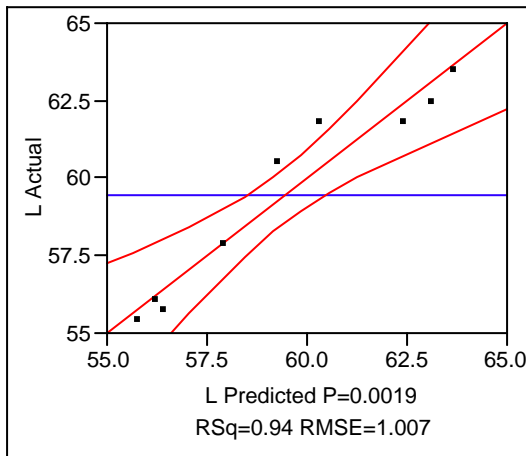


Figure 1: Parity plot of predicted versus actual values for DDGS contrast.

The correlation between outlet temperature and dryer residence time is consistent with the hypothesis that DDGS color change in a dryer is based on the Maillard reaction. Increasing outlet temperature should accelerate browning associated with proteins reacting with sugars such as hexoses and pentoses. Likewise, reducing the dryer residence time (i.e. blower speed) at this temperature reduces the overall conversion. Syrup addition, however, was expected to darken DDGS due to its addition increasing the protein and sugar content of the product. The syrup instead seems to have a lightening effect possibly due to the light color of syrup compared to the other materials.

Table 3: Regression model parameters for color contrast in DDGS.

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	60.875319	2.543375	23.93	<.0001
Blower Speed	0.1726591	0.04835	3.57	0.0160
Syrup Addition	0.0418249	0.014253	2.93	0.0325
Outlet Temperature	-0.057743	0.007393	-7.81	0.0006

Color is often used as an indicator of DDGS quality. Thus, its prediction is an indicator that other nutritional parameters can also be predicted based on dryer operation and inlet feed composition.

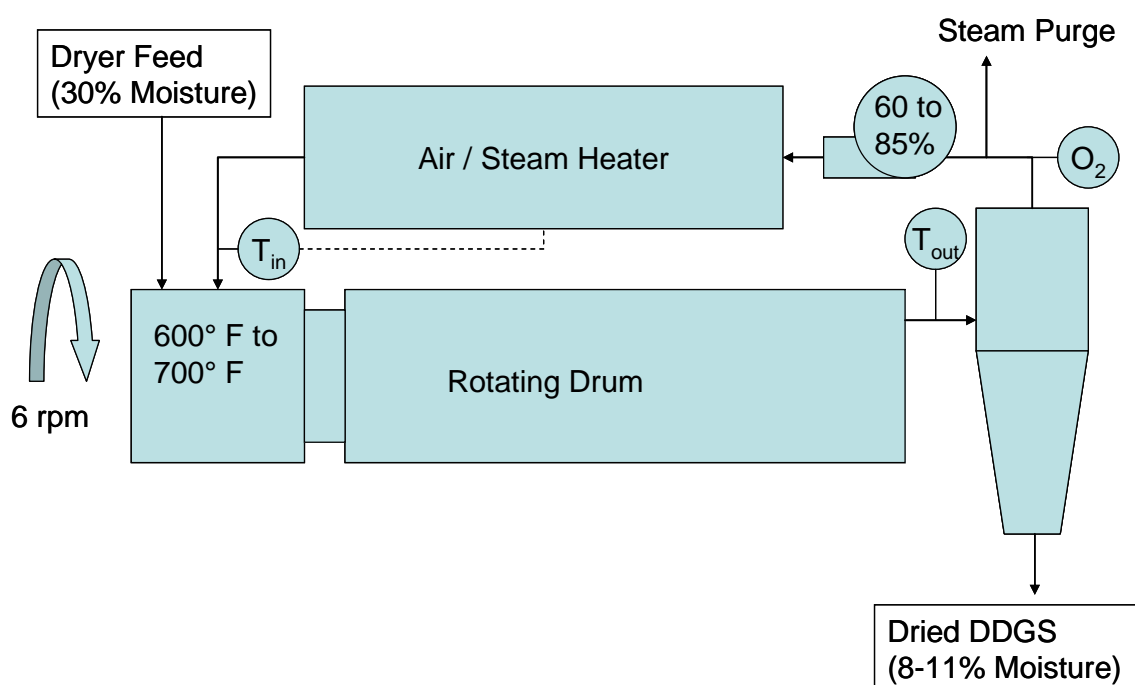


Figure 2: Schematic of the dryer with the locations of measurements for temperature, oxygen, and moisture.

5.3 Free Fatty Acid (FFA) Content and Dryer Conditions

Free Fatty Acid (FFA) content was determined in the nine Dupps dryer samples by New Jersey Feed Laboratories. Based on these results, the dryer inlet temperature, oxygen percentage, and blower speed affect the amount of FFA in the animal feed. This is an important finding because the FFA content is a predictor of rancidity of the feed and affects its shelf-life (2). The values for the model are shown in Table 4, and a parity plot showing the fit is shown in Figure 3. The variance explained by the model is 0.90 ($R^2=0.90$).

Table 4: Regression model of FFA percentages in oil based on drying parameters

Term	Estimate	Std Error	t Ratio	Prob> t
Intercept	0.5159858	0.097999	5.27	0.0033
Inlet Temperature	-0.00036	0.000138	-2.61	0.0477
Blower Speed	-0.002758	0.000917	-3.01	0.0299
Oxygen Percent	0.0036839	0.00067	5.50	0.0027

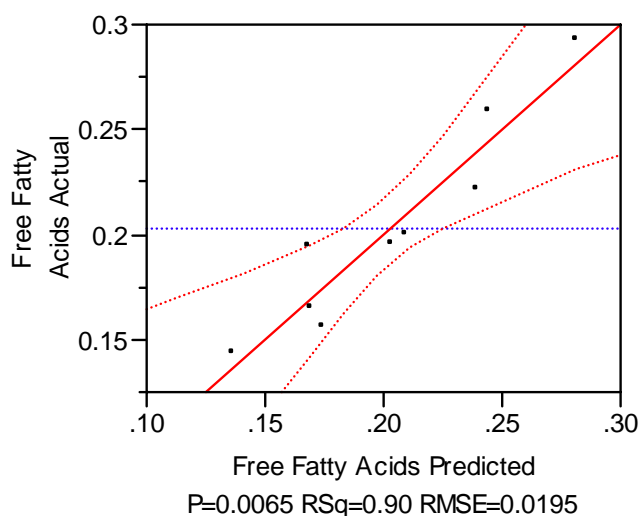


Figure 3: Parity plot of FFA values vs. model predicted values

5.4 Current Status

Amino acid composition and digestible protein of the dryer samples from the previous trial are being analyzed by two outside feed labs in addition to our own measurements. Protein digestibility measures for swine are still being validated on-site. The results are being analyzed and will be reported in the next grant report.

Recently, the NCERC has made extensive modifications to the plant dryer systems, which will be used next quarter. The addition of weigh belts to measure the mass flow of wet and dry DDG and

an on-line moisture sensor will generate more data and will provide greater control over the drying process. A short trial is in progress testing the new equipment.

Plans for Next Quarter

Next quarter the focus will shift to plant processes that are before distillation and how they can affect DDGS quality. Because these processes are further upstream, they are less likely to affect DDGS physical properties, but more likely to affect the overall nutritional content. A plant experiment has already been designed (see the previous grant update) to create a neural net model of liquefaction and saccharification parameters that affect fermentation. This experiment should be completed by the end of the next quarter.

In the winter, a large experiment (35 days) is planned to provide a data set of over 100 points for neural net modeling of the animal feed co-product value. After this data is created, an extensive lab analysis period will occur followed by neural-net and regression modeling of the entire corn-to-ethanol process.

In addition, theoretical models of the plant processes will be developed as time permits to confirm the physical interpretation of the regression and neural-net models.