Microwave Drying Evaluation for Wet Beet Pulp Initiative

Summary Report
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Purpose

Microwave drying is an emerging technology that could be used as an alternative to the current method which most often uses heat from burning natural gas. Microwave energy causes the molecules of the material irradiated (referred to as the "load") to vibrate more rapidly, creating friction and hence heat. Drying takes place in a different way than the current standard, with heat being generated within the molecules of the feedstock itself rather than being applied from an outside source. This method claims not only to be more energy efficient than the current method but also to do less harm to the feedstock, preserving nutritional characteristics of the product for livestock feed.

Goal

Focus of this project has two phases. The first goal is to evaluate the efficiency of utilizing microwave drying technology on wet beet pulp. Drying efficiency of microwave vs. traditional drying will be evaluated. The second goal will involve evaluation of ADF, NDF and potential crude protein availability through analytical determination. Microwave dried beet pulp will be compared with the conventional method that uses natural gas.

Background

Cellencor Inc. was founded 2007 by Dr. Bruce Wicking upon the discovery that microwaves can enhance an enzymes' ability to hydrolyze cellulose. Dr. Wicking brought his new found technology from Australia to the United States to evaluate its value to the emerging ethanol industry. It was during this time Cellencor began to examine the use of microwaves with distiller's grains. During the fall of 2007, preliminary tests were conducted at BECON pilot facility with a small multimode Amtek industrial microwave. The initial results were positive and scaling up the system became Cellencor's top priority. Partnering with Alliant Energy and Ferrite (the world's largest manufacturer of industrial microwaves), Cellencor was able to conduct tests at five different ethanol plants using a completely mobile microwave system which was pre-installed in two standard 40 foot shipping containers.

The results from these trials were impressive. Not only was there a significant energy savings (~1000 BTU/lb of water removed for the microwave trailer versus 1,600 to 2,200 BTU/lb of water removed in traditional gas fired rotary kiln drum dryers), there was also a marked improvement in product quality along with no harmful emissions. Because of the emissions improvement, a microwave dryer doesn't need a regenerative thermal oxidizer in most instances. It was also determined that there was a very significant improvement in product quality due to the low-temperature nature of microwave drying compared to the very high temperatures produced by conventional direct fired dryers. Based on these results and the potential for enzymatic applications, Cellencor acquired a pilot system for further testing to continue research on the effect of microwaves on distiller's grains and other agricultural products.

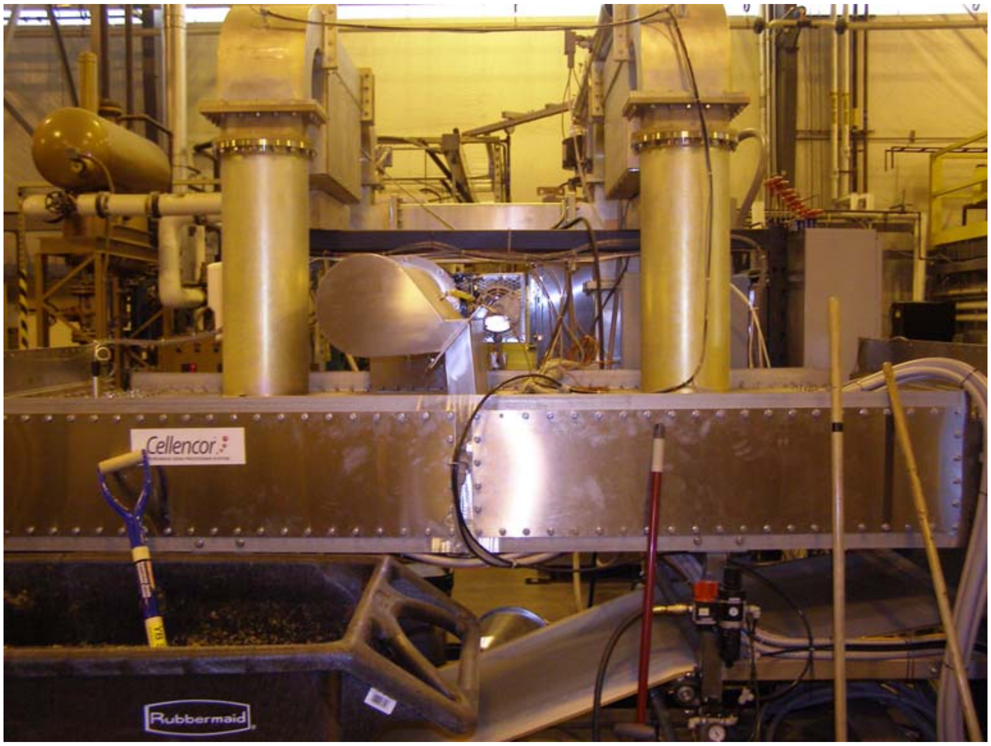
In November of 2008, Cellencor began installing an ImageWave™ microwave with a 75kW generator at the BECON pilot facility. Since then, many different products have been tested. Although the size of the system is smaller than a full scale line, it does provide great insight into how a material will react in an industrial microwave system. Trials are ongoing as Cellencor continues to expand its knowledge base. Additionally, Cellencor is in negotiations with several companies regarding installing systems for drying a wide variety of products from high value feeds to pharmaceutical ingredients.

Investigation with beet pulp: preparation and ingredients

Approximately 150 pounds of wet beet pulp was obtained from Southern Minnesota Beet Sugar Cooperative in Renville, Minnesota. Cellencor, Inc., a company working with microwave dryers, agreed to run tests on the beet pulp using their test facility located at BECON (Biomass Energy Conservation Facility) in Nevada, Iowa. Larger microwave dryers, like one used in a 50 million gallon per year ethanol plant, would have a chamber measuring 6' wide by 60' long, depending on the type of microwave system used. The plant would have 3 lines consisting of 5 – 12' length of cavities, with each line containing 12 – 100 kW microwave generators.

The test microwave dryer used at Cellencor is a variable powered unit which can range in microwave output from 0 to 75 kW, using a 480V / 3 phase connection. The microwave dryer is about 75% efficient – 101 kW in converts to the 75kW maximum output of the unit. It runs at the industrial microwave frequency of 915 MHz. This frequency is less than the standard kitchen microwave, which is 2450 MHz, producing a longer wavelength microwave, which better penetrates the load material. Two electric blowers are used that use 4 kW heaters to move moisture out of the chamber during a run as needed.

The load, the beet pulp for our experiments, passes through the microwave chamber on a conveyor belt made of Teflon fabric. The chamber runs a length of 12 feet, with the conveyor belt measuring 40" wide. Rods at either end of the chamber, termed "chokes," prevent microwave radiation from escaping the chamber, providing a safe environment surrounding the unit for operators and spectators.



This is the widest view available of the microwave drying system. The two cylinders entering the chamber from the top are the waveguides that direct the microwave energy into the cavity. Inside the rectangular chamber is a conveyor belt that carries the material to be dried from right to left.


Chokes (rods with circular ends), located at each end of the microwave dryer conveyor system, prevent microwave energy from escaping the chamber.

The following parameters can be controlled by the experimenter to affect more or less heating of the load:

1) The width and height of the load. The biomass on the conveyor belt can be passed using a smaller width of the conveyor belt by narrowing metal bars on the side of the entry to the chamber; likewise, the thickness of the biomass passing through can be controlled using a horizontal bar that the biomass must pass by before entering the chamber. The maximum width and height for the test unit are 20" wide by 2.5" high. For our tests the 16" was used for width with a 2" height of beet pulp.


Beet pulp enters the microwave chamber via a conveyor belt. What enters is adjusted for width and height.

2) Microwave power. The output power of the microwave can be varied from 0 – 75kW.
3) Conveyor belt speed. How fast the conveyor moves through the microwave chamber can be regulated.
4) The type of material being dried is also a variable – in our case, only beet pulp was used. Differences would include mass density, porosity and free vs. bound water content, just to name a few. The system run by Cellencor has been used primarily to dry distiller's dried grains and solubles.

Testing- Efficiency of microwave drying

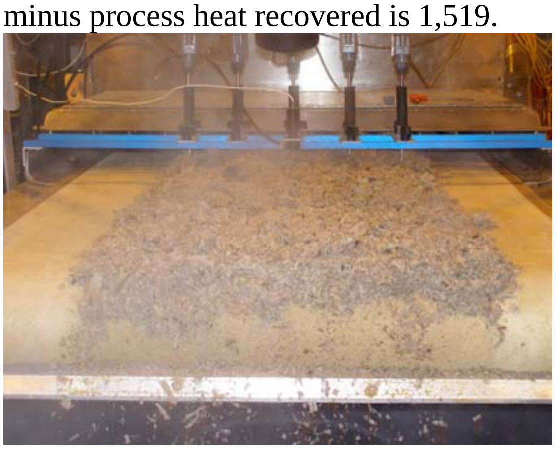
The beet pulp was delivered to the test site in 7 – 5 gallon pails and was frozen. The pulp was removed from the buckets and allowed to thaw somewhat before microwave drying was undertaken. It was decided to run the pulp through once to "defrost" – the pulp lost one pound of moisture during defrost, starting at 149 pounds and ending at 148.

For the second pass, not knowing what to expect (as Ken Kaplan and his team had never run beet pulp through the dryer before), the microwave power was set to 25 kW to start and 50 kW once a complete load of beet pulp was in the chamber. For this and runs three and four, the belt speed was set to 50 inches/minute.

Runs three and four were run at maximum power or 75kW during the period of full load in the microwave chamber. A summary table of the data collected follows.

Microwave Drying Data - January 13, 2009								
Cellencor, Inc.								
Tests at BECON facility in Nevada, Iowa								
Start Weight (lbs)	Run	Power (kW(start/process))	End Weight (lbs)	Weight Difference	Total BTU	Total BTU minus process heat recovered	Gross BTU/lb	Net BTU/lb
149	1st - defrost	10	148	1				
148	2nd	25/50	123	25	52,761	46,380	2,110	1,855
123	3rd	25/75	93	30	55,169	48,788	1,839	1,626
93	4th	25/75	63	30	47,130	42,325	1,571	1,411

The average of runs 3 and 4 to total BTU is 1,705; the average of the runs for total BTU minus process heat recovered is 1,519.



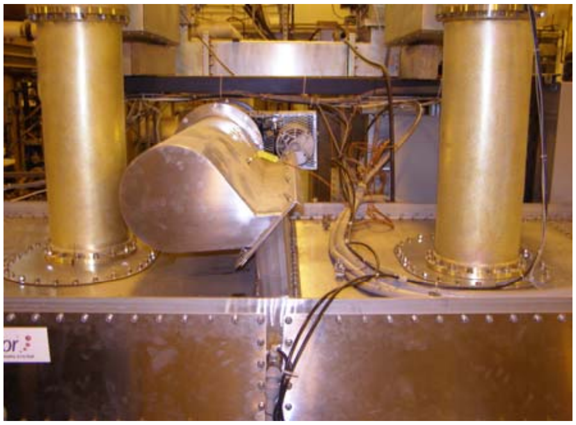
Steam rises from beet pulp exiting the microwave dryer.

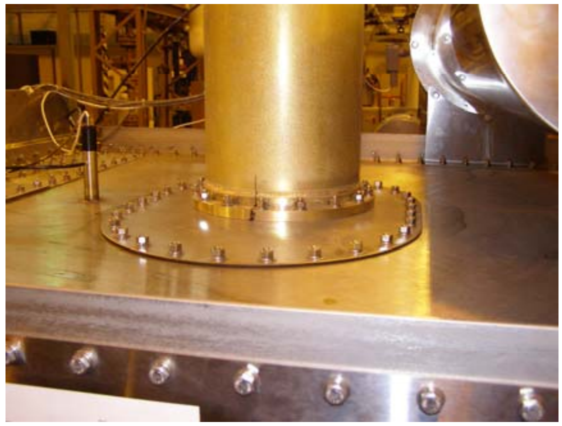
Cellencor Vice President Ken Kaplan tests for exiting moisture content with his hand.

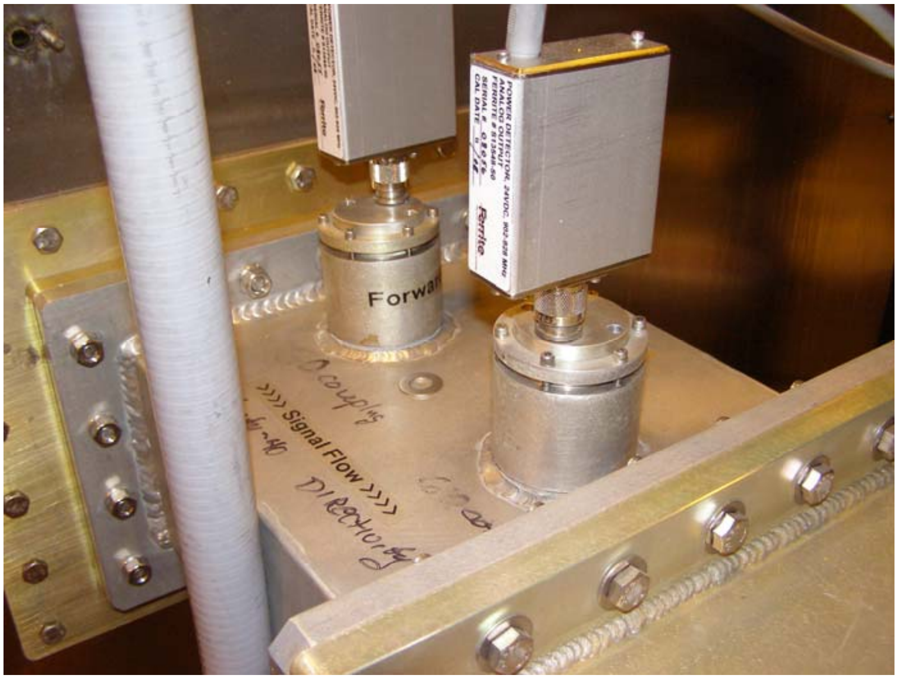
Testing – Round 2, March 12, 2009

A second set of tests was done on 299 pounds of wet beet pulp acquired on March 11, 2009. The trip was made to BECON for tests on March 12.

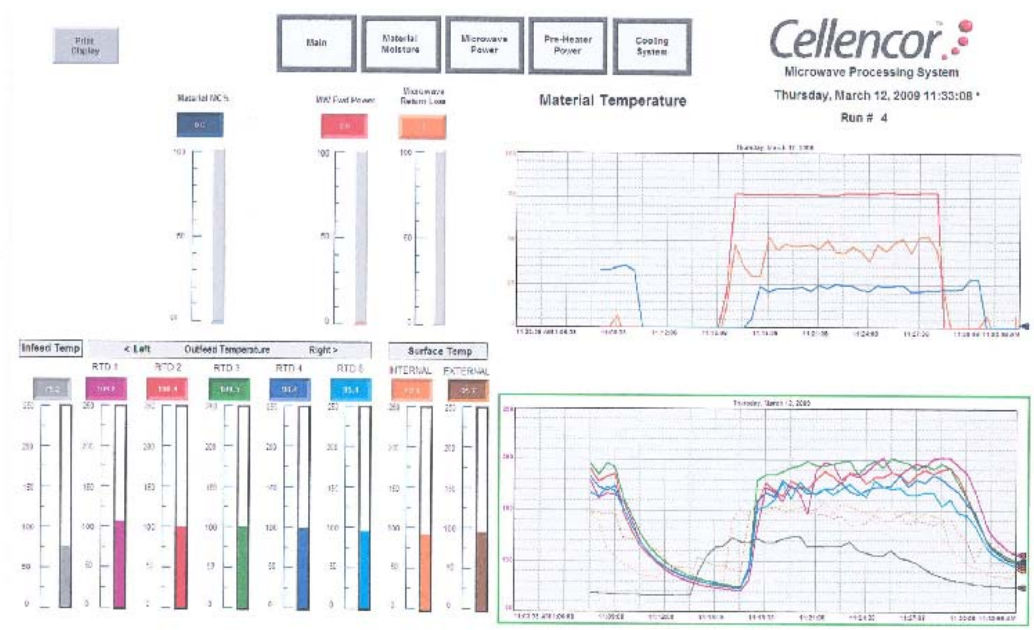
Improvements had been made to the pilot microwave system. The two wave guides were moved, the first slightly to the left side of the cavity (looking in the direction product moves on the conveyor belt) and the second was moved to the right. This move was to optimize the system for better wave patterns inside the chamber for more effective heating. Devices were also put into place where the reflected microwave energy returning to the generator was now measured so that the microwave return loss could be minimized by the operator during the run by controlling process variables, allowing a higher percent of the microwave energy to be absorbed by the product on the conveyor belt.


Wave guides have been moved since January in their orientation on the microwave drying chamber.


The waveguide furthest downstream on the was moved toward the right.



New detectors help minimize the microwave energy reflected back to the generator. This is termed “microwave return loss,” and controlling this parameter helps improve system efficiency.



The orange power bar (left side, top) and graph line (right side) monitor the microwave return loss during a run. The first 6 bars on the lower left monitor the temperature profile from left to right of the material in the microwave cavity; the orange and brown bar monitor internal and exit temperature with an IR sensor.

Two defrost runs were done to remove ice chunks from the wet pulp. Following this, seven passes were made to dry the beet pulp. A summary of test results is included in the table below.

Microwave Drying Data - March 13, 2009
Cellencor, Inc.
Tests at BECON facility in Nevada, Iowa

Start Weight (lbs)	Run	Power (kW(start/process))	End Weight (lbs)	Weight Difference	Moisture end run%	Total BTU	Microwave RF Power	Total BTU/lb	MW RF BTU/lb
299	1st two runs defrost	10/20	295	4	82.22				
295	1st	75	254	41	79.67	82,553	62,564	2,013	1,526
254	2nd	75	203	51	72.19	74,970	56,597	1,470	1,110
203	3rd	75	157	46	65.86	66,461	50,319	1,445	1,094
157	4th	60	125	32	58.02	49,237	37,428	1,539	1,170
125	5th	40	108	17	50.06	27,017	20,660	1,589	1,215
108	6th	30	94	14	42.79	19,284	14,233	1,377	1,017
94	7th	30	85	9	39.23	18,204	13,439	2,023	1,493
Total/Average -->				210		337,726	255,240	1,608	1,215

Microwave RF Power is now included in the monitor output as an indication of what the raw energy use could be. Total BTU input numbers did show improvement in general from the first visit in January, with most passes falling in the 1,400-1,500 BTU/lb range.

Factors suggested by Ken Kaplan that could improve the overall performance of the system and lower BTU usage included:

1. In an industrial system processes are optimized in a multi-chambered process to vary microwave energy applied to the load as the load proceeds down the conveyor belt. As the material dries it requires less microwave energy to obtain similar drying results to the higher power needed in the earlier drying stages. Microwave drying systems for DDGS are up to 6 chambers and running microwave generators capable of 125kW.
2. The actual tweaking of the microwave system is necessary to totally optimize the process. This means finding the right process variables necessary for the material being dried.
3. An improved ventilation system, the system that carries the moisture out of the chamber, is to be added to the pilot setup at BECON. This would allow more moisture to be removed in a pass.

Testing – Round 3, April 7, 2009

Scientists at Cellencor, Inc. traveled to the Co-Products Lab in Waseca and picked up approximately 300 pounds of wet beet pulp in early April. Independent of AURI staff, a third round of microwave treatments was applied to dry this collection of beet pulp.

For this third trial Cellencor was able to dry the beet pulp in 3 passes after one defrost run – from 73% down to 14%. A total of 235 pounds of water was eliminated in the 3 passes.

Further details of these runs are shown the following two tables.

Pass No.	Microwave Power (kW)	Belt Speed (in/min)	Exhaust (CFM)	Highest Output Temp (°F)
Defrosting #1	15	40	750	120
Drying #1	75	25	750	200
Drying #2	75	25	750	188
Drying #3	75	50	750	190

Drying Pass No.	Belt Speed (inches /minute)	Water Removed (lbs)	Total Energy* (BTU/lb water)	Final Moisture (%)
1	25	109	1634	73
2	25	88	1481	47
3	50	38	1658	14
		Total 235	**Average 1581**	

* Gross electric line power

Testing- Digestibility for livestock diets

The feed industry in Minnesota and the United States offers a tremendous value added opportunity for marketing many grain and fiber processing co-products. Evaluating the effect microwave drying has on wet beet pulp as it relates to livestock nutrition is a critical focus area of the microwave drying initiative.

Microwave dried beet pulp samples from the first test conducted by Cellencor Technologies along with a traditional dried sample of beet pulp were submitted to Dairyland Laboratories, Incorporated at Arcadia, Wisconsin. The goal for nutrient evaluation was to focus primarily on crude protein and fiber availability differences within the two samples. Samples were not compared to the other due to geographical differences within production and soil fertility differences during the growing season.

Samples were evaluated using wet chemistry methods. Crude protein, acid detergent fiber, neutral detergent fiber, lignin and energy values were identified. Further testing was conducted to aid in determining nutrient availability differences including (1) Acid Detergent Insoluble Crude Protein (ADP-ICP) as a percent of total crude protein, (2) Neutral Detergent Fiber Digestibility 48 (NDFD 48), and (3) In-Vitro True Dry Matter Digestibility 48 (IVTDMD 48).

<u>Acid Detergent Insoluble Crude Protein (AD-ICP 48 % of crude protein)-</u>
Acid detergent fiber residue is subjected to rumen fluid for 48 hours. Digestion and crude protein analysis is conducted to **determine the protein fraction bound to the fiber** (also known as heat damaged or unavailable protein attributed to silage conditions or drying processes in this situation). Research conducted indicated the microwave dried beet pulp had a 10.13% insoluble crude protein determination or 89.9% of the total crude protein is available to ruminate. The conventional dried beet pulp showed an AD-ICP result of 48.8% or 51.2% of the total crude protein is available to ruminate.

<u>Neutral Detergent Fiber Digestibility 48 (NDFD 48)-</u>
NDFD is the measurement of dry matter after the feedstuff has been digested in rumen fluid for a standard amount of time or in this case, 48 hours. Factors that affect NDFD are:

1. Temperature at the time of cutting - Fiber is more digestible when formed in cool, wet conditions.
2. Leafiness - leaves are more digestible than stems.
3. Heat Damage - will lower the digestibility.
4. Maturity - In legumes, NDFD slowly decreases during the first stage of growth and then rapidly decreases when the cell and stem diameter increase.
5. Plant Genetics.

Dairyland Laboratories, Arcadia, Wisconsin describes the NDFD 48 process as:

"In-vitro procedures analyze the feedstuff after a sample has been dried (forced air oven at 62ºC to constant weight) and ground thru a 6mm screen (Wiley Mill) so that about 70% of the resultant particles are between 6 and 8mm in size. The dry, ground sample is placed into a dacron bag and the bag is placed into an incubation flask. The flask is filled with a mixture of rumen fluid extracted fresh daily from four matched animals. The mixture of rumen fluid from multiple animals helps to decrease the among-animal variation that can occur if only one donor animal is used. The strained rumen fluid from each of the four animals is collected about one hour post-feeding and maintained at a constant temperature in a buffered, anaerobic environment (similar to the natural ruminal environment) complete with a solution that mimics the buffering action of saliva. Collecting rumen fluid from the cattle and mixing it with the sample and buffer requires about 20 minutes and then the in-vitro flasks are placed into an incubator.

Time, temperature and pH are critical parameters during the collection and mixture processes. Time is kept short (usually less than 20 minutes to collect four animals) so that there is minimal temperature change (less than 3ºC) during the 20 minutes from animal to incubator and the pH change is less than 0.5 units.

The sample and rumen fluid mixture are kept together in a temperature controlled, buffered anaerobic environment for the desired number of hours. 48 hours is the standard analytical package.

No matter what is the extent of ruminal or intestinal incubation time, the calculations are similar. Digestibility coefficients are calculated as:

(1)

$$\frac{\text{(amount of nutrient in) - (amount of nutrient out)}}{\text{(amount of nutrients in)}} \times 100$$

“nutrient” can be dry matter, starch or NDF
“nutrient in” is the amount of the nutrient contained in the original sample
“nutrient out” is the amount of the nutrient after ruminal or intestinal digestion or both

(2)

nutrient content multiplied by digestibility coefficient

“nutrient content” is the amount of starch or NDF in the original sample as % DM
“digestibility coefficient” is calculated by Formula #1 (should be less than 1)”

Analysis of the microwave dried beet pulp and conventional dried beet pulp showed a significant difference of 10.98% between the two samples. The microwave dried beet pulp had a NDFD 48 measurement of 78.11% as compared to the convention dried beet pulp of 67.13%. These results indicate greater nutrient and fiber digestibility in rumen fluid for the microwave dried beet pulp.

<u>In-Vitro True Dry Matter Digestibility 48-</u>
In-vitro true dry matter digestibility (IVTDMD) is a measurement of ‘true’ dry matter digestibility. This is different than NDFD due to the test evaluating

total dry matter including starch and fiber. Dairyland Laboratories in Arcadia, Wisconsin explains the test as:

"IVTDMD 48 requires the client to know both the extent of dry matter and NDF digestion in rumen fluid. Extent means that the feedstuff would be in rumen fluid for a long time period (approximately 100 hours) so that the maximum amount of dry matter and NDF would be degraded by the digestive system. The amount of NDF that remains after such a long incubation period is defined as "indigestible" NDF…that quantity of NDF that is "totally" unavailable to the ruminant digestive system. NDF that remains after 30 or 48 hours of ruminant digestion is termed "undigested" NDF…that quantity of NDF that is not digested in the specific time period but that, if left in the rumen fluid longer, could be more extensively digested. This is one reason why short digestion times such as 24 to 48 hours cannot be used in the calculation of IVTDMD. When van Soest defined IVTDMD, he used the concept that the cell wall (NDF) contained the most important limits to digestion because 100 minus NDF (cell contents) were virtually entirely available to the ruminant digestive system. Further, he postulated that only the dry matter that was not undigestible NDF was available for the ruminant digestive system and, therefore, the "true" dry matter available for digestion."

Research AURI conduct evaluated the microwave dried beet pulp to the conventional dried beet pulp for IVTDMD 48. Differences between the two samples were not as significant as the previous tests. Total dry matter digestibility for the microwave beet pulp was 91.52% compared to 87.65% for the conventional dried beet pulp.

<u>Conclusion</u>

Industrial microwave technology appears have the potential to be an improved system for drying sugar beet pulp. Two factors contribute to this statement: the overall energy cost used to dry beet pulp and the effect of the drying treatment on the quality of feed that is produced in the process.

Runs conducted at BECON with the pilot system show the promise of reduced BTU use. BTU input numbers continued to improved from the first set of tests to the final third drying evaluation. They can be further improved should the system be "straightened out" and allowed to proceed as a single continuous process, avoiding the numerous transition periods that were required for our tests. This longer system would also allow a user to optimize the process as the pulp proceeds down the conveyor system. Further optimization of such factors as alignment of waveguides, evacuation of moisture and monitoring of parameters affecting BTU input, such as microwave return loss, can only serve to improve the overall efficiency of a system. Use of heat collected from water used to cool the microwave producing magnetrons could also serve to improve overall efficiency.

Final microwave drying research indicated a drying efficiency of 1,581 Btu to remove a pound of moisture. Cellencor Technology claims the potential to achieve 1,000 Btu per pound of moisture removed in a continuous industrial scale system. Industry averages currently range in the area of 1,400 to 2,200 Btu required evaporating a pound of moisture.

Improvement in feed quality is the second consideration. Due to the nature of different drying methods, there was some indication that the material dried by microwave method could have a greater nutrient availability when fed to livestock. Nutrient availability of the feedstock dried using microwave technology indicates the potential for tremendous value added improvements to ruminate animal performance. Microwave dried beet pulp was compared to conventional dried beet pulp focusing on *crude protein* availability, total *fiber* digestibility in a rumen, and total *dry matter* digestibility in the rumen.

Research conducted at Dairyland Laboratories in Arcadia, Wisconsin indicated an improvement in crude protein availability of 38.7% for the microwave dried beet pulp in rumen fluid over conventional dried beet pulp. Microwave dried beet pulp also showed an improvement in neutral detergent fiber digestibility of 10.98%. Total dry matter digestibility did not show a significant different but indicated an improvement for the microwave dried beet pulp.

Research AURI conducted was on a limited scale. Data collected evaluating microwave drying focused on *drying efficiencies only*. Nutrient availability testing was *not* replicated, rather used only as a potential indicator for predicting value added opportunities when utilized as a livestock energy and protein source.

Acknowledgment

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