## BALE BAGGING PROPERTIES AND RATE OF COTTON BALE WEIGHT CHANGE DURING STORAGE Richard K. Byler USDA/ARS Cotton Ginning Research Unit Stoneville, MS Andrew G. Jordan Jordan Associates Memphis, TN

### Abstract

A total of 83 specimens of bale bagging material, which had been used previously in whole-bale studies quantifying the effect that bale bagging materials have on bale weight change, were tested for water vapor transmission rate (WVT) using the procedure ASTM E96. The WVT rates of the specimen were correlated with whole-bale weight changes from the previous study. These materials included fully coated woven polypropylene with and without perforations and linear low-density polyethylene with and without perforations, all prepared by the manufacturer. The ASTM E96 procedure was used to determine the WVT characteristics of the bagging. The packaging materials covered a wide range in WVT. The resulting WVT data were used to predict the transmission rate for the entire exposed area of the bag and compared with the actual half time to equilibrium bale weight as determined in previous work. The WVT data of bagging materials agreed well with the bale weight change rate obtained previously. The approach demonstrated in this study shows promise of being a more rapid and lower cost method, which will assist the cotton industry and packaging manufacturers to better meet the requirements of the industry.

### **Introduction**

In the U.S. commerce cotton bales weighing approximately 226 kg (500 lb) are covered with bagging to protect them during transportation and storage. Annually, bagging materials are reviewed and approved for use by the Joint Cotton Industry Bale Packaging Committee (JCIBPC) coordinated by the National Cotton Council. From this review, the JCIBPC annually publishes *Specifications for Cotton Bale Packaging Materials*, (NCC, 2008). Since 1968, the specifications have been adopted into the USDA regulations and have been a requirement for any bale used as collateral in USDA loan programs. For a bagging design to be included in the specifications, it must be evaluated and approved by representatives from a committee whose members represent interests of cotton farmers, ginners, cotton warehousing, cotton merchants, and textile spinners.

Cotton is sold by weight without regard to moisture content (mc). Before the JCIBPC was formed in 1968, burlap bagging, which was highly permeable to moisture (Byler and Jordan, 2008), was used exclusively as bale cover; furthermore, the bales were not fully covered leaving large amounts of exposed cotton. The burlap cover did not inhibit bales coming to equilibrium with ambient conditions after ginning. There are distinct marketing and processing advantages for fiber to be at ambient moisture equilibrium. In addition to the change in bale weight affecting the total price, fibers whose moisture is in natural equilibrium with ambient conditions are better able to resist damage during the cleaning and spinning processes at the mill. More recently the JCIBPC promoted packaging materials and practices so that there would be no unprotected bale surface. Polyolefin-based materials such as Linear Low-Density Polyethylene film (LLDPE) and woven polypropylene (WPP) were introduced for testing in the early 1970's, and were adopted for use in 1974 and 1976, respectively. Benefits are related to cost competitiveness, performance, light weight, improved strength, and adaptability in automated packaging systems.

### Linear Low Density Polyethylene

By 2008, film bags made from LLDPE were used to cover nearly one-half of the U.S. cotton crops. Film bags are virtually impermeable to moisture (Byler, 2008; Byler and Jordan, 2008). The non-porous film inhibits baled cotton lint from reaching its natural moisture equilibrium within a reasonable time period. Furthermore, the fact that film bags are resistant to air movement, decreases the efficiency of mechanical bale stuffing lines because the lines must be slowed to allow air in a bagging stuffer to escape as the bale was being inserted. To facilitate mechanically stuffing bales into bags, manufacturers commonly add 4 to 16 vent holes typically 1 to 1.5 cm diameter in the sides of the film bag to allow air to escape as the bale is being forced into the bag. Intuitively, it is assumed that the air vent holes allow some degree of moisture vapor transfer but the rate has not been quantified. Some polyethylene

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film manufacturers have made efforts to provide perforations to film bags to increase the water vapor transmission (WVT) characteristics. There is an industry need to detail and publish the effect of vent holes, as well as the effect of perforations on moisture movement. While early field demonstrations have shown WVT can be improved, perforations have caused an associated decrease in film's durability and toughness. Breaking the link between increased WVT and decreased performance is viewed as a significant marketing opportunity for a supplier to demonstrate a film formulation or construction that increases WVT without affecting toughness.

## Woven Polypropylene

Woven polypropylene was introduced to the cotton industry as a bale cover because of its superior strength, toughness and light weight. The first adoption of WPP was in a simple woven fabric construction typically 4.7 yarns/cm (12 yarns/in) in the warp direction and 3.9 yarns/cm (10 yarns/in) in the weft direction and having a total of 8.6 yarns/cm (22 count in the English textile system). The early fabrics had no coatings or methods to prevent fabrics from fraying. Therefore the interstices between the intersection of each yarn (18.3 interstices/cm<sup>2</sup> in the early versions) effectively served as perforations, allowing moisture vapor to move from the side of higher vapor pressure to the side with the lower vapor pressure.

Anthony (1982) showed that woven uncoated polypropylene bags virtually were as permeable to moisture vapor movement as were burlap bags. Woven materials had a disadvantage, however, as WPP bags were cut or were torn during handling, fabrics released shreds of polypropylene filament tape (yarn) which become entangled with cotton fiber. Plastic yarns become further shredded during spinning mill processing, potentially creating many contaminants in cotton yarns and fabrics. Polyolefin fibers have a lower specific density than cotton fibers and as a result are not removed during typical textile cleaning processes, which separate impurities from fiber based on the principles of inertia.

Even with the improved protection from dirt, grease, and other external bale contaminants, the bagging itself posed a contamination risk. In steps to reduce contamination risk of the bagging, the JCIBPC, beginning in 1981, conducted experimental trials to reduce the amount of woven polypropylene bale pieces that emanate from the bag. Trials successfully demonstrated that intimately coating the woven fabrics with a thin plastic film reduced stray yarns by almost 100%. Testing successfully confirmed that the technology for extruding a thin polypropylene film to the surface of the woven polypropylene fabrics was practical and affordable with a nominal increase in manufacturing cost. The film thickness typically was 0.025 mm (1 mil) and was bonded to the base woven fabric. By 1985 the industry called for coating all WPP bags with an extrusion coating of polypropylene film. There was concern about the loss of moisture vapor transfer capability. Also bags were somewhat stiff and did not have the handling characteristics of other bags being used which by their bias construction would allow flexibility in fitting a various range of bale sizes. As a compromise, the industry allowed for coatings to be applied in parallel strips alternating with coated and uncoated areas. The strip-coating gave improved varn stability and allowed for bag flexibility and moisture vapor transfer. Strips in general were 4.2 cm (1.75 in) apart. Compared with loose weave, WPP strip coating reduced the contamination risk by 75 to 95 % (Jordan, 2003). Moisture vapor permeability of strip coated WPP was acceptable by the industry with only small reduction in vapor transfer, as compared with uncoated WPP and burlap. (Anthony and Herber, 1991).

# **Bag Perforation**

Though practice and data indicated a reduction in risk of the bagging to become a contaminant, many spinners averred that the uncoated areas of the strip coatings were unacceptable to spinners (Jordan, Thompson, 2004, report to the JCIBPC). In 2004, the industry moved to reduce risk further by requiring woven polypropylene bagging to be coated on 100% of the bale surface area. Manufacturers were requested to provide moisture transfer capability to coated fabrics by perforations. Some manufacturers immediately demonstrated various methods of perforations. Typical perforations were patterned after the house wrap industry, in which small pinholes from 4.5 to 7.8 holes/cm<sup>2</sup> (30 to 50 holes/in<sup>2</sup>) were created on the bale surface. Full-bale experiments successfully demonstrated that pinholes typical of the house wrap industry could improve the moisture vapor transfer capability or permeability. In unpublished tests, Anthony showed that moisture transferred freely in bales covered in perforated WPP. Though not published in Anthony's paper, this author (Jordan) reports that the perforated bag used in Anthony experiments contained 4.7 perforations/cm<sup>2</sup> (30 perforations/in<sup>2</sup>). Side by side tests demonstrated that moisture transfer in the perforated bag included in Anthony's demonstration was almost as rapid as in strip coated WPP. Anthony's early tests did not fully describe characteristics of the perforations, but showed that an increase in moisture vapor transfer was possible. Such data requires quantification.

While full-bale research experiments are effective in determining bale weight changes, the data is limited only to the one bale treatment in one set of conditions. For complete elucidation of various bagging treatments and environmental treatments using full scale bales, multi-bale replicated tests under a wide range of environmental and handling treatments would be required. Such tests following statistically sound experimental design would be prohibitively expensive. There is an urgent need to gauge bale moisture transfer characteristics based on fundamental parameters of the bagging. The goal of this work will be to develop a protocol for performing relatively limited, basic, and inexpensive laboratory tests on a bagging swatch, by means of simple apparatus in order to predict full bale performance in a range of environmental conditions.

### **Moisture Relationships**

Moisture ratio has often been used when bulk products are studied with changing moisture content. Assuming the weight of the dry matter in bales does not change when fiber mc changes, the moisture ratio is equal to the bale weight ratio, WR, defined as (Byler, 2008):

$$WR = (W(t) - EW)/(W(0) - EW)$$
(1)

where W(t) = the bale weight at time=t EW = the equilibrium bale weight, and W(0) = the bale weight at time=0

Many agricultural researchers have used the model:

Moisture ratio = 
$$\exp(-b^*t)$$
 (2)

where b = a drying constant with units of time<sup>-1</sup>. Equations 1 and 2 can be combined and rearranged as:

$$W(t) = (W(0) - EW) * exp(-b*t) + EW.$$
(3)

If data were collected for bale weight over time nonlinear regression can fit the data with the model:

$$W(t) = a * exp(-b*t) + c$$
 (4)

where a, b, c = parameters chosen by regression

The parameter "c" is the equilibrium bale weight, "b" is the weight change coefficient related to time, and the parameter "a" represents the total bale weight change. Fitting equation 4 to data is fairly simple and the model allows bales of different original weights, different total weight change, and bale equilibrium weight to be normalized so that they can be easily compared. The model would not be expected to fit the data well at small time, the time it takes for the first 5 to 10% of the total weight change.

On full bale studies, if the model fits the data well, it would not be necessary to collect data until the bale reaches equilibrium; because, the equilibrium bale weight could be projected from interim data. The decaying exponential model is common in engineering work and has many useful properties. One of the properties is that the period of time for the weight to change from the initial weight to one-half the initial weight, is the same no matter where on the curve the measurement started. This time period for half of the bale weight change is a useful indicator of the rate of bale weight change.

Standard Test Methods for Water Vapor Transmission of Materials, ASTM E 96, was employed by Simpson et al., (2007) to determine the WVT, of WPP and LLDPE bagging materials with and without perforations punched in the samples. WVT data should relate well with the rate of bale weight change, the parameter "b" in equation 4, as described by Byler (2008). Moisture diffusion into and out of bales can be considered to be restricted by two parts, the bale bagging and the baled fiber itself. Byler and Jordan (2008) found that there was no statistical difference in the moisture movement rate into bales with no covering and those with woven burlap or cotton bags. Evidently the WVT rate was great enough for the burlap and cotton covers that the diffusion rate was controlled predominately by the bale itself. At the other extreme LLDPE bags and fully coated WPP bags with no perforations restricted diffusion considerably.

As discussed above, the data collection time involved--at least two months and up to one year, and the size of the test units--a cotton bale, make the bale bag testing as has been done by Anthony (1982 and 2005), Byler (2008), and Byler and Jordan (2008) time consuming and expensive. The ASTM E96 procedure is much faster, taking at most several weeks, and involves much smaller study units. As conducted in this study, samples could be tested in as few as 10 days. The long-term goal of the project is to be able to estimate the bale weight change based on relatively faster and less expensive tests of the bale bagging.

### **Materials and Methods**

This study was conducted in three parts. Samples of bagging materials used previously in determining the effect of bagging on the rate of bale weight change were studied further. Table 1 has a brief description of the specimens included and the bale numbers they were cut from which relate to previously documented bale weight change during storage. In Part I WPP samples from bags used by Byler and Jordan (2008) were tested. The bagging used with bale 2299 was manufactured on a circular loom which produces a bag without seams. Unlike the extrusion coating process for flat fabrics where one pass of the extruder completely covers the fabric, coating circular woven bags which have no seam is a two step process. To coat the circular bag, an extruded layer of polypropylene must be added to each side of the bag. Overlap from the extruder on either edge of the flat bag creates a "fin" consisting only of the polypropylene laminate at the crease where the bag was folded. Three samples from the edge area were tested. From the same bag three samples with no perforations and six samples with one hole each were included in the testing.

The perforations in bales 2298 and 2299 were not made with sharp pointed pins normally expected in the packaging industry, but apparently with larger diameter punches which rupture the yarn and coating in the area of the perforation as shown in Figure 1.



Figure 1. Punch style perforation in coated woven polypropylene typical of 1 perforation/160 cm<sup>2</sup> (bale 2296, 2297) or 1 perforation/80 cm<sup>2</sup> (bale 2298, 2299).

Six bagging samples used with bale 2296 with one hole each plus three samples with no perforations were included in the testing. Bale 2296 was a spiral sewn bale, sewn on a bias from a single sheet of fabric approximately 96 in wide. The single sheet was coated with the extrusion laminate prior to sewing into the spiral bag construction unlike the circular weave describe in 2299 which must be run through two extruders, one for each side of the bag. Bale 2296 also had a 3.25 cm uncoated strip running full length along the edge of the spiral seam. Running at a 45 degree diagonal to the longitudinal axis of the bale, the uncoated seam represented 2 meters of seam length on the bale surface. Due to a testing oversight, samples of the uncoated seam of the spiral bag were not tested. A close up photo of the uncoated and coated strip is shown in Figure 2. Previous work (Simpson and Jordan, 2006, unpublished data) has shown uncoated strips of WPP have a significantly higher WVT rate and cannot be ignored. To fill the data gap, MVT data on strip coated WPP from Simpson and Jordan was used. Additionally, after completing tests and observing the apparent anomaly of the data, a closer look at the seamless bags showed numerous cracks or fissures in the coating as depicted in Figure 3. Numerous areas of the bag had imperfections

typically 2 to 3 fissures/cm<sup>2</sup> (15 to 20 fissures/in<sup>2</sup>). It was observed that there were 4 strips running in the weft direction of the fabric each running approximately 1/4 the full length of the diagonal cut sheet comprising the bag. None of these areas had been selected by the technician in selecting specimens for the WVT tests.



Figure 2. Strip coated WPP with laminate coating on the right and uncoated, loose weave on the left side of the photo.



Figure 3. Fissures or laminate failures in WPP coating.

In Part II, 12 specimens of WPP bagging with no perforations taken from bale bags used in the testing described by Byler (2008) were included. In addition, 14 samples with no holes or one hole were included, plus eight samples with one hole each were included in the testing from bagging used in the testing describe by Byler and Jordan (2008).

In Part III, four samples of cotton bagging and four samples of woven burlap bagging were included from bales tested as described by Byler and Jordan (2008). In addition, 12 samples of LLDPE bagging, some with punched perforations and some with no perforations, as used by Byler (2008) and eight samples of LLDPE bagging with perforations cut in them, as used by Byler and Jordan (2008), were included.

Eighteen Model 68 vapometers, (Thalwing Albert Instrument Co., West Berlin, NJ) were employed in the determination of WVT. These are metal cups 5.08 cm (2 in.) deep with a screw closed ring with a neoprene gasket holding the specimen in place exposing a 6.35 cm (2.5 in.) diameter area for vapor transmission. A heated wax and rosin mixture was used to improve the seal for lower WVT materials and for WPP bagging which tended to be more irregular in thickness, as described in the ASTM standard. Figures 4 and 5 are photographs of WPP bagging samples in vapometers. Figure 6 shows an additional sample after removal from the vapometer. Dry calcium chloride desiccant was placed in the cup, then the material being tested was securely attached to the open top of the holder. The assembly was weighed periodically while being stored in a chamber maintained at 50% RH and 23°C. The WVT was obtained from the slope of the straight line portion of the weight change/time data divided by the area of material, as described in the Standard. The WVT was expressed in units of  $g/h m^2$  in this document. The slope

was obtained by the procedure GLM, part of the SAS (2003) statistical package and has units of g/day in this document.

Study Part	Number of specimens studied	Description of bagging	Bale ID in previous study
Ι	9	9 Woven polypropylene fully coated 1000D 8x8 weave, perforated with Langston-style punch with nominal 1 perforation/160 cm <sup>2</sup> (spiral sewnweave yarns run 45 degrees from the longitudinal bale axis and 3.25 cm uncoated seam) Langston brand.	
	12	Woven polypropylene fully coated 1000D 8x8 weave, perforated with Langston style punch with nominal spacing of 1 perforation/80 cm <sup>2</sup> , flat construction (weave runs in direction of longitudinal bale axis, circular woven seamless, Langston brand	2299
II	12	Woven polypropylene, fully coated, 1000D 6X9 weave flat construction (weave runs in direction of longitudinal bale axis, taped seam (not constructed on bias) Intertape Polymer Group brand	2232, 2233, 2234
	14	Woven polypropylene fully coated (same as 2299 above)	2298,2299
	8	Woven polypropylene fully coated (same as 2296 above)	2296, 2297
	8	LLDPE film 6 mil (0.152 mm) thickness with no perforations or air vent holes, Lone Star Brand	2300, 2301
III	4	Woven burlap, spiral sewn 304 g/m <sup>2</sup> (10 oz/40 in by 1 yard, 3.4 lb/bag)	2287, 2288
	4	Woven cotton, spiral sewn 170 $g/m^2$ (1.9 lb/bag) Approved for experimental use in 2007.	2291, 2292
	12	LLDPE film 6 mil (0.152 mm) thickness with 0.05 cm dia. (0.5 mm) pinholes punched on a 2.54 cm (1 in.) grid covering the bag surface, Flex Sol Packaging brand.	2225, 2226
	8	LLDPE film 6 mil (0.152 mm) thickness with 1.0 cm dia. vent holes cut with four rows 30 cm apart placed on the longitudinal bale axis and four holes/row placed around the periphery ( two holes/3456 cm <sup>2</sup> area) Flex Sol brand, approved for use in 2007.	2320

Table 1. Bale bagging included in the study. Full bale study conditions were approximately 23°C and 85% RH.



Figure 4. Photo showing specimen of WPP bagging, with no perforations, in vapometer with clamping ring in place.



Figure 5. Photo showing specimen of WPP bagging, with one perforation, in vapometer with clamping ring removed.



Figure 6. Photo showing specimen of WPP bagging, with two perforations, after being removed from vapometer.

After the WVT rate was determined for the specimens, the data were combined to get an estimate of the WVT for the four sides of the bale exposed during the testing of bale weight changes (Byler and Jordan, 2008; and Byler, 2008). Moisture transfer from the area of bale tops and bottoms was ignored considering the multiple folds and layers of bagging on the tops and the multiple layers and intimate contact with the concrete surface of the experimental chamber of the bale bottoms. The perimeter of the bale multiplied by the height was considered to be the exposed area. The total area was considered to be 1.4\*2\*(0.54+0.8) or 3.75 m<sup>2</sup>. For bales with bags of solid film (bale 2300, 2301) or for bales with uniform and evenly spaced perforations (bales 2225 and 2226 with 2.54 cm x 2.54 cm perforation grid) combining of WVT data was not required as WVT data coefficients as developed from the specimen tests were appropriate to predict the moisture rate through the bale bagging surface. On the other hand for "hybrid" fabric constructions which have non-uniform surfaces or areas of bagging with different alterations to encourage water vapor transfer, the WVT calculations were more involved. Each distinct area was tested and WVT coefficients were weighted based on proportional areas of the bale surface covered by each material type. For example, bales 2296, 2297, 2298 and 2299 had perforations spaced so far apart that it was impossible to get a representative sample of the entire grid area above the test cup; therefore, tests for the "hole" area were conducted separately for the areas with solid coatings. Similarly for uncoated seams and areas for fissures which were discovered on bales 2296 and 2297 after tests were completed, data from similar WVT tests under the same test protocol by Simpson and Jordan were used. Finally, the estimate of the maximum water vapor transmission rate through the bale was compared with the rates of bale weight change, from previously published data.

### **Results and Discussion**

The weight data over time from the standard ASTM test for the different specimens were analyzed statistically and fit with straight lines. The first two data points were omitted from determining the best fit equations, because the ASTM E96 requirements call for use of data only after a steady state rate of change has been reached. These data were fit well by the linear model, generally with R<sup>2</sup> values of at least 0.998. Figures 7 and 8 show some of the weight gain data collected, typical of all data, and the straight-line fit to the data. Figure 7 shows data for four different WPP bagging specimens with no perforations and can be observed to have a very low slope. The offset for each of these was allowed to be different because of the different initial weights of the vapometer, the desiccant, and the bagging specimen. Figure 8 shows WVT data for the same type of bagging as Figure 7, but each specimen had one hole which had been made by the manufacturer to increase WVT for the bag. Not all data for the samples with one hole fit as well as that in Figure 8, the perforations were observed to not be uniform in size. Additionally, close examination of the spiral sewn bags showed significant areas of bagging with numerous areas wherein the coatings had cracked. This was especially true where there were twisted tapes or creases in the bagging which occurred during extrusion coating process.

Bag material specimens were cut from a number and variety of manufacture of used bale bagging which had been studied previously. The slopes were determined and are tabulated in Table 2, along with identifying information.



Figure 7. Plot of weight gain of four vapometer cups with WPP bagging containing no perforations measured over different time periods resulting in a slope of 0.0063 g/day, for all data with chamber conditions of 50%





Figure 8. Plot of weight gain of four vapometer cups with WPP bagging containing one hole resulting in a slope of 0.052 g/day for all data with chamber conditions of 50% RH and 23°C.

Study part	Specimen material	Description of specimen	Bale ID in previous study	Vapometer weight gain slope, g/day	WVT, g/h·m <sup>2</sup> (50% RH, 23°C)
Ι	WPP	Bagging with no seam, no	2299	0.00188	0.0247
	WPP	perforations Bagging with no seam, one pinhole perforation (0.14 cm equivalent diameter)	2299	0.0263	0.346
	WPP	Bagging with extrusion coating overlap, no perforations	2299	0.0180	0.237
	WPP	Bagging with no perforations	2296	0.00757	0.0996
	WPP	Bagging with one pin hole perforation	2296	0.0772	1.010
Π	WPP	Bagging with no perforations	2232, 2233, 2234	0.0189	0.249
	WPP	Bagging with no perforations	2299	0.00626	0.0824
	WPP	Bagging with one pinhole perforation	2296, 2297	0.0517	0.680
	WPP	Bagging with one pinhole perforation	2298, 2299	0.0459	0.604
	WPP	Bagging with two pinhole perforations	2299	0.0750	0.987
	Cotton	Woven fabric bagging	2291	3.169	41.7
III	Burlap	Woven fabric bagging	2287	4.048	53.3
	LLDPE	Bagging film with no hole	2225, 2226	0.0023	0.0303
	LLDPE	Bagging film with one 0.05 cm dia, hole	2226	0.0423	0.557
	LLDPE	Bagging film with no hole	2320	0.0023	0.0303
	LLDPE	Bagging with one 1.0 cm (0.39 in.) dia. vent hole	2320	0.4415	5.81

Table 2. Vapometer data for different bagging materials.

For the bales 2298 and 2299, a 0.19 m<sup>2</sup> (288 in<sup>2</sup>) area was examined and perforations were found to be spaced nominally in a 12.7 cm x 12.7 cm (5 in by 5 in) pattern twice-punched—(two passes with a punch roll) providing a nominal hole pattern of 1 hole/80 cm<sup>2</sup>. The perforations were measured and found to have an average open area of 0.018 cm<sup>2</sup> (0.003 in<sup>2</sup>) or an equivalent hole diameter of 1.6 mm. For the bales 2296 and 2297, perforations were spaced in a nominal 12.7 cm x 12.7 cm spacing single pass providing a hole pattern of 1 hole/160 cm<sup>2</sup>. The holes were measured and were found with an average open area of 0.016 cm<sup>2</sup> or an equivalent hole diameter of 1.5 mm. Additionally, on close examination it appeared that there were missing perforations (breaks in the normally regular pattern of holes) which could be explained by missing pins on a circular perforator roll. Such irregularity added to the confounding of the treatments for the perforated WPP bags.

Samples of bagging were examined and the data from the WVT testing combined to estimate the water vapor transmission rate for the entire exposed bag. This calculated rate was tabulated along with the half time to equilibrium, which had been determined previously based on storing relatively dry bales of cotton in these bags in a high humidity environment over a period of months, (Table 3). The bag transmission rate data can be observed to relate to the half time to equilibrium data in an inverse way, as would be expected. The logarithm was taken of each of these data and plotted, (Figure 9). Considering the range of the data and the relatively inexact estimates involved in modeling whole bale bags by samples cut from the bags, the relationship demonstrated in Figure 9 was considered to be good.

Bale ID in previous study	Material	Weight gain rate; estimated for 3.7 m <sup>2</sup> exposed area from WVT data of bagging samples (kg/day) (50% RH, 23°C)	Estimated effective bag WVT (g/hr/m <sup>2</sup> )	Measured half time to equilibrium; from bale study (days) (obtained at approximately 85% RH, 24°C)
2300, 2301	LLDPE film, no perforations	0.0027	0.0307	1136
2298, 2299	WPP, perforated with hole/80 $cm^2$	0.0170	0.189	340
2296, 2297	WPP, perforated with 1 hole/160 $cm^2$ and 2 meters of 3.2 cm. uncoated strip at seam and numerous fissures in film coating.	0.027 (specimens only) 0.0812 weighted for imperfections*	0.914	124
2320	LLDPE, with 16 - 1 cm diameter holes at nominal 48 cm grid spacing	0.0099**	0.111	85
2225, 2226	LLDPE, with perforations	0.246	2.77	77
2291, 2292	Woven cotton	3.75	42.2	20
2287, 2288	Woven burlap	4.78	53.9	20

Table 3. Bale ID, description of bagging, rate of moisture transfer from WVT data, and measured half time to equilibrium from previous work.

\* It was discovered after vapometer studies were completed, that there was a significant area of uncoated strip at the seam and numerous fissures in the laminate. WVT data of uncoated WPP (strip coated) and perforation (2.54 pinholes/cm<sup>2</sup>) were obtained from research by Simpson and Jordan (unpublished data, 2006) and used in determining the weighted WVT for bales 2296 and 2297.

**\*\*** ASTM E96 method is generally limited to testing permeable and semi-permeable materials. Testing 6.35 cm diameter samples of LLDPE film with 1 cm. diameter hole may not be considered appropriate for WVT tests.



Figure 9. Log-log plot of estimated bagging water vapor transmission rate compared to observed bale weight change rate.

It should be noted that the rate of gain for the spiral WPP covered bale bag was considerably greater than that originally predicted based on the perforations alone. However, when the large amount of uncoated exposed seam area and numerous fissures, which apparently occurred as a result of laminate cracking was considered, the weighted WVT coefficients increased considerably provided a good fit to the semi-log curve. For "hybrid" bags, that is bags with several different treatments which cause water vapor transfer to occur, each component must be considered separately and a resulting overall WVT coefficient can be determined by weighting the coefficients to their proportional area of bagging. In the case of the bags with 1 perforation/80 cm<sup>2</sup> or 1 perforation/160 cm<sup>2</sup>, these data show the perforations occur at such a low frequency that the contribution to WVT coefficients by the perforations is small as compared to the contribution by the uncoated areas and cracks or fissures in the bag.

The significant outlier to the relationship in Figure 9, is the bag with 1 cm diameter die-cut holes. The apparent contribution to full bale weight gain is much higher than could be predicted by WVT tests, as conducted in this test. It is noted that the ASTM E96 test method is to be used only on permeable and semipermeable materials. These tests verified that the ASTM E96 large open areas such as the 1 cm diameter hole may not be used reliably. The equation representing the line in Figure 9 was found to be:

Half time = 
$$146 *$$
 Estimated Effective Bag WVT  $^{-0.536}$  (5)

This equation could be used to estimate the effect on bale weight change, based on the WVT data for a cotton bale bag. However, it should be used with caution because it is based on preliminary data, is strictly empirical, and has not been thoroughly tested and verified.

#### **Conclusion**

The long term goal of the project is to establish a method of predicting the rate of change of bale weight based on measurement of the bale bagging properties. Based on the data shown in Table 3 and Figure 9, covering a wide range of moisture diffusion rates, it appears that the WVT data correlates well with the bale weight change data and that this approach is reasonable. Additional data and development of the procedures are needed. This approach and

these data should be useful to cotton bale bagging manufacturers as they deal with the problem of producing bagging which meets requirements of the cotton industry.

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## <u>Disclaimer</u>

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