NEW CD WARP CONTROL SYSTEM

FOR

THE CORRUGATING INDUSTRY

USING A NEW
CONCEPT IN MOISTURE SENSING
AND CONTROL

BY

DRYING TECHNOLOGY, INC

A New CD Warp Control System
For the Corrugating Industry

Introduction: **Brief history of Drying Technology, Inc**

Drying Technology, Inc., (DTI) was introduced to the corrugated board CD warp problem in the late 1980's as a result of a request for a proposal and quote for a warp control system. Later, the research department of a large paper manufacturing company requested a similar proposal. We complied with each by proposing a system that included use of our basic, patented Delta T sensing technology[1] that requires two temperature sensors and a mathematical model derived from first principles to sense and control linerboard moisture content (MC). The first company soon dropped their project, and the paper company informed us that they would develop their own system; however, they never did.

Later, we modified our basic moisture sensing technology to provide a more practical and effective method for sensing linerboard (liner) MC exiting a preheater. This new liner MC sensing method was incorporated into our earlier warp control system concepts which now offer an excellent chance for solving the industry's CD warp control problem. All that remains is to test it on a corrugator.

The Warp Control Problem:

It is well known that linerboard (liner) expands when wet and shrinks as it dries. Further, when two liners are joined in a corrugated board, the difference in the top and bottom liner MCs must be below about 1% to prevent warp. Therefore, a control system that is capable of maintaining this "no warp" MC difference under conditions of differing corrugator speed, liner basis weights, and incoming MCs, should be successful in virtually eliminating CD warp in corrugated board.

Controlling moistures for the purpose of reducing or eliminating warp is not a new concept; however, in practice its effectiveness has been limited by the lack of a reliable and rugged moisture sensor. Some warp control systems were designed with conventional IR moisture sensors traveling back and forth across the liner width to scan the liner MC. However, the harsh environment of a corrugator, the relatively high cost of conventional IR sensors, equipment for moving the IR sensor across the web, and the unreliability of conventional IR moisture sensors appears to have forced the use of liner surface temperature as substitute for liner MC. It will be shown below that prediction of MC using temperature is quite poor and significantly reduces the effectiveness of control systems using this approach.

Non-Conventional Moisture Sensing:

Work commenced on the Delta T moisture/dryer model conceptualization in 1975 followed by completion of the derivation of the model (equation 1) in 1979. A moisture sensing and control system was successfully applied to eight veneer dryers during the period 1982 to 1984 using this non-conventional method for sensing and controlling MC using two temperature sensors and a mathematical model derived from first principles. A paper describing its derivation was presented in November 27 – 28 at the North American Wood Symposium, MS. State, MS., followed by two patent[2] applications filed in 1984 and 1985. Patents were granted in 1987 and 1988. The model for continuous drying is:

$$\mathbf{MC = K_1\,(\Delta T)^{p} - K_2/S^{q}} \qquad \mathbf{(1)}$$

The product moisture content (MC) is related to the temperature drop (ΔT) of hot air after contact with the wet product; and (S) is the production rate or dryer speed; Ks are constants, and p & q are exponents. The use of proprietary methods developed over the past 23 years eliminates the need to determine exponents and constants. It should be noted that raw delta T renders the model inoperative. Proprietary methods must be applied to make it work.

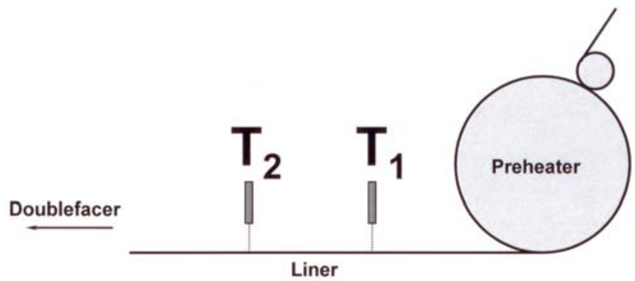
The Delta T model initially was used to predict product MC exiting dryers, ovens, kilns, and the like with a high degree of accuracy and reliability. It does not require costly and time-consuming calibration as do conventional moisture sensors. The controlled variable, (ΔT), the difference in two temperatures, is easily determined which enables MC sensing in very harsh environments. The Delta T been validated by over 350 successful installations on such dryer-types as flash, spray, fluidized-bed, rotary, and conveyor during the drying of a variety of products. [3]

Modification of the Delta T:

Later, it was found that the Delta T principle not only could predict the MC from a drying operation, but also from webs such as textiles and liner that are cooling after exiting a preheater. Two successive surface temperature sensors are placed immediately after the preheater such as in figure (1) for the purpose of sensing the top or bottom liner MC. The basic Delta T model remained the same with the exception that the (ΔT) term is determined in a slightly different manner.

If the evaporation rate from the liner is a function of the MC and the cooling rate (T_1 -T_2) is a function of the evaporation rate, if follows that MC is proportional to the cooling rate.

Figure (1) – Location of Temperature Sensors
For MC Measurement of Liner

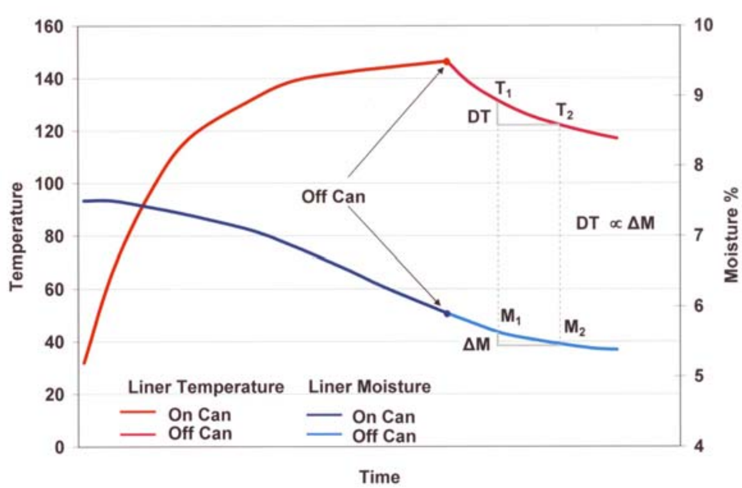


$$\Delta T = T_1 - T_2$$

Figure (2) shows the relationship between the delta t measurement on the cooling curve and the corresponding liner moistures. The liner temperature (red) is shown as it enters the preheater from the left and heats up. Upon exiting the preheater, the liner temperature follows a cooling curve. Temperatures T_1 and T_2 are used to predict moisture (M_2) shown on the (blue) moisture curve.

.

Figure (2) – Liner Temperature & MC
To and From a Preheater



Development of Simulation Model Data:

A simulation program was written using the information from this article. The simulation uses a finite time-element approach for solving heat and mass transfer balances from the time the paper comes in contact with the preheater to a distance after the preheater. The paper temperature and moisture content were tracked in small increments over this distance. The results from the simulation were compared to the data and charts found in the literature to verify the correctness of the calculations. Such operating parameters as speed, preheater wrap, basis weight, and incoming paper MC were varied over a wide range of operating conditions.

The next step was to include the Delta T moisture sensor technology in the simulation. Data was recorded for each basis weight by running a matrix of operating conditions at various speeds, preheater wrap percentage, and incoming moisture. Approximately 200 different conditions were run and recorded based on the following,

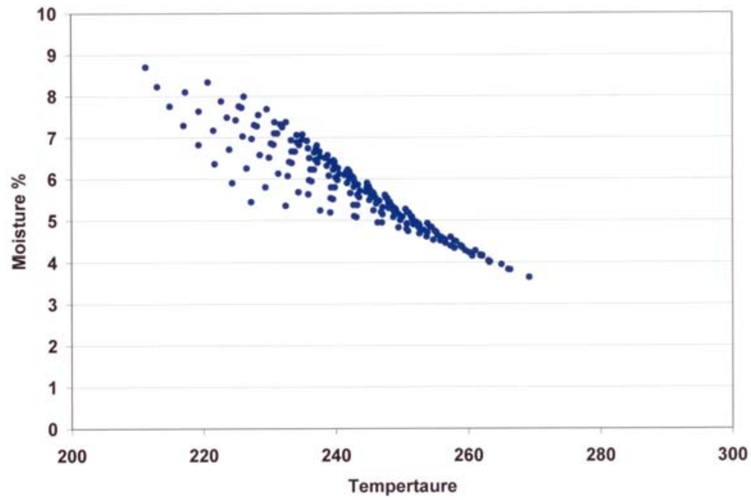
Speed	150 m/s to 225 m/s in 25 m/s increments
Preheater Wrap	30% to 90% in 10% increments
Incoming Liner MC	6.0% to 9.0% in 0.5% increments

The data was analyzed and the Delta T principle applied to determine the correlation between the delta t value and moisture of the liner at a distance beyond the preheater. Excellent correlation exists for all four basis weights used. These results are proof that the Delta T principal could be applied to the cooling of the paper after the preheater to determine the moisture of the paper. It was also noted that the paper temperature alone did not correlate well with paper moisture as shown in figure (3) below.

MC Vs Liner Temperature Shows Poor Correlation:

Although numerous attempts have been made over the years to use temperature to predict liner MC, correlation between MC and temperature is quite poor as seen in figure (3). Therefore, temperature of the liner should not be used as a surrogate for liner MC in a warp control system, which is in agreement with comments found in the literature[5].

Figure (3) – MC Vs Temperature
For 42 lb linerboard



MC Vs Delta T Value shows excellent Correlation:

As mentioned above, the evaporation rate from the liner is proportional to the MC, and the cooling rate is proportional to the evaporation rate. Therefore, delta T is proportional to MC. A plot of MC vs delta T for 42 lb liner at the same simulation conditions as used in figure (3) shows delta T to be an excellent predictor of MC as seen in figure (4) below.

Figure (4) – MC Vs Delta T
For 42 lb linerboard

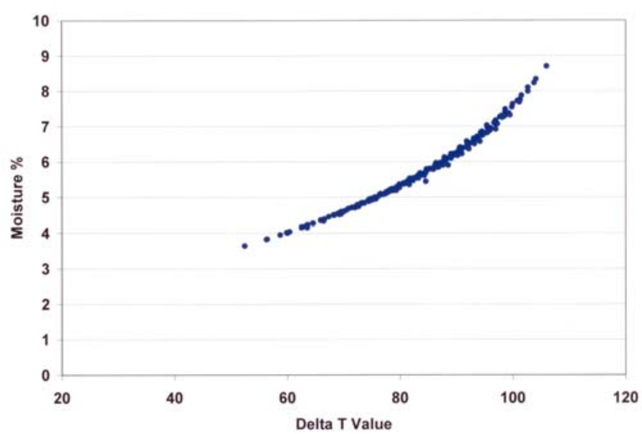
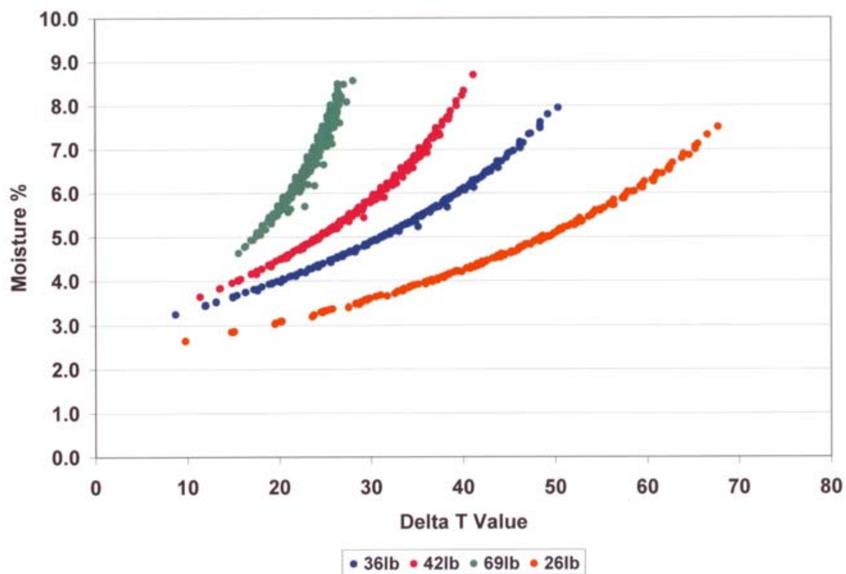


Figure (5) shows excellent correlation between MC and delta T for four basis weights; therefore, liner MC should be easily predicted and controlled based on delta T. This presents proof that use of the Delta T method of MC sensing and control can be used to improved CD warp control in the corrugating industry.

Figure (5) – MC Vs Delta T At
Various Basis Weights



Development of the Delta T Warp Control System:

Recognizing that warp might be eliminated or significantly reduced by maintaining a difference between the top and bottom liner MCs, simulations were run at various differences in top and bottom liner MCs that were assumed to be at "no warp" conditions.   Both temperature and the delta T method of providing relationships at "no warp" conditions were compared. The results are shown in figures (6) and (7) below.

Figure (6), a plot using the simulation data, shows poor correlation between bottom and top temperature for the "no warp" conditions. These results reinforce our earlier conclusion that the use of temperature as a surrogate for MC would not provide an adequate basis for a warp control system.

Figure (6), Bottom Vs Top Liner Temperatures

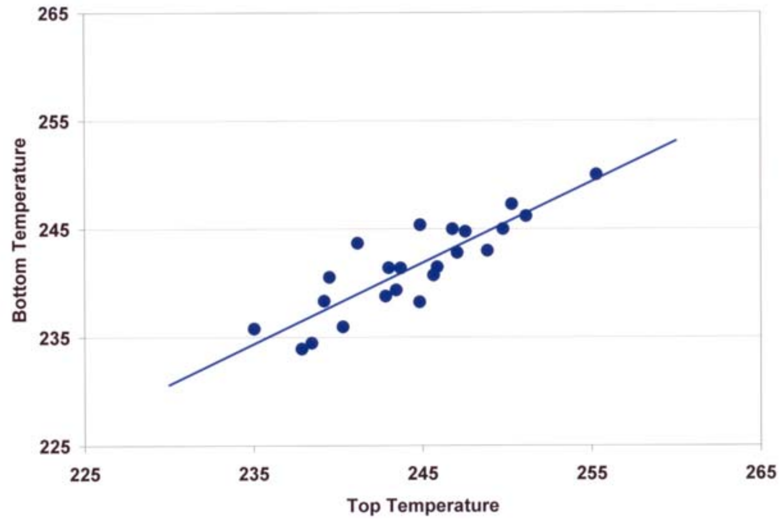
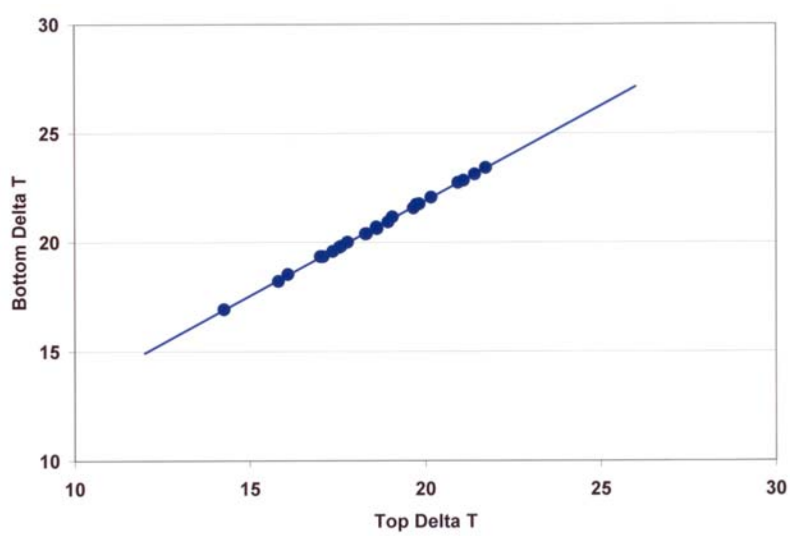


Figure (7), a plot using the same simulation data, shows that the use of the delta T method for sensing MC produces a “no warp” relationship with excellent correlation.

Figure (7), Bottom Vs Top Delta T Values At “No Warp” Condition



A warp control system can now be designed that maintains the “no warp” delta T relationship.   Similar relationships are generated for various differences in MCs at the “no warp” condition. This “no warp” relationship holds even for board made from liners at different basis weights.

Warp Control Algorithm Development:

The next step in the process was to determine the relationship between the top and bottom delta t values at the conditions of ‘no warp’. The application of the Delta T had to be made without knowing the actual moisture of the liners, since liner moisture would be difficult to obtain on a production line. Assumptions were made concerning the moisture relationship between the top and bottom liners that would result in “no warp.” Four assumptions for “no warp” differences between top and bottom moisture were tested. These were “no warp” with:

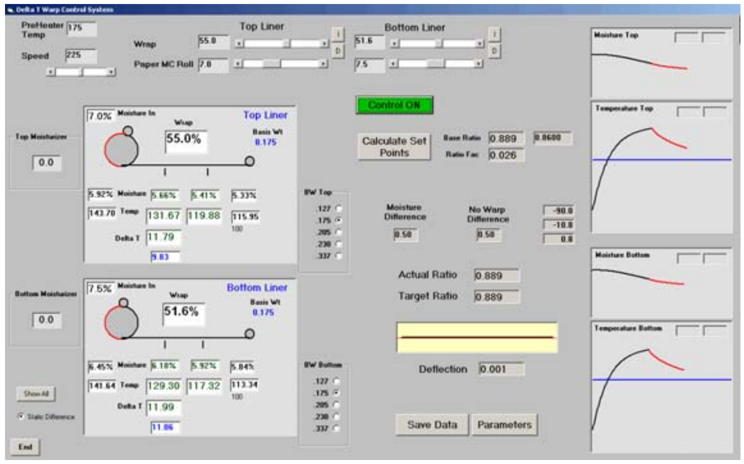
(1) The bottom liner moisture is 0.5% greater than top moisture.
(2). The bottom liner moisture is 0.7% greater than top moisture.
(3) The bottom liner moisture is 1.0% greater than top moisture.
(4) A varying difference based on the bottom moisture.

Data was gathered by running the simulation with varying incoming liner moistures and wrap arm positions. The wrap arms were adjusted to satisfy the assumption of a specific difference between the top and bottom liners and then the data was recorded. These data points would represent the ‘no warp’ conditions.

The ‘no warp’ data was analyzed and the Delta T principal was applied. There was an excellent relationship between the top and bottom delta t values during the ‘no warp’ conditions. An excellent relationship was found for all four “no warp” conditions (figure (7)). The initial test was made with the same liner on top and bottom. Additional test were made with two different liners and the results were the same. The control algorithms would be set up to maintain the relationship between the delta t values by adjusting the wrap arms.

The control algorithms were programmed into the simulation to test the automatic control of the wrap arms to maintain ‘no warp’ conditions. The error in the relationship between the top and bottom delta t values was used to initiate a control response. The basic scheme was to control the wrap arms in a way to maintain an equal distance from 50% warp. This would help to eliminate a preheater warp from reaching a minimum or maximum value too quickly. Another constraint is the minimum temperature required for gluing. Moisturizers could also be used to adjust moisture if needed.

Figure (8) – Simulation Program Screen Display



Conclusions and Recommendations:

It is commonly known that if the difference in the top and bottom liner MCs could be easily measured and controlled, a warp control system for virtually eliminating warp in the finished board might be a possibility. Based on work described above, we propose a warp control system based on a new, simple, non-conventional MC sensor for use in controlling the moisture of each liner.

This new CD warp control method can be supplied in the following listed packages:

1. If allowed, Integrate the Delta T warp system into an existing wet end control system.

2. A stand-alone Delta T warp control system.

References:

1. Robinson, John, “Improve Moisture Control,” *Chemical Engineering Progress*, vol. 88, no. 12, pp. 28-33,

2, US Patents 4, 701, 857 & 7,777,604

3. Robinson, John & Douglas, Roger, “Improve Moisture Control for Profit,” *The Process Engineer*, April 2005, 3 pgs.

4. Taylor, Bruce, “The Interaction of Paper Moisture and Temperature and its effect on Corrugated Board Quality,” *Corrugating International*, Vol. 1, No. 3, pp. 39-50.

5. ibid.

Rev. 12.5.2010