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A new criterion for "time to condition", with data on rapid conditioning of opened fibre assemblies

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SUMMARY

This report follows on from work reported at the Nice 99 meeting. It proposes a new criterion for determining time to condition in a much more precise manner than the current method. Use of this criterion will allow the use of both more realistic conditioning times, and in some cases, shorter times for routine work using rapid conditioning apparatus.

Additional data is presented on rapid conditioning of both clean and greasy fibres. It shows that increasing air velocity from 0.5 m/sec to 2 m/sec in rapid conditioning has only a small effect on reducing conditioning time from the dry side. However, it was found that conditioning from the wet side was significantly faster than conditioning from the dry side.

It is shown that fibres do not respond rapidly enough to changes in relative humidity, such that hysteresis becomes a factor in conditioning for diameter measurement. However, it is cautioned that the allowable cycling time in IWTO-52 should be re-examined.

INTRODUCTION

Over the last few IWTO meetings various papers have been presented to this and other groups on issues connected with conditioning of samples under IWTO-52. In consequence a small working group was established to examine some of the known and suspected problems related to conditioning.

One of the issues on which this author had carried out some preliminary work was the time to condition criterion, and a possible new criterion was offered to the Nice 99 meeting¹. This criterion was more cumbersome to apply than was deemed desirable, and the issue has been re-examined in this work.

Another issue tackled in the earlier work was whether the published regain-rh hysteresis relationship had any practical effect on diameter measurement. Whilst it was concluded that the effects on sample mass could not be readily detected under normal cycling of an airconditioning plant complying with IWTO-52, it was considered that there still appeared to be some unknowns in respect of the effect of relative humidity changes on the measurement of mean fibre diameter. This current investigation has therefore attempted to determine how fast individual fibres respond to changes in rh, and to determine the shape of the diameter-rh hysteresis curve.

¹ Some data on humidity-regain hysteresis and the possible influences on moisture equilibrium determination, P. Baxter, IWTO report SG03, Nice, Dec 1999

TIME TO CONDITION**Theory**

Previous work was based on empirical criteria. The current method in IWTO-52 is based on determining when the rate of mass gain diminishes to a specified rate, which was presumably judged to be a "practical" determination of stability. The paper referenced above, and earlier work by Treloar², showed that this criterion is inadequate, especially for anything other than loose fibre. Comments have also been made that the criterion is difficult to apply in practice because the very small increments in mass required to be determined close to equilibrium are often submerged in the statistical "noise". A new criterion suggested at the Nice 99 meeting was based on determining the shape of the moisture regain curve against time, and then using a relatively arbitrary difference (0.5% regain) from the long-time equilibrium regain as being the point at which time to condition would be determined. This method would, however, also be relatively clumsy to apply.

The previous paper tried to make use of the observation by Watt³ that first-stage absorption of water vapour follows Ficks law. However, plots of regain against the square root of time solely served to confirm that Ficks law is only obeyed in the initial stage of moisture absorption. The second stage process (called the "quasi-equilibrium" stage by Watts, but which may be 25% of the total), takes much longer, but may be the more important in terms of determining time to condition, especially for fibre assemblies at high relative density. Watts investigated an exponential relationship for the 2nd stage process and suggested that this was a reasonable approximation.

The absorption of moisture by a mass of fibres is not dissimilar to the problem of the rate of cooling of a body experiencing a sudden change in its environment (such as in quenching), in that the rate of change diminishes as the difference from a long-time equilibrium decreases. This problem can be approached from an energy-balance basis⁴, and if this is followed, an equation of the following form can be obtained:

$$(T - T_{\infty}) / (T_i - T_{\infty}) = \exp (-k.t) \quad \dots\dots\dots (1)$$

where: T parameter of interest at time t
 T_∞ parameter of interest at infinite time (equilibrium)
 T_i parameter of interest at start (t = 0)
 k a constant
 t elapsed time

Practice

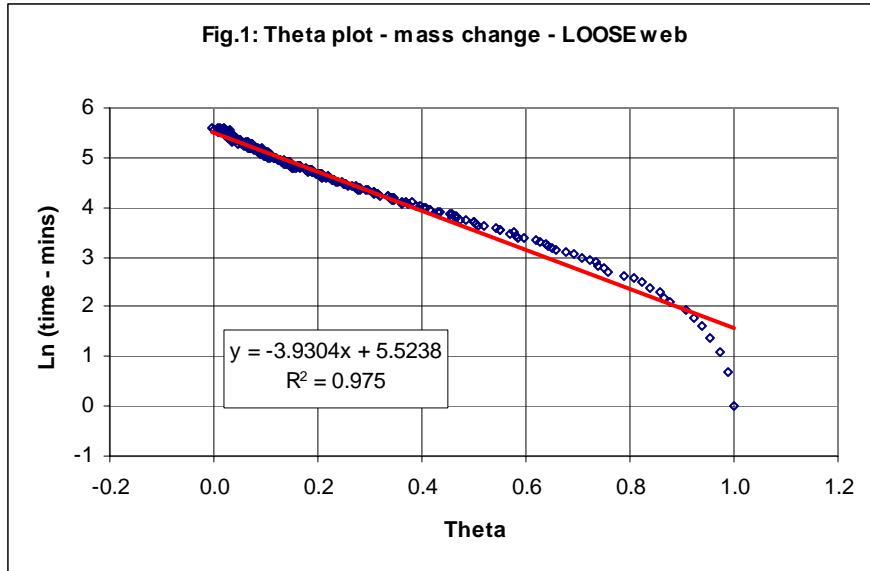
It can be seen that as T approaches T_∞ the left hand side approaches zero, which suggests a logical approach towards minimising the statistical noise referred to previously. In practice, if the natural log of time [ln(t)] is plotted against the left hand side of the above equation, which for convenience has been called θ [theta], then the intercept on the vertical axis is the point at which T = T_∞, or, in other words, when equilibrium has been reached. By using the linear regression option on a spreadsheet, this point can be accurately and rapidly determined.

The method was first tested against the regain data presented at Nice. An example of such a plot can be seen in Figure 1.

² Time intervals for achieving moisture equilibrium of wool samples in the standard atmosphere for conditioning, I.M. Treloar, IWTO report SG03, Florence, May 1999

³ Kinetic study of the wool-water system, Part 2, The mechanics of two stage absorption, I.C. Watt, Text. Res. Jnl., 1960, 30, 644

⁴ Fundamentals of heat transfer, F.P. Incropera & D.P. de Witt, John Wiley & Sons, 1981, 181



The two-stage nature of the regain process can be clearly seen in the plot. In order for this procedure to be used it is necessary to restrict the range of the plot to the 2nd stage. This is effectively for θ values between 0 and 0.85. If too many points are included before the 2nd stage is established, or after stability is achieved, the regression becomes biased due to 1st stage curvature and noise respectively. This procedure was used on the examples shown at Nice, with the outcomes shown in Table 1:

Table 1: Comparison of times to condition for various sample configurations

Configuration	Packing density (kg/m ³)	Time to condition (hrs)		
		IWTO-52	Nice 99	“Theta”
Loose fibre	7	2.7	7.3	4.0
Shirley web	28	3.8	8.3	9.0
Scoured log	65	7.1	31.2	29.7
Yarn – loose	25	3.3	6.2	8.2
Yarn – tight	337	5.9	39.5	17.6
Woollen cloth	151	6.5	35.1	38.1
Worsted cloth	183	5.0	38.8	39.7

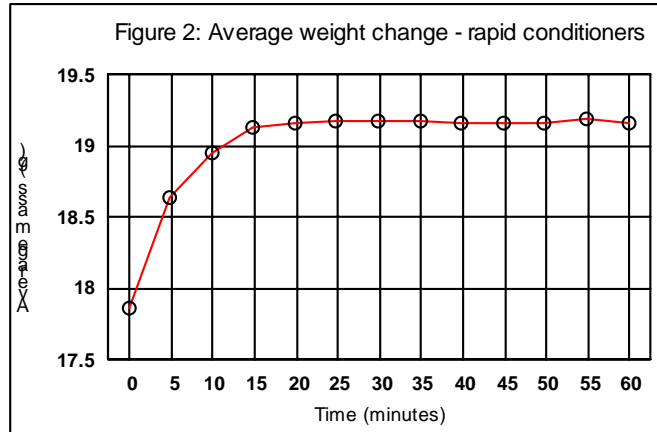
With the exception of the loose fibre (for which 4 hours accords more with expectation), and the tightly-wound yarn, the time to condition figures obtained with the new method agree well with those obtained by the slightly more cumbersome method proposed in Nice 99. These two exceptions are due to imperfections in the original data sets, and the rather arbitrary nature of the 0.5% criterion chosen in the Nice 99 paper.

Rapid conditioning

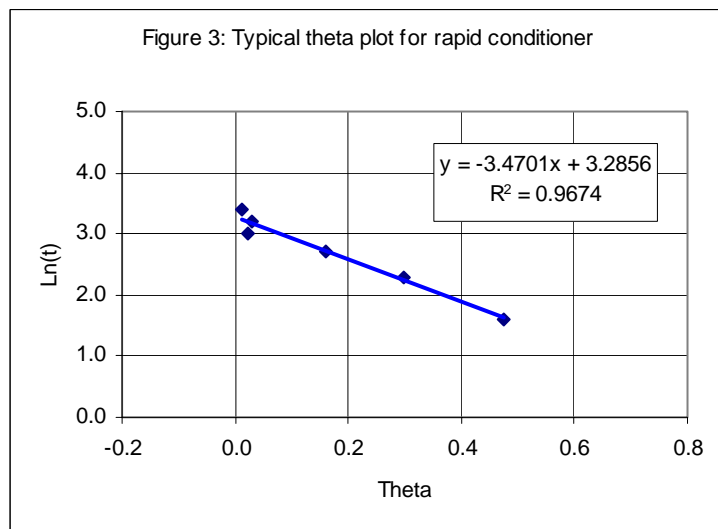
It had been reported that the current IWTO-52 time to condition criterion was difficult to use with rapid conditioners (method D). One of the issues is that the conditioning time is relatively short, and it is necessary to reduce the sampling frequency from the stipulated 15 minutes in clause 6.1. The most rapid frequency with which a team can sequentially remove, weigh and replace the requisite number of samples (20) is of the order of once every 5 minutes, as indicated in clause 7.2.4 (c). With some devices the samples appear to have almost reached equilibrium in 15 minutes or so, but the normal statistical fluctuations in the masses of the samples may mean that the criterion will be satisfied for individual samples over a wide range of times. It is not uncommon to find that in one 5 minute interval the sample

mass has lost 0.05%, and then in the next has apparently gained 0.1%, and then in the next it is stable and so forth. In practice this introduces a significant uncertainty in determining the end point, and may mean that the standard deviation of the time to condition is relatively high compared with the mean. This problem is compounded by the need to assess final stability over a 15 minute period. The net result is that the “standard exposure time”, when the standard deviation, multiplied by 3.5 times is added to the average, may appear quite excessive compared with what can be seen by plotting the mean mass gain curves.

A set of rapid conditioning data was examined to compare the current criterion against the proposed new criterion. Figure 2 shows the average mass gain curve for 100 determinations:



On average the samples seem to achieve equilibrium in 20 minutes or so. However, when the mean and standard deviation are taken into account, the standard exposure time required for this data set on this equipment was actually 102 minutes. The same data was used to test the new criterion. A theta plot for a typical sample is shown in figure 3:



It may be observed that the intercept is 3.2856, which is equivalent to 26.7 minutes in this particular case. If this process is carried out for all the samples, the comparative statistics in Table 2 are obtained:

Table 2: Comparison of IWTO-52 with new criterion, for rapid conditioner data

	IWTO-52	“theta”
Average time to condition (mins)	48.8	20.6
Standard deviation (mins)	15.3	6.7
Standard exposure time (mins)	102.4	44.0

Intuitively the average value of 20 minutes makes sense when one looks at figure 2. By using a graphical process to determine the time to condition for each sample, where each measurement makes a contribution to the precision of the answer (rather than just a single interval, as with the current method in IWTO-52), the overall SD is significantly reduced. The reduction in SD is precisely what one may expect, given that the average number of points plotted in the theta graphs is about 5 ($\sqrt{15.3^2/5} = 6.8$). The reduction in standard exposure time is both significant and of benefit in a commercial laboratory.

RATE OF CONDITIONING

On reviewing Tables 1 and 2, and comparing the conditioning times for Shirleyed web (8 or 9 hours for this particular sample by the conventional method, and 44 minutes using a rapid conditioner), one is tempted to question the limiting rate at which fibres may be conditioned. It should be noted that in Table 1 the data was obtained on individual samples. In practice, once the procedure had been carried out on 100 samples as required by IWTO-52, the standard exposure time for conventionally exposed samples would be of the order of 24 hours in this particular environment.

We should note at this point that the air velocity over the samples under conventional conditioning in this laboratory was less than 0.05 m/sec, and for rapid conditioning was on average 0.5 m/sec. Clearly air velocity has a very significant effect on the rate at which samples can be conditioned. However, further investigation along this line of reasoning becomes difficult when mass is used to determine time to condition, since there is a limit to how rapidly and precisely one can weigh a sample, especially in an environment with high air velocities.

The OFDA 2000 instrument offers another viewpoint. The purpose of determining standard exposure time is, in many commercial core test laboratories, primarily in order to determine the time required to expose samples for diameter measurement, since this is one of the principle precise measurements which is heavily influenced by the conditioned state of the sample. The OFDA 2000 instrument allows us to expose samples to high air velocity whilst measurement of diameter is in progress, and therefore gives us direct access to the required information. The only limiting factor is the time required to scan a slide, which, in this case, can be approximately 30 seconds. The calculation of time to condition can be the same as has been proposed above, with mean fibre diameter being used instead of mass or regain.

A series of experiments was set up to examine the rate of conditioning under high velocity airflow. In the work that follows, when a fan was used, the air velocity over the fibre sample was in the region of 1.5 to 2.0 m/sec. During most of these experiments the conditioning atmosphere RH was measured using an independent calibrated RH probe situated in close proximity to the sample.

Method and samples

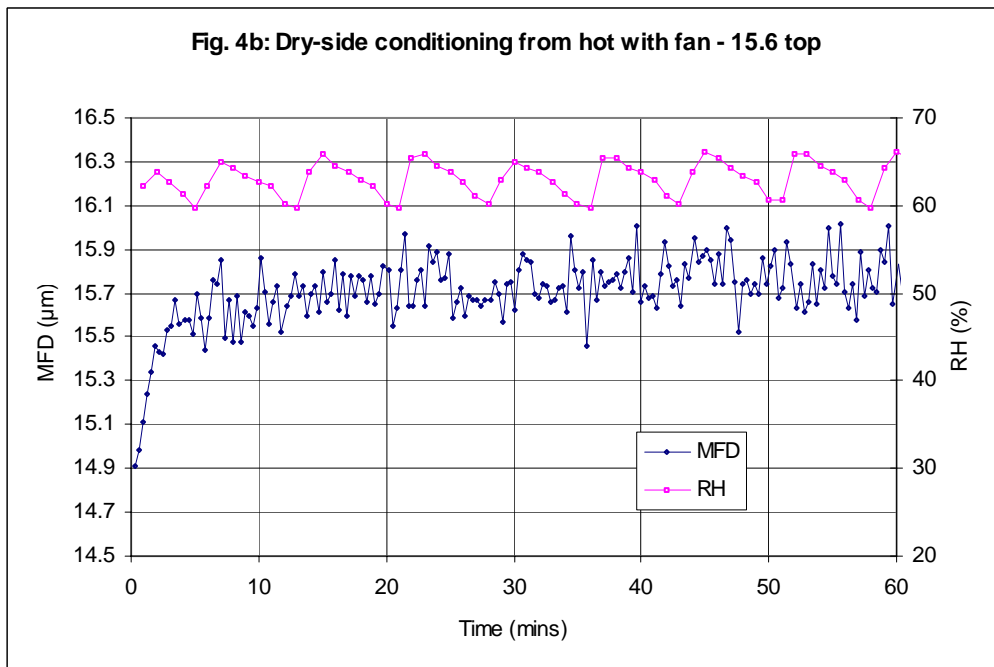
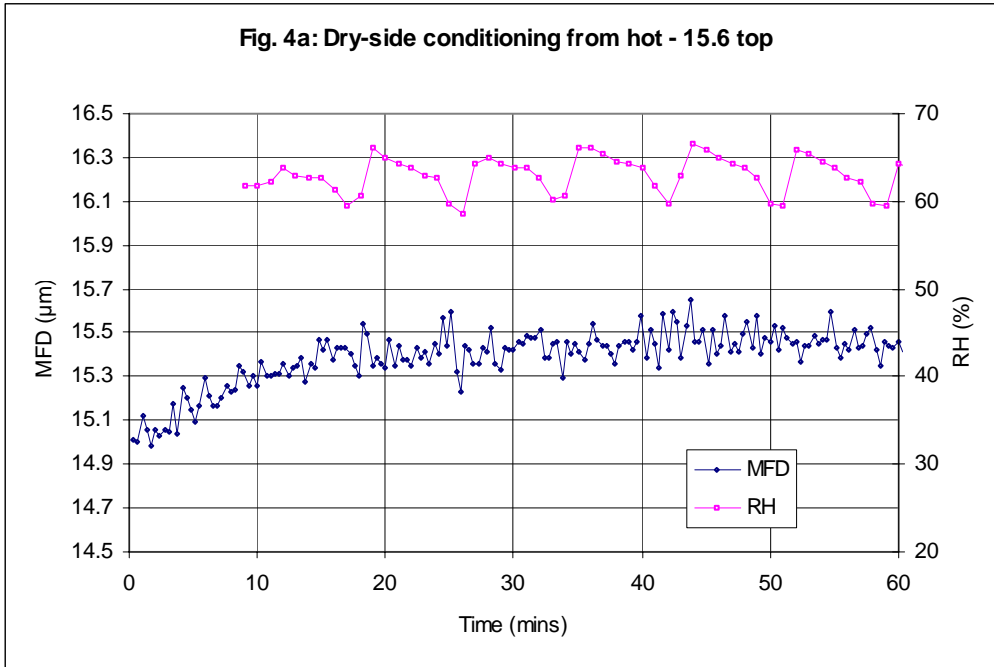
Investigations were initially carried out using two tops and two greasy samples, each of which were extremes on the diameter scale (nominally 15.6 and 37.4 μm tops and 16.5 and 34.5 μm greasy samples). Extremes are useful in this type of investigation because they allow immediate identification of real versus interfering effects, although the consequence is that the effects found may be exaggerated when compared to normal conditions of use.

For each of the samples, the same prepared specimen was kept in the wire slide whilst it was pre-conditioned by either drying in a fan-assisted oven at 105 °C for 15 minutes, or left sandwiched between two saturated tissues (which did not contact the fibres). Initial experiments had shown that cooling the samples in a desiccator before placing on the instrument was not a reliable method for ensuring a "dry" starting condition, since the fibre mass was so small that even a small amount of water vapour encountered in the transfer processes was sufficient to be absorbed during the cooling. Most of the "dry" starting condition specimens were taken from the oven hot, immediately placed in a polythene bag and transferred as fast as possible whilst hot to the instrument. The "wet" specimens were easier to transfer with minimal delay.

Two air movement conditions were investigated in each case. Half of the measurements were carried out with the instrument in a corner of the air-conditioned room where air movement was detectable but not strong (less than 0.05 m/sec). For the other half of the measurements, the sample preparation fan supplied with the instrument was mounted within 150 mm of the slide and directed to blow across and down into the slide at an angle of about 45°. This provided substantial airflow across the fibres during measurement, but not enough to cause significant disturbance to individual fibres.

Nevertheless, it was still difficult to ensure a completely “dry” or completely “saturated” specimen on first reading. The difficulty of determining the initial condition becomes immediately apparent on studying some of the subsequent plots. When one bears in mind that the first complete sample measurement took between 20 and 35 seconds, and that in some cases much of the subsequent moisture content change took place over the course of the first few measurements, it should be clear that the initial conditions were always imprecisely known. This is illustrated in figure 4.

Figure 4: Typical conditioning curves for mean fibre diameter, at low and high air velocities



Results

The data was used to generate “theta” plots and thereby establish the time to condition for each specimen. The results are summarised in Table 3.

Table 3: Comparisons of time to condition for low and high air velocities

Sample	From	Fan	Finish RH	MFD			linear theory	RWG03 Dec-99	plus hysteresis	Theta plot		T to C mins
				start	finish	diff.				slope	const.	
15.6 top	dry	no	59	15.01	15.43	0.42	1.00	0.7	0.7	-2.64	3.08	21.7
	dry	yes	65	14.91	15.78	0.87	1.13	0.7	0.7	-3.12	2.44	11.5
	wet	no	63	16.59	15.83	0.76	0.64	1.3	1.1	-3.50	2.41	11.1
	wet	yes	65	16.78	15.82	0.96	0.61	1.3	1.1	-1.55	0.68	2.0
37.4 top	dry	no	60	36.17	37.91	1.74	2.50	2.3	2.3	-3.02	3.80	44.6
	dry	yes	63	36.10	38.26	2.16	2.65	2.3	2.3	-2.65	2.60	13.4
	wet	no	58	42.76	38.57	4.19	1.78	3.3	2.9	-3.70	2.68	14.6
	wet	yes	66	42.35	38.83	3.52	1.45	3.3	3.0	-1.48	0.79	2.2
overnight	wet	yes	69	43.19	37.93	5.26	1.29	3.2	2.9	-1.97	1.26	3.5
superfine greasy	dry	no	65	15.64	16.30	0.66	1.17	0.7	0.7	-3.06	2.70	14.9
	dry	yes	61	15.65	16.37	0.72	1.10	0.7	0.7	-2.05	1.19	3.3
	wet	no	65	19.05	16.74	2.31	0.64	1.3	1.2	-3.27	2.13	8.4
	wet	yes	59	19.01	16.81	2.20	0.76	1.3	1.2	-2.26	1.01	2.7
crossbred greasy	dry	no	65	33.27	34.55	1.28	2.47	2.1	2.1	-2.39	3.38	29.4
	dry	yes	63	32.80	34.23	1.43	2.37	2.1	2.1	-1.97	2.10	8.1
	wet	no	65	41.39	35.74	5.65	1.38	3.0	2.7	-3.35	3.09	22.1
	wet	yes	61	39.78	34.45	5.33	1.48	2.8	2.5	-2.90	1.53	4.6
overnight	wet	yes	69	44.72	36.16	8.56	1.23	3.1	2.8	-4.52	3.90	49.6

Several aspects of Table 3 require explanation. The column headed "linear theory" indicates the change anticipated between the starting diameter and the equilibrium diameter assuming that wool swells or shrinks at a constant rate of 0.11% per %RH. Whilst this general rule of thumb has been confirmed by Edmunds and Ranford⁵ in the range from 50 to 75% RH, it seems less applicable beyond these limits, and in general terms the rate of change is not constant over any of the range. The next column "RWG03, Dec-99" refers to the Edmunds and Ranford report, and to ratios taken from the raw data used in that report (supplied courtesy Ranford). The average ratios from dry to 65%, and from 65% to saturated were found to be relatively similar in that report for a range of diameters. The next column "plus hysteresis" attempts to correct for the fact that the RWG03 data was all obtained on the absorption curve, whereas in practice, the 'saturated to 65%' condition change relies on desorption. The WIRA data referred to by Edmunds & Ranford suggests that the desorption curve for wool lies about 2% higher in sample regain for any given RH in the middle of the range. In the region of 65% rh, this 2% regain gap is approximately equivalent to a 10% difference in RH. An allowance of 1% of the final MFD has been taken off the RWG03 difference for the wet-side estimates. The two columns headed "Theta plot" refer to regression parameters from the conditioning diagrams, and the last column shows the time to condition in minutes calculated from this diagram.

Two rows are also worthy of mention – entitled "overnight" in the first column. The crossbred greasy sample was inadvertently left under wet tissue overnight before its last set of measurements (with fan), and the corresponding behaviour of the sample was quite different to what was expected. To examine this behaviour, a slide of the 37.4 top was also left under wet tissue overnight to establish whether it performed in a similar manner, which it appeared not to. It has been suggested that the difference in behaviour may be related to the moisture absorption/desorption characteristics of the grease/suint coating.

General Observations

Table 3 contains a lot of information. Simply considering the time to condition column, it is clear that it took longer to condition from the dry side, and that, even at this very low density, conditioning from the dry side remained a relatively slow process without the use of a fan. By using the fan, shorter conditioning times were achieved with fibres in this open condition. As noted above, samples at approximately 25 kg/m³ require conditioning for 24 hours at low air velocities (<0.05 m/sec), but this can

⁵ Conditioning effects on fibre diameter and curvature of the 12th series of IH tops, A.R. Edmunds & S.L. Ranford, IWTO report RWG 03, Nice, Dec 1999

be reduced to 40 minutes or so at moderate air velocity (~0.5 m/sec). Here samples at below 5 kg/m³ were conditioned from the dry side in about 10 to 13 minutes at an air velocity of ~2 m/sec. However, this might equate to not much less than about 30 minutes standard exposure time if the mean plus 3.5 sd criterion were applied. It could be concluded that little is to be gained in increasing the air velocity above approximately 0.5 m/sec. An interesting point is that samples brought from the wet side appeared to equilibrate in a matter of 2 to 3 minutes at an air velocity of 2 m/sec.

Some further general relationships can be summarised in Table 4:

Table 4: Comparisons of theory and practice relating to conditioning hysteresis

Differences	wet-dry hysteresis	theory @8%	dry>eq	rwg03	wet>eq	rwg03
15.6 top	0.19	0.14	0.6	0.7	0.9	1.1
37.4 top	0.59	0.33	2.0	2.3	3.9	2.9
superfine greasy	0.44	0.14	0.7	0.7	2.3	1.2
crossbred greasy	0.70	0.31	1.4	2.1	5.5	2.7
coarse overnight	0.81	0.32			6.9	2.8

The apparent differences between starting and the equilibrium condition on approaching from the dry side, and on approaching from the wet side, were in all cases greater than the simplified assumption of an 8% rh equivalence (columns 2 and 3)

The differences between the “dry condition” and equilibrium at 65% rh were, for both the tops and greasy wool, similar to expectation from the Edmunds & Ranford data (columns 4 and 5). Whilst the figures determined in this work are lower than those determined by the latter, this may be attributed to the noted difficulty in measuring the starting condition sufficiently rapidly.

With the exception of the 15.6 top, the differences between “wet” and equilibrium were in excess of the figures obtained on the OFDA 100 at WRONZ. The discrepancies appear to be greater with the greasy wool. The differences were exacerbated when the fibre was left exposed to moisture overnight.

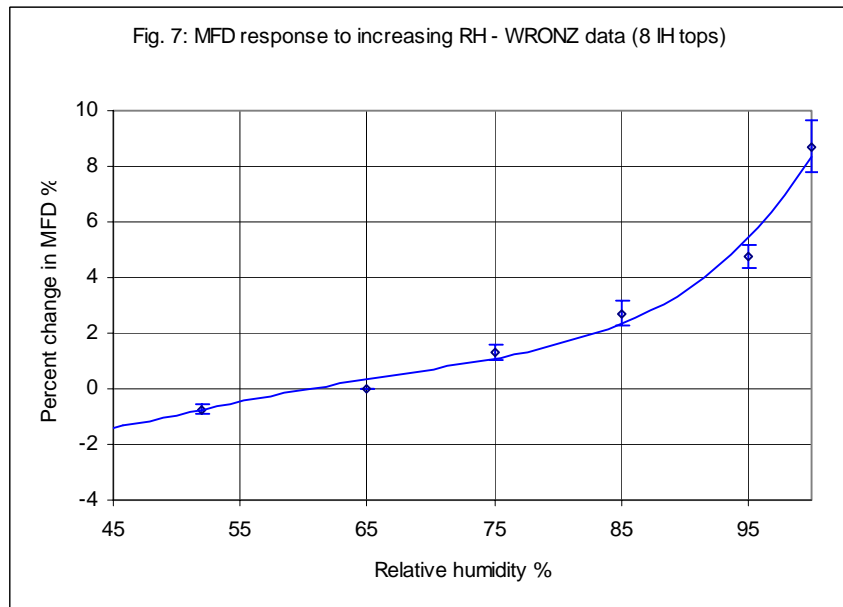
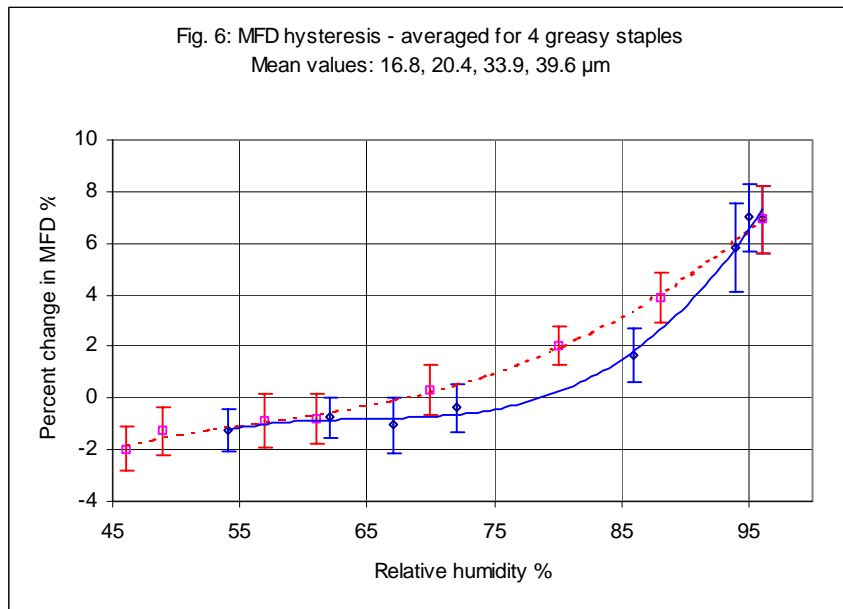
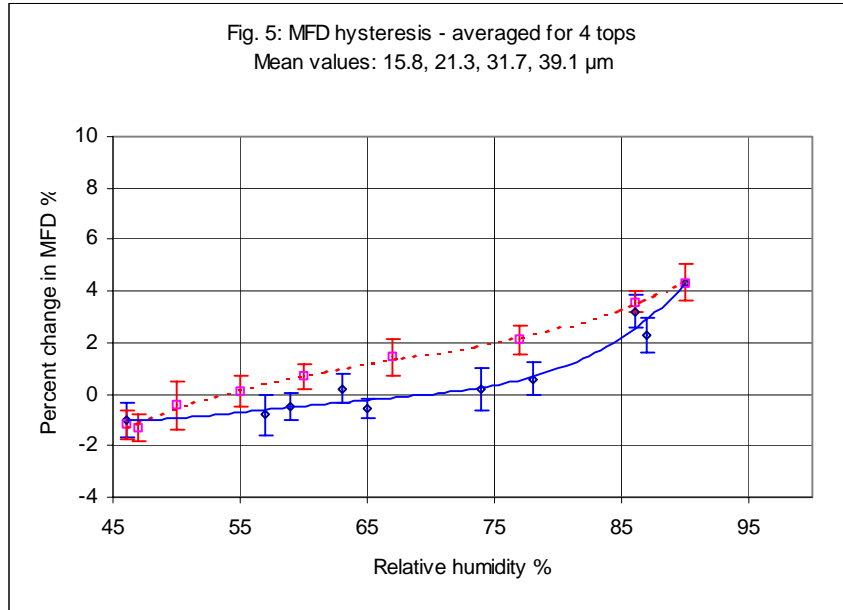
DETERMINATION OF DIAMETER-RH HYSTERESIS CURVES

This data suggested that better understanding was required of the shape of the diameter-rh hysteresis curve, and prompted an investigation under changing conditions of humidity. The author did not have access to an environmental chamber, and therefore the range of relative humidity values that could be achieved was limited to between 40% and approximately 95%.

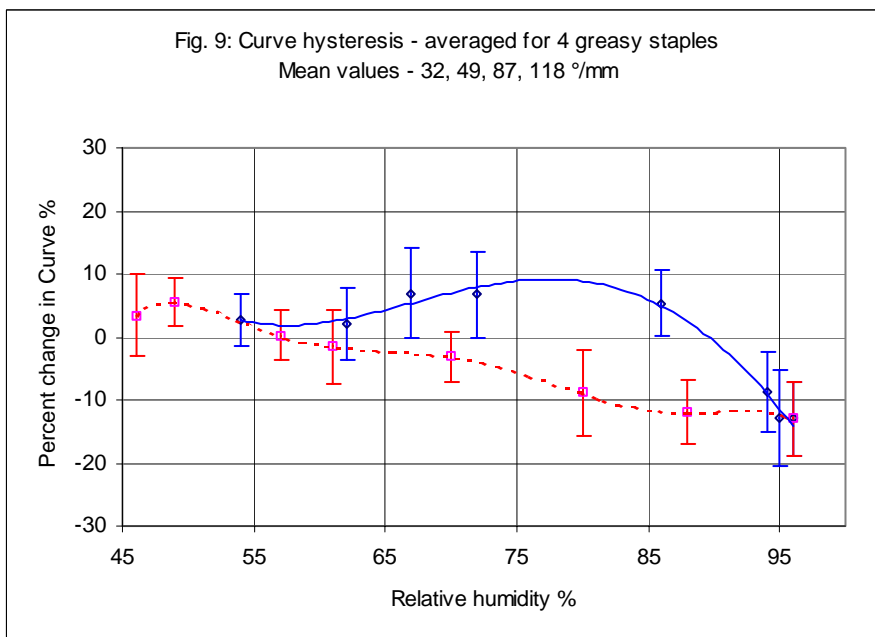
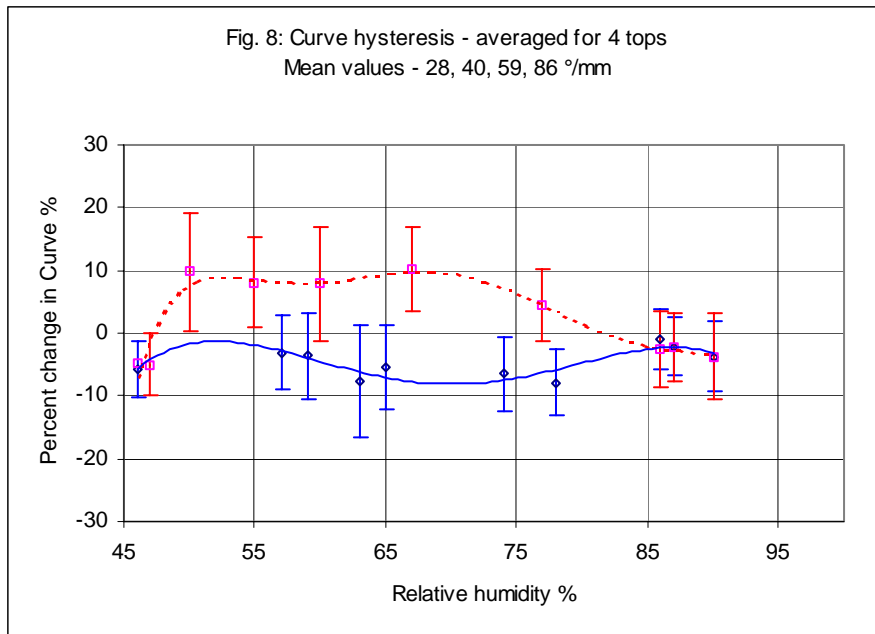
For this work, 4 specimens were mounted on one OFDA 2000 slide. A special routine was made available to allow all 4 specimens to be measured as separate samples. The relative humidity of the room was changed by utilising an humidifier, a steam generator, and an airconditioner. Two experiments were carried out using 2 sets of specimens – 4 tops covering the range 16 to 39 µm, and 4 greasy staples covering a similar range.

The results indicated that the diameter change data from all 4 specimens could be combined if the changes in diameter were normalised using the mean fibre diameter of each specimen.

Figures 5 and 6 show the hysteresis curves obtained for tops and for greasy wool respectively, and figure 7 allows comparison with the data obtained by Edmunds and Ranford on IH tops on the OFDA 100 instrument. In all cases the error bars represent the standard deviation of percentage diameter change values at each rh level (i.e. across all 4 specimens in each case). In figures 5 and 6, the lower curves are for increasing relative humidity, whilst the dotted lines show the desorption phase.



Out of interest the same analyses were carried out for mean curvature. Unfortunately the equivalent raw data was not available from the WRONZ investigation. Figures 8 and 9 show the response of mean curvature to relative humidity cycling for tops and greasy wool.



No immediate explanation presents itself for the differences between the two plots, nor for the tendency of these tops to retain their curvature with increasing relative humidity. Figure 3 of the Edmunds & Ranford report shows a very clear reduction in mean curvature as the rh is increased.

DISCUSSION

A new criterion is suggested for determining time to condition for methods C and D in IWTO-52. It allows the time to condition for individual samples to be estimated much more precisely than the current method, and this gives significant benefit when using these methods since imprecision penalises the standard exposure time. A draft of an example procedure is attached as it would apply to Appendix D.

It appears that there is a limit to which the time to condition can be shortened. Even with a very low fibre density and a high air velocity, the conditioning time could not be much improved over that obtained with standard rapid conditioning equipment, with air velocities of the order of 0.5 m/sec. However, it was

observed that much more rapid conditioning could be achieved from the wet side, (with the single exception of greasy wool left exposed to moisture for an extended period).

Whilst the diameter-rh hysteresis curves obtained are consistent with known facts concerning the differences between wet- and dry-side conditioning, they do not completely answer the question as to whether these would play any part in affecting diameter measurements during 'normal' cycling of a conditioning plant. It has previously been suggested⁶ that the combined effects of humidity cycling and hysteresis could lead to "creep" of the equilibrium regain. None of the data obtained in this and the previous investigation suggests that this would be the case, but it should be noted that the cyclic variation in the environments used in these investigations took place over about 8 to 10 minutes, rather than the 30 minute period mentioned in Appendix B1 of IWTO-52.

Whilst wet-side conditioning was very rapid under a high air-velocity regime, under the normal air velocities encountered in conditioning rooms, the rates of response of the fibres to small changes in relative humidity appeared to be relatively slow (as compared to our plant cycling time of 6 or more times an hour). For example, there is no evidence of cyclic behaviour in the diameter-time plot in figure 4, or in any of the other diameter-time plots, and a fourier analysis of one of these responses showed no identifiable time-dependent reaction.

Watt's paper³ has some relevance in this regard. It was observed that hysteresis did not seem to occur whilst a sample was in the first stage of conditioning, but once a sample is in the second stage and close to equilibrium, hysteresis was displayed if the humidity was reduced. The amount of hysteresis appeared to be related to the size of the humidity step. Samples exposed to even small negative humidity gradients tried to accommodate to the changed condition relatively rapidly, but the time to do so was still a matter of minutes even at the elevated temperatures used in this work (35 and 50 °C).

It may be surmised that humidity hysteresis in wool may be similar to mechanical hysteresis, in that the size of the hysteresis gap generally increases as the forcing function amplitude is increased. Watt surmises that 2nd stage absorption "is consistent with a relaxation mechanism involving the rupture of interchain bonds to allow the decay of swelling stress caused by the entry of water into the fibres during the first stage of absorption". If this were the case, then initial desorption occurring after the 2nd stage of absorption would be the Fickian response, as his plots suggest, leaving the fibre with residual strain attributable to these ruptured bonds. Within the regain range of interest, the size of the 2nd stage remains proportional to the size of 1st stage absorption, and therefore for small changes in regain or humidity, it would be logical to assume that the size of the hysteresis loss would be smaller.

If this is the case, the expected hysteresis amplitude for conditioning rooms complying with the standard should be much smaller than the extreme cases of wet-dry comparisons illustrated by this work. Nevertheless, it may be prudent to tighten the 30 minute allowable cycling period in the standard, since, as the cycling period increases, there is more opportunity for the wool to keep pace, depending, of course, on it's packing density and airflow regime. It was observed in the work reported at Nice (figure 4, report SG 03) that regain cycling was observable with very low density fibre assemblies even on a 10 minute environmental cycle. Storey⁶ noted that creep, of the order of 0.7% regain, was observed in the Torriden humidity room, although the cycling period was not reported.

ACKNOWLEDGMENTS

Thanks are due to S. Ranford for the detailed data from the Nice 99 report RWG03. The assistance of BSC Electronics in providing modified software, and Wool Technologies Pty Ltd in loaning the OFDA 2000 instrument are gratefully acknowledged.

⁶ The influence of prior treatments on the moisture absorption of wool, L.F. Storey, WIRA Bull., 1945, 10, No. 3, 33

APPENDIX – PROPOSED AMENDMENTS TO TIME TO CONDITION CRITERIA

Section 6 could be deleted, with the criteria specifically defined in each method.

For **methods A and B**, some initial suggestions were made by Treloar⁷. Referring to Table 1, a simple final weight criterion could be based on a change of not more than 0.1% in 1 hour for densities up to 50 kg/m³, and 0.1% in 4 hours for densities above 50 kg/m³.

Methods C and D would follow similar formats. The example text below is a replacement for sub paragraphs (c) through (e) in method D. The **note** is retained.

For application to method C, it would only be necessary to supply a different definition for the final weight, and it is suggested that the criteria for methods A and B be used. (i.e. replace the second sentence in the first paragraph below with: Weighing shall be repeated until 2 weighings at least 1 hour apart for densities up to 50 kg/m³, or 4 hours apart for any greater density, show an increase in the mass of the sample of not more than 0.1% of the last recorded mass.)

The samples shall be weighed immediately after preconditioning (W_i), and thereafter at 5 minute intervals. The time of exposure (t) shall be recorded for each weighing. Weighing shall be repeated until 2 weighings at least 15 minutes apart show an increase in the mass of the sample of not more than 0.1% of the last mass recorded.

For each weight recorded whilst the sample was exposed (W), calculate the parameter θ from the initial weight (W_i) and the final weight (W_f) as follows:

$$\theta = (W_f - W) / (W_f - W_i)$$

For each recorded weight calculate the natural logarithm of exposed time, $\ln(t)$.

For each sample, plot $\ln(t)$ against θ for values of θ less than 0.85 and until the first value of zero is encountered. The plot should be almost a straight line. Either draw a best-fit straight line on the plot, or calculate the linear regression. In either case, record the intercept C on the $\ln(t)$ axis (for $\theta = 0$), and convert this back to a time to condition in minutes, by calculating the exponent, e^C .

Calculate the average (T) and standard deviation (s) of the time to condition for all samples. The standard exposure time (SET) is calculated as follows:

$$SET = T = 3.5 s$$

⁷ Time intervals for achieving moisture equilibrium of wool samples in the standard atmosphere for conditioning, I.M. Treloar, IWTO report SG 03, Florence, 1999