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INFLUENCES ON COMPARISONS BETWEEN THE MEAN FIBRE DIAMETER OF WOOLS MEASURED BY AIRFLOW AND BY PROJECTED IMAGE METHODS

B. P. Baxter
SGS Wool Testing Services

SUMMARY

Different methods of measuring the mean fibre diameter of wool samples utilise different physical principles, and therefore sometimes give different but equally valid results. This paper summarises the important measurement principles in the airflow and projected image methods, and discusses, through a review of published information, the differences which may arise due to the influences of fibre properties, diameter distributions, test methods, and the apparent effects of type of wool or source animal. The paper concludes by suggesting that corrections can be made for some effects, but that in general, more recognition must be given to the likelihood of valid and significant differences in many comparison situations. It is also recommended that some factors need to be further investigated.

1. INTRODUCTION

The airflow method[1,2] of measuring the mean fibre diameter of wool is relatively easy to perform, economical, and widely adopted and standardised in wool producing and consuming countries other than the Americas. Many people in the wool trade incorrectly assume that it is the standard method, whereas, in fact, it is a derived or secondary method.

The projection microscope method[3] of measuring mean fibre diameter (and diameter distribution) is a fundamental method traceable to international metrology standards. It is, however, a cumbersome and expensive method, and is not now widely used outside the American market. Consequently there have been searches for alternative but similar methods using modern technology. A number of instruments and test methods have been developed which utilise some automated method of measuring projected images, including the PiMc[4], FDA[5], FIDAM[6], and OFDA[7]. (The FDA, and its more recent successor, the Sirolan Laserscan, do not, strictly speaking, measure projected images, but rather characteristics of a diffraction pattern produced by fibre snippets in a laser beam[8].)

Because of the prominent position which the airflow method occupies in the trading of raw wool, new test methods for mean fibre diameter are compared to this method, even though the comparisons are sometimes inappropriate. In general terms there is good agreement between the airflow and projected image methods for the majority of wools, but in individual cases there may be differences in mean fibre diameter of several micrometres. This paper outlines some of the reasons why the airflow and projected image methods often give quite different although equally valid results.

2. BASIC PRINCIPLES OF THE TEST METHODS FOR RAW WOOL

In the airflow method, greasy wool cores are prepared by blending, scouring, drying, carding and blending, and conditioning in a standard atmosphere. Specimens of precise mass are then placed in a chamber of precise dimensions, and air is forced through the packed mass of fibres. The airflow value is determined by the resistance to flow (in the case of raw wool, by measuring the flow rate at a standard pressure).

Fundamentally the airflow primarily measures specific surface - the amount of fibre surface area per unit mass. The method is therefore indirect, and airflow instruments must be calibrated using wools of "known" diameter. Even though they are calibrated with Interwoollabs International Harmonisation (IH) tops on which there are projection microscope values determined by international round trials, the IH values used for calibration are actually the results of round trial airflow measurements on these tops - so the calibration method is not traceable to international metrology standards in anything other than a loose manner, and is fundamentally somewhat incestuous.

Airflow measurements are therefore indirect and the results can be influenced by different shape factors and packing geometries within the instrument produced by different types of wool. This is especially true when the characteristics of the wool being measured diverge significantly from the characteristics of the calibration wools. The method relies on most wools of similar diameter being otherwise similar, and having diameter distributions which are approximately normal, and which follow the type of general relationship originally proposed by Ott[9] and subsequently explored on a number of occasions by other authors (see Bow & David[10] for a recent review). (Ott proposed a classification of wools based on an empirical correlation between standard deviation and mean fibre diameter, determined on a large number of commercial top consignments). In general terms this is reasonably satisfactory. However, some wools have "abnormal" fibre densities, cross sectional shapes or surface characteristics (eg. lambswool, and medullated wool, which are both mentioned in the standards as unsuitable for measurement by the airflow), and other wools have between-fibre variation which differs significantly from the Ott relationship (a notable example being the 1991/92 33.5 IH top, which has a coefficient of variation more than 2 % away from the Ott line). So wools with fibre characteristics and diameter distributions away from the "norm" will give different results on the airflow.

In the projection microscope method, raw wool core samples are again blended, scoured, dried, and conditioned, and small representative specimens taken, from which short snippets can be cut with a microtome. The snippets, of average length 0.4 to 0.8 mm in the current version of the test method, are spread on a microscope slide with a mounting fluid (oil). The slide is placed in a projection microscope, and the width of at least 400 to 1000 randomly selected projected images of the snippets are measured at a magnification of 500X. The magnification is calibrated by standard optical methods (using a reference graticule slide), and it can therefore be seen that the method relies only on simple principles of metrology, although in practise the method is known to be significantly operator-dependent, because of difficulties in consistently and accurately identifying the image boundaries.

Whilst the mechanism of producing and measuring projected images may vary in the other automated instruments mentioned above, the basic principle of carrying out many width determinations on individual randomly selected projected fibre snippet images, is similar in each case. In the FDA or Laserscan, the fibre snippets are dispersed in an alcohol-water mixture and pumped past a laser beam. The degree of occlusion of the laser beam within a fixed image area is used to calculate the diameter of each snippet. In the FIDAM and OFDA, the snippets are dispersed in air over a glass slide, which is then moved under a microscope with an attached video camera. Image analysis software is used to automatically identify fibre snippets and to measure them across their diameter. The PiMc system is not now used commercially, but the snippets were again presented on a glass slide, but dispersed in alcohol, and their diameters were calculated after an operator individually identified each snippet image on a monitor.

3. INFLUENCES OF FIBRE PROPERTIES

The following properties of the wool fibre have an effect on the comparisons between airflow and projected image methods: specific gravity, crimp, ellipticity, and possibly scale geometry.

3.1 Specific gravity

The behaviour of a fluid passing through a packed mass of particles can be modelled mathematically by the hydrodynamic equations of Kozeny[11], and others have subsequently extended the model to cover airflow through fibres as a means of measuring diameter (see Cassie[12] for an early application to wool). The equation for airflow includes the variables of plug porosity, pressure drop across the plug, the viscosity of air, the specific surface of the fibres, and a dimensionless shape factor[13]. (Other variables are normally fixed for a particular design of apparatus - length and cross-sectional area of the plug.) Of these, the specific surface is the property assumed to be measured. If a fixed mass of fibre is placed in the instrument, as in the test methods referred to, the porosity of the plug is also dependent on the specific gravity of the fibres. This effect is quite significant, with a 1% change in specific gravity giving a 2.5% change in mean fibre diameter, and indeed Cassie used the relationships to examine variations in wool fibre densities. At the time this work was carried out, a 2.5% variation in diameter was considered tolerable, but now a variation of 0.5 microns on a mean fibre diameter of 20 microns is not considered acceptable.

One obvious source of significant specific gravity variation is medullation.

3.2 Crimp

The effects of crimp on airflow measurement have not been discussed to any great extent in the literature. Kritzinger et al.[14] determined that there was an effect and that it was different at different diameters, but that it was not of practical importance in terms of a proposed method of correcting airflow measurements. Unfortunately, from the reference quoted it is not clear as to what the magnitude of the effect was - the regression ANOVA's simply indicate that it was a detectable effect. However, what was of little practical importance in 1964 bears no relationship to what is of commercial importance in the 1990's. Crimp has also been recognised as an important variable in the relaxation behaviour of wool structures such as yarn[15], and by extension of this concept it can be seen that it may have an important effect where comparisons are made between wool samples which have suffered different processing routes prior to measurement. This has been shown in a number of investigations (see section 5.6) which have demonstrated that significantly different airflow values may be obtained on certain wools if the samples are put through a relaxation process, although the connection with crimp has not been formally established.

In terms of projection microscope measurements this parameter has also only been cursorily examined, as far as this author can ascertain. There have been many papers published concerning the effects of fibre ellipticity on the results of projection microscope measurements (see below), but few make more than passing reference to crimp. Rossouw[16] showed that on Merino, NZ Romney, and NZ Corriedale fibres the major elliptical axis twisted along the fibre almost in phase with and at the same frequency as the fibre crimp. These findings were confirmed by Collins & Chaikin[17], and are apparently in accordance with similar results on human hair. Edmunds[18], in a recent detailed analysis of the ellipticity effect, connects different rates of change of fibre twist with breed, but it is feasible that the breed could also be a reflection of different crimp frequencies.

It is conceptually clear that if the length of a fibre snippet is less than some small proportion of the crimp wavelength, such a snippet will tend to lie on a glass slide with its major axis parallel to the surface of the slide, and will therefore present a significantly greater profile than the average. On the other hand, once the snippet length exceeds more than about 20 % of the crimp wavelength, the snippet is more likely to lie with the plane of the crimp wave parallel to the glass. In this latter situation the bias in profile measurement will vary depending on the average length of the snippet (as explained by Edmunds), since the elliptic axis rotates along the fibre and therefore different proportions of the ratio of minor to major axes will be presented in profile. The situation changes once the snippet length exceeds about a wavelength, however, since then the 3-dimensional geometry of the crimp wave becomes important - the relaxed shape of an individual fibre is more that of a spiral than a plane wave, and this will be distorted by the compressive influence of the cover slide/mounting medium surface tension or mass effects. The mechanisms have been superficially discussed in the literature, but in terms of rates of change of axial twist rather than crimp. Additionally, the natural distribution of snippet lengths, crimp frequencies and individual fibre diameters in a single specimen make the overall problems of modelling somewhat complicated.

The direct effects of crimp do not therefore appear to have been specifically demonstrated for profile measurement methods, although they were considered in the original design of the FDA measurement system, as described by Lynch and Michie[19]. They concluded that as long as the laser beam diameter was confined to about 200 microns, the maximum effects of fibre curvature would be kept below 2% (ie. 0.4 microns at an MFD of 20 microns) - thus again illustrating that what was considered acceptable in 1976 may cause concern today. However, it is unclear as to what is the actual beam diameter in the measuring cell, since the laser illumination is not uniform, being the result of diffraction at the circular pinhole, and one cannot define the boundary of the central intensity peak (see Glass & Dabbs8 for more detailed consideration of this aspect). Glass & Dabbs indicated that in the FDA 200, the beam diameter in the diffraction plane (ie. the cell position) is of the order of 300 microns - somewhat in excess of Lynch & Michie's recommendations (although the earlier authors state that the effects are not significantly greater than would be expected for a beam of 200 micron diameter with uniform irradiance).

The Laserscan has a different optical bench with different geometry, and whilst the diffraction plane beam diameter is not explicitly given in the Glass & Dabbs paper, it can be calculated from a consideration of the geometry and diffraction pattern intensities as being around 500 to 600 microns. Whilst the much increased beam diameter assists in the measurement of broad fibres, we have no indication what the effect will be in relation to crimp. It can be assumed from Lynch & Michie's observations that the effects are not insignificant. We can also note that their calculations did not appear to take into account the subtle effects of fibre ellipticity and the relationship between the elliptic axis rotation and the crimp wave; nor did they consider complications due to possible orientation biases in the presentation of snippets, which could arise due to the hydrodynamic characteristics of the measuring cell and its immediate upstream vicinity. The latter point was subsequently recognised and eventually a new measuring cell design with greater turbulence was released, but it not known to what extent the hydrodynamics were investigated.

3.3 Ellipticity

There have been a number of studies on the effect of fibre ellipticity on profile measurement results, and these have been touched on in section 3.2. The paper by Edmunds18 covers both the theory and considers much of the published data. Edmunds shows that snippet length is a major factor in profile measurements of both mean fibre diameter and the distribution of fibre diameter, and this therefore reflects on the comparisons between similar methods which use different lengths, such as ASTM D2130[20] (0.2 mm), IWTO-8 (0.4 to 0.8 mm), and IWTO(E)-47 (1.5 to 2.0 mm). Blankenburg et al.[21] report measurements of ellipticity on the 1991/92 calibration wools and mohairs which demonstrate significant effects due to ellipticity and snippet length on comparisons of mean fibre diameter. Both papers indicate that current methods of profile measurement in which snippets are distributed on a glass slide are likely to give significantly different mean fibre diameters to those obtained by airflow on certain types of wool. The differences will be affected by the snippet length and fibre diameter, but could be as much as 1.5 microns on some wools.

Most of the literature concerns itself with the somewhat obvious effects of ellipticity on profile measurements. The story does not end here. Downes[22] examined the effects on airflow, and concluded that the effect is "small". However, once again, what was considered "small" in 1975 may not necessarily be considered small today. Downes' figures would indicate that a difference in average ellipticity between calibration and measured wools of 0.1 (which may not be unreasonable according to Blankenburg's data) could result in a difference in airflow of about 0.7 %, or about 0.1 to 0.2 microns over the range of mean fibre diameters 20 to 30 microns.

3.4 Scale geometry

Scale heights and frequency vary significantly between wool and other animal fibres. Wortmann and Arns[23] gave a comprehensive set of comparisons of scale heights. It is logical to consider that scale geometry may have an effect on profile measurements, and although Turpie et al.[24] drew attention to scale geometry differences as a possible contributor to differences in calibrations of the FDA 200 and OFDA for wool and mohair, the author has found no reference to any investigation along these lines. The effects of fibre surface roughness are mentioned in passing in several references on airflow (see Lord[25], for example), and consideration of the physical principles suggests that there should be an effect due to changes in specific surface, but again no references were found which address this particular subject. The possibility of significant effects on the comparisons between the methods referred to in this paper must therefore remain speculative.

4. FIBRE DIAMETER DISTRIBUTION EFFECTS

In section 3.1 a variable in the airflow method was mentioned without explanation - the shape factor. This refers to the shape of the pores in the plug left by the fibres and through which the air flows. For fibres of nearly circular cross-section, the average effect of the shape of these pores is largely determined by the distribution of diameters of the fibres in the sample - in the extreme case of no variation in diameter, the pores would approximate a triangular cross-section. In the other extreme of a wide distribution of diameters, the smaller fibres would tend to fill the gaps between the broader fibres, giving a more irregular distribution of cross-sectional shapes, as well as smaller average pore sizes and more tortuous stream paths, thereby giving a much increased resistance to airflow. The shape of the distribution, particularly in terms of skewness, also affects the relationships between measures of location such as mean, mode and median, and small changes in the tails of the distribution could have significant effects on both the mean fibre diameter and the standard deviation of diameter.

4.1 Coefficient of variation

The effects on airflow of different coefficients of variation between calibration and measurement wools are very significant and were considered in detail by James and David[26] Whilst the work was published over 20 years ago, the lessons still have to be learnt in many quarters, and it is therefore worth quoting their final paragraph:

As the precision of measurements of A.F. fineness has increased, so also has the concern about discrepancies between A.F. and P.M. measurements. Some of these discrepancies may be reduced by applying the correction shown in Fig. 4; this can be as large as 2 % of the mean A.F. diameter below 20 µm.

2 % of 20 microns is 0.4 microns. The author has in several investigations calculated that even on quite large data sets for which one would expect a degree of averaging to occur, lack of correction for this effect can lead to overall biases of 0.3 microns or more. One of the problems is that the situation changes every time a new set of calibration tops is issued, and in effect the goalposts appear to move each time this happens. The situation with respect to the use of the 1991/92 IH series for calibration of the OFDA and Sirolan Laserscan is covered in two recent papers[27,28].

4.2 Deviations from normality

In the discussion of the effects of specific gravity in 3.1 above, it was noted that in the airflow equation the pore shape factor is an important variable, and in reality the specific surface is what is actually measured by the method. It was also noted that specific surface is dependent on porosity, which is also a function of the distribution of fibre diameters. It could therefore be argued that significant departures from the norm, whatever that may be, in the distribution of fibre diameters will have an effect on the measurement result. We tend to assume that the shapes of wool fibre diameter distributions are all similarly normal, or nearly normal (ie. lognormal, as indicated by Lunney and Brown[29]). However, there are some wools, for example fleeces from certain bloodlines, bulk classed wools, and badly-blended interlots for which this assumption does not hold, and indeed tops with significantly deviant distributions are sometimes produced.

From a practical point of view, Whiteley and Thompson[30] came to the conclusion that for Australian greasy wools, measurement of standard deviation (or coefficient of variation) was an adequate indicator of coarse fibre statistics, thereby implicitly suggesting that for practical purposes differences in distribution shape between sale lots are not significant. Lunney[31] approached this area from a different perspective, but came to the same conclusion that third and higher order statistics were less useful than second order (ie. standard deviation), even for tops with quite deviant distribution shapes. However, both papers were really concerned with selecting useful statistics for categorising the distribution shapes, rather than considering whether there might be any effect on the mean fibre diameter measured by different techniques.

The author has found no reference to work on this specific aspect, and this is perhaps not surprising, since projection microscope measurements are generally insufficiently precise to give useful data on distribution shapes, and it is only recently that suitable instruments have become available. It would appear that only in the last decade or so have mean fibre diameter comparison differences of less than 0.3 microns or so started to assume major significance. However, it can be shown mathematically that for fibres of approximately circular cross-section, nearly normal distributions which have identical mean fibre diameters and standard deviations, but which are significantly different in shape, and therefore have significantly different skewness and kurtosis values, will in fact have the same fibre surface area for the same mass of fibres (ie. the specific surface will not change). Whilst it is not easily possible to estimate the knock-on effects on the pore shape factor, it does nevertheless seem reasonable to suppose that the effects on airflow will therefore be quite small. This situation will not necessarily pertain for abnormal distributions, such as bimodal (see below).

4.3 Very broad wools, and wools from primitive sheep

With some broad wools, particularly those from British mountain and Asiatic breeds, the fibre diameter distributions are not only wide, but often contain fibres up to and beyond 300 microns. Indeed, some sheep, such as the Awassi[32] and other primitive breeds have distinctly bimodal distributions. These broad fibres are also often highly medullated or kempy and therefore significantly affect specimen density, which therefore gives erroneous airflow readings. Very small numbers of such fibres can also have a major effect on the true mean and standard deviation. They consequently create problems with all the projected image methods, if only because the numbers of such fibres may be relatively small and therefore difficult to sample representatively. With the automated methods of measurement, different scale ranges may be needed for very broad fibres, and there could be situations where such fibres are rejected by the instrument hardware or software without the operator's knowledge, leading to significantly erroneous results. For example, the FDA 200 has an effective imaging area of approximately 300 microns in diameter according to Lynch & Michie19, and therefore cannot measure very broad fibres. In the projection microscope test method there is possibility of a bias against very broad fibres because of the requirement to reject images which are not completely within the boundaries of the measurement screen, or which have more than half their width outside the central circle. It is therefore not uncommon to find consistent differences ofseveral microns between the results from different methods on these wools.

5. EFFECTS SPECIFICALLY RELATED TO TEST METHODS

The following errors or influences may affect one or both results in a comparison situation: calibration errors, residual grease, fibre length, overall sampling and test method precision, preparation effects, and relaxation effects.

5.1 Calibration errors

Calibration errors occur in all measurements other than attribute counts. No calibration method is perfect, and all calibrations carry an associated uncertainty. Indeed, for some types of measurement it is a requirement that the uncertainty of calibration be taken into account in estimates of measurement precision, although this notion does not appear to have been discussed at IWTO. The associated problems are discussed in the constituent parts of the international standard ISO 5725[33]. In our type of measurement where calibration wools have to be used, the error of calibration comprises two components: variability between different samples of the reference materials, and variability due to the measurement processes used in calibration. The combined effect is a bias. Over a period of time the biases usually cancel out and can be regarded as random errors, but in practice, if two measurements are carried out on different instruments, whether they be of the same type or not, each measurement will carry a component of bias due to the errors of calibration of each instrument.

In the case of the airflow, OFDA, and FDA or Laserscan, the calibration methods are currently all indirect and require checks to be made on the instruments either during or after calibration. The lack of a wide range of suitable calibration materials has however limited the application of true verification procedures using different materials to the ones used for calibration. The current methods therefore carry a danger that if the calibration samples are not representative, there could be significant bias from this source. As indicated in section 4.1 above, investigations have been carried out on the 1991/92 series of IH tops with a view to establishing their usefulness for calibrating the OFDA27 and Laserscan28 instruments. These indicated that whilst there were sample to sample differences, these were generally not enough to give significant variation between instrument calibrations.

The same reference wools are used to calibrate airflow instruments, and it seems reasonable to suppose that the same conclusions would apply. However, the fact that the samples of calibration reference material are effectively the same does not mean that the instrument calibrations will be the same. This can be easily be demonstrated by reference to the results of the twice-yearly Interwoollabs round trials, where participants are required to calibrate their instruments just prior to measuring the round trial samples. Significant differences have been observed in this data, and, depending on mean diameter, it is not uncommon to find biases of 0.3 microns or so between laboratories. This point was reinforced by an Australian Wool Surveillance Authority (AWSA) investigation carried out in 1990[34].

In the case of the projection microscope, the calibration process is theoretically traceable to international standards of metrology, but in practice IWTO-8 is vague in respect of accuracy and traceability requirements, and so far little consideration appears to have been given to this problem. Review of published statistics shows that differences of 0.5 microns or more between laboratories are not unusual.

5.2 Residual grease and contamination

It is assumed that when measuring the diameter of fibres that they are in fact clean. The IWTO test methods specify cleaning requirements. However, if the fibres are coated with oil or grease, the effective diameter will be increased and the measurements of mean fibre diameter will be biased. These effects were studied many years ago for airflow, and were recently reconsidered for the measurement of greasy wool by Zelilawska and Jackson[35]. Whilst their data showed significant effects above approximately 3 % residual grease, they suggested no significant effect on the airflow measurements for alcohol-extractable matter contents up to 2 %. It should be noted, however, that their data contained few residual grease content values below 1 %, thereby making it difficult to ascertain whether the relationship was linear or, as suggested, asymptotic at low levels. Their paper referred to earlier work by Richards[36], but subsequent investigations by Downes & McKelvie[37] suggested that the relationship with diameter and added oil may be linear rather than asymptotic. The situation is further confused in that different solvents behave differently, and some, such as ethanol, additionally extract lipids from the wool fibre itself. Work carried out using the OFDA[38] suggested that residual grease tended to be present both as distinct "blobs" attached to the fibres, and as an irregular coating on the fibres, and in the latter form caused an apparent increase in diameter of a similar magnitude to that evidenced by earlier work on the airflow, ie. approximately 1 % for each 1 % increase in residual grease, or 0.2 to 0.3 microns per percent. With the FDA or Laserscan system of measurement residual grease might, perhaps, be considered to cause less of a problem since the snippets are immersed in an alcohol/water mixture in which some residual grease may be soluble, although the solubility may be variable depending on the level and chemical composition and age of the coating.

Other contaminants, such as mineral matter or vegetable matter are also discussed in the referenced material, and cause varying amounts of error in the airflow test, of the order of 0.1 to 0.3 microns per percent. Samples for airflow measurement prepared from greasy wool almost inevitably contain some residual matter from these sources, since even after scouring, measurable quantities remain in the wool, which are seldom completely removed by Shirley analyser preparation. Such contaminants are largely ignored or avoided by the projected image methods of measurement.

5.3 Fibre length

The effects of fibre length have already been mentioned in respect of projected image methods of measurement in sections 3.2 and 3.3 above. However, it is also recorded that fibre length has a measurable effect on airflow, probably as a result of different packing factors. James and Bow[39] showed changes in effectivediameter of around 0.3 microns on both tops and staples when they were cored or cut into short lengths. More recently, Liu[40] showed significant effects of about 0.1 microns between fibre lengths of 10 and 15 to 20 mm.

5.4 Precision

Precision does not really belong in this list of potential biases, since it is, by definition, a summary of random effects. However, it has to be noted that in comparisons of any two test results, whether they be from the same or different instruments, the random effects are effectively "frozen". They will average out over a sufficient number of comparisons, but this very obvious statement is often overlooked by the trade. It is worth pointing out that whilst currently the airflow, OFDA and Laserscan share similar levels of precision on fine wools, the same cannot be said of the fundamental method. No matter how many specimens are tested, the precision of mean fibre diameter determinations from the projection microscope on a single sample will never equal that of the other methods - currently the 95% confidence limits for this method are at least 50% higher than those for the other methods.

5.5 Preparation effects

In theory there should not be biases within or between methods due to preparation effects, since the procedures should be written in such a way to avoid these problems. However, this point could also be made about all the other effects noted in this paper, most of which have been known about for some time, and in practise preparation effects do become, or appear to become significant in many cases. In some situations, as noted above, effects which when originally investigated were considered to result in "acceptable" errors, now are considered to cause unacceptable variation, simply because of changes in trading patterns.

One obvious example is the effect of Shirley analysing on airflow measurement, or indeed on any other diameter measurements carried out on the processed wool. If Shirley analysing is carried out in strict accordance with the test method, then theoretically it should have no significant effect on the measured fibre diameter. In practise, because the method requires many repeated passes of material for certain types of wool, some laboratories have adopted their own standardised procedures which cause slight but significant biases if appropriate care is not taken, particularly on broader wools. Austin[41,42] showed that significant and systematic differences in mean fibre diameter can occur in the product box with coarse wools because of differential fibre separation. In the data reported, variations across the product box varied from approximately 0.2 to over 3 microns. He recommended the use of a subsequent airblending or "fluffing" stage; and in a later attempt to minimise this problem Baxter[43] subsequently suggested increasing the size of airflow specimens, but neither proposal was widely adopted. Lüpke et al[44] showed in one particular investigation that average differences of 0.2 micron or so can exist between wools sampled before and after the Shirley analyser process.

Other examples abound in the literature. Baird & Barry[45] in reviewing the performance of a Sirolan Laserscan instrument give a good example of the types of bias problems that crop up during the development of test methods; whereas Edmunds[46] commented in detail and emphasized problems connected with conditioning which are inherent in all wool fibre diameter measurements, but which are often overlooked. As an indicator of magnitude, it has been shown in investigations of major coretest laboratories by independent authorities (eg. AWSA[47]), that differences between laboratories of the order of 0.3 microns or more can and do legitimately occur with the airflow method due to very slight differences in preparation, calibration or measurement techniques.

5.6 Relaxation

The effects of relaxation have been touched upon in section 3.2 when crimp was discussed. Whilst not referred to specifically as a relaxation process, Henning & McKelvie[48] dealt with this subject by comparing the results of different calibrations using tops prepared in different ways, including steaming and washing. They showed measurements of airflow mean fibre diameter differing by an average of 0.6 microns, over a range from about 20 to 37 microns, when the calibration tops were steamed, so we must assume that the effects can be of major significance.

The effect may also be relevant to the current debate on the Waring blendor technique, where the wools are prepared for testing by conditioning from the wet rather than the dry side[49]. It also has potential significance where wools are stored in different environments for different periods of time. There is a possibility that the state of relaxation could affect comparisons between the OFDA, PM and the FDA or Laserscan, since in the latter instruments the fibre snippets are dispersed in a mixture of alcohol and water and might therefore always be relaxed, whereas in the OFDA and PM methods, the snippets are dispersed in air and oil respectively and could therefore be more likely to retain their relaxed or unrelaxed state, possibly resulting in an orientational bias as discussed in sections 3.2 and 3.3.

6. CHARACTERISTICS OF THE WOOL SAMPLE OR SOURCE ANIMAL

Characteristics of the sample or animals may appear to have an effect on the comparison between methods, although in most cases such effects can be traced back to physical mechanisms categorised above.

6.1 Lambswool

A warning that lambswool gives systematically finer results in the airflow method compared to the projection microscope is specifically given in IWTO 28. The standard quotes work carried out by Robinet and Franck[50], indicating a maximum difference of 6.7 %, or over 1 micron. This may be a reflection of the more hairy nature of the birthcoat, with a greater tendency towards medullation[51] and therefore a lower fibre specific gravity, but it is also considered that the tapered shape of the fibre tips may contribute to the differences, since these will alter the packing factor.

6.2 Medullated and kempy wool

Medullated wools are also mentioned in IWTO 28 as producing significantly lower mean fibre diameter values from airflow than from projection microscope. As mentioned above, the reason is the significantly lower specific gravity of medullated fibres, and data shown in the standard suggests that differences may be of the order of 1 micron or more.

6.3 Breeding factors

Different breeds of sheep with similar mean fibre diameters can have significantly different fibre diameter distribution characteristics, and with the coarser wools, different tendencies towards the production of medullated fibres. In the former case there may be differences in the comparisons between test methods because of differences in coefficient of variation, and in the latter case the differences will be due to differences in the average fibre specific gravity.

6.4 Animal feed and nutritional deficiencies

Different flock, pasture, and grazing management practises with nominally identical mobs can lead to different variation in fibre diameter along the fibre due to different nutritional levels[52] at various times (eg. diameter variations of over 8 microns are not unusual on individual fibres in western Australia). This will lead to different levels of coefficient of variation. The results of measurements of CoV will depend on how the wool is sampled (if snippets were taken from the same length portion of the staple, assuming that all the mobs had been shorn at the same time, it is likely that the differences would be different to the situation where snippets were obtained by minicoring, and there could feasibly be corresponding significant differences in distribution characteristics). Heavy seasonal influences and different environmental factors on a year on year basis will also affect the feed characteristics of flocks, so that different results could be obtained in test method comparisons carried out on individual flocks or mobs at different times.

It may also be noted that whilst the projection microscope method and the OFDA measure individual fibre image widths at discrete points, as indicated previously the FDA 200 and Laserscan average the width over a fibre length of about 300 or 500 microns respectively. James[53] showed that very significant fibre diameter variations can take place over fibre lengths of two diameters or so. Recent work with a single fibre profile accessory for the OFDA shows diameter varying significantly (by several microns) over fibre lengths of 5 microns or less. Short term variation in the diameter of fibres is therefore not measured to the same extent in the FDA/Laserscan type of instrument, and consequently in some cases the CoV values may be significantly lower, as indicated by Teasdale[54].

Some nutritional deficiencies can lead to changes in the chemical composition and corresponding physical properties of the wool fibre material. One well-known example is copper deficiency, which can lead to the production of steely wool with lack of any crimp definition[55]. As indicated above, this could have a significant systematic effect on some projected image methods of measurement, and may also affect the airflow method, so that systematic differences become apparent.

6.5 Sampling location on the animal

It is well known that samples of wool taken from different locations on the body of an animal have different properties (eg. Onions[56]). However, not only are there significant variations in fibre diameter, length, crimp, surface density, medullation, etc., but also the variability (or CoV) of these properties. For similar reasons outlined above, this results in significant differences between test method comparisons when samples are taken from different parts of the animal's fleece. Comparison differences of up to 0.3 microns have been found[57] in one analysis.

6.6 Handle

Crimp has been identified as a major contributor in the assessment of handle. It is possible therefore for wools with different handle but otherwise similar properties to apparently produce differences in comparisons between test methods.

7. CONCLUSIONS

Many factors could affect comparisons between airflow and projected image results. Some of these share common physical causes. In many sample populations, these factors balance out and affect only the scatter of the differences. In certain cases, however, especially where investigations are directed at specific flock, animal, or even method characteristics, the sample population may not be representative of the overall universe of populations, and in these cases, and where individual results are being compared, it is feasible and in several cases it has been observed, that one or more of the effects discussed may predominate, and result in unexpected biases. The magnitude of such biases could vary from 0.1 to several microns in exceptional cases.

One of the effects, that of fibre diameter distribution width (measured as standard deviation or coefficient of variation), is well documented, and lends itself to correction of results when the s.d. or C.o.V. data is available. Several investigations carried out by the author have confirmed that lack of correction can, in certain circumstances, lead to a significant bias between mean fibre diameters from the two types of measurement. It is recommended that where the data is available, such corrections are made before comparison statistics are determined. In the near future it is anticipated that medullation will be measured by the OFDA, and when this becomes available, further simple corrections for fibre density might also be feasible.

In other cases it is often currently impossible to make allowance for the dominant factor because there is insufficient or no objective measurement data on that factor. It is important, however, that the possibility of such effects be born in mind whenever comparisons are being made, so that, if at all possible, such factors can be isolated, or at least recognised. It is suggested that the effects of crimp have been overlooked or over-simplified in previous work, and that the influences of relaxation on crimp must also be more thoroughly investigated.

Finally, caution must be expressed concerning the recent insistence that all new fibre diameter test methods must reference against the airflow method. Whilst this may be a commercial convenience, it is a technically unfeasible demand. Undoubtedly sample sets can be chosen which will give the required 1:1 correspondence on average, and indeed it is important to demonstrate the relationship between any new method and the standard trading measurement. That does not mean, however, that we can continue to ignore the significant technical incompatibilities which have been reported in the literature between airflow and the projected image systems, and which will continue to give rise to significant differences in results in certain cases.

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