IMPLICATIONS OF MEDULLATION AND FIBRE DIAMETER DISTRIBUTION ON WOOL DIAMETER MEASURED BY AIRFLOW[1]

NELSON MANZONI DE OLIVEIRA[2] and JOHN P. KENNEDY[3]

ABSTRACT - The specific gravity (related to medullation as assessed by three techniques) and fibre diameter variability of 242 wool samples (encompassing the range of diameters between 22.0 and 38.0 μm) were considered to evaluate the accuracy of diameter estimates as obtained from the Airflow apparatus. Data are presented showing the improvement obtained on diameter estimates of highly medullated wools, within a precision comparable to others reported for non-medullated fibres. Results on the techniques employed to assess medullation (Projection Microscope, Medullameter and InfraAlyser) have also been discussed.

Index terms: sheep, specific gravity coefficient of variation

INFLUÊNCIA DA MEDULAÇÃO E DA DISTRIBUIÇÃO DE DIÂMETRO DA FIBRA NO DIÂMETRO DA LÃ MEDIDO PELO AIRFLOW

RESUMO - A gravidade específica (relacionada à medulação avaliada por três técnicas) e a variabilidade do diâmetro de fibra de 242 lãs (abrangendo diâmetros de 22.0 a 38.0 μm), foram consideradas para avaliar a precisão de diâmetro obtido pelo aparelho Airflow. Dados são apresentados mostrando a melhoria das estimativas de diâmetro de lãs altamente meduladas, dentro de uma precisão comparável a outras relatadas para lãs não meduladas. Resultados sobre as diferentes técnicas empregadas para acessar grau de medulação (Microscópio de Projeção, Medulômetro e InfraAlyser) foram discutidos.

Termos para indexação: ovino, gravidade específica, coeficiente de variação.

INTRODUCTION

The most widely used commercial method for measurement of fibre diameter of wool is using the Airflow instrument. This basically works by considering the fibre surface area and wool mass relationship in the chamber (Anderson 1954). Although it gives reliable estimates for a relatively wide range of wools, accuracy is not satisfactory when one deals with coarse wools (Ross 1958), even if all steps involving sampling, sample preparation and measurements have been followed correctly. Besides the many factors affecting the Airflow results studied by Richards (1954), Anderson (1954), Ross (1958), James & Bow (1968), Downes & McKelvie (1969) and Henning & McKelvie (1969), the lack of agreement between Airflow and Projection Microscope (baseline for comparison) diameter also arises from inherent characteristics of wool such as medullation and fibre diameter distribution.

The knowledge that the precision of Airflow results is lower with medullated wools is incorporated in the satandard of the International Wool Textile Organization (1973), which recommends special calibration for this type of wool. The lower than normal specific gravity (1.30-1.31) of these wools is the main source of discrepancies. The mechanisms by which fibre density affects the Airflow fibre diameter measurements are explained by Richards (1954). In summary, it seems that the relation of fibre surface area to mass is not well satisfied in medullated wools.

The Kozeny equation (Cassie 1942) governs the relationship among those parameters involved in the Airflow method and it has

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[2] Méd. Vet., M. Zoot., Ph.D. - EMBRAPA/Centro Nacional de Pesquisa de Ovinos (CNPO). Caixa Postal, 242, CEP 96400-970, Bagé, RS, Brazil.

[3] Assoc. Prof. School of Fibre Sciences and Technology University of New South Wales. P.O. Box 1 - 2033 - Kensington, NSW, Australia.

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been used to evaluate the effects of some factors which are not expected in the equation. Basically, the equation relates a flow rate of air through a mass of fibres packed at constant volume to diameter.

Of those parameters included in the Kozeny equation, two important are: mass and density of the wool to be measured (Richards 1954). It is assumed, however, that specific gravities of different wools do not differ (Connell & Andrews 1974). Thus, measurement on medullated fibres is not in accordance with the theory of the Airflow method (Sullivan & Hertel 1940; Fowler & Hertel 1940; Cassie 1942 cited by Anderson 1954), because factors which change gravity of wool (in the present work, the medulla) may change the volume packed in the chamber and consequently an important component of the Kozeny equation, viz. porosity, is altered. This is the volume of air space to the total space in the packed tube.

The equations relating both the volume (V) and porosity (e) of wools in the chamber are described by Connell & Andrews (1974) as **V = m/p** and **e = 1-V/Vc**, where **m** is the mass of wool, **P** is the specif gravity and **Vc** is the volume of the chamber. The normal values of **e** in the constant pressure instrument for accepted values of **P** in unmedullated wools lie within a limit of 0.7584 and 0.7603, however, as **e** appears to be decreased when medullated fibres are measured, this would probably lead to an apparent finer mean fibre diameter.

The coefficient of variation (CV) of fibre diameter seems to be another factor which affects Airflow measurements (Anderson & Warburton 1949). This was also studied by James & David (1968), Fell et al. (1972) and Smuts et al. (1985). Differences are derived from the differential CV between the IWTO standard tops used to calibrate the Airflow (International Wool Textile Organization 1973) and the samples measured. James & David (1968) suggested that when comparing two mean fibre diameters as given by an Airflow (d_1), a correction for the effect of CV should be $d_1 = do\ (1+Co^2)$ where **do** is the Projection Microscope diameter and **Co** its fractional CV.

This study was done to evaluate the dependence of Airflow measurements on the factors previously considered. Additionally, due to the possible influence of medullation on diameter, and attempt was made to estimate correction equations for medullation as assessed by the use of three methods.

MATERIALS AND METHODS

Two hundred and fourty two wools, encompassing the range of diameters between 22.0 and 38.0 μm were studied. Wools were grouped into 1.0 μm intervals which included non-medullated wools and wools of varying degrees of medullation. The numbers of samples and the values obtained with the Projection Microscope (PM) are presented in Table 1.

It is stressed that medullated wools are not obtained at random. The Benzol Teste (Elphick 1932) was performed to detect the presence of medulla, principally when selecting finer wools. The values of standard deviation (SD) given in Table 1 represent the SD of the mean of fibre diameter, so that these show that within each diameter interval both medullated and non-medullated wools covered a fairly good range of diameter.

Measurements

Fibre diameter - Diameter measurements for Airflow (AF) and PM were carried out at the School of Wool and Pastoral Sciences, UNSW. Procedures for sample preparation and AF measurements were in accordance with the International Wool Textile Organization (1975). The PM measurements followed the standard method laid down in the International Wool textile Organization (1961). Snippet length varied from 0.4 mm to 0.6 mm depending on the sample mean fibre diameter, as recommended by the International Wool textile Organization (1961) and later by Browne & Hindson (1982).

All PM fibre diameter were obtained at least at ± 0.4 μm accuracy at 95% confidence level. The numbers of fibres measured on each sample, therefore, depended on its variability. At first, a minimum of 400 fibres was measured, from which the variance (s^2) was calculated and its value replaced in the equation below.

$n = (t\ s/e)^2$

where n = number of fibres to be measured

TABLE 1. Distribution of medullated and non-medullated wools within 1.0 μm intervals of fibre diameter as measured by the Projection Microscope.

Diameter interval (μm)	Nº of slides	Mean diameter (m)	Mean diameter (SD)	Mean CV (%)	Mean CV (SD)	PM maximum medullation (%)	Nº of fibres measured
22	6*	22.4	0.29	19.0	1.9		2450
	7**	22.6	0.23	23.6	4.3	10.3	3883
23	6	23.6	0.33	20.2	1.3		2820
	9	23.5	0.27	22.4	3.7	13.3	4881
24	5	24.5	0.27	20.2	4.0		2250
	4	24.4	0.21	21.6	3.7	7.8	2038
25	4	25.5	0.21	20.0	2.3		2162
	9	25.4	0.27	21.0	3.1	13.9	4740
26	5	26.3	0.35	22.3	2.0		3223
	10	26.6	0.25	23.7	4.0	18.3	5733
27	4	27.6	0.43	21.1	1.0		2699
	9	27.3	0.21	20.8	2.3	9.5	5120
28	6	28.4	0.28	22.2	3.1		4277
	12	28.5	0.27	22.2	3.2	22.6	7628
29	10	29.4	0.31	21.2	2.0		6323
	4	29.4	0.21	25.4	4.0	8.8	2635
30	6	30.6	0.28	20.2	2.2		3655
	10	30.5	0.23	24.2	3.6	11.5	7426
31	12	31.5	0.16	21.4	2.4		8731
	13	31.3	0.28	21.2	4.4	17.7	8867
32	8	32.4	0.25	21.7	3.3		5968
	8	32.7	0.18	22.3	1.2	17.0	8650
33	4	33.5	0.24	20.9	1.5		2888
	8	33.3	0.35	21.3	3.4	14.4	5783
34	7	34.3	0.21	21.6	2.9		5995
	11	34.5	0.27	21.6	2.3	16.7	8712
35	7	35.4	0.33	18.7	2.1		4782
	14	35.5	0.26	20.9	2.5	19.7	12389
36	6	36.4	0.31	20.5	1.8		5237
	3	36.3	0.12	21.8	2.4	15.9	2455
37	2	37.5	0.42	20.5	2.1		1499
	6	37.4	0.18	21.1	2.7	22.7	5175
38	3	38.3	0.12	21.4	1.1		2520
	4	38.3	0.46	20.2	2.8	9.5	3077
Total	242					22.7	166571
Mean		30.3		21.5	3.0	3.6 ± 4.9	

* Non-medullated samples
** Medullated samples

t = 1.960 (Student's value at 95% confidence level and infinite degree of freedom)

e = ± 0.4 (allowance in μm for error about mean)

This, therefore, indicated whether or not additional measurements on the sample should be made to reach the desired significance level. The procedure is in accordance with the American Society For Testing and Materials (1972) and led to the measurement of large numbers of fibres (see Table 1), mainly in coarser wools in which the variance was higher.

Degree of medullation - Three different methods of medullation assessment were used on individual samples:

1. Projection Microscope (PMM)

The percentage of medullated fibres in all of the 242 samples was estimated at the same time as diameter measurement (International Wool Textile Organization 1964). In the present study, however, both narrow and continuous types of medulla were not distinguished at the place of measurement.

2. Medullameter (MM)

The percentage area of medullation in 86 of these samples was assessed photo-electrically by the SAWTRI Medullameter, at the South Africa Wool and Textile Research Organization Institute SAWTRI - Port Elizabeth, South Africa.

The principles of measurement, instrument calibration, sample preparation and testing procedures are set out in Lappage & Bedford (1983) as the SAWTRI Medullameter based upon WRONZ design (Smuts et al. 1983). According to the former authors the medullameter readings "provide detailed knowledge of medulla distribution as well as an overall index which can be expressed as area of medulla as a ratio to area of fibre". The values observed were found to be closely related to percentage area of medullation as measured on a PM.

3. InfraAlyser (IM)

Medullation measurements were also done by near infrared reflectance on an InfraAlyser 400R instrument, on 50 samples at the Wool Research Organization of New Zealand - WRONZ - Christchurch, New Zealand.

The theory of Near Infrared Reflectance Spectroscopy technology has been reviewed by Keogh (1984). There have been many attempts to introduce NIRS as a routine method of wool measurement (Andrews et al. 1976/1977; Sabbach & Larsen 1978; Scott & Roberts 1978; Connel & Norris 1980 e 1981; Connell et al. 1982; Connell 1983; Keogh 1984). Ranford et al. (1987) used an InfraAlyser 400R to estimate the degree of medullation of wool, suggesting that it could be satisfactorily assessed, when using specific wavelengths.

The results using NIRS were obtained as an average of eight InfraAlyser 400R readings which were made upon small portions of a 10 g samples (large cell) and are expressed as percentage area of medulla.

Specific gravity (SG) - The density of 91 of the original 242 samples was measured on a Stereopycnometer instrument, model SPY-2, at the WRONZ. The theory of the Stereopycnometer technology as well as its calibration and operation are given in the Stereopycnometer Manual 3/82 of QuantaChrome Corporation. The instrument has been designed to measure the volume of solids by employing the Archimedes principle. The displaced fluid used was dry Helium gas which, due to its small atomic dimension, can penetrate the finest pores and crevices (e.g., medulla) approaching one Angstron or 10^{-10} m in dimension, thereby assuring maximum accuracy. As the quantity of material used may affect the results, the present measurements were carried out employing the large cell (156.4 c.c.), which permits the results being obtained at 0.1% accuracy. The sample used weighed about 7.0 g of scoured wool, with fibres previously cut into approximately 2.0 cm lenght.

Density values were obtained from the following operational equations $\mathbf{Vp = Vc + \{Va / (1 - P2/P3)\}}$

where Vp = total volume in the cell (c.c.)

Vc = Volume of the sample cell holder (156.4 c.c.)

Va = Added volume

P2 = Pressure reading after pressuring cell

P3 = Pressure reading after added Va

then $\mathbf{p = m / Vp}$

where p = density (g/c.c.)

m = wool mass (in grams)

Of these 91 samples, medullation in 50 was measured on the InfraAlyser and in the remaining 41 medullation was measured on the Medullameter.

Data Analysis - The data were subjected to regression analyses (Steel & Torrie 1981) which were carried out using the SPSS Program (Nie et al. 1975). To attain the aims proposed, three relevant sections were considered:

a. to determine the extent to which AF measurement (Y) are dependent on PM diameter (X_1), CV of diameter (X_2) and medullation (PMM or MM or

IM) (X_3), three sets of multiple linear regressions were fitted which are described in the general model

$Y_i = \beta_o + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + E_i \dots$ (a.1)

where E_i = residual error of observations (Σ 0 and ^{2})

Anderson & Warburton (1949) observed that any estimate of AF diameter (d_1), for nearly circular fibres, is a function of PM diameter (do) and its fractional CV^2 (Co^2) which is given by d_1 = do $(1 + Co^2)$. Therefore, an additional analysis was run were X_1 and X_2 were replaced by X_1X_4 where X_4 was equivalent to $(1 + Co^2)$. The results derived from both analysis showed similar R^2 and therefore model (a.1) results were discussed.

From the previous model, partial multiple regressions were also considered to evaluate either the effects of density measurements or coefficient of variation, while holding the other constant.

b. Assuming other factors were found to be important, an attempt was made to supplement AF measurements to predict "true" diameter (PM value) more accurately by considering the model

$Y_i = \beta_o + \beta_1 X_{1i} + \beta_2 X_{2i} + E_i \dots$ (b.1)

where Y_i = observation on the i th PM diameter

X_{1i} = effect of i th AF diameter

X_{2i} = effect of i th PMM or MM or IM

E_i = residual error of observations (Σ_i = 0 and ^{2})

c. The relations between density parameters were examined by simple regression analyses relating SG to medullation as assessed by the different techniques.

RESULTS AND DISCUSSION

Theoretical effects of medullation and coefficient of variation

Medullation - The Kozeny equation (Cassie 1942) has been generally accepted as giving sufficiently accurate prediction of diameter when wool density and its mass are constant. However, even if there is no significant variation in the weighed mass of wool, changes in density (for example, by medullation) would result in apparent changes in mass (or actual change in volume in the chamber), which, in turn, by affecting Q in the Kozeny equation, would lead to inaccurate diameter estimates. From this general equation, Connell & Andrews (1974) observed that the apparent effect of diameter (Ad) can be expressed as

Ad = d Ap/p (2p V + m/2p V – m)

then Ad = 1.275 d (Ap/p) . . . . . (1)

Thus, the extent to which medullation affects density was considered to predict theoretical changes in fibre diameter at a given degree of medullation.

The results obtained from the regression of SG (Y) on PMM (X_1) are given by the equation below

Y = 1.299 – 0.0034 (X_1) . . . . . (2)

There was a highly significant effect ($P < 0.01$) of the degree of medullation (PMM) on density (SG) which was in the direction expected (i.e., the specific gravity decreased and the percentage medullation increased).

By means of equation (2), the SG of unmedullated wools, and wools having 5.0%, 10.0%, 15.0% and 20.0% medullation was predicted and the values used in the equation (1), from which Table 2 was prepared. This shows theoretical expectations of fibre diameter changes in wools with varying degrees of medullation. However, within some diameter ranges, PMM and consequently SG (e.g., PMM = 20.0% and SG = 1.231) were extrapolated beyong the range studied.

Values in Table 2 indicated that increases in the degree of medullation from 5.0% to 20.0%, by affecting density, apparently decreased fibre diameter from 1.8% to 6.8%, the effect (in micrometres) being much greater in coarser wools.

The predicted value for density of unmedullated fibres (1.299 g/c.c.) was in good agreement with that of 1.3 g/c.c. obtained by Connell & Andrews (1974) over a wide range of Australian wools. The apparent decrease in fibre diameter as a result of density changes, was slightly lower than that observed by Richards (1954).

The decrease in fibre diameter resulting from medullation, shown in Table 2, can be explained by decrease in porosity (e) within the chamber. This derives from an apparent increase in wool mass (m') due to medulla, which can be expressed as

m' = m p/p' . . . . . . (3)

where p' = density of medullated fibres

The relative change in AF diameter due to relative change in mass studied by Richards (1954) who, from the Kozeny equation, represented the effect as

m dF/F dm = – (3 – e) /e . . . . . (4)

where d = mean fibre diameter (μm)

F = flow rate of air (cm³)

Therefore, by applying equations (3) and (4), the estimated AF diameter can also be theoretically obtained if one assumes that there is variation in mass of wool (m'), but no variation in density (e.g., 1.3 g/c.c.).

The results presented in Table 3, show the apparent increase in mass and consequent decrease in porosity due to varying density in medullated wools.

According to Richards (1954), the values obtained from equation (4) are to be regarded as percentage variation in diameter for a given percentage variation in mass. Therefore, relative to the first value (-2.955), the accumulative relative effect observed (-0.019; -0.036; -0.054; -0.074) decreased fibre diameter, for example, at 26 μm by 0.49 μm, 0.94 μm, 1.40 μm and 1.92 μm, repectively. These are very similar to those decreases observed in Table 2, and reinforce the previous statement that medullation can apparently alter the weighed

TABLE 2. Apparent mean fibre diameter change (μm) on the Airflow apparatus in wools of different specific gravities.

Diameter range (μm)	Specific gravity (g/c.c.)*				
	1.299	1.282	1.265	1.248	1.231
22	0**	-0.4	-0.8	-1.1	-1.5
24	0	-0.4	-0.8	-1.2	-1.6
26	0	-0.5	-0.9	-1.3	-1.8
28	0	-0.5	-1.0	-1.4	-1.9
30	0	-0.5	-1.0	-1.5	-2.0
32	0	-0.6	-1.1	-1.6	-2.2
34	0	-0.6	-1.2	-1.7	-2.3
36	0	-0.6	-1.2	-1.7	-2.3
38	0	-0.7	-1.3	-1.9	-2.6

* Values predicted from equation (2)

** Values obtained from equation (1)

TABLE 3. Apparent change in mass of wool (m') due to changes in density from medullation and effects on fibre diameter estimates.

PM Medullation (%)	Density (g/cm³)*	Wool mass (m') Eq. (3)	Porosity (e)	Relative change AF/ relative change is mass Eq. (4)
0	1.299	2.5	0.7584	-2.955
5	1.282	2.535	0.7550	-2.974
10	1.265	2.569	0.7517	-2.991
15	1.248	2.604	0.7484	-3.009
20	1.231	2.640	0.7448	-3.028

* Values from table 2

mass of wool (e.g., 2.5 g ± 0.4 mg) packed in the chamber and causes errors in the AF results.

Coefficient of Variation - The effect of the differential in CV between both IWTO standard tops used to calibrate the AF instrument and the measured samples was considered in order to determine theoretical errors in sample fibre diameter estimates. James & David (1968) showed that to find the corresponding AF values of measured samples (d_1), the following calculations should be performed

$\mathbf{d_1 = do\ (1 + C_1^2 / 1 + Co^2)}$ ..... (5)

where **do** is the PM fibre diameter of the calibrating top, C_1 is the fractional CV of the sample and Co is the fractional CV of **do**.

Since the fibre diameter and CV of the IWTO tops used lie, respectively, within the ranges of 18.5 µm to 34.9 µm and 20.0% to 25.5%, the regression equation below was obtained to predict CV (Y) from fibre diameter (X_1) of the calibrating tops which correspond to each diameter interval studied

$\mathbf{Y = 14.532 + 0.3269\ (X_1)}$ ..... (6)

$n = 8$; $r = 0.94$; $s^2 = 0.59$

Thus, predictions of CV derived from equation (6) could be satisfactorily obtained, at an error of about only 0.8%. This resulted in more accurate estimates of Co than when one considers its average, as Smuts et al. (1985).

Table 4 was constructed from the results obtained in equations (6) and (5). For example, an IWTO calibration top would have a Co = 0.224 at, say, 24.0 µm, so that a sample with similar diameter and C_1 = 0.27 would be 0.5 µm coarser when measured on the AF instrument. From Table 4 it can be seen that the maximum AF-PM difference due to variation in CV was obtained at 38.0 µm (3.9%).

Although not all values of CV in Table 4 were encountered at all diameter intervals (actual data), they represent the limits of CV observed. The results found the previous sections will be later compared with actual effects obtained in this study.

Observed effects of medullation and coefficient of variation

A summary of the regression analysis (model a.1) is presented in Table 5. It shows three sets of analysis which evaluated the effects of medullation (as assessed on the Projection Microscope - PMM, Medullameter - MM and InfraAlyser-Im) and CV (adjusted by PM diameter) upon the AF fibre diameter.

The results show that, irrespective of method of measurement, medullation had a highly significant effect on diameter whereas CV had no significant effect on that of wools in which medullation was estimated by the InfraAlyser

TABLE 4. Theoretical expectation of Airflow error due to differential in coefficient of variation between calibration top and measured sample.

CV (%)	Fibre diameter (µm)								
	22*	24	26	28	30	32	34	36	38
17	21.6**	23.5	25.4	27.3	29.1	31.0	32.8	34.7	36.5
19	21.8	23.7	25.6	27.5	29.3	31.2	33.1	34.9	36.8
21	21.9	23.9	25.8	27.7	29.6	31.5	33.3	35.2	37.0
23	22.1	24.1	25.0	27.9	29.8	31.7	33.6	35.5	37.3
25	22.3	24.3	25.2	28.2	30.1	32.0	33.9	35.8	37.6
27	22.5	24.5	25.5	28.4	30.4	32.3	34.2	36.1	38.0
29	22.8	24.7	25.7	28.7	30.7	32.7	34.6	36.5	38.4

* PM fibre diameter
** AF fibre diameter

TABLE 5. Multiple linear regression coefficients; model (a.1) where the medullation assessment method (MAM; X_3) is equal to PMM or MM or IM.

Variables	Models				Residual
	PM	MAM	CV	βo	SD (μm)
PMM					
Simple R	0.992	-0.059	-0.079		
Mult. R^2	0.986	0.993	0.994		
βi value	1.033	-0.083	0.036	-1.509	
βi (Se)	0.006	0.005	0.008	0.255	
					0.38
MM					
Simple R	0.983	0.188	-0.180		
Mult. R^2	0.967	0.976	0.977		
βi value	1.052	-0.146	0.045	-2.326	
βi (Se)	0.018	0.025	0.021	0.813	
					0.50
IM					
Simple R	0.977	0.209	0.155		
Mult. R^2	0.955	0.975			
βi value	1.036	-0.132		-0.540	
βi (Se)	0.025	0.020		0.619	
					0.40

method, and therefore was dropped from the multiple regression equation.

Considering the level of medullation found, the variation in AF diameter which was not accounted for by the models fitted was quite small (0.6% – 2.5%). These are slightly lower than that of 3.4% observed by Smuts et al. (1985), who measured mohair fibre diameter. The residual errors of AF diamter prediction were low and similar in all analysis.

Simple correlations between AF diameter, CV and medullation were not significant at the level of 5% in all cases. This means that both parameters were fairly well distributed at all diameter ranges studied, indicating that their possible influence on AF results (e.g., caused by the increase of either medullation or CV with the increase in fibre diameter) were somehow isolated.

The sequential multiple determination coefficients indicate that, after the inclusion of the PM variable in the models, medullation had relatively much higher effects than CV. The relative magnitude of its effects varied from 0.7% to 2.0% depending on whether medullation (%) was estimated by area of medullation (MM and IM methods) or number of fibres (PMM method). Both effects are represented by their regression coefficients as micrometre change in the AF diameter per one percent change in medullation or CV. It appears that a similar increase in medullation for PMM and the other two methods did not result in similar apparent reductions in fibre diameter ($P < 0.05$). However, the results suggested that both the MM and IM methods were similar ($P > 0.05$) in explaining apparent changes in AF diameter caused by variations in percentage area of medullation.

The direction of both medullation and CV effects observed agreed with calculations made in the previous section, but the extent to which these affected AF diameter appeared to be of a different order of magnitude.

Table 6 presents the predicted AF diameter, expressed as deviation from PM value, for wools up to 20.0% medullation (PMM method). Comparing these results with those in Table 2, it can be seen that apparent decreases in mean fibre diameter by actual values of medullation were lower than those when relating medullation to SG. However, due to the correlation between PMM and SG found (-0.35), one presumes that their reciprocal prediction might not be sufficiently accurate. Thus, the values in Table 2 should be interpreted with some caution.

It appears that such a situation might also occur if one intended to obtain similar information by using the MM and IM methods, owing to their fairly low correlation with SG (-0.47 and -0.40, respectively).

It is rather difficult to explain why these correlations were low. Density determinations were made on wools covering a wide range of medullation. The results seem to indicate that significant changes in degree of medullation were not accompanied by corresponding variations in density. A hypothesis to explain the trends, would probably lead to consideration of the displacement method employed. It is likely that the gas did not totally penetrate those fibres containing the discountinuous type of medulla (that is, no "open" extremities for penetration). In such circumstances, these fibres would be treated as non-medullated. One presumes that the fibre lenght of the samples used for density measurements may have had an influence on the results. It is possible that shorter fibre lenght would better expose the medulla.

TABLE 6. Predicted AF fibre diameter deviation (μm*) from PM diameter in medullated wools. PMM method.

PM Diameter (μm)	Degree of medullation (%)			
	5	10	15	20
22	-0.4*	-0.8	-1.3	-1.7
24	-0.4	-0.8	-1.2	-1.6
26	-0.3	-0.7	-1.1	-1.5
28	-0.2	-0.6	-1.1	-1.5
30	-0.2	-0.6	-1.0	-1.4
32	-0.1	-0.5	-0.9	-1.3
34	-0.1	-0.4	-0.9	-1.3
36	0	-0.4	-0.8	-1.2
38	0	-0.3	-0.7	-1.1

The effects of CV (adjusted for medullation effects) were much lower than those expected by theory. Considering the range of CV in this study (17.0% – 29.0%), the maximum predicted error on AF estimate, due to CV variation, was 0.5 μm, which is in constrast with that of 1.9 μm shown in Table 4.

The results found contrasted somehow with those of Smuts et al. (1985) on mohair. They observed a significant effect of CV but no due to medullation as measured on a Medullameter. However, the levels of % of medullation studied by these authors (0.5% – 6.6%) were lower than those evaluated in this study; 0.1% – 11.9%) for the MM method and 1.5% – 13.9% for the IM method.

Prediction of Projection Microscope fibre diameter

From the results previously obtained, the accuracy of fibre diameter estimates of medullated wools, as measured by the Airflow, is dependent on the degree of medullation of wools as well as their CV. It seems, therefore, reasonable to consider such factors to obtain more reliable AF results which should be closer to those from the PM ("true" fibre diameter). In general, the CV of the measured samples is not known in practice. However, from the results obtained, its exclusion from fibre diameter prediction would only imply a predicted random error of not more than 0.5 μm. This assumes that values of CV from 17.0% to 29.0% are found equally in wools from 22.0 to 38.0 μm. The expected errors, therefore, would be lower since such a distribution might not be encountered.

The results from model (b.1) are presented in Table 7. This summarizes prediction equations of PM fibre diameter for a given AF diameter and medullation, as assessed by the

TABLE 7. Multiple linear regression coefficients; model (b.1) where the medullation assessment method (MAM; X_2) is equal to PMM or MM or IM.

Variables	Models			Residual
	PM	MAM	βo	SD (μm)
PMM				
Mult. R^2	0.986	0.993		
βi value	0.964	0.075	0.834	
βi (Se)	0.005	0.005	0.165	
				0.38
MM				
Mult. R^2	0.967	0.977		
βi value	0.936	0.139	1.770	
βi (Se)	0.016	0.023	0.531	
				0.48
IM				
Mult. R^2	0.955	0.977		
βi value	0.940	0.123	1.149	
βi (Se)	0.023	0.019	0.570	
				0.38

three methods studied. Examination of the equations reveals the high accuracy with which PM diameter can be predicted from all models (99.3% – 97.7%), with a residual error of not more than 0.48μm.

For the different medullation assessment methods, a plot of the pairwise comparison between the actual AF and PM results is shown in Fig. 1, 2 and 3 (items a); while the improvement in AF estimates by applying the correction equations developed (Table 7) is shown in the items (b) of the same Figures.

The largest observed differences between AF and PM values were about 2.5μm (Figures 1a and 2a) and 1.5μm (Figure 3a), which were respectively reduced to approximately 1.0 and 0.5 m, when predicting PM diameter from AF diameter plus medullation. Overall, a relatively better agreement between both observed and predicted PM diameters was obtained, regardless of medullation assessment method used to supplement AF measurements.

CONCLUSIONS

1. The degree of medullation, assessed by the Projection Microscope or the Medullameter or the InfraAlyser instrument, and coefficient of variation of wools, significantly affected mean fibre diameter as measured by the Airflow method. Medullation had a much greater effect than coefficient of variation, but both effects were substantially smaller than those theoretically predicted. The relatively low correlation between specific gravity and medullation (either % area of medullation or % number of fibres), show that theoretical predictions of AF diameter, taking into account their reciprocal relations, might not lead to accurate results.

2. There was no large bias caused by the differential in coefficient of variation between the measured samples, and IWTO standard tops used to calibrate the AF instrument; despite the fact that the ranges of both fibre diameter and coefficient of variation of wools were beyond those of the calibrating tops. The results

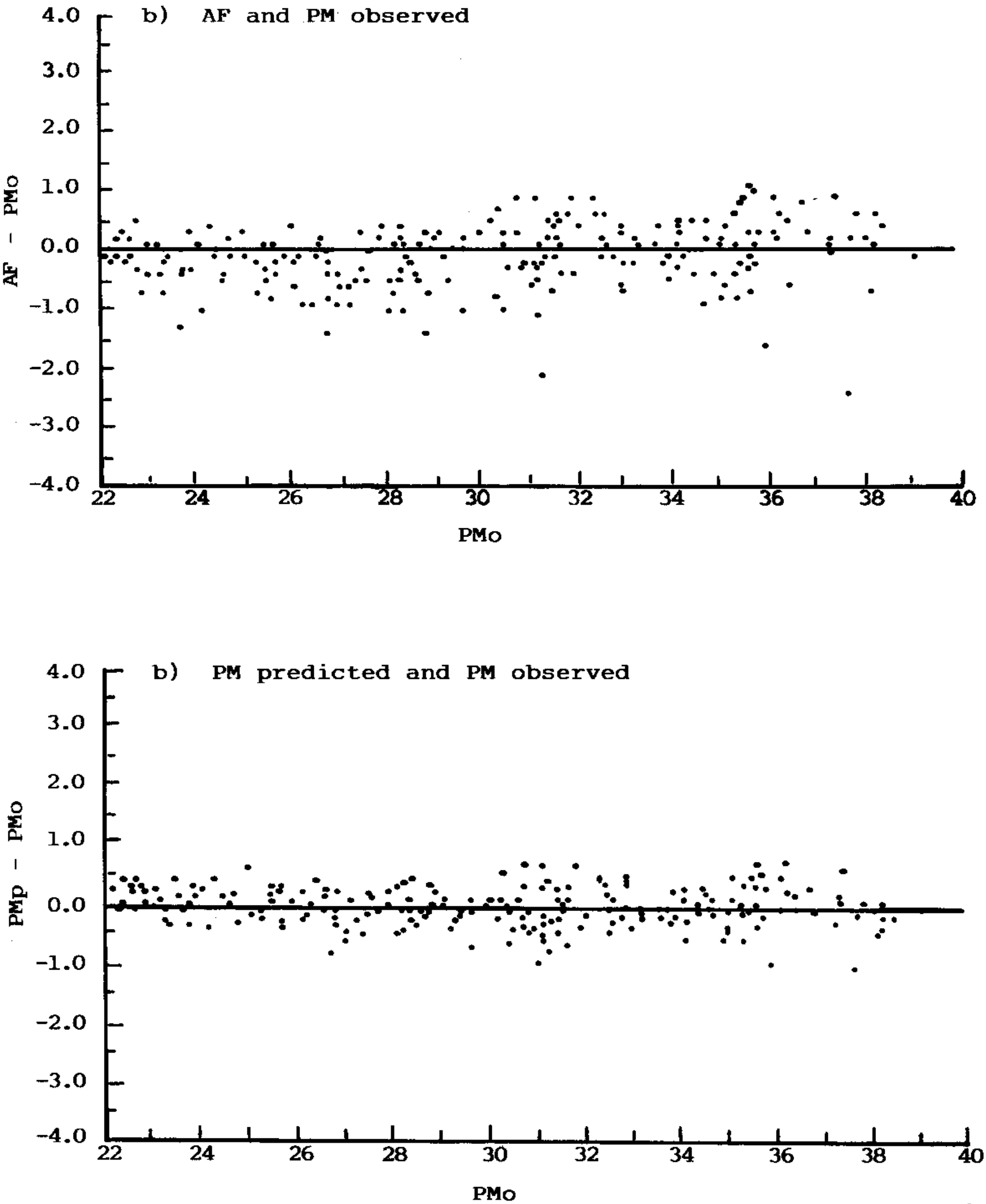
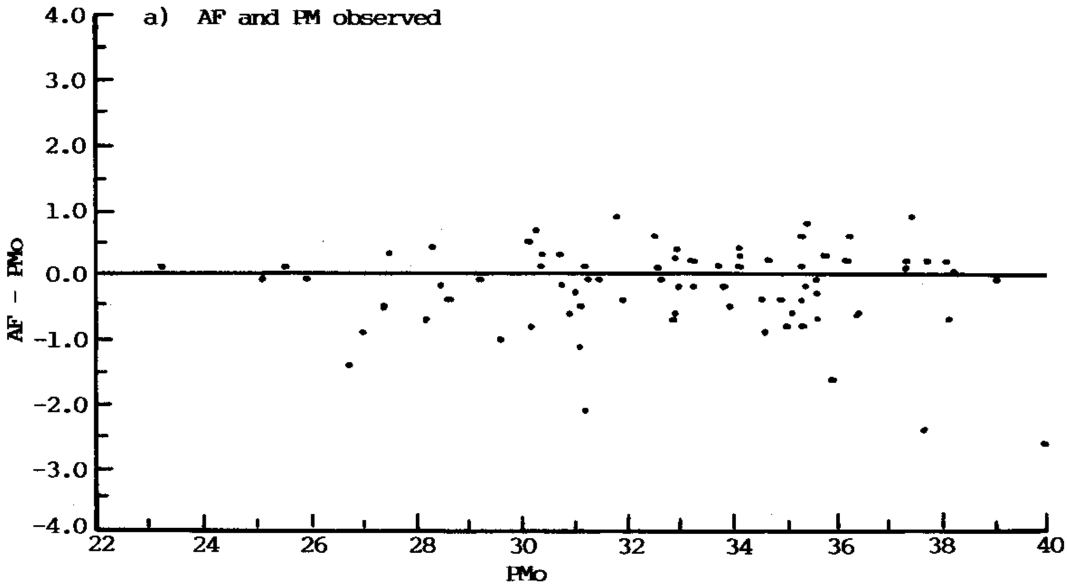


FIG. 1. Pairwise comparison of mean fibre diameter (μ m) for samples where medullation was assessed by the PMM method.



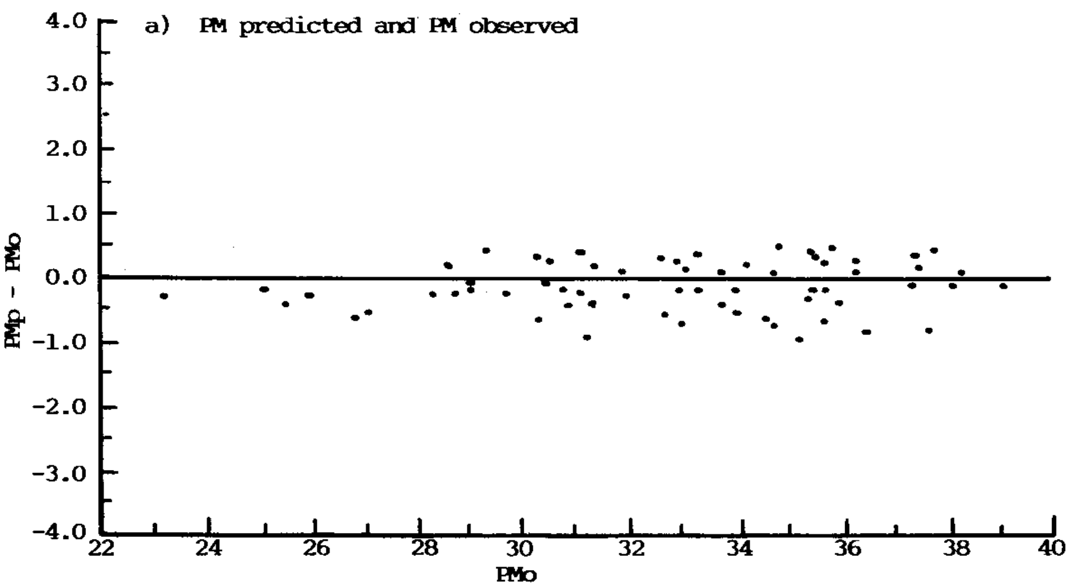


FIG. 2. Pairwise comparison of mean fibre diameter (μm) for samples where medullation was assessed by the MM method.

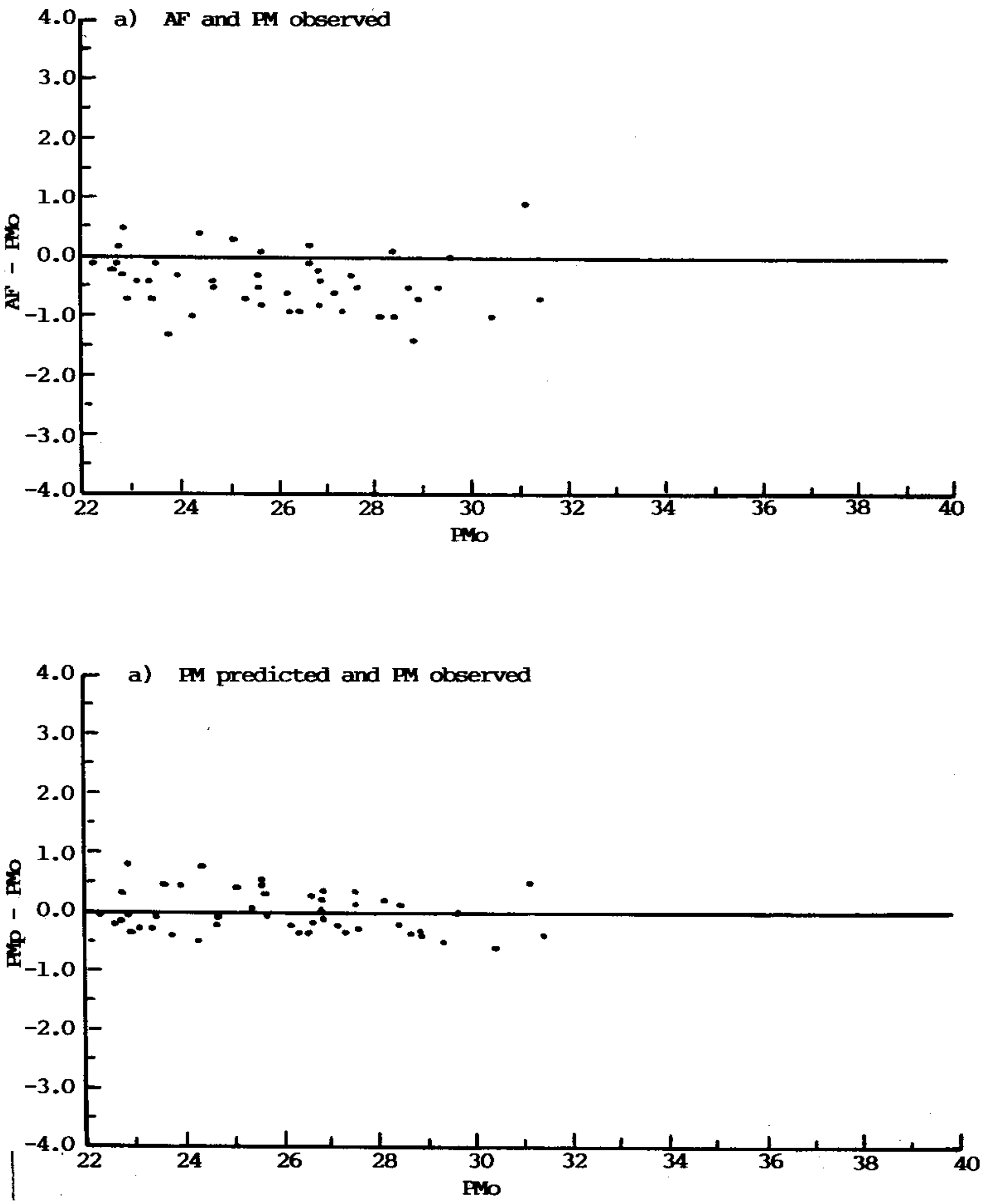


FIG. 3. Pairwise comparison of mean fibre diameter (μm) for samples where medullation was assessed by the IM method.

suggested that the latter were suitable for the samples examined.

3. Both the medullameter and the InfraAlyser instruments were similar in predicting changes in fibre diameter at equal variations in % area of medullation. This suggests a relatively overall advantage of the InfraAlyser instrument, since it can be used in other wool measurements.

4. When fibre diameter measurements of medullated wools are carried out on an Airflow, the supplementary information of levels of medullation provides a means of more accurate results, which are closer to "true" diameter. A 95% confidence limit varying from ±0.75 μm to ±0.94 μm (depending on the correction method used) was observed, for corrected AF values compared with PM values, which were within the range or below those reported on non-medullated wools. The results suggest an Appendix in the IWTO standard showing that AF can be satisfactorily used to measure fibre diameter of medullated wools, if correction equations are applied in the way described. These are easily employed, as do not require any modification either on the test procedures or on the AF instrument normally used.

5. Correction equations developed for both the MM and IM methods may be routinely employed, since medullameter and InfraAlyser instruments give faster, more automated, and probably less biased medullation evaluation.

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