

Classification of Tea Grades including Long Leaf Types by Sieve Analysis

¹M T Ziyad Mohamed, ¹G L C Galahitiyawa, ¹M A Chamindra and ²W C A De Silva
¹Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka
²De Silva, Abeywardene & Pieris (Pvt) Ltd, State Bank of India Building, Colombo 1,
Sri Lanka

ABSTRACT

Particle size distributions of Broken or Small leaf grades have been successfully analysed by sieve analysis techniques and it has been shown that these distributions are polydispersed mixtures of particle sizes that are lognormally distributed and based on a mathematical model, the two parameters which fully describe these distributions viz. the mean values and their standard deviations together with their confidence limits have been ascertained for BOP and BOPF (De Silva, 1972). Although earlier it was thought that the methods of sieve analysis were inapplicable to characterize the particle size distribution of long leaf grades because of the large differences in the maximum and minimum dimensions of the particles constituting long leaf grades, it is now established that the particle size distributions of long leaf grades too are polydisperse mixtures of particle sizes that are lognormally distributed provided sizes of long leaf particles are taken to mean the second largest of the dimensions of such particles. Applying the mathematical model proposed by De Silva (De Silva, 1972) the relationships between the probits of cumulative undersize and the corresponding fineness moduli of the particle sizes have been established for true to type grades corresponding to OPA, OP, OP1, BOP1, Pekoe, Pekoe 1, FBOP, FBOP1, FBOPF, FBOPF1. From these relationships the mean values and the standard deviations, which fully describe the particle size distributions of these grades, either within long leaf type or pekoe type or hybrid type are presented. However, further research is needed to establish the confidence limits of these parameters.

Key words: particle size analysis, long leaf grades

BRIEF REVIEW OF RESEARCH ON PARTICLE SIZE ANALYSIS

Earliest attempts to specify standards for graded teas were only successful in reporting results obtained by fractionating grades into three broad nominal particle size ranges in one series of experiments (Evans, 1931; 1932) and into eight nominal particle size ranges in another series of experiments (Lamb, 1937a; 1937b; 1939; 1940). Subsequently it has

been established that High Grown BOP and BOPF grades are polydisperse mixtures of sizes distributed lognormally (De Silva, 1972) and that these distributions could be completely characterized by the means and the standard deviations of the particle size distributions measured on a logarithmic scale or a "Fineness Modulus" scale which is a more convenient scale and bears a known relationship to a logarithmic scale.

Based on this work, the Technical Committee on Tea of the International Organization of Standardization (ISO/TC 34/SC 8), in 1994 proposed a method of classification of tea grades based on collections of data on grades produced in various countries. In this method, titled "ISO 11286 - Tea - Classification of grades by particle size analysis" – according to which, a particular tea grade is defined mainly based on the particle size distribution, using meshes having aperture sizes between 0.125 mm and 2.0 mm.

A Mathematical Model

The average particle size of a polydisperse mixture could be computed from the distribution of particle sizes. Even though sieve analysis techniques had been used to generate the distribution of particle sizes of High Grown BOP and BOPF, it has been stated that this technique may be unsatisfactory for characterization of grades such as Orange Pekoe and some of the other Low-Country grades, where large differences are observed between the maximum and minimum dimensions of particles (De Silva, 1972). This concept needs review.

In the mathematical model proposed by De Silva (De Silva, 1972) to accommodate the results of sieve analysis of Broken grades the average size of particles transmitted through a B.S. sieve and retained on another B.S. sieve one step smaller having a nominal No. N has been defined as the arithmetic average of the aperture sizes of the two sieves defined by

$$D_N = \frac{1}{2} [d_N + \sqrt{2} \cdot d_N]$$

i.e. $D_N = \frac{1}{2} d_N [1 + \sqrt{2}]$ - (1)

The average size, defined by equation (1) refers to the average equivalent diameters of the tea particles considered as spheres, which is more or less true for true to type grades such as Pekoe, Pekoe 1, BOP, BOPF, D1, etc. In the case of grades such as OPA, OP, OP1, BOP1, etc it is quite inappropriate to convert their average particle sizes to diameters of equivalent spheres. The particles of these grades in no way resemble spheres. They are highly eccentric and elliptic in shape. Therefore it is necessary to find a meaning to, the sizes of the particles corresponding to grades such as OPA retained on sieves during sieve analysis.

Whether an irregularly shaped particle will pass through a given sieve or will be retained depends usually on the second largest linear dimension of the particle. This is true not only for more or less spherical particles associated with tea grades such as Pekoe, BOP, BOPF, etc. but also for long leaf particles having circular or elliptic cross sections associated with tea grades such as OPA, OP, OP1, BOP 1 etc. Accordingly, once the average particle size given by equation (1) is taken to mean or specify the average of the second largest linear dimension of irregularly shaped tea particles, the mathematical model proposed by De Silva will accommodate the results of sieve analysis of not only Broken grades of tea but also of long leaf grades of tea.

Using British standard set of sieves (BS 410, 1960) where the aperture size of one sieve is $\sqrt[4]{2}$ times as large as the next smallest sieve, De Silva's (1972) model gives the following equation

$$d_{N+Z} = d_N (\sqrt[4]{2})^Z \quad - (2)$$

where

d_N = aperture size of reference mesh having a nominal mesh number N

d_{N+Z} = aperture of mesh Z steps larger than the aperture size of mesh having a nominal number N.

It follows from equation 1 and 2 that

$$D_{N+Z} = \frac{1}{2} d_N (\sqrt[4]{2})^Z [1 + \sqrt[4]{2}] \quad - (3)$$

Where D_{N+Z} = average size of particles retained on a B.S. sieve Z steps larger than a reference mesh having a nominal No. N

Following the classification system devised by D.A. Abrams (Henderson and Perry, 1955) which has been used by the American Society of Agricultural Engineers for determining the performance of feed grinders, De Silva (De Silva, 1972) in introducing his mathematical model has defined Z in equation (3) as the "Fineness modulus" of tea particles retained on a B.S. sieve Z steps larger than a reference sieve having a nominal number N during sieve analysis using a complete set of B.S. sieves.

If the B.S. test sieve corresponding to nominal No. 60 and having an aperture size of 250 microns is taken as the reference sieve, then from equation (3) it follows that Z is zero for the reference sieve and that

$$D_{60} = \frac{1}{2} d_{60} [1 + \sqrt[4]{2}]$$

$$= 125 [1 + \sqrt[4]{2}] - (4)$$

If the fineness modulus of particles retained on a sieve Z steps larger than the reference sieve is taken as F_{60+Z} then

$$F_{60} = 0 \quad - (5)$$

$$F_{60+Z} = Z \quad - (6)$$

then equation (3) combined with equation (4) could be re-written as follows:-

$$D_{60+Z} = 125 [1 + \sqrt[4]{2}] [\sqrt[4]{2}]^Z$$

$$\therefore = 125 [1 + \sqrt[4]{2}] [\sqrt[4]{2}]^{F_{60+Z}} \quad - (7)$$

Equation (7) gives the relationship between average particle size retained on a mesh Z steps higher than the reference mesh No. 60 and Fineness Modulus of such particles during sieving operations using a complete set of B.S. Test Sieves. This equation could be transformed into form in equation (8).

$$\log D_{60+Z} = (\frac{1}{4} \log 2) F_{60+Z} + \log 125 [1 + \sqrt[4]{2}] \quad - (8)$$

Equation (8) establishes a linear relationship between average particles sizes retained on B.S. sieves measured on a logarithmic scale and Fineness Moduli measured on an arithmetic scale.

During preliminary attempts to classify long-leaf and semi-leafy grades by Sieve Analysis it was found, that under modified conditions of operating the sieve shaker, that the sizes of particles as redefined in this paper and retained on different meshes of a complete set of B.S. Test Sieves were lognormally distributed, thereby justifying the use of the mathematical model proposed by De Silva (De Silva, 1972), even for the characterization of long leaf grades. If the particle sizes are transformed to a Fineness Modulus scale then the particle sizes measured on this scale will be normally distributed. Accordingly \check{Z} , the mean of this distribution and s, the standard deviation of the distribution, completely define the particle size distribution of the tea grade in question. The equation describing this distribution will be

$$\phi(Z) = \frac{1}{s \sqrt{2\pi}} e^{-\frac{(Z - \check{Z})^2}{2s^2}} \quad - (9)$$

The two parameters which define the above normal distribution viz. \check{Z} and s could be estimated graphically by plotting values of cumulative per cent undersize and the corresponding fineness modulus values, on probability paper having probability co-ordinates for one axis and linear co-ordinates for the other axis or mathematically using probit transformations followed by regression analysis, as described below.

For the normal distribution given by equation (9) the expected percent by weight retained on a sieve z steps higher than mesh No. 60 is

$$Y_{60+z} = \frac{1}{s\sqrt{2\pi}} \int_Z^{Z+1} e^{-\frac{(Z-\check{Z})^2}{2s^2}} \cdot dz \quad (10)$$

And the relationship between probit of cumulative per cent of sizes less than a size corresponding to a Fineness modulus Z (Finney, 1947) is given by

$$Y_z = 5 + \frac{(Z-\check{Z})}{s} \quad (11)$$

Equation (11) indicates a linear relationship between the probit of proportion undersize (i.e. Y_z) with respect to Fineness Modulus (i.e. Z). Accordingly the parameters \check{Z} and s could be estimated using linear regression analysis. These estimates could be further refined by adoption of maximum likelihood solutions (Finney, 1947).

MATERIALS & METHODS

An Endecott Sieve Shaker and a complete set of 17 B.S. Test sieves (BS 410) supplemented with a further 3 sieves having apertures larger than No. 4 B.S. Test Sieve corresponding to aperture sizes of $4(\sqrt[4]{2})$, $4(\sqrt[4]{2})^2$, and $4(\sqrt[4]{2})^3$ mm were used in sieve analysis. The diameter of each test sieve was 8" (20.3 cm) and the specifications of the sieves are given in Appendix 2.

The shaking machine was capable of accommodating ten test sieves. These were nested one above the other, so arranged that any one sieve had screen openings larger than the ones below. A solid pan (receiver) was placed under the bottom sieve. A lid was placed on the top most sieve and the whole assembly was fixed tightly to the vibratory platform of the sieve shaking machine.

The sieve shaking machine was capable of vibrating the test sieves electro-magnetically at 50 Hz and their movement combined vertical motion with a rotational action. This gave thorough stratification and caused the presentation of the particles at all angles to the sieve apertures. The shaking machine had a built-in control with a scale reading from 0 to 10 to vary the intensity of vibration, and a 0-to-60-min. time switch. A stop clock, however, was used instead of the built in timer, to determine intervals of shaking.

Having decided to use 100g samples for sieve analysis, preliminary experiments were directed to determine (a) suitable period of shaking and (b) suitable intensity of vibration and (c) particle degradation. It was possible to obtain more or less reproducible results with 100 g replicate samples having a common origin by adopting a period of 10 minutes for sieve shaking at the maximum intensity of vibration (corresponding to a scale reading of ten of the machine). This standardized method of fractionating was adopted in all the experiments reported, here.

True-to-type samples of the Grades investigated were prepared from Grades commercially produced at St Joachim Tea Factory located in the Ratnapura District, Sri Lanka as depicted in the flow charts given in Appendix 3.

Duplicate samples of each of the true-to-type grades extracted in the manner described (Appendix 3) were fractionated in accordance with the standardized procedure into size ranges reported under results.

Results

The results of sieve analysis of true to type grades giving the percentage weights retained on B.S. Test Sieves are presented in Appendix 4. Cumulative percent undersize corresponding to percent weight retained on B.S. Test Sieves, derived from data presented in Appendix 4 are presented in Appendix 5.

Provisional regression equations were first computed without attaching any weights to the probits of percentage undersize for each of the grades investigated. These equations were subsequently used to obtain maximum likelihood solutions. The method of computation is illustrated in Appendix 6.

Correlation co-efficients corresponding to the provisional regression equations were highly significant ($P < 0.001$) for all the grades investigated being greater than 0.9. The maximum likelihood solutions were utilized to obtain estimates of the parameters, which completely describe the particle size distribution, viz. \bar{Z} , the mean Fineness Modulus of the grades and s , the standard deviation of the distributions of particle size as measured on a Fineness modulus scale.

The maximum likelihood solutions obtained together with the corresponding mean Fineness Moduli and their standard deviations, are given in Table 1.

Table 1. Maximum Likelihood Solutions describing the Particle Size distribution of Grades together with Mean Fineness Moduli of the distributions and their Standard deviations

Family	Grade	Maximum Likelihood Solutions	\bar{z}	s
Long Leaf	OPA	$Yz = 0.617 z - 4.743$	15.8	1.6
	OP	$Yz = 0.780 z - 5.653$	13.6	1.3
	OP 1	$Yz = 0.724 z - 3.258$	11.4	1.4
	BOP 1	$Yz = 0.762 z - 2.819$	10.3	1.3
Pekoe	PEKOE	$Yz = 0.828 z - 6.628$	14.0	1.2
	PEKOE 1	$Yz = 0.873 z - 6.155$	12.8	1.1
Hybrid	FBOP	$Yz = 0.658 z - 1.980$	10.6	1.5
	FBOP 1	$Yz = 0.723 z - 2.181$	9.9	1.4
	FBOPF 1	$Yz = 0.712 z - 1.826$	9.6	1.4
	FBOPF	$Yz = 0.665 z - 0.188$	7.8	1.5

DISCUSSION

For the purpose of discussing the results presented in Table 1, we have classified tea grades produced in Sri Lanka into three broad categories whose brief descriptions are as follows:

(a) Long Leaf Family:

In the grades belonging to this family, there are very large differences in the minimum and maximum dimensions easily discerned visually and the particles are elliptic in shape. The relevant grades are OPA, OP, OP 1 and BOP 1.

(b) Pekoe Family:

In the grades belonging to this family, the three dimensions taken in directions mutually at right angles are more or less the same, for the simple reason that the actual differences cannot be discerned visually. Grades belonging to this family consists of Pekoe, Pekoe 1, BOP, BOPF, FBOPF 1 (non tippy) etc.

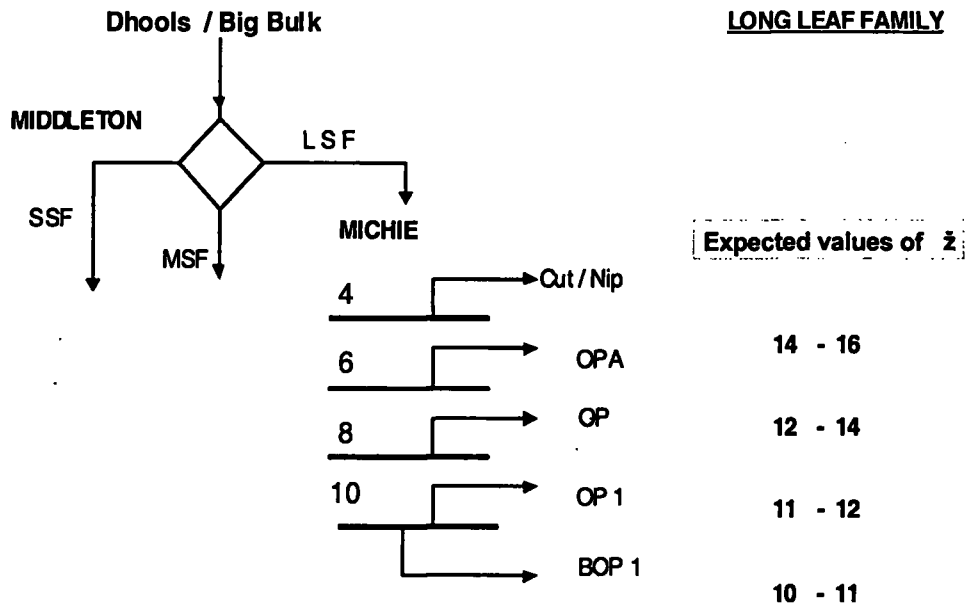
(c) Hybrid Family:

In the grades falling into this category of hybrids lying between long leaf type and Pekoe type, whilst some of the particles are elliptic in shape, and some others are near spherical in shape. For example in the grade FBOPF 1 (tippy type) the tippy particles are elliptic in shape and non tippy particles are near spherical in shape.

Even though the broad classification of grades is a new concept it needs to be accepted in order for research to proceed on the correct lines, to enable the research workers to establish standards for tea grades in accordance with trade requirements and to achieve this, we solicit the co-operation of the trade in our future research plans.

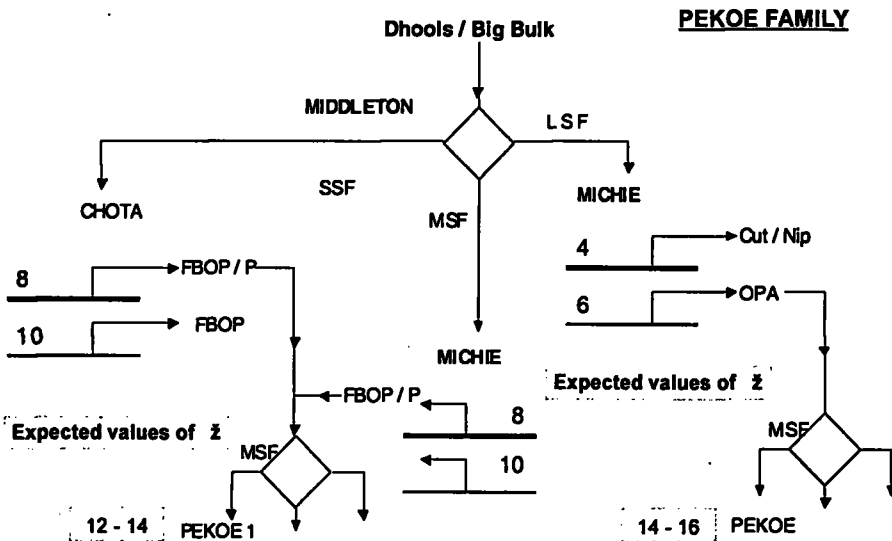
Results establish the fact that sieve analysis provides a reliable method of characterizing grades belonging to the long leaf family consisting of OPA, OP, OP 1, BOP 1 as well as grades belonging to the Pekoe family viz. Pekoe and Pekoe 1 etc. by the particle size distribution. The values of \bar{Z} , the mean Fineness Moduli of the grades and s , the standard deviation of the distributions given in Table 1, completely characterize the grades that have been investigated under three categories, namely long leaf type, Pekoe type and hybrid type. The values of \bar{Z} are the mean sizes of the grades as measured on a fineness modulus scale and these values are in accordance with the sizes of measures used for extraction of these grades as described below:

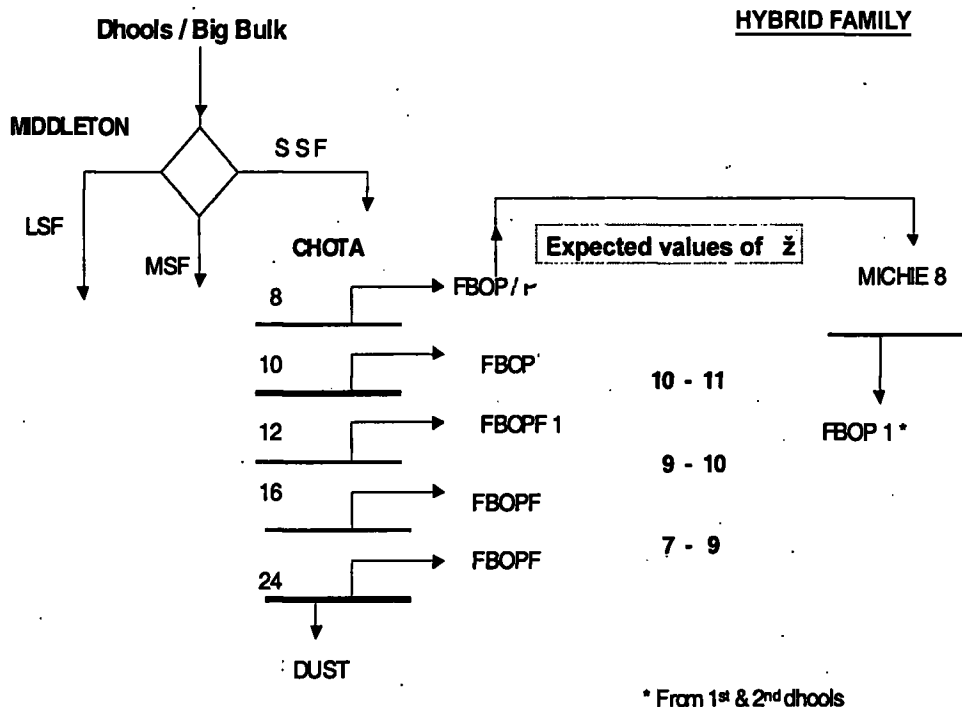
Commercially, the grades belonging to the long leaf family are first separated from the grades belonging to the Pekoe family and other hybrid grade by the use of the Myddleton sifter. Thereafter, these grades are fractionated into OPA, OP, OP 1, BOP 1 using Michie sifters as depicted in the flow chart below, which also includes expected means of the particle sizes of these grades, as measured on a fineness modulus scale.



Comparison of the observed mean values of \bar{z} given in Table 1, with the expected values shown in the above flow chart indicates that the observed values are in accordance with the meshes used for the extraction of the relevant grades.

Grades belonging to the Pekoe family and other hybrid family extracted from the Middleton sifter as the undersize fractions corresponding to mesh sizes of 5 and 8 mm are further fractionated into Pekoe, Pekoe 1 etc. as depicted in the flow charts below.





The present work establishes the fact that with the adoption of large size meshes it is possible to characterize long leaf types as well as pekoe types and hybrid type. However, further research is needed to establish the confidence limits of these parameters, which characterize the particle size distributions.

Furthermore, based on the findings from this study, it was also concluded that method proposed by the Technical Committee on Tea of the International Organization of Standardization (ISO/TC 34/SC 8) is not applicable to long leafy grades of tea. This is because meshes with larger perforations, up to 6.70 mm, have to be used for separation, as the particle sizes and shapes are too eccentric, compared to more or less spherical shape of broken grades.

REFERENCES

- British Standards Institution (1969). B.S. 410: Specifications for Test Sieves. British Standards Institution, London.
- De Silva, W C A. (1972). The Tea Quarterly, Volume 43, Parts 1 & 2, 21 - 35.
- Evans, D I, (1931). Annual Report of the Tea Research Institute of Ceylon 1930, 30 - 39.
- Evans, D I, (1932). Handbook Concerning Tea Manufacture at St Coombs - Tea Research Institute of Ceylon Bulletin No. 9, 72 pp
- Finney, D J, (1947). Probit Analysis. Cambridge University Press, Cambridge. 256 pp

- Fisher, R. A. & Yates, F(1938):Revised in 1963; Statistical Tables for Biological, Agricultural & Medical Research, Oliver & Boyd Press, London.
- Henderson, S M. & Perry, R L. (1955). Agricultural Process Engineering. John Wiley & Sons, Inc. New York, 402 pp
- Lamb, J. (1937 a). Annual Report of the Tea Research Institute of Ceylon 1936, 60 - 89.
- Lamb, J. (1937 b). Grading tea with stamped aluminium sieves-I. Tea Quarterly 10, 191-195.
- Lamb, J. (1939). Grading tea with stamped aluminium sieves-II. Tea Quarterly 12, 79 –182.
- Lamb, J. (1940). Grading tea with stamped aluminium sieves-III. The Arnott Filter Sifter. Tea Quarterly 13, 82 –85.

Appendix 1

Nomenclature

(A complete set of British Standard test sieves is implied where applicable)

- a = $\frac{1}{2} dN [1 + 4^{0.2}]$ the average size of particles retained on a mesh having a nominal No. N (microns)
- b = $4^{0.2}$ (dimensionless constant)
- D = Geometric average size of particles of a polydisperse mixture (microns)
- D_N = Average size of particles retained on a sieve z steps larger than N (microns)
- D_{N+z} = Average size of particles retained on a sieve z steps larger than N (microns)
- d_N = Average aperture size of sieve having a nominal No. N (Microns)
- F_N = Fineness Modulus of particles retained on a sieve having a nominal No. N (dimensionless) defined by $F_{60} = 0$
 $F_{60+z} = z$
- F_{N+z} = Fineness Modulus of particles retained on a sieve z steps larger than a Sieve having a nominal No. N, F_{60} being taken as zero
- g = Abbreviation for grams
- N = Nominal Mesh No. (dimensionless)
- Y_z = Probit of cumulative percent of sizes less than a size corresponding to a Fineness Modulus z (dimensionless)
- y_{60} = Per cent by weight of particles retained on Mesh No. 60 (dimensionless)
- y_{60+z} = Percent by weight of particles retained on a mesh z steps larger than mesh No. 60 (dimensionless)
- z = Fineness Modulus of particles retained on a sieve z steps larger than a sieve having a nominal No. 60 (dimensionless)
- \bar{z} = Mean Fineness Modulus of a poly-disperse mixture of particles (dimensionless)
- s = Standard deviation of normally distributed particles sizes of tea grades as measured on a Fineness Modulus scale.

In addition to these, other standard mathematical symbols have been adopted.

Appendix 2

Specification of test sieves

A complete set of sieves conforming to BS 410 (1969) having a ration between successive sieves equal to $\sqrt[4]{2}$ or 1.19, was used.

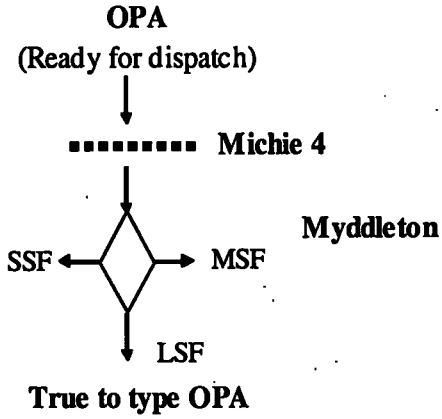
Nominal mesh No.	Aperture width (microns)	Mean size of particles retained (microns)	Fineness modulus of particles retained
3	6700	-	-
3-	5600	6150	18
4+	4700	5150	17
4	4000	4350	16
5	3350	3675	15
6	2800	3075	14
7	2400	2600	13
8	2000	2200	12
10	1680	1840	11
12	1400	1540	10
14	1200	1300	9
16	1000	1100	8
18	850	925	7
22	710	780	6
25	600	655	5
30	500	550	4
36	420	460	3
44	355	388	2
52	300	328	1
60	250	275	0

Appendix 3:

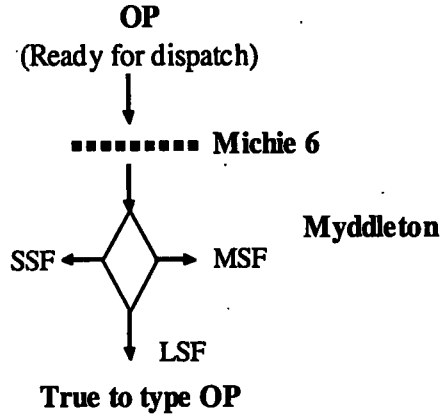
Flow chart describing the method of preparing true to type grades

Family: Long leaf

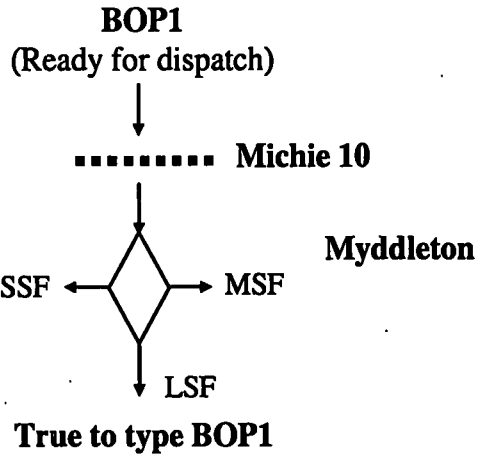
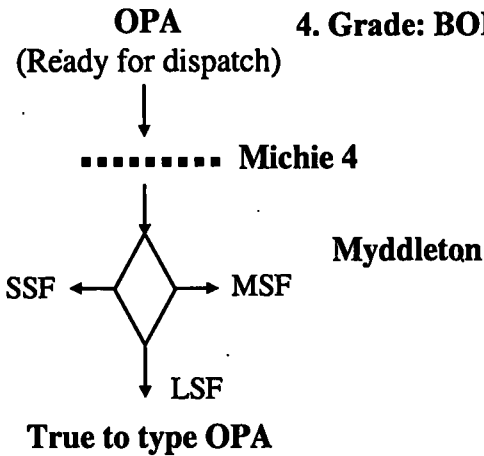
1. Grade: OPA



2. Grade: OP

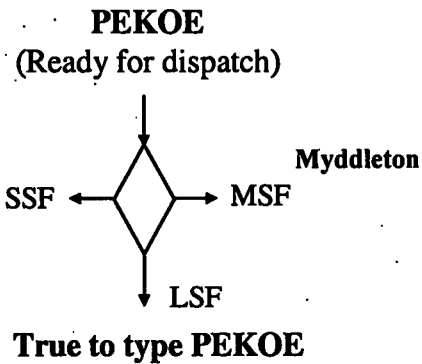


4. Grade: BOP1

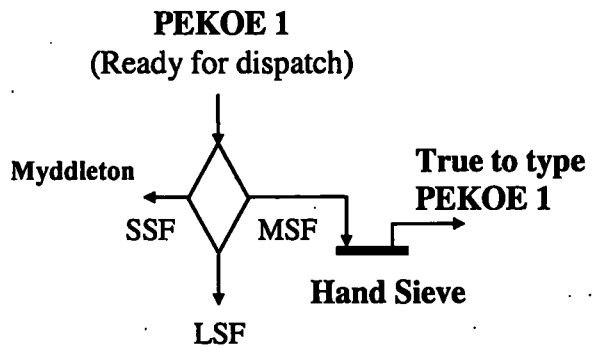


FAMILY: PEKOE

1. Grate: Pekoe

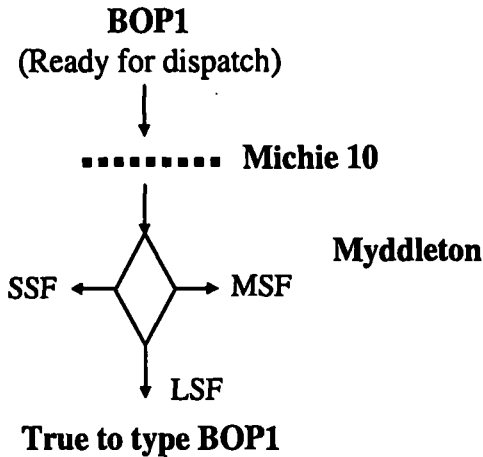


2. Grade: Pekoe 1

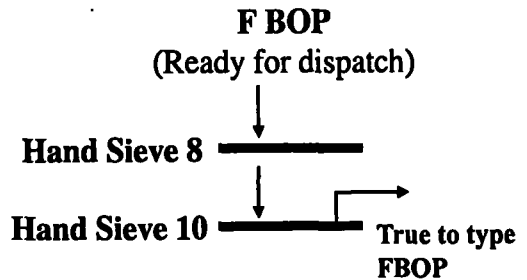


**Appendix 3 Contd....
Hybrid Family**

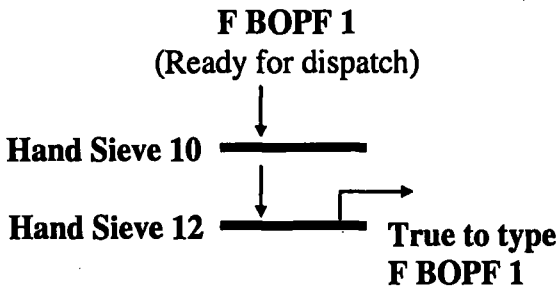
1. Grade: F BOP 1



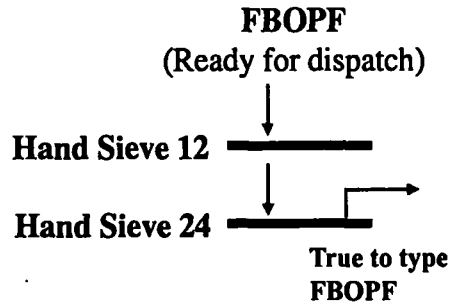
2. Grade: F BOP



3. Grade: F BOPF 1



4. Grade: F BOPF



Key to abbreviations:

SSF – Small size fraction – undersize fractions coming through a 5 mm mesh in a Myddleton sifter

MSF – Medium size fraction – fraction over 5 mm and through 8 mm mesh in a Myddleton sifter

LSF – Large size fraction – fraction over 8 mm mesh in a Myddleton sifter

Appendix 4

Results of sieve analysis of true to type grades																							
SIEVE	N	3	3 ⁻	4+	4	5	6	7	8	10	12	14	16	18	22	25	30	36	44	52	60	BP	
SPECIFICATIONS	d _N	6700	5600	4760	4000	3350	2800	2400	2000	1680	1400	1200	1000	850	710	600	500	420	355	300	250	0	
	D _N	-	6150	5180	4380	3675	3075	2600	2200	1840	1540	1300	1100	925	780	655	550	460	387.5	327.5	275	-	
	F _N	-	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	-	
GRADE	REF	Weights (%) retained on B.S.sieves																					
OPA	R1	0.61	3.49	14.96	24.45	34.62	13.15	4.29	2.33	1.06	0.84											0.20	
	R2	0.81	4.09	17.16	26.42	29.32	13.32	4.03	2.33	1.30	0.94												0.27
OP	R1	0.00	0.02	0.20	0.46	7.92	41.90	24.92	13.68	6.85	2.70												1.36
	R2	0.06	0.04	0.36	0.43	6.25	45.61	22.75	14.21	6.15	2.60												1.55
OP 1	R1					0.35	1.32	7.66	29.11	30.91	18.05	6.94	4.84	0.67	0.12								0.02
	R2					0.31	0.84	7.10	27.39	31.31	18.13	8.10	5.80	0.77	0.18								0.06
BOP 1	R1				0.01	0.06	0.16	0.33	1.68	39.42	21.83	16.13	15.88	3.24									1.26
	R2				0.01	0.04	0.17	0.45	2.33	34.37	26.09	16.61	14.80	3.53									1.61
FBOP 1	R1				0.04	0.00	0.09	0.22	1.79	24.34	30.91	15.36	17.98	5.77									3.50
	R2				0.01	0.02	0.10	0.23	1.57	22.44	33.99	15.06	17.53	5.86									3.18
FBOP	R1					0.00	0.07	1.07	6.91	29.74	32.94	10.44	13.15	3.73	1.35								0.60
	R2					0.02	0.27	4.72	19.26	30.47	20.16	10.97	10.10	2.78	0.86								0.39
PEKOE	R1	0.00	0.01	0.55	3.91	16.91	36.81	28.23	10.13	2.38	0.65												0.41
	R2	0.00	0.01	0.05	3.43	13.73	35.20	28.44	13.34	4.27	0.99												0.54
PEKOE 1	R1	0.00	0.01	0.01	0.08	1.44	11.01	29.62	42.65	12.32	1.78												1.07
	R2	0.00	0.01	0.06	0.05	1.99	12.86	26.33	33.97	15.81	4.60												4.32
FBOPF	R1					0.00	0.01	0.01	0.23	3.31	21.31	28.01	20.73	14.79	6.63								4.99
	R2					0.00	0.01	0.01	0.22	2.87	18.81	27.95	20.55	15.53	7.99								6.06
FBOPF1	R1					0.00	0.05	1.19	9.16	37.57	19.29	19.20	8.42	3.52	1.21								0.40
	R2					0.02	0.19	1.99	11.84	34.59	20.46	19.08	7.40	3.08	1.04								0.33

Appendix 5

Results of sieve analysis of true to type grades																						
SIEVES	N	3	3 ⁻	4 ⁺	4	5	6	7	8	10	12	14	16	18	22	25	30	36	44	52	60	BP
PECIFICATIONS	d _N	6700	5600	4760	4000	3350	2800	2400	2000	1680	1400	1200	1000	850	710	600	500	420	355	300	250	0
	D _N	-	6150	5180	4380	3675	3075	2600	2200	1840	1540	1300	1100	925	780	655	550	460	387.5	327.5	275	-
	F _N	-	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	-
GRADE	REP	Weights (%) undersize corresponding to B.S.sieves																				
OPA	R1	99.39	95.90	80.94	56.49	21.87	8.72	4.43	2.10	1.04	0.20											
	R2	99.19	95.10	77.94	51.52	22.21	8.89	4.86	2.54	1.23	0.27											
OP	R1	100.00	99.98	99.78	99.32	91.40	49.50	24.59	10.90	4.06	1.36											
	R2	99.94	99.90	99.54	99.11	92.86	47.26	24.50	10.29	4.15	1.55											
OP 1	R1					100.00	99.65	98.33	90.67	61.56	30.65	12.60	5.66	0.81	0.15							
	R2					99.69	98.85	91.74	64.35	33.04	14.91	6.81	1.01	0.24	0.06							
BOP 1	R1				99.99	99.93	99.76	99.43	97.76	58.34	36.51	20.38	4.50	1.26								
	R2				99.99	99.95	99.78	99.32	97.00	62.63	36.54	19.93	5.13	1.61								
FBOP 1	R1				100.00	99.96	99.96	99.87	99.65	97.86	73.52	42.61	27.24	9.27								
	R2				100.00	99.99	99.97	99.87	99.64	98.07	75.63	41.64	26.58	9.04								
FBOP	R1					100.00	99.93	98.86	91.94	62.21	29.27	18.83	5.68	1.95	0.60							
	R2					99.98	99.71	94.99	75.73	45.26	25.09	14.13	4.02	1.25	0.39							
PEKOE	R1	100.00	99.99	99.44	95.53	78.62	41.81	13.58	3.44	1.06	0.41											
	R2	100.00	99.99	99.94	96.51	82.78	47.58	19.14	5.80	1.53	0.54											
PEKOE 1	R1	100.00	99.99	99.98	99.90	98.46	87.44	57.83	15.18	2.85	1.07											
	R2	100.00	99.99	99.93	99.88	97.88	85.02	58.69	24.72	8.91	4.32											
FF	R1						100.00	99.99	99.98	99.75	96.44	75.14	47.13	26.40	11.62	4.99						
	R2						100.00	99.99	99.98	99.76	96.89	78.08	50.13	29.58	14.05	6.06						
FF1	R1						100.00	99.95	98.76	89.60	52.03	32.74	13.55	5.13	1.61	0.40						
	R2						99.98	99.79	97.80	85.97	51.38	30.92	11.85	4.44	1.36	0.33						

Appendix 6

Method of arriving at the maximum likelihood solution to describe the Particle size distribution of tea grades

The method is illustrated by taking sieve analysis results relating to the OPA grade from Appendix 5. The percent undersize particles and corresponding fineness moduli values together with their corresponding probit values are as follows:

F M	Replicate 1		Replicate 2	
	Cum. Under %	Probit	Cum. Under %	Probit
18	95.90	6.7392	95.10	6.6546
17	80.94	5.8756	77.94	5.7701
16	56.49	5.1637	51.52	5.0381
15	21.87	4.2227	22.21	4.2348
14	8.72	3.6418	8.89	3.6531
13	4.43	3.2940	4.86	3.3454
12	2.10	2.9665	2.54	3.0400
11	1.04	2.6737	1.21	2.7429
10	0.20	2.1218	0.27	2.2522

Probit values were calculated for various undersize percentages from statistical tables [Fisher & Yates, 1938]. The regression analysis of the above data yields the following provisional equation, with a correlation coefficient of 0.979.

$$Y = 0.5415 Z - 3.5010$$

The mean value of the distribution is 15.7, with a standard deviation of 1.8.

Provisional equation thus arrived at, gives equal weightage for all the data points. As in a normal distribution, it is necessary to give higher weightage for data points closer to the mean value, than to the points at the tail end of the distribution.

Weighting coefficients were arrived at using values from statistical tables (Fisher and Yates, 1938: Table IX).

Corresponding to the expected probits calculated from the provisional regression equations, the maximum working probits, ranges and the weighting coefficients are tabulated in Table 2

Table 2. Weighting coefficients and probit values used to arrive at the first maximum likelihood solutions.

	Proportion	Expected Probit from provisional equation	Minimum Working Probit	Range	Weighting Coefficients	New probit
z	p	Y	Y-P/Z	1/z	W=Z ² /PQ	Y-P/Z+p/Z
18	0.96	6.25	1.3362	5.4926	0.35310	6.5816673
17	0.79	5.70	3.2724	3.2025	0.53159	5.8163572
16	0.54	5.16	3.7272	2.5421	0.63018	5.0999297
15	0.22	4.62	3.6711	2.6967	0.60363	4.2652001
14	0.09	4.08	3.3955	3.8331	0.46488	3.7326696
13	0.05	3.54	3.0148	7.3041	0.28224	3.3534935
12	0.02	3.00	2.5786	18.5220	0.13112	3.0061356
11	0.01	2.46	2.1101	63.6800	0.04578	2.8265
10	0.00	1.91	1.6130	298.0000	0.01139	2.3133

The first maximum likelihood solutions arrived at, using these weighting coefficients, was

$$Y = 0.6167 Z - 4.7432$$

Corresponding to this solution, the mean value of the distribution is 15.8 with a standard deviation of 1.6. Proceeding in the same manner using the first likelihood solution, further refinements were carried out to arrive at the next most likelihood solution which was $Y = 0.6345 Z - 5.0337$. This equation gives a mean value of 15.8 and standard deviation of 1.6 from the distribution. Mean values and standard deviations of the second maximum likelihood solution are more or less the same as those given by the first likelihood solution. Accordingly, the first likelihood solution worked out was taken as the most appropriate equation.

For varying values of Z there exists one to one correspondence between the probits given by the equation $Y = 0.6167 Z - 4.7432$ and the percent undersize leading to a linear relationship between percent undersize and fineness modulus as illustrated by the straight line in Figure 1 (using the grade OPA as an example), along with data plots corresponding to experimentally determined average percent undersizes and their fineness moduli values. From these graphs the provisional values of the mean of the particle size distributions and their standard deviations could be computed by taking \check{Z} as the value of \check{Z} corresponding to a percentage undersize of 50% and taking as the standard deviation (s) the difference in the values of \check{Z} corresponding to 84.13% and 50% undersize or 50% and 15.87% undersize as illustrated in Figure 1.

Similarly maximum likelihood solutions were worked out for other grades as well. These equations are presented in Table 1.

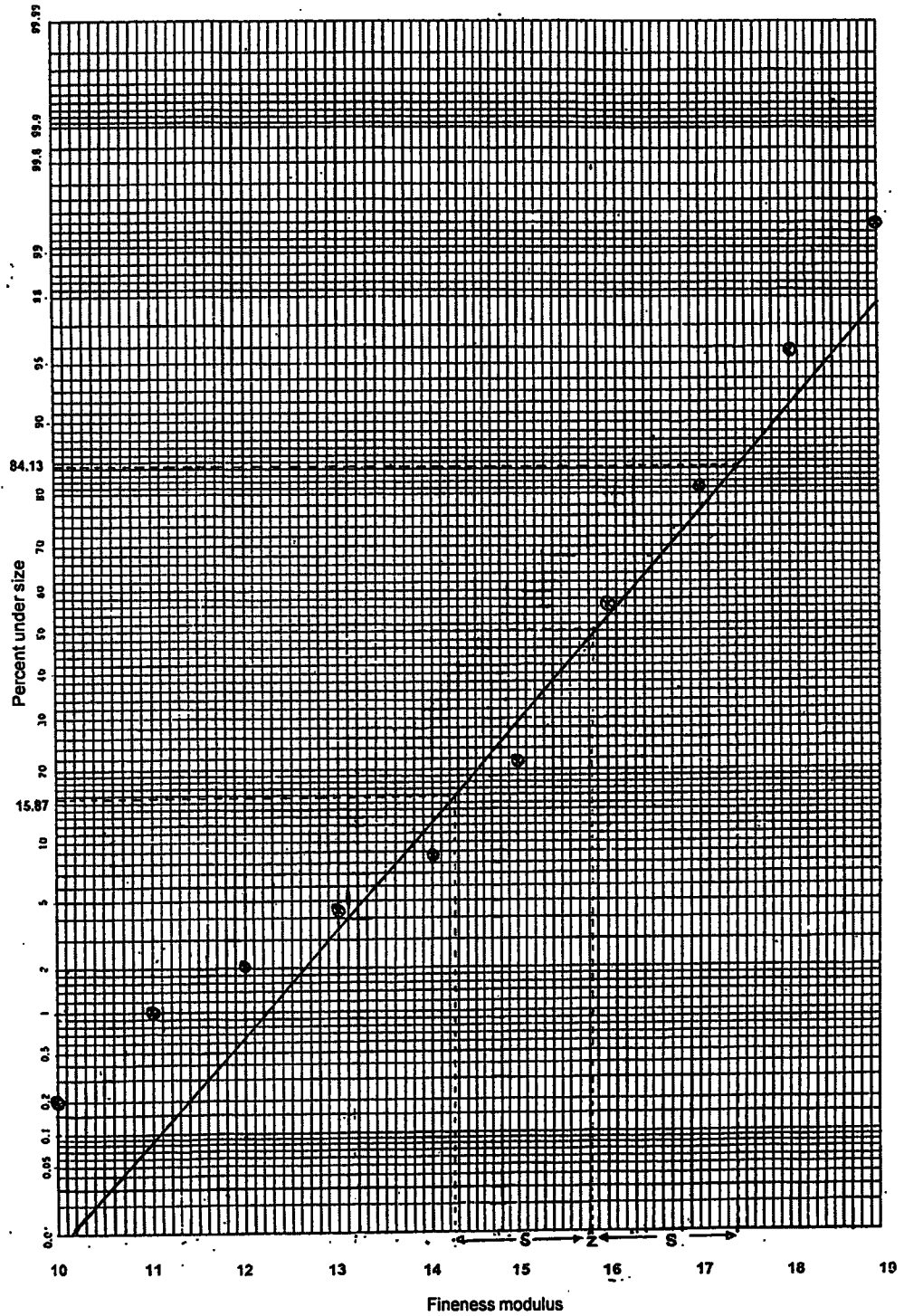


Figure 1. Mean particle size distribution of well-sorted OPA grade as measured on a fineness modulus scale