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REPORT NO. 23

OF 1972

BRANDSTOFNAVORSINGSINSTITUUT
VAN SUID-AFRIKA

FUEL RESEARCH INSTITUTE
OF SOUTH AFRICA

ONDERWERP:
SUBJECT:

THE PREDICTION OF TROMP DISTRIBUTION CURVES FOR CYCLONE WASHERS

AFDELING:
DIVISION: ENGINEERING

NAAM VAN AMPTENAAR:
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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

REPORT NO. 23 OF 1972

THE PREDICTION OF TROMP DISTRIBUTION CURVES FOR CYCLONE WASHERS

SYNOPSIS

A mathematical model has been developed by means of which it is possible to predict the Tromp distribution curve at any mean separation specific gravity within the range 1,3 to 1,5. These curves serve as a reference against which the efficiency of other cyclone washers may be compared.

THE PREDICTION OF TROMP DISTRIBUTION CURVES FOR CYCLONE WASHERS

1. INTRODUCTION

The D.S.M. cyclone washer has become an important unit in the coal processing plant of several South African collieries. The engineer in charge is frequently faced with the problem of assessing the performance of the washer - a task which could be greatly simplified if some "standard" of performance were available against which comparison may be effected.

Numerous washing tests, under stringent control, have been performed in the cyclone washer of the Fuel Research Institute. The results of such tests are, therefore, perfectly suited to serve as a basis for obtaining reference Tromp curves against which the performance of other cyclone washers may be compared. The separation specific gravities (S.G.) of the tests conducted at the Institute range from 1,3 to 1,5; however they do not include all possible separation S.G.'s within this range. It therefore becomes necessary to treat the test results in such a way as to be able to predict or interpolate the Tromp curve to a separation S.G. not obtained experimentally. Accordingly, the object of the present study was to establish a mathematical model of the particular washing process which could be fitted statistically to the test results and which could subsequently be used to obtain reference Tromp curves at any separation S.G. within the range covered.

2. THE BASIS OF THE MODEL

The basis of the model is the "ideal" washer which is defined as one in which no misplacement of material occurs and in which the placement of the material is instantaneous.

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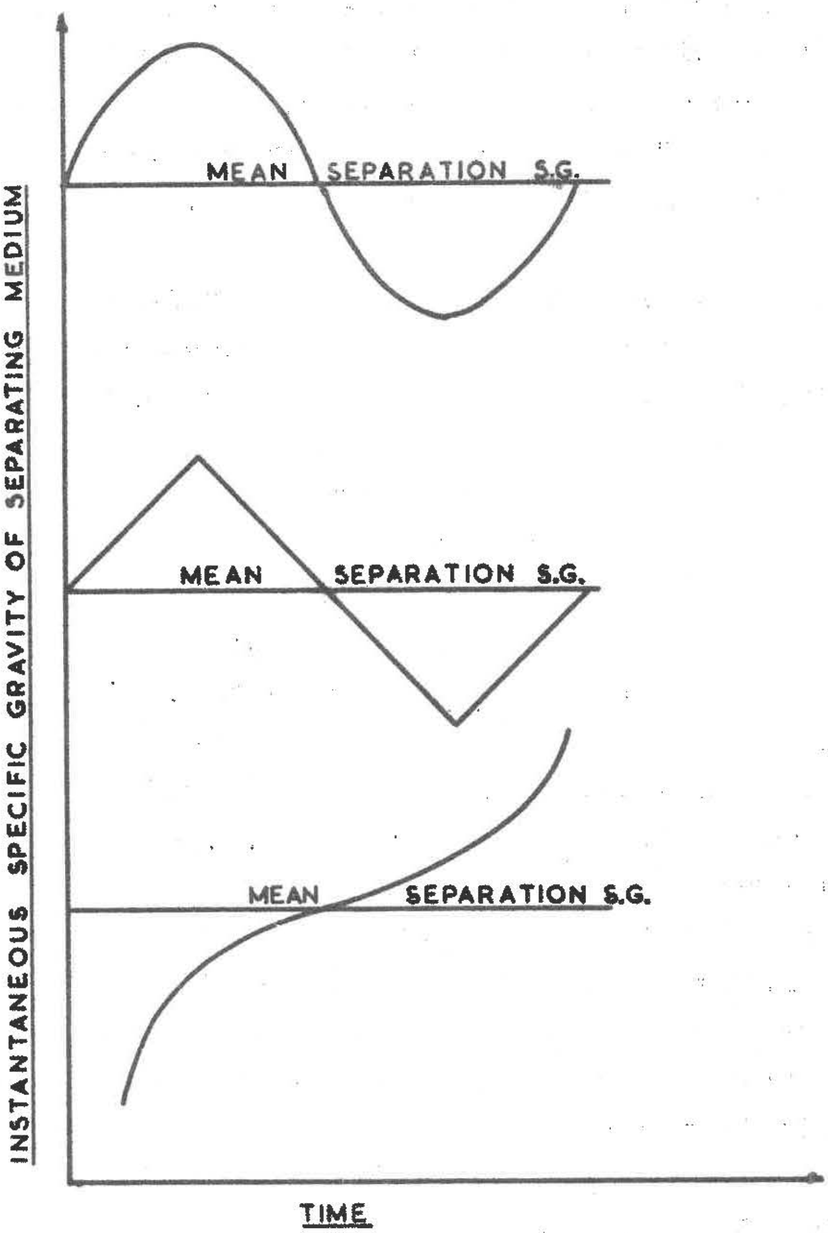

INSTANTANEOUS SPECIFIC GRAVITY OF SEPARATING MEDIUM
MEAN SEPARATION S.G.
MEAN SEPARATION S.G.
MEAN SEPARATION S.G.
TIME

FIGURE I

In the practical situation there are a number of factors which cooperatively cause the misplacement of material and consequently affect the shape of the Tromp curve. The ideal washer can be made to simulate the practical situation by causing the instantaneous S.G. of the medium to oscillate about a fixed level. This level can then be defined as the mean separation S.G., provided the locus of the instantaneous S.G. of the medium satisfies the following conditions:-

(a) The period during which the instantaneous S.G. of the medium exceeds the mean separation S.G. must equal the period during which the converse holds true.

(b) The locus of the instantaneous S.G. of the medium, during the period in which it exceeds the mean separation S.G., must be the mirror image of the locus during the remainder of the washing period.

Functions which satisfy both conditions are illustrated in figure 1.

As the washer is ideal, all of the material having a S.G. of less than that of the medium will divert to the float or product stream, whereas all material having a S.G. greater than that of the medium will enter the sink or discard stream. Since for part of the washing period, the instantaneous S.G. of the medium exceeds the mean separation S.G., it follows that some of the material in the product stream will have a S.G. greater than the mean separation S.G. The material may then be regarded as being "misplaced" relative to the mean separation S.G. The discard stream will likewise contain misplaced material of which the S.G. is less than the mean separation S.G.

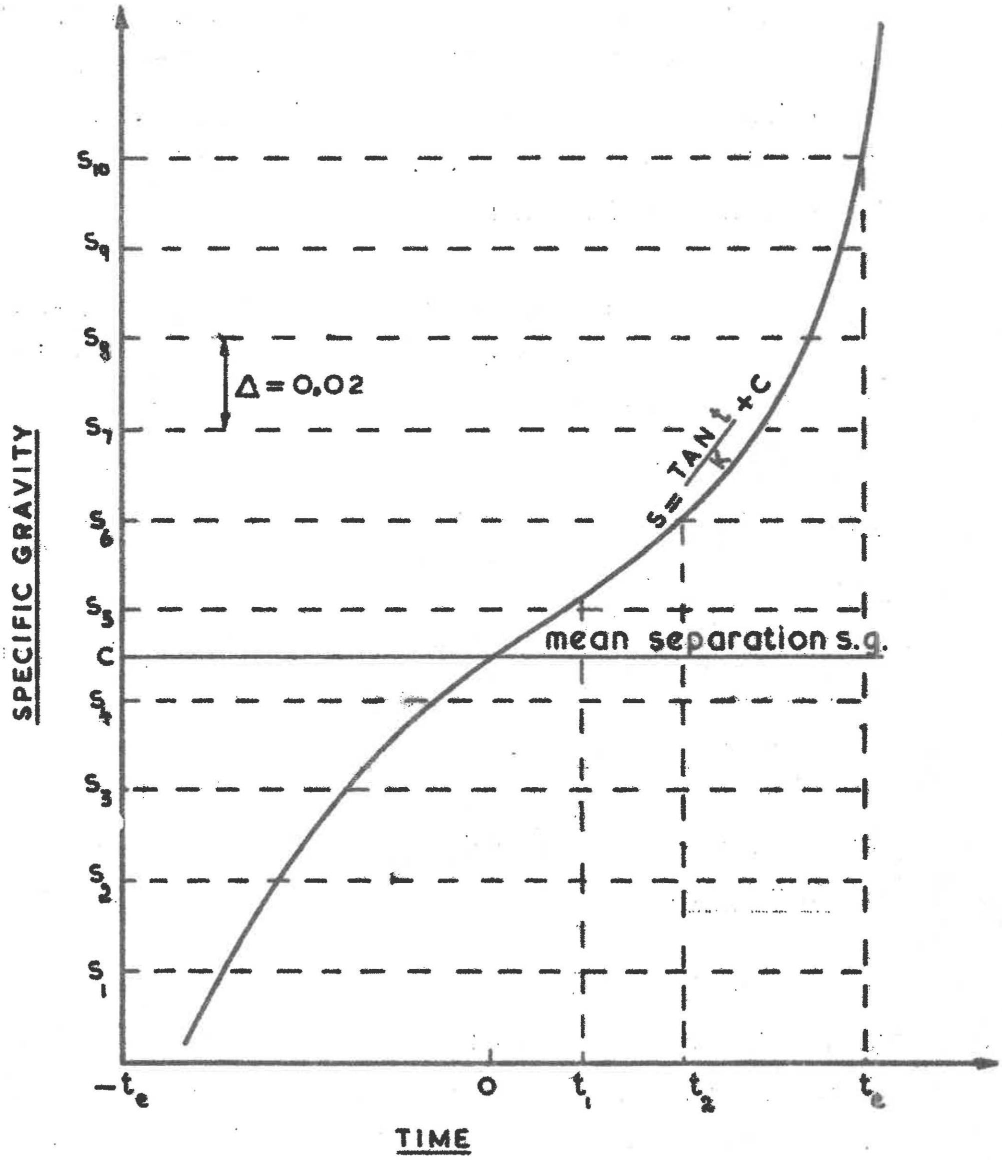

FIGURE 2: SPECIFIC GRAVITY-TIME DIAGRAM

3. THE SPECIFIC GRAVITY-TIME DIAGRAM

The application of the model may be most clearly illustrated with the aid of the S.G.-time diagram. Of the various functions shown in figure 1, the tangent curve was found to be the most suitable for describing the locus of the instantaneous S.G. of the medium and this function is reproduced on the S.G.-time diagram in figure 2. The equation of the locus of the instantaneous S.G. of the medium is given by:

$$S = \frac{\text{Tan } t}{k} + C \qquad (1)$$

wherein S is the instantaneous S.G. of the medium;
t is time;
C is the mean separation S.G., and
k is a quasi constant which, at a later stage, will be shown to be a function of the mean separation S.G.

At this stage it is necessary to recapitulate briefly the method of construction of the Tromp curve, which is the locus of the so-called distribution coefficient. The Tromp curve is constructed by drawing a smooth curve through discrete distribution coefficients calculated as mean values of, and therefore plotted along the centre line of, discrete consecutive S.G. intervals. (These intervals have been standardised at the Institute to 0,02 S.G. units.)

The mean distribution coefficient, D, for any specific gravity interval is generally defined by the following equation:-

$$\frac{D}{100} = \frac{M_p}{M_T} \qquad (2)$$

wherein M_p is the mass of float material contained within the specific gravity interval under consideration, and
M_T is the mass of unwashed material contained within the same S.G. interval.

Equation 2 may be rewritten in terms of the appropriate areas on the S.G.-time diagram. As the procedure is the same for all S.G. intervals this will be done for one interval only, viz. interval S_5 to S_6 in figure 2. With reference to figure 2 it follows that

$$M_p = F\int_{t_1}^{t_2} (S - S_5)dt + F(S_6 - S_5)(t_e - t_2) \qquad (3)$$

and

$$M_T = 2F(S_6 - S_5)t_e \qquad (4)$$

wherein F is the feed rate of unwashed material to the washer, and
t_e is half the duration of the washing process.

Substitution of equations 3 and 4 into equation 2 gives the distribution coefficient of the interval as:

$$\frac{D}{100} = \left[\int_{t_1}^{t_2} (S - S_5)dt + \Delta\,(t_e - t_2)\right] \Big/ 2\Delta\, t_e \qquad (5)$$

wherein $\Delta = 0{,}02$ = the width of a S.G. interval.

Equation(5) can be solved quite readily provided t_e and k, the latter contained implicitly in S, are known. Clearly, the upper limit for t_e is $\pi/2$, in which case an infinite number of S.G. intervals would be involved, all of which would have distribution coefficients greater than zero. In practice the distribution coefficient rapidly tends to zero as the number of intervals above the cutpoint interval* increases. The distribution coefficient for

/the .....

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* The specific gravity interval containing the mean separation S.G. is termed the cutpoint interval. Intervals of which the mean S.G. is greater than the mean separation S.G. are considered to be above the cutpoint interval on the S.G.-time diagram.

the 6th interval above the cutpoint interval is usually zero and in this study this limit was adopted and accordingly t_e is given by:

$$t_e = \text{arc Tan}\left[k(S_5 + 5\Delta - 2C)\right] \qquad (6)^*$$

Equations 5 and 6 interrelate the three variables of interest, viz., the distribution coefficient D, the mean separation S.G. C, and the quasi-constant k which is implicitly contained in the equation of the locus of the instantaneous S.G. of the medium.

4. THE QUASI-CONSTANT

In theory one could evaluate the quasi-constant for any washing test provided the cutpoint and any one distribution coefficient are known. In practice, however, the true value of a distribution coefficient is unknown - this is due to the unavoidable inclusion of experimental error. This is particularly so for distribution coefficients corresponding to S.G. intervals in which the ratio $M_p:M_T$ is either very small or close to unity.

In this study the value of the quasi-constant, for any given washing test, was obtained as follows. A value was assigned to the quasi-constant and the distribution coefficients for the cutpoint interval and the two adjacent intervals were computed using the appropriate equations. (The calculations were restricted to these three intervals as it was felt that $M_p:M_T$ is unsatisfactory for other intervals.) The three computed coefficients were then compared with the corresponding

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* Note that S_5 in this case refers to the upper limit of the cutpoint interval and the fact that this also represents the lower limit of the interval for which the illustrative equations 3 to 5 were developed is purely coincidental.

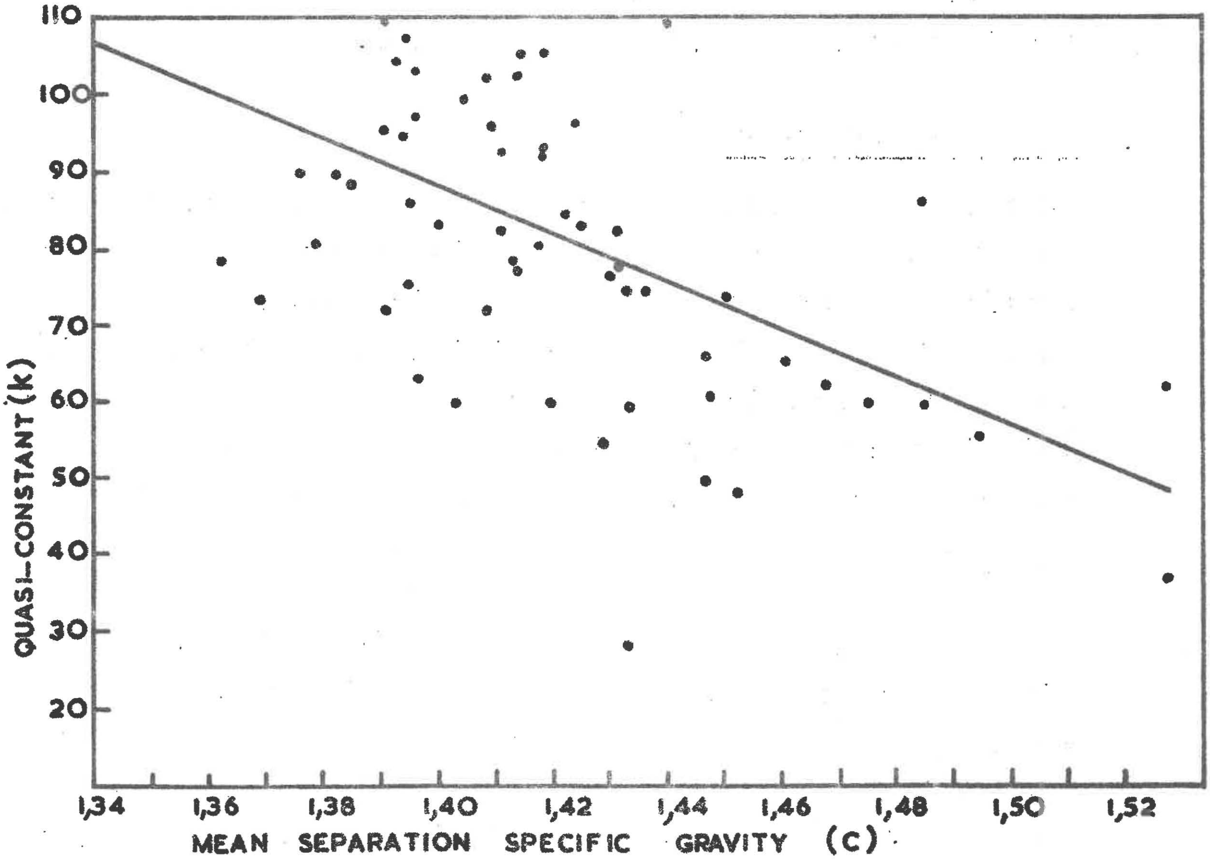

FIGURE 3: QUASI-CONSTANT VERSUS MEAN SEPARATION SPECIFIC GRAVITY

experimentally determined coefficients and the sum of the differences squared was obtained. This process was repeated until the sum of the differences squared was minimised. The value of the quasi-constant so obtained was considered to be correct and was taken to correspond to the experimentally determined cutpoint.

The results of a large number of test washing operations were treated in this way and a plot of the quasi-constant versus the mean separation S.G. was prepared and is reproduced in figure 3. The scatter of the coordinates serves as an indication of the variance to be expected even under close operating control.

A straight line was statistically fitted to the quasi-constant versus mean separation-S.G. plot to obtain an analytical relationship which could be used in the computation of the sets of distribution coefficients at different mean separation S.G.'s. This assumption of linearity is of course open to question. It must, however, be pointed out that the linear relationship applies only to the range covered by the available test data so that extrapolation beyond these limits is not advisable. The equation for the linear relationship was found to be:

$$k = 481{,}2 - 282{,}7\ C \qquad (7)$$

It can be seen from equation 7 that the quasi-constant is a function of the mean separation S.G., C.

5. REFERENCE CURVES

A set of seven distribution coefficients, each 0,02 units apart, was considered a sufficient description of the Tromp curve at any particular mean separation S.G. Accordingly, such sets were computed at various mean separation S.G.'s, using equations 5*, 6 and 7. The results of such calculations are reproduced in Table 1.

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* Note that equation 5 is a typical equation only applying to the S.G. interval S_5 to S_6 in figure 2. Similar equations have to be derived for other intervals.

6. ACCURACY OF THE MODEL

The difference between the computed and the experimentally determined coordinates of a Tromp curve affords a measure of the accuracy of the model. As these differences may be either positive or negative the arithmetic mean of the modulus of the differences, for each of the 7 intervals, was computed for 64 test washing operations. The results are summarized below.

Interval designation	Mean difference (rounded off)
3rd interval preceding the cutpoint interval	1 unit
2nd " " " " "	2 "
1st " " " " "	2 "
Cutpoint interval	2 "
1st interval following the cutpoint interval	3 "
2nd " " " " "	2 "
3rd " " " " "	1 "

It can be seen that the model simulates the practical situation well.

7. APPLICATIONS

One of the more important applications of the predicted coordinates of the Tromp curve is to serve as a basis for comparing the efficiency of other cyclone washers against that of the Institute's washer. As an illustration hereof the results obtained during an acceptance test conducted at a colliery are compared with the data listed in Table 1.

ACCEPTANCE TEST VERSUS PREDICTED VALUES
MEAN SEPARATION S.G. = 1,481

Origin	Distribution coefficients (rounded off)						
Test data	92	86	68	34	12	6	3
Predicted	94	88	70	34	13	6	3

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It can be seen that the efficiency of the washer, under the conditions that prevailed during the acceptance test, was comparable to that of the Institute's washer. Periodic checks of this kind can serve to keep track of plant deterioration occurring during service.

Another application would be to point out errors occurring in the determination of the Tromp curve proper. If any one of the experimentally determined coordinates of the Tromp curve differs significantly from the corresponding predicted value, then retrospective investigation is indicated.

T.C. ERASMUS
CHIEF RESEARCH OFFICER

Pretoria.
6th December, 1972.
TCE/EMc

TABLE 1

Mean Separation S.G.	Distribution Coefficients					
1,340	96	92	74	26	8	4	2
1,341	96	92	76	28	9	4	2
1,342	96	92	77	30	9	4	2
1,343	97	93	79	32	9	4	2
1,344	97	93	80	35	10	4	2
1,345	97	93	82	37	10	5	2
1,346	97	94	83	40	11	5	2
1,347	97	94	84	42	12	5	2
1,348	97	94	85	45	12	5	2
1,349	97	94	86	47	13	5	3
1,350	97	95	86	50	14	5	3
1,351	98	95	87	53	14	6	3
1,352	98	95	88	55	15	6	3
1,353	98	95	88	58	16	6	3
1,354	98	95	89	60	17	6	3
1,355	98	96	90	63	19	7	3
1,356	98	96	90	65	20	7	3
1,357	98	96	91	67	21	7	3
1,358	98	96	91	70	23	7	3
1,359	98	96	91	72	25	8	3
1,360	98	96	92	74	26	8	4
1,361	96	92	75	29	9	4	2
1,362	96	92	77	31	9	4	2
1,363	96	92	78	33	10	4	2
1,364	97	93	80	35	10	5	2
1,365	97	93	81	37	11	5	2
1,366	97	93	82	40	11	5	2
1,367	97	94	83	42	12	5	3
1,368	97	94	84	45	13	5	3
1,369	97	94	85	47	14	6	3
1,370	97	94	86	50	14	6	3
1,371	97	95	86	53	15	6	3
1,372	97	95	87	55	16	6	3
1,373	98	95	88	58	17	6	3
1,374	98	95	88	60	18	7	3
1,375	98	95	89	62	19	7	3

/TABLE 1 (CONT.) ....

TABLE 1 (CONT.)

Mean Separation S.G.	Distribution Coefficients						
1,376	98	96	90	65	21	7	3
1,377	98	96	90	67	22	8	3
1,378	98	96	91	69	24	8	4
1,379	98	96	91	71	25	8	4
1,380	98	96	91	73	27	9	4
1,381	96	91	74	29	10	4	2
1,382	96	92	76	31	10	5	2
1,383	96	92	77	33	10	5	2
1,384	96	92	79	36	11	5	2
1,385	96	93	80	38	12	5	3
1,386	97	93	81	40	12	5	3
1,387	97	93	82	43	13	5	3
1,388	97	93	83	45	13	6	3
1,389	97	94	84	48	14	6	3
1,390	97	94	85	50	15	6	3
1,391	97	94	86	52	16	6	3
1,392	97	94	86	55	17	7	3
1,393	97	95	87	57	18	7	3
1,394	98	95	88	60	19	7	3
1,395	98	95	88	62	20	7	3
1,396	98	95	89	64	22	8	4
1,397	98	95	89	66	23	8	4
1,398	98	96	90	68	25	8	4
1,399	98	96	90	70	26	9	4
1,400	98	96	91	72	28	9	4
1,401	96	91	73	30	10	5	2
1,402	96	91	75	32	11	5	2
1,403	96	91	76	34	11	5	3
1,404	96	92	78	36	12	5	3
1,405	96	92	79	38	12	5	3
1,406	96	92	80	41	13	6	3
1,407	96	93	81	43	14	6	3
1,408	97	93	82	45	14	6	3
1,409	97	93	83	48	15	6	3
1,410	97	94	84	50	16	6	3
1,411	97	94	85	52	17	7	3
1,412	97	94	86	55	18	7	3
1,413	97	94	86	57	19	7	3
1,414	97	94	87	59	20	8	4

/TABLE 1 (CONT.) ....

TABLE 1 (CONT.)

Mean Separation S.G.	Distribution Coefficients						
1,415	98	95	88	61	21	8	4
1,416	98	95	88	64	22	8	4
1,417	98	95	89	66	24	9	4
1,418	98	95	89	68	25	9	4
1,419	98	96	90	69	27	9	4
1,420	98	96	90	71	29	10	4
1,421	95	90	73	31	11	5	3
1,422	95	90	74	33	11	5	3
1,423	96	91	76	35	12	5	3
1,424	96	91	77	37	12	6	3
1,425	96	92	78	39	13	6	3
1,426	96	92	79	41	14	6	3
1,427	96	92	80	43	14	6	3
1,428	96	92	81	45	15	6	3
1,429	96	93	82	48	16	7	3
1,430	97	93	83	50	17	7	3
1,431	97	93	84	52	18	7	3
1,432	97	94	85	54	19	8	4
1,433	97	94	86	57	20	8	4
1,434	97	94	86	59	21	8	4
1,435	97	94	87	61	22	8	4
1,436	97	95	87	63	23	9	4
1,437	98	95	88	65	25	9	4
1,438	98	95	89	67	26	10	4
1,439	98	95	89	69	28	10	4
1,440	98	95	90	70	30	10	5
1,441	95	89	72	32	12	5	3
1,442	95	90	73	34	12	6	3
1,443	95	90	75	35	13	6	3
1,444	95	91	76	37	13	6	3
1,445	96	91	77	39	14	6	3
1,446	96	91	78	41	15	6	3
1,447	96	92	79	44	15	7	3
1,448	96	92	80	46	16	7	3
1,449	96	92	81	48	17	7	4
1,450	96	93	82	50	18	7	4
1,451	97	93	83	52	19	8	4
1,452	97	93	84	54	20	8	4
1,453	97	93	85	56	21	8	4

/TABLE 1 (CONT.) ....

TABLE 1 (CONT.)

Mean Separation S.G.	Distribution Coefficients						
1,454	97	94	85	58	22	9	4
1,455	97	94	86	60	23	9	4
1,456	97	94	87	62	24	9	4
1,457	97	94	87	64	26	10	5
1,458	98	95	88	66	27	10	5
1,459	98	95	88	68	29	11	5
1,460	98	95	89	69	31	11	5
1,461	94	89	71	33	12	6	3
1,462	95	89	72	34	13	6	3
1,463	95	89	74	36	14	6	3
1,464	95	90	75	38	14	7	3
1,465	95	90	76	40	15	7	3
1,466	95	91	77	42	16	7	4
1,467	96	91	78	44	16	7	4
1,468	96	91	79	46	17	8	4
1,469	96	92	80	48	18	8	4
1,470	96	92	81	50	19	8	4
1,471	96	92	82	52	20	8	4
1,472	96	92	83	54	21	9	4
1,473	97	93	84	56	22	9	4
1,474	97	93	84	58	23	9	4
1,475	97	93	85	60	24	10	5
1,476	97	94	86	62	26	10	5
1,477	97	94	86	63	27	11	5
1,478	97	94	87	65	28	11	5
1,479	97	94	87	67	30	12	5
1,480	98	95	88	68	32	12	5
1,481	94	88	70	34	13	6	3
1,482	94	88	71	35	14	7	3
1,483	94	89	72	37	15	7	4
1,484	95	89	74	39	15	7	4
1,485	95	89	75	41	16	7	4
1,486	95	90	76	42	17	8	4
1,487	95	90	77	44	17	8	4
1,488	95	90	78	46	18	8	4
1,489	95	91	79	48	19	9	4
1,490	96	91	80	50	20	9	4
1,491	96	91	81	52	21	9	4
1,492	96	92	82	54	22	10	5

/TABLE 1 (CONT.) ....

1·341	96	92	76	28	9	4	2
1·361	96	92	75	29	9	4	2
1·381	96	91	74	29	10	4	2
1·401	96	91	73	30	10	5	2
1·421	95	90	73	31	11	5	3
1·441	95	89	72	32	12	5	3
1·461	94	89	71	33	12	6	3
1·481	94	88	70	34	13	6	3
1·501	93	87	68	35	14	7	4

1·360	98	96	92	74	26	8	4
1·380	98	96	91	73	27	9	4
1·400	98	96	91	72	28	9	4
1·420	98	96	90	71	29	10	4
1·440	98	95	90	70	30	10	5
1·460	98	95	89	69	31	11	5
1·480	98	95	88	68	32	12	5
1·500	97	94	87	67	33	13	6
1·520	97	96? 4.	86	66	34	14	7

Mid intervals.

(pencil notes on main table)

1·340	26		
1·341	28 – 74		1·360
1·361	29 – 73		1·380
1·381	29 – 72		1·400
1·401	30 – 71		1·420
1·421	31 – 70		1·440
1·441	32 – 69		1·460
1·461	33 – 68		1·480
1·481	34 – 67		1·500
1·501	35 – 66		1·520

TABLE 1 (CONT.)

Mean Separation S.G.	Distribution Coefficients						
1,493	96	92	82	56	23	10	5
1,494	96	92	83	57	24	10	5
1,495	97	93	84	59	26	11	5
1,496	97	93	85	61	27	11	5
1,497	97	93	85	63	28	12	5
1,498	97	94	86	64	30	12	6
1,499	97	94	86	66	31	13	6
1,500	97	94	87	67 (100)	33	13	6
1,501	93	87	68 (103)	35	14	7	4
1,502	94	87	70	36	15	7	4
1,503	94	88	71	38	16	8	4
1,504	94	88	72	39	16	8	4
1,505	94	88	74	41	17	8	4
1,506	94	89	75	43	18	8	4
1,507	95	89	76	45	19	9	4
1,508	95	90	77	46	20	9	4
1,509	95	90	78	48	20	9	5
1,510	95	90	79	50	21	10	5
1,511	95	91	79	52	22	10	5
1,512	96	91	80	54	23	10	5
1,513	96	91	81	55	25	11	5
1,514	96	92	82	57	26	11	5
1,515	96	92	83	59	27	12	6
1,516	96	92	83	60	28	12	6
1,517	97	93	84	62	29	13	6
1,518	97	93	85	63	31	13	6
1,519	97	93	85	65	32	14	6
1,520	97	90 (94?)	86	66 (100)	34	14	7

Extract (full distribution 50 mid point) — Symmetrical about 50.

1.35	97	95	86	50	14	5	3
1.37	97	94	86	50	14	6	3
1.39	97	94	85	50	15	6	3
1.41	97	94	84	50	16	6	3
1.43	97	93	83	50	17	7	3
1.45	96	93	82	50	18	7	4
1.47	96	92	81	50	19	8	4
1.49	96	91	80	55	20	9	4
1.51	95	90	79	50	21	10	5

restricted to limiting value with "mid" point

1.344	97	93	80	35	10	4	2
1.501	93	87	68	35	14	7	4
1.348	97	94	85	45	12	5	2
1.507	95	89	76	45	19	9	5
1.352	98	98	88	55	15	6	3
1.513	96	91	81	55	25	11	5
1.354	98	95	89	60	17	6	3
1.516	96	92	83	60	28	12	6
1.355	98	96	90	63	19	7	3