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The Centrifuge Kerosene Equivalent as Used in Establishing the Oil Content for Dense Graded Bituminous Mixtures

By F. N. HVEEM
Staff Materials and Research Engineer

OCTOBER, 1946

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Establishing The Oil Content For Dense Graded Bituminous Mixtures

By F. N. HVEEM*

PROBABLY the first and most frequent question which the bituminous paving engineer is required to answer concerns the quantity of binder which would be most satisfactory when mixed with a given aggregate. In the early years engineers relied on personal experience and usually decided on the proper amount of asphalt by visual inspection of the mix. Many rule of thumb guides have been employed ranging from appearance and "feel" of an asphaltic concrete mix to the "wormy crawl" and chocolate brown color thought to identify a proper oil mix. More scientific procedures include stain tests, proportioning by void ratio, and a number of formulas usually based on the sieve analysis of the aggregate.

Among the formulas probably the best known is the McKesson-Frickstad developed for the oil mix type of pavement. Several modifications of the McKesson-Frickstad formula have been developed in the Western States among which are the New Mexico, Nebraska and Wyoming Formula, etc.

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TABLE OF SURFACE AREA EQUIVALENTS

Table 1 10 Sieves			Table 2 7 Sieves			Table 3 6 Sieves			Table 4 4 Sieves			Table 5 4 Sieves			Table 6 3 Sieves		
Sieve No. Pass.	Sieve No. Ret.	Constant	Sieve No. Pass.	Sieve No. Ret.	Constant	Sieve No. Pass.	Sieve No. Ret.	Constant	Sieve No. Pass.	Sieve No. Ret.	Constant	Sieve No. Pass.	Sieve No. Ret.	Constant	Sieve No. Pass.	Sieve No. Ret.	Constant
270*		300															
200	270	200	200		260	200		260	200		260	200		260	200		260
100	200	120	100	200	120												
50	100	60				50	200	90	50	200	90						
30	50	30	30	100	46							30	200	72			
16	30	16				16	50	22									
8	16	8	8	30	12				8	50	17				8	200	45
4	8	4	4	8	4	4	16	6				4	30	9			
3/8	4	2	3/8	4	2	3/8	4	2									
3/4	3/8	1	3/4	3/8	1 *2	3/4	3/8	1 *2	3/4	8	2	3/4	4	2	3/4	8	2

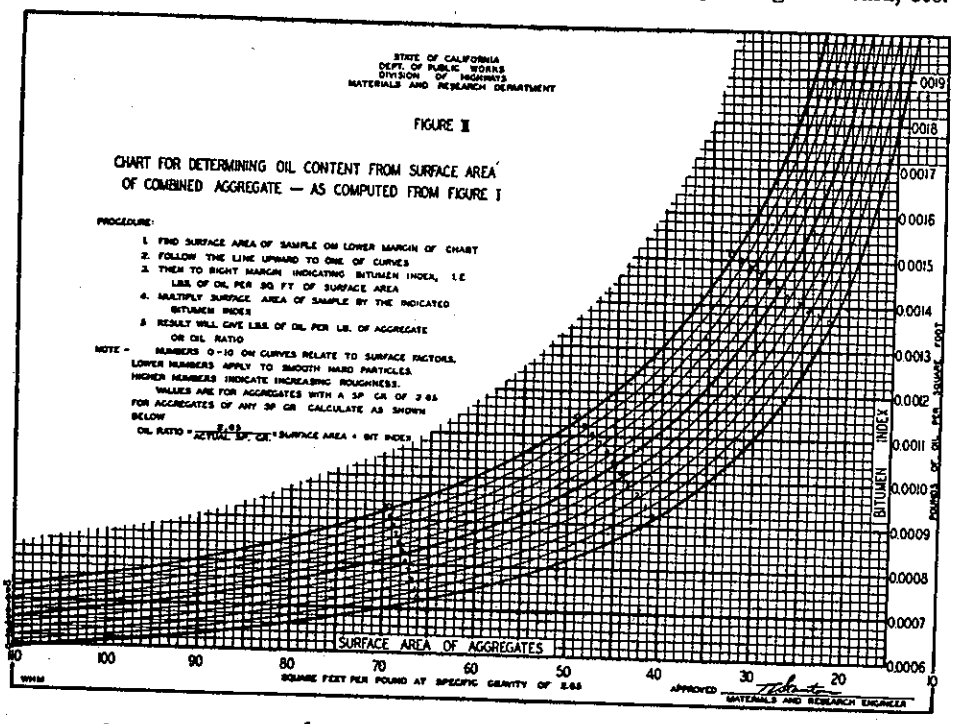
* Silt remaining in suspension and removed by elutriation.

Note: Value shown in Tables 2, 3, 4, 5, & 6 for passing #200 sieve applies to average dust. Will be in error for some materials.

APPLICATION: Use table according to number of test sieves used. Reducing number of sieves will reduce accuracy. By sieve analysis determine the amount of each size of aggregate. Express in terms of per cent of total. Multiply the per cent of each size by the constant given for that size. The constant is the equivalent area in sq. ft. of one pound of material of that size. Add results and total will represent surface area of the entire sample in terms of square feet per pound.

In California the procedure followed for the past 10 years is the Surface Area Method.[1]

Most engineers have long been aware that the optimum quantity of asphalt bears no consistent relation to the volume of voids in the mixture and the rather widespread application of methods based on the surface area of the aggregate indicates that the quantity of asphalt is more nearly related to the superficial surface area than to any other simple factor. For example, the surface area method as used in California has been reasonably satisfactory and can be expected to give quite close approximations in the hands of experienced engineers. Nevertheless, any preliminary estimation of asphalt based on surface analysis alone has possibilities for error and it has been evident for some time that improvements or additions to the



* Senior Physical Testing Engineer, Materials and Research Department, California Division of Highways.

[1] "Role of the Laboratory in the Preliminary Investigation and Control of Materials for Low Cost Bituminous Pavements" by Thos. E. Stanton, Jr., and F. N. Hveem, presented at the Fourteenth Annual Meeting of the Highway Research Board, December, 1934.

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method are desirable; first, in order to make the method more universally applicable and second, to reduce the time and experience required.

SURFACE AREA METHOD

A brief summary of the surface area method is as follows:

Hypothesis. The quantity of asphalt required to bind particles of mineral aggregate together to form a stable paving mixture will bear some relation to the superficial surface area of particles to be covered; although the quantity can not be calculated as a direct simple function of surface area alone.

The determination is complicated by other factors which may be analyzed as follows:

Internal friction is the major element contributing to bituminous pavement stability and as asphalt is a lubricant, that property serves to limit the quantity which can be used without destroying the stability of the mixture. Lubrication effects depend upon the roughness of the solid surface as well as the thickness and viscosity of the lubricating film and any predetermination of the optimum binder content must take into account both surface area and the character of the particles. The surface area method involves the calculation of surface area through the use of constants assigned to the various particle sizes as determined by standard testing sieves. **(See Table 1).** After having calculated the surface area it is then necessary to determine the bitumen index or the quantity of asphalt required to cover one unit of available surface. It was found that the bitumen index or film thickness must vary as an inverse function of the surface area indicating that in order to form a stable mix a *group* of small particles must be coated with a thinner film than can be used on a group of large particles. This relationship is shown by the shape of the curves in **Figure 1.**

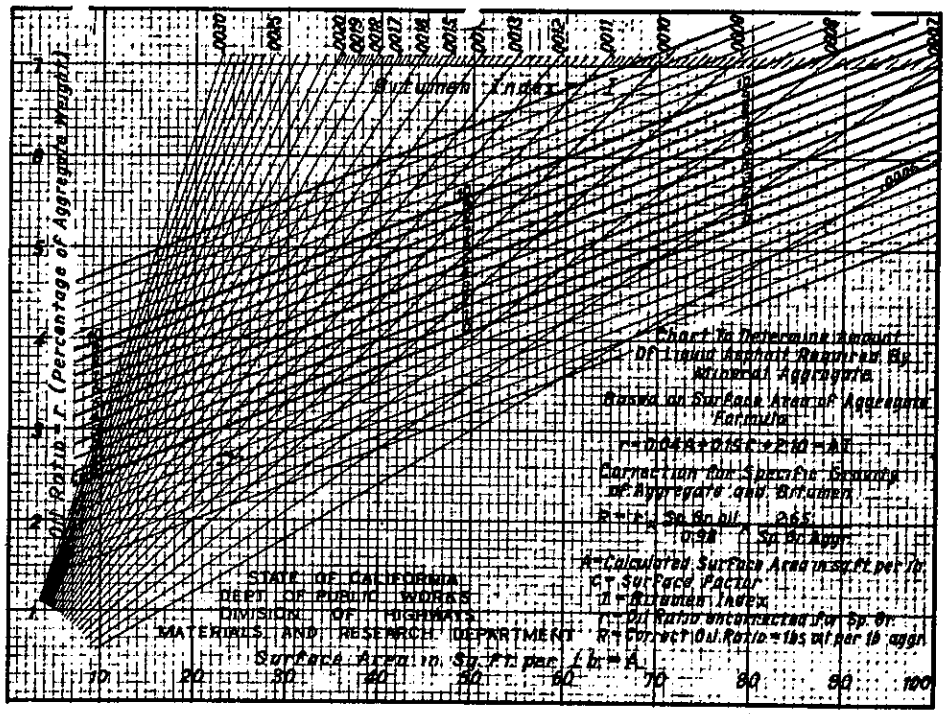

FIGURE II

CHARACTER OF PARTICLE SURFACE

In addition to this variable caused by differences in aggregate graduation, an allowance must be made for the character of the particle surface. This means that rough irregular particles have a greater surface area and are less easily lubricated than smooth polished grains. Therefore, a thicker film of oil or asphalt can be used on particles of crushed lava or sandstone than will be tolerated by particles of quartz or chert. These differences are covered arbitrarily by the series of curves shown on **Figure 1.** The lower curves apply to particles with a smooth glassy surface and the higher curves apply to particles of increasing roughness. The essential operations are covered by the notations on **Table 1** and on the Chart, **Figure 1,** and consist of the following steps: sieve analyses of the aggregate, calculation of the surface area, selection of the surface factor curve corresponding to the particle roughness. The bitumen index is then determined from the combination of *assumed* surface factor and *calculated* surface area using chart, **Figure 1.** The product of the bitumen index and surface area value represents the oil ratio after corrections have been made for specific

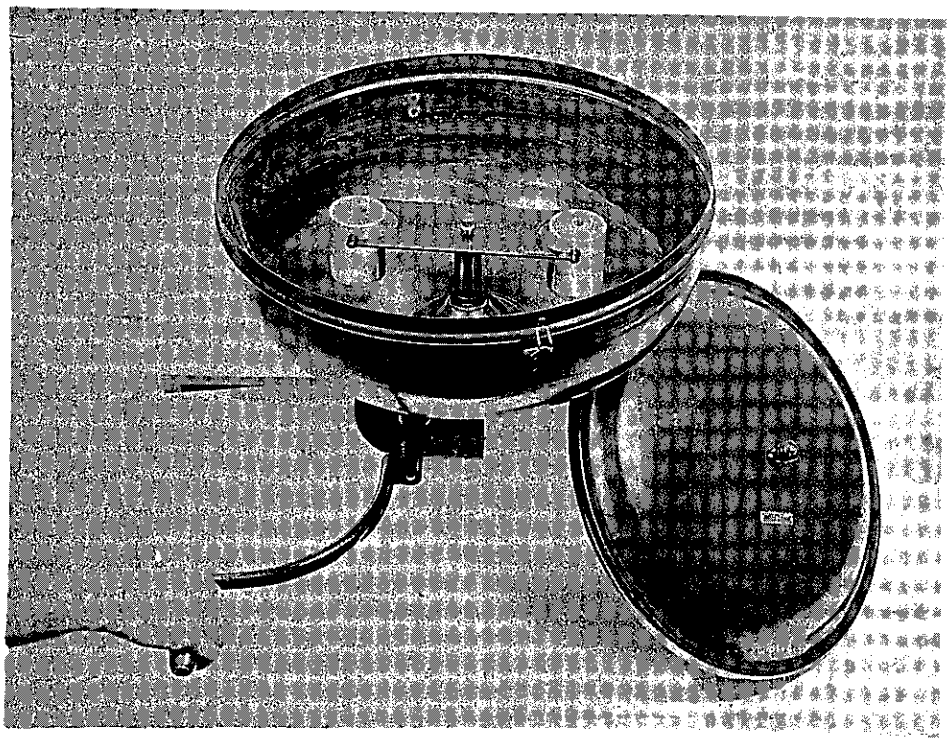

Figure IX

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gravity of both asphalt and aggregate. This relationship is shown also by chart, **Figure II,** where the surface factor curves are straight lines and the oil ratio may be read directly.

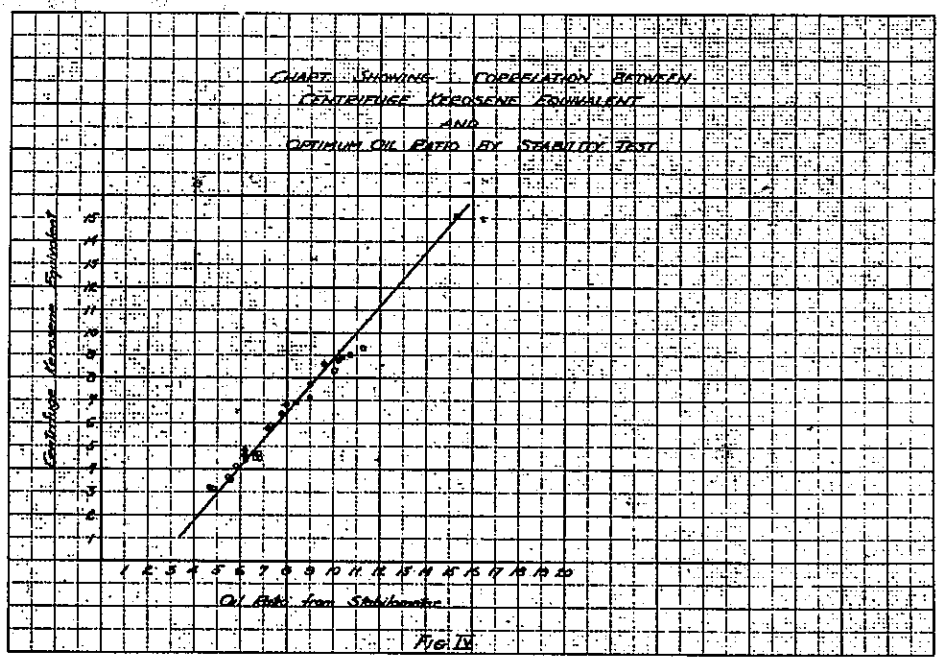
OIL ABSORPTION

The accuracy of the foregoing method of determination therefore rests on the sieve analysis and the ability of the engineer to select a surface factor curve which is appropriate for the particular aggregate. This operation presents some difficulties to the inexperienced engineer or to the laboratory not equipped with a stabilometer or other means for actually measuring the degree of lubrication in the mix. Furthermore, while particle roughness may be approximately classified by inspection, true absorption by the aggregate is difficult to evaluate without tests and it is well known that many oil mixtures become dry and display a tendency to ravel subsequent to construction, even though apparently containing sufficient oil when first mixed. Many bituminous paving engineers have realized that some accurate method is needed for anticipating absorption of oil on the road. In California this difficulty was to some extent met in the laboratory by adding additional oil to samples after a preliminary drying period. In Utah Mr. Levi Muir has long employed an absorption test but as this procedure engenders considerable delay in the handling of tests, a method has been developed and is described herewith which requires the use of only simple equipment to give a rapid approximation of the ultimate absorption capacity of the aggregate and which also can be used for predetermination of the oil content without preliminary sieve analysis.

EARLIER METHODS

It has long been realized that a logical step from the calculation of the surface area would be the development of some means for accurately measuring the superficial surface area *or surface capacity* of irregular particles without the need for time-consuming sieve analysis and calculations which at best give only approximate results.

About 10 years ago it was found that the oil or asphalt requirement of filler dust could be closely estimated by observing the height to which a limited quantity of kerosene would be drawn through a column of dust



placed in a glass graduate. Attempts were made to apply the procedure to graded sands up to 10 mesh but results were not completely consistent; however, this does not mean that the possibilities were completely explored.

It can also be shown that very good results are obtainable by selecting a closely screened fraction of sand and coating to a uniform film thickness with liquid asphalt; this method called the "Funnel Test" was used for over a year in the California Laboratory and has the advantage of requiring no special equipment but does require sieve analysis and from one to two hours to complete the operation. It has been dropped in favor of the more rapid method described below.

One common factor stands out in all the more promising experiments and trials: It is evident that any determination based on the use of a standard liquid **must develop conditions wherein the particles are covered by a film of the liquid without any excess being held in the voids between the particles.**

During the course of these studies a related method was reported by one of the field engineers, Mr. C. V. Kane, then Resident Engineer for the California Division of Highways. Kane's method consisted of saturating an aggregate with gasoline and then draining off the excess through a 200 mesh sieve at room temperature. A chart was developed for translating the quantity of gasoline retained in the sample to the equivalent optimum oil ratio of the aggregate. However, when this procedure was investigated in the laboratory it was soon found that it was applicable only to a limited variety of materials and gradations and it was also evident that the errors were due to the gasoline not draining out of the small voids in dense graded mixtures. Pursuing the idea that the liquid must be removed from the voids or pores in the aggregate, centrifuging was resorted to; first, using a standard centrifuge operating at a speed equivalent to 1,000 times gravity as prescribed for the centrifuge moisture determination on soils.

C.K.E. METHOD

After a number of trials and adjustments a test procedure was developed which appears to have excellent correlation with the stability test and consequently with field experience. In order to provide a medium free from immediate evaporation losses, ordinary kerosene is used to saturate a sample of aggregate. By a series of trials the speed of the centrifuge was reduced to give a force equivalent to 400 times gravity. It became clearly evident that a nice proportionality must be maintained between the viscosity of the liquid used and the force employed to remove the excess from the voids in the sample. The surface capacity of an aggregate is composed of three factors; namely, surface area which varies with gradation, variation due to roughness of the particle surfaces, and variation due to true porosity or absorption into the parti-

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cles themselves. Therefore, the speed of the centrifuge must be adjusted so that a proper relation will be maintained between the film of kerosene on the surface of the particles and the quantity absorbed within the particles.

Briefly then, the procedure consists of saturating a representative fraction of the aggregate passing the No. 4 sieve with kerosene and then centrifuging for two minutes under a force equal to 400 G. The quantity of kerosene retained by the sample has been designated "The Centrifuge Kerosene Equivalent."

For those interested in the theoretical considerations involved, the following brief discussion including some of the mathematical relations may be of interest.

DEVELOPMENT OF THE METHOD

The limiting condition for extended increase of bitumen content in a paving mixture is the loss of stability in the mixture. Therefore, using stabilometer tests to determine this limit the relation between the optimum oil ratio and surface area was reinvestigated using a variety of aggregates in a number of gradations. This study indicated the desirability of revising the surface factor curves formerly used with the surface area method; and as the original group of 10 curves had been found insufficient to cover the entire range from very smooth to highly absorbent aggregates, a new system has been established to permit unlimited expansion and is based on the use of a new surface factor designated as "K."

This relationship is shown on chart, **Figure III**, and is so arranged that the value of $K = 1.0$ represents the average most-frequently-encountered aggregate which has little, if any, absorption and is equivalent to the older surface area curve No. 4, **(See Fig. I)** which, after years of experience, has seemed to be most frequently used for the common run of aggregates encountered in California. Hard trap rock, dense basalt, crushed granite or crushed hard limestone are some of the types represented by $K = 1.0$. Aggregates of increasing porosity or surface roughness are covered by high values of K, while particles having smoother and more polished surfaces are indicated by values less than 1.0. The entire relationship is then shown by chart, **Fig. III**, which, with calculated surface area corrected for specific gravity and the correct selection of the factor "K" to indicate the surface texture and porosity of the particles, permits an accurate determination of the oil ratio or weight of liquid asphalt required per unit weight of aggregate.

Experiments with the Centrifuge Kerosene Equivalent have also demonstrated that there is an excellent direct correlation between these values and the optimum oil ratio as determined by stabilometer tests on trial mixtures. This relationship is shown on chart, **Figure IV.**

From these two relations it is possible to develop a mathematical expression for the optimum oil ratio in terms of the C.K.E., the percentage of aggregate passing a No. 4 sieve, and the average specific gravity of the aggregate.

Neglecting the specific gravity temporarily for simplification:

The relation between optimum oil ratio and the surface area of the aggregate as shown on **Figure III** can be expressed by the following formula:

$$\text{Oil Ratio}_{mix} = K_m \, .0067 \sqrt{SA_{mix}} \qquad (a)$$

when K_m = Surf. Constant of the entire mix *

SA_{mix} = Surf. area of the entire mix

The relation between optimum oil ratio and C.K.E. as shown on chart, **Figure IV**, may be expressed by the formula:

$$\text{Oil Ratio}_{pass\ no\ 4} = \frac{0.85 \text{ C.K.E.} + 2.5}{100} \qquad (b)$$

Equation (a) applies to any part of the aggregate mixture, so writing it for the passing No. 4 we have:

$$\text{Oil Ratio}_{pass\ no\ 4} = K_f \, .0067 \sqrt{SA_{pass\ no\ 4}} \qquad (c)$$

where K_f = surf. constant for the passing No. 4 aggregate

$SA_{pass\ no\ 4}$ = surf. area of the passing No. 4 aggregate

Combining equation (c) with equation (b):

$$\frac{0.85 \text{ C.K.E.} + 2.5}{100} = K_f \, .0067 \sqrt{SA_{pass\ no\ 4}} \qquad (d)$$

Since the surface area of the aggregate retained on the No. 4 sieve is small compared to the surface area of that passing the No. 4, we may write the following approximate relation:

$$SA_{pass\ no\ 4} = \frac{SA_{mix} \times 100}{\%\ \text{passing No. 4}} \qquad (e)$$

* Surface factors are designated as K_c, surface constant for the coarse aggregate retained No. 4; K_f, surface constant for the fine aggregate passing No. 4; K_m, surface constant of any given combination of coarse and fine aggregate. Further values could be individually assigned to any fraction of the aggregate as desired.

It has been found by experience that except for rare cases where a fine aggregate passing the No. 4 sieve is blended with coarse aggregate of greatly different surface characteristics the surface constant for the entire mix K_m is not significantly different from that for the material passing the No. 4 represented by K_f.

So substituting K_m for K_f

and $\frac{SA_{mix} \times 100}{\%\ \text{passing No. 4}}$ for $SA_{passing\ no\ 4}$

in equation (d) and solving for K_m we have:

$$K_m = \frac{0.85 \text{ C.K.E.} + 2.5}{100 \times .0067 \sqrt{\dfrac{SA_{mix} \times 100}{\%\ \text{Passing No. 4}}}} \qquad (f)$$

Substituting this in equation (a):

$$\text{Oil Ratio}_{mix} = \frac{(0.85 \text{C.K.E.} + 2.5)\, .0067 \sqrt{SA_{mix}}}{100 \times .0067 \sqrt{\dfrac{SA_{mix} \times 100}{\%\ \text{passing No. 4}}}}$$

Simplifying:

$$\text{Oil Ratio}_{mix} = \frac{(0.85 \text{ C.K.E.} + 2.5)}{100} \sqrt{\frac{\%\text{passing No. 4}}{100}} \qquad (g)$$

From this we see that the oil ratio may be estimated from the C.K.E. and the amount passing the No. 4 sieve as long as the *character* of particles smaller than No. 4 are similar to the particles retained on the No. 4.

If the specific gravity of the aggregate is materially above or below 2.65 a correction must be applied to the C.K.C. An alignment chart (See Scales A, B, & C on chart, Fig. III) has been constructed corresponding to formula g) with a specific gravity correction scale appended at the bottom of the sheet.

Any design or type of centrifuge can be used which will handle samples weighing 100 grams (with centrifuge cups approximately two inches inside diameter) and which can be operated at a speed subjecting the sample to a force of 400 times gravity. In view of the relatively low speed required, the operation is entirely practicable for a hand-operated centrifuge which can be readily carried into the field for control testing. The equipment used here was secured from the Emil Greiner Company, 161 6th Avenue, New York, catalog No. CE-8535. A safety dome cover is required in order to develop the necessary speed and prevent spattering of the kerosene. With this particular centrifuge the necessary force can be developed by turning the handle approximately 45 revolutions per minute. If other equip-

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ment is used, the radius of the centrifuge arm to the center of the sample can be calculated as follows:

$r \times (RPM)^2 = 14{,}000{,}000$

Where r = radius in inches to center of gravity of soil sample

RPM = revolutions per minute of centrifuge head.

Attached herewith is a working drawing showing the new head assembly and centrifuge cups which were constructed in our own shops to fit the above centrifuge. A sheet of filter paper (white Dumas, No. 28315, B.K.H.Co., or similar paper) is placed over the perforated brass disk in the centrifuge cups.

See photograph, **Figure IX**, which shows the complete centrifuge and special head and cup assembly.

OIL RATIO FROM C.K.E.

The procedure is as follows:

1. Secure a representative dry sample of aggregate and by sieving determine the percentage by weight of the material passing the U. S. Standard No. 4 sieve.
2. Place exactly 100 grams of the dry aggregate passing the No. 4 sieve in a tared centrifuge cup fitted with a screen on which is placed a disk of filter paper.
3. Place the bottom of the centrifuge cup in kerosene until the aggregate becomes saturated.
4. Centrifuge the saturated sample for two minutes at a force of 400 times gravity.
5. Weigh the sample after centrifuging and determine the amount of kerosene retained as per cent of dry aggregate. This value is called the Centrifuge Kerosene Equivalent (abbreviated to C.K.E.).
6. If the specific gravity of the aggregate is appreciably different from 2.65, apply a correction to this C.K.E. according to the scale at the bottom of the chart, Figure III, Scale "E."
7. Using this corrected C.K.E. and per cent aggregate passing No. 4 sieve, the indicated oil ratio may be obtained from the alignment chart, Figure III, Scales "A," "B," and "C."
8. The oil ratio determined under 7 is the required oil ratio for the combined fine and coarse aggregate, applying to liquid asphalts having a viscosity range of 100 to 1,000 seconds Saybolt Furol at 140° F.

This method is simple and the operation can be carried through in 15 minutes or less and has been given a thorough trial for the past year by field engineers in California. Correlation between the Centrifuge Kerosene Equivalent and the oil content (found to be satisfactory on the road) is excellent, being accurate in at least 95 per cent of the cases.

FINE AGGREGATE CONSTANT (K_f)

If this procedure is used by the resident engineer or superintendent to control the oil content of the work during construction, the foregoing procedure appears to be adequate; however, when the C.K.E. values are determined in a central laboratory as a basis for oil content recommendations to the field engineer, it is then desirable to classify the aggregate in terms of appropriate surface factors in order that the field engineer may apply the necessary corrections due to changes in grading as indicated by surface area calculations. For this purpose chart, **Figure V**, is furnished which permits the assignment of a surface constant K_f from the C.K.E. As indicated by the development of equations (f) and (g), the value of K_f may be taken as equivalent to K_m and thus represent the entire aggregate in a large majority of cases; however, certain instances may arise wherein the coarse aggregate is of markedly different character than are the fines used in the C.K.E. determination, and some correction may be necessary to arrive at a composite surface factor representing the combined coarse and fine aggregates. For this determination the coarse aggregate must also be classified and given a surface constant designation (K_c).

COARSE AGGREGATE CONSTANT (K_c)

A representative sample of dry coarse aggregate weighing 100 grams passing the $\frac{3}{8}$ inch and retained on the No. 4 sieve is placed in a glass funnel of approximately 4 inches diameter. Sample and funnel are submerged in a beaker containing light lubricating oil, grade S.A.E. No. 10, for five minutes at room temperature. The funnel is then lifted and the oil permitted to drain for 15 minutes while the sample is maintained at a temperature of 140° F. The sample is then weighed and the percentage increase in weight due to oil absorbed or retained on the surface is noted. This value is referred to the chart, **Figure VI**, and converted to the surface constant K_c.

COMBINED CONSTANT (K_m)

After having determined the surface constant K_f for the fine aggregate and K_c for the coarse aggregate, it is then necessary to compute the value of K_m for the given combination of fine and coarse. When the coarse and fine materials are all of the same type, the values of K_c and K_f should be identical when determined by the methods described above. When the two values are markedly different, by reference to chart, **Figure VIII**, it is possible to arrive at the value of K for the composite mix by using the surface area calculated from sieve analysis of the combined aggregates and the percentage of material retained on the No. 4, together with the values (K_c-K_f). As noted on the chart, K_m is calculated by applying the indicated correction to K_f. If the value of K_c-K_f is negative, the correction will be negative; if the value of K_c-K_f is positive, the correction will be positive.

In other words, if, for example, the coarse aggregate were appreciably more absorbent than the fine materials, it is obviously necessary to increase the value of K for the combined mix over the value indicated for the fines alone. When the value of K_m is thus determined, reference may be made to the chart, **Figure III**, on which the corrected oil ratio may be reached by using the calculated surface area, the average specific gravity of the aggregate, and the value of K_m (Scale D to Scale B).

VISCOSITY OF ASPHALT

All of the foregoing methods have been designed to give the oil ratio requirement for use with the more fluid grades of the liquid asphalt; for example, grades SC-2 and 3, MC-2 and 3, or others of similar viscosity. If heavier grades are used, for example SC-5 or 6 or paving asphalts of varying consistency measured by penetration, it is usually necessary to increase the estimated quantity in line with the increasing absolute viscosity.

Thus far we have been unable to develop a universally successful method for applying this correction to all grades of asphalt for all construction conditions and types of aggregate, and it is evident that further work is required on this phase of the problem. However, a tentative method has been established to indicate direction and magnitude which is reasonably satisfactory and may be used as shown on chart, **Figure VIII**,

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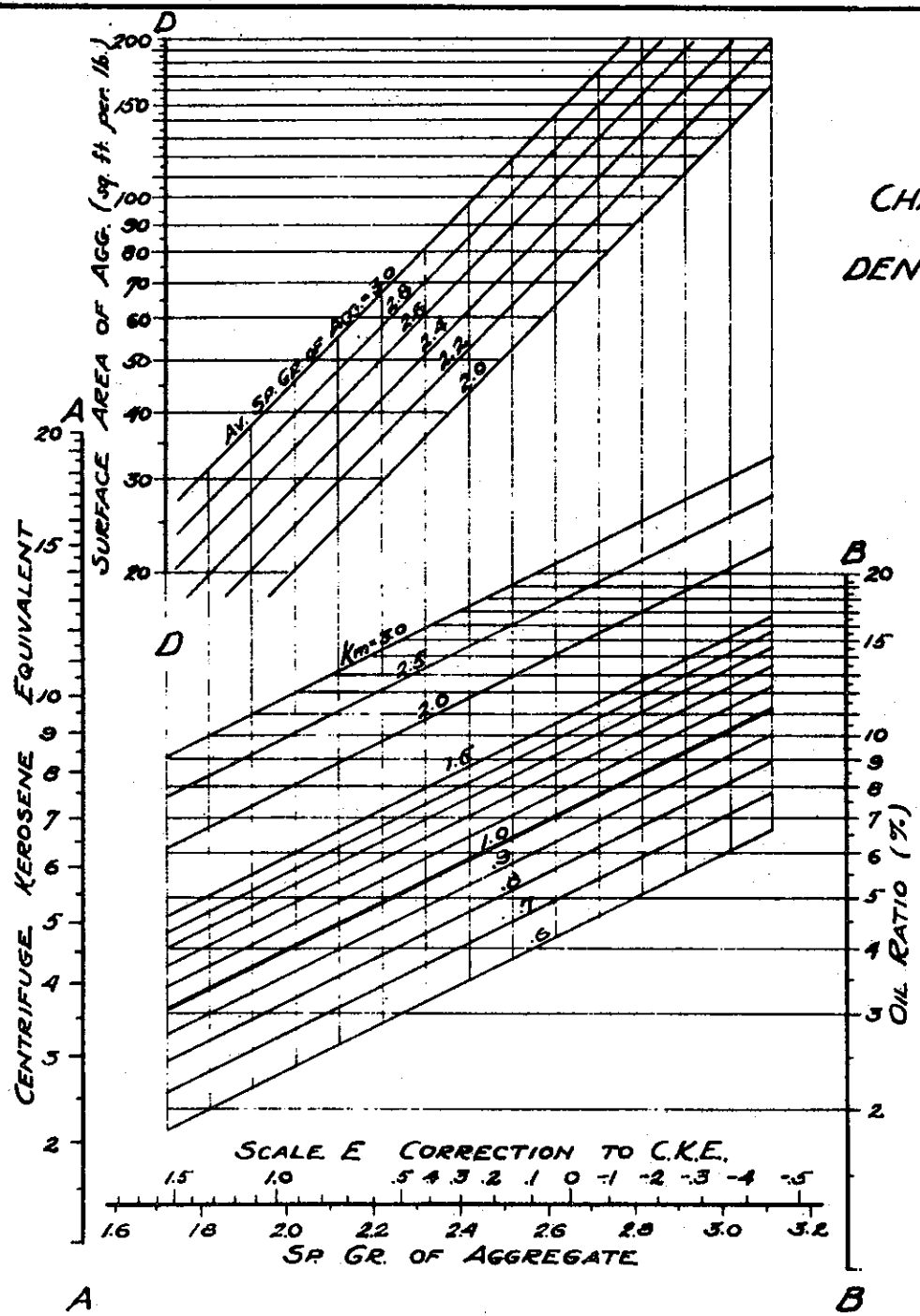

CHART FOR COMPUTING OIL RATIO FOR DENSE GRADED BITUMINOUS MIXTURES

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Procedure

Case 1. Given C.K.E., sp. gr. of aggregate and percent passing #4 sieve. Correct C.K.E. as indicated by scale E. Find corrected C.K.E. on scale A. Find percent aggregate passing #4 sieve on scale C. Intersection of straight line with scale B = oil ratio.

Case 2. Given surface area, sp. gr. and K_m of aggregate. Find surface area on scale D. Proceed horizontally to curve corresponding to sp. gr. of aggregate. Then down to curve corresponding to K_m. Then horizontally to scale B for oil ratio.

Oil Ratio = lbs of oil per 100 lbs. of aggregate and applies directly to oils of SC-2, MC-2 and RC-2 grades. A correction must be made for heavier liquid or paving asphalts. Fig VIII

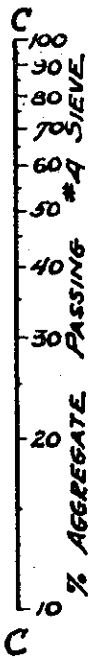

FIG III

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CHART FOR DETERMINING K_f FROM C.K.E.

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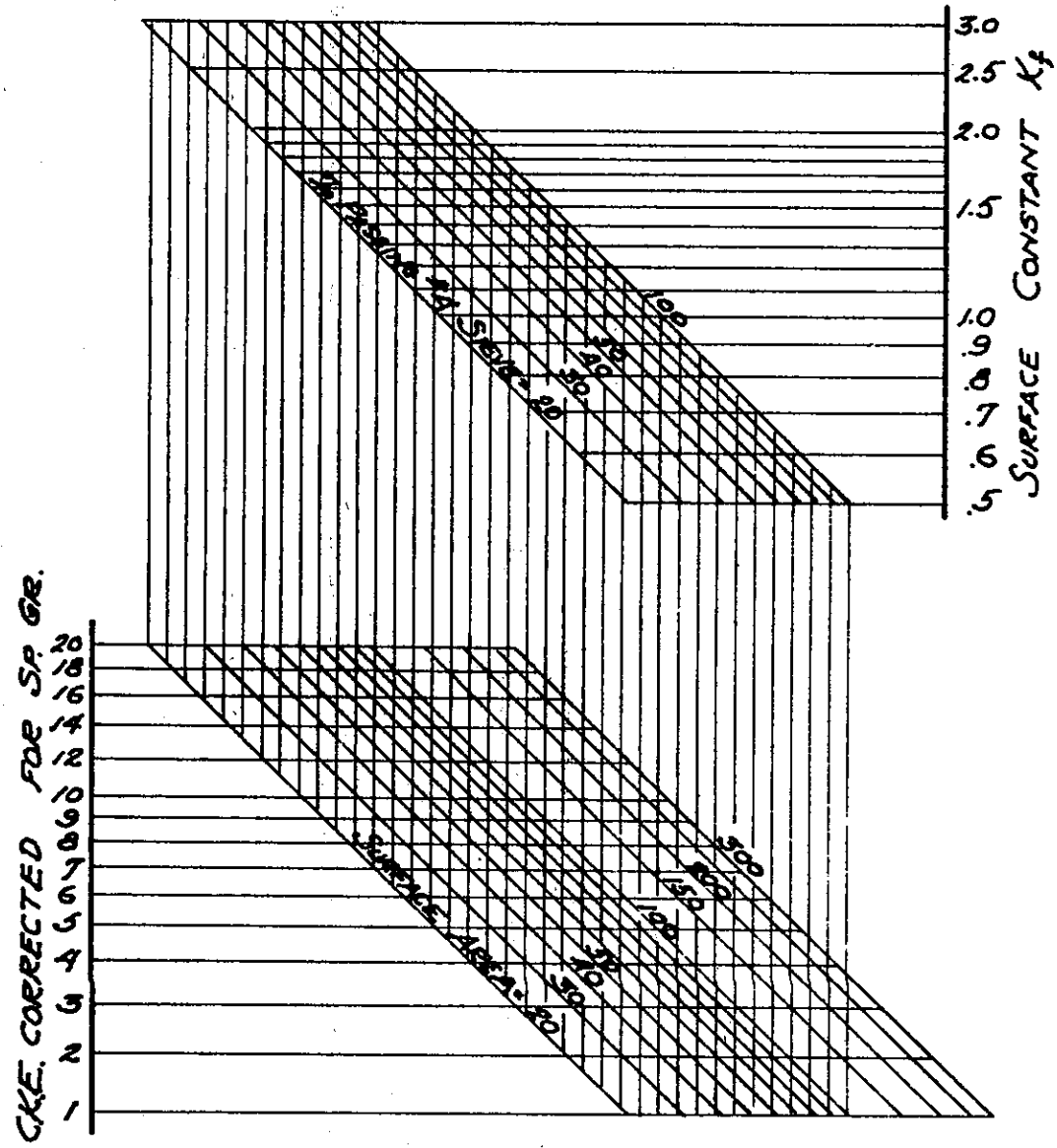

$$\text{CKE CORRECTED} = \text{CKE} \times \frac{\text{sp. gr. fine}}{2.65}$$

NOTE: Do not confuse this correction to CKE with that used in Fig III

Fig V

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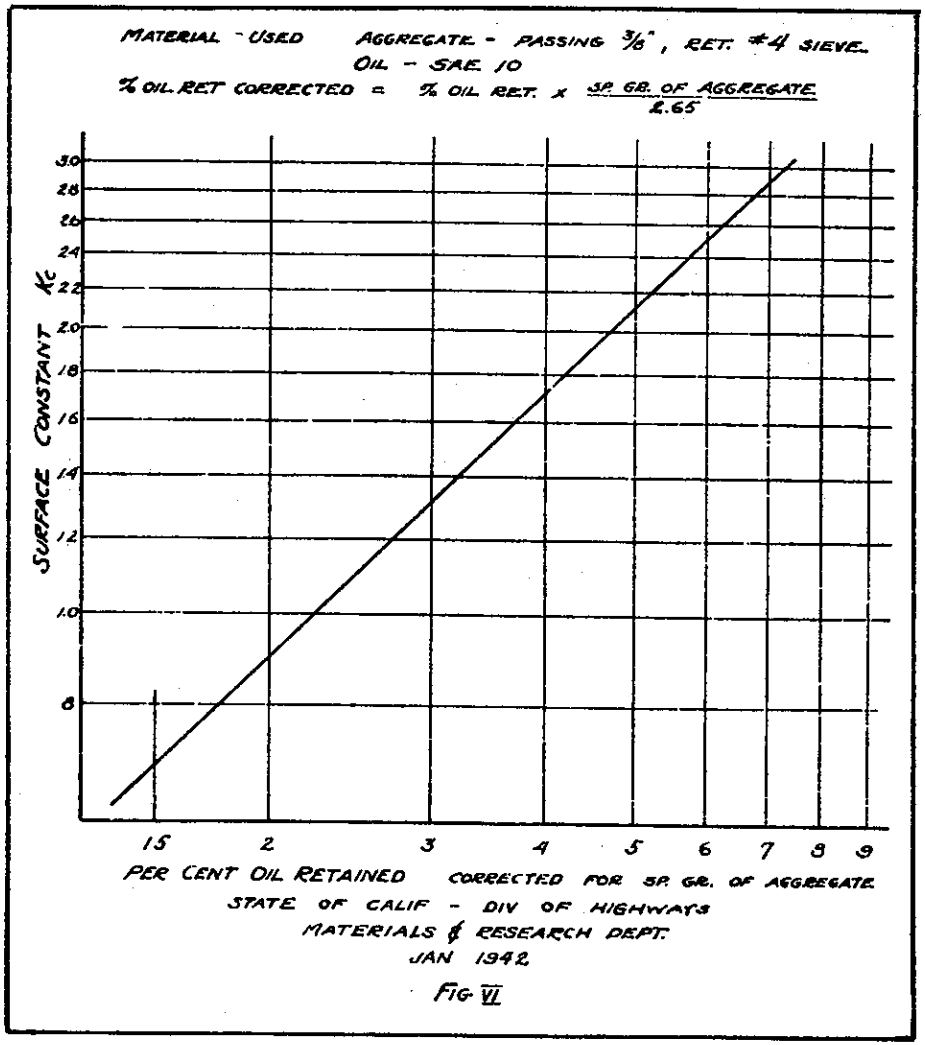

Chart for determining Kc from coarse aggregate absorption

Note this Folder contains charts most often required and may be detached for ready reference after procedure is well understood.

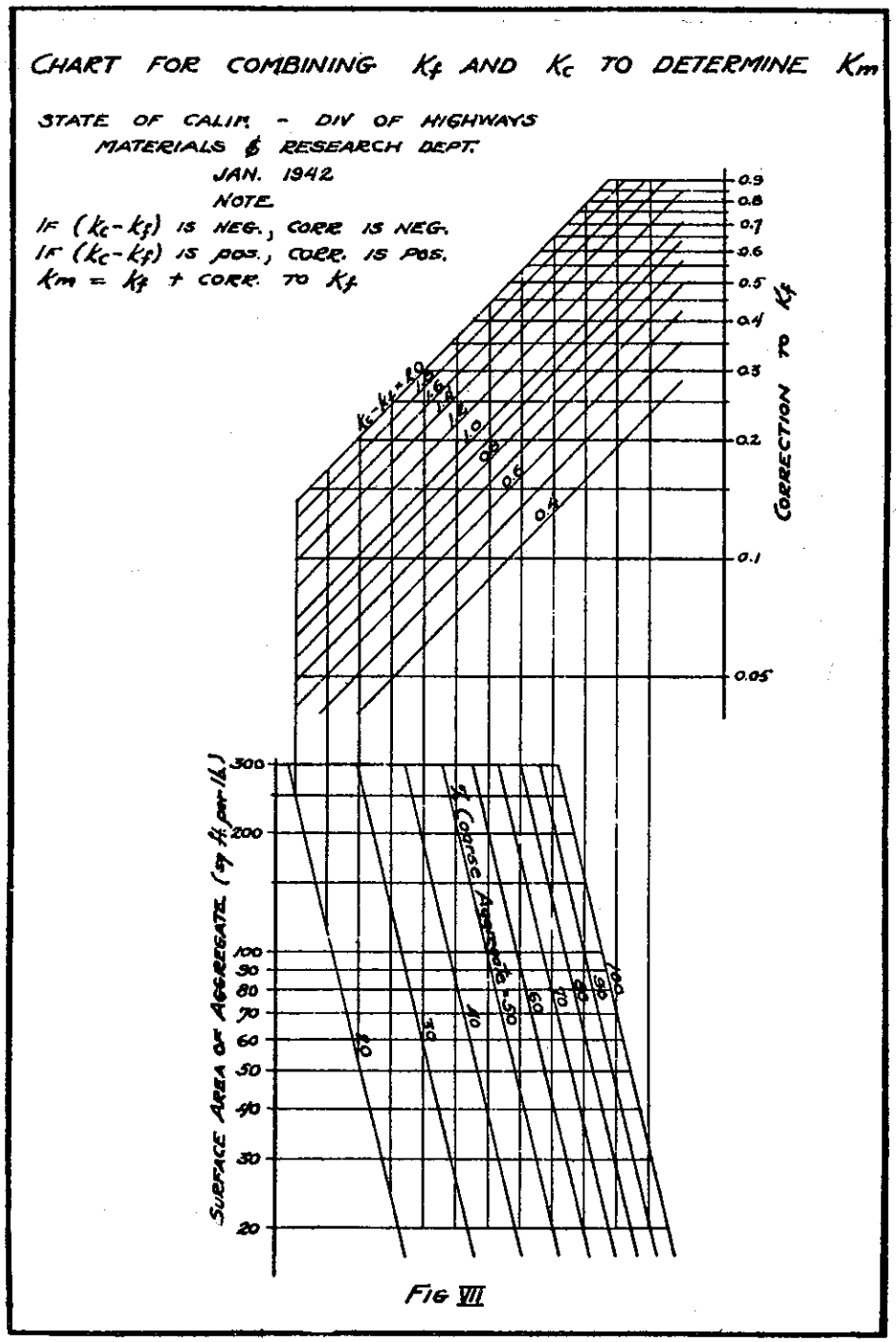

FIG VII

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Tentative Chart for Correcting Bitumen Requirement Due to Increasing Viscosity or Lower Penetration of Asphalt

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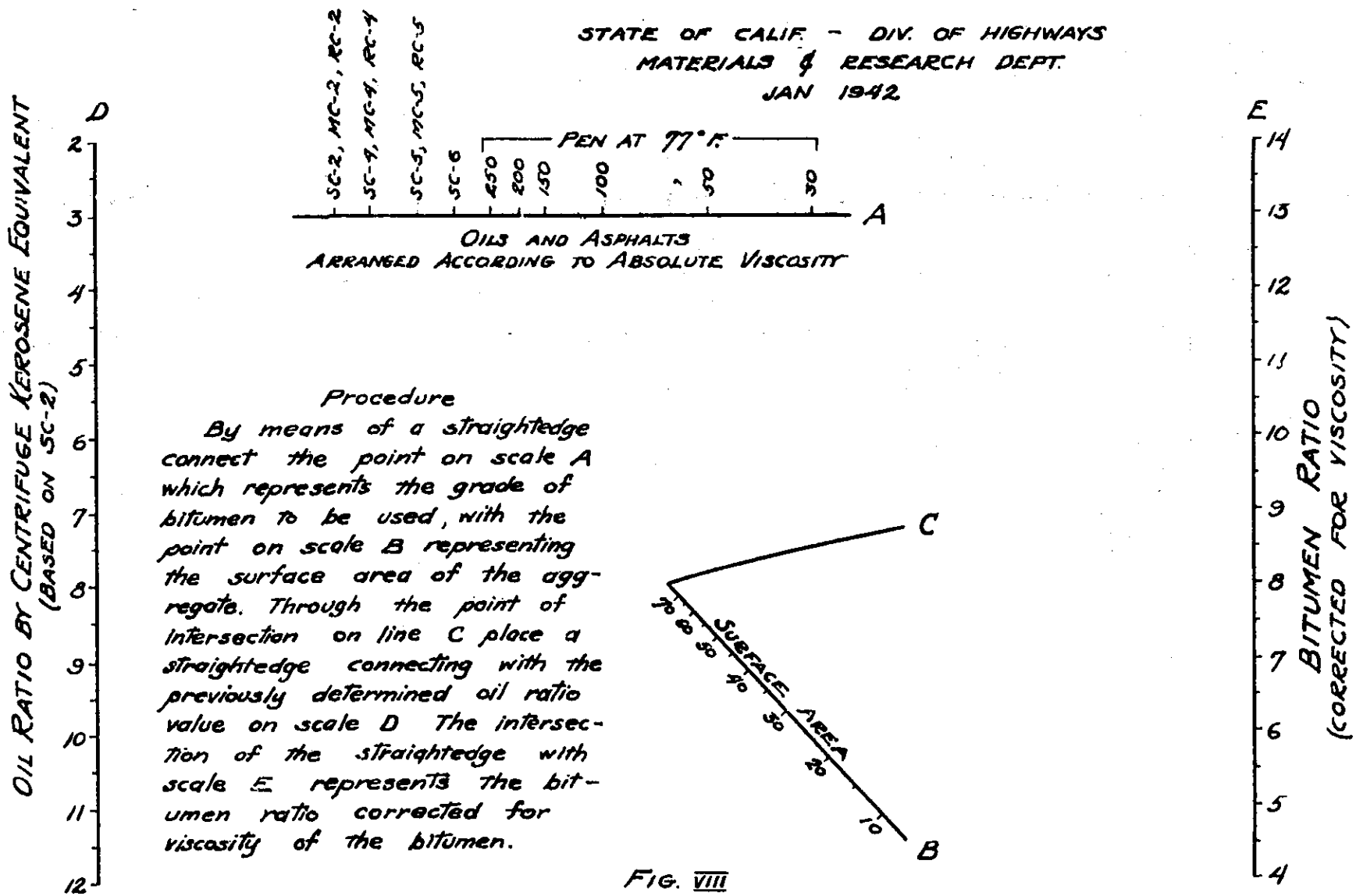

Procedure

By means of a straightedge connect the point on scale A which represents the grade of bitumen to be used, with the point on scale B representing the surface area of the aggregate. Through the point of intersection on line C place a straightedge connecting with the previously determined oil ratio value on scale D The intersection of the straightedge with scale E represents the bitumen ratio corrected for viscosity of the bitumen.

FIG. VIII

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with the admonition that complete dependence can not be placed on the results whenever the aggregates are highly absorbent, contain unusual quantities of fine dust, or have a very low voids ratio. It is, of course, evident that whenever the voids in the mixture are quite low and the surface capacity is high, a point is often reached where the quantity of asphalt calculated to cover the surfaces becomes greater than the void volume in a particular combination. Regardless of other considerations, the volume of asphalt must be maintained safely below the volume of the voids in the aggregate. Whenever the values of K_m are approximately equal to 1.0 (in other words, an average aggregate) this correction may be applied with considerable confidence. Whenever K_m is greater than 1, indicating absorbent aggregate, it then appears that the heavier asphalts are not necessarily absorbed to the same degree as are the lighter oils and cutbacks. This condition may reach a stage where no increase of asphalt can be made in line with increasing viscosity. With these precautions the chart, **Figure VIII**, may be used to indicate a correction to the oil ratio previously estimated either by the surface area calculation or by the centrifuge kerosene equivalent method above described.

On chart, **Figure VIII**, by means of a straightedge connect the values on scale A (which represent grade of oil to be used) with values on scale B, representing the calculated surface area of the combined aggregate. Through the point of intersection on line C place a straightedge connecting with the previously determined oil ratio value on scale D. The intersection of the straightedge with scale E represents the oil ratio corrected for viscosity or consistency of the asphalt.

APPLICATION OF METHODS

Case I. In which it is desired to determine the optimum oil ratio (Grades 2-3-4) for an aggregate whose characteristics do not change abruptly on the No. 4 sieve size. This is the most usual case and applicable to all road mix construction with local material, e.g.

(1) By screening determine the per cent by weight of aggregate passing the No. 4 sieve.
(2) Determine C.K.E.
(3) If the specific gravity is less than 2.4 or greater than 3.0 correct the C.K.E. by adding or subtracting the amount determined from the bottom of Figure III, Scale E.
(4) From the per cent of aggregate passing the No. 4 sieve and the corrected C.K.E. the oil ratio may be determined from the alignment chart, Figure III, Scales A, B, and C.

Case II. In which it is desired to find the optimum oil ratio of a fine aggregate having certain surface characteristics combined with a coarse aggregate of different surface characteristics. This is more complicated than Case I, but perfectly general.

(1) From the wash grading calculate the surface area according to the method of Stanton and Hveem.
(2) Determine the C.K.E. by the method described.
(3) Correct C.K.E. for specific gravity of the fines by the following formula:

$$\text{C.K.E.}_{\text{(Corrected)}} = \text{C.K.E.}_{\text{(Uncorrected)}} \times \frac{\text{Sp. Gr. fine}}{2.65}$$

(4) Using this C.K.E. (Corrected), the surface area and per cent by weight of aggregate passing the No. 4 sieve determine the surface constant K_f by the use of Figure V.
(5) Determine K_c by the method described, **Figure VI.**
(6) Determine K_m by the use of **Figure VII.**
(7) Using the surface area, average specific gravity of the total mix and K_m, the optimum oil ratio for the total mix is then determined by the use of **Figure III**, Scale D to B.

Note: Theoretically there should be a correction applied to the surface area and per cent of aggregate passing and retained on the No. 4 sieve due to the difference in specific gravity of the coarse and fine. The effect of these corrections is small and partly compensating so that they may be neglected.

Example No. 1—Unblended soil for Road Mix Surface Treatment.

Data:

Per cent passing #4 sieve=70%
Specific gravity, coarse =2.4
Specific gravity, fine =2.6

$$\text{Specific gravity mix} = \frac{1}{\frac{.30}{2.4} + \frac{.70}{2.6}} = 2.54$$

C.K.E. =5.0

(1) From Figure III, Scales A, B, and C Oil Ratio =5.6%

Note: If the C.K.E. had been corrected for specific gravity of the aggregate, the corrected C.K.E. would have been 5.1% and the oil ratio 5.7%. This small variation in calculated oil content is ordinarily not significant as a range of 0.1 per cent is less than the normal error in construction proportions. Few mixtures are critical within 0.1% either above or below the theoretical optimum.

Example No. 2—Blend of hard dense river gravel retained on No. 4 sieve with quite absorptive fine material passing No. 4 sieve.

Data:

Specific gravity, coarse =2.65
Specific gravity, fine =2.25
Per cent coarse =50%

$$\text{Specific gravity mix} = \frac{1}{\frac{.50}{2.25} + \frac{.50}{2.05}} = 2.43$$

Surface area mix = 46 square feet
C.K.E. =11.8

Per cent oil absorbed by coarse=1.5%

(1) C.K.E. $= \frac{11.8 \times 2.25}{2.65} = 10.0$ (Corrected)
(2) Figure V, $K_f = 1.8$
(3) From Figure VI, $K_c = 0.7$
(4) From Figure VII, Corr. = −0.3
$K_m = 1.8 - \text{corr.} = 1.8 - 0.3 = 1.5$
(5) From Figure III, Oil Ratio = 7.2%

Assuming that it is desired to use an oil heavier than SC-2 or MC-2, say SC-6, taking Example No. 2 with oil ratio of 7.2 and referring to chart, **Figure VIII**, it will be indicated that the quantity will be 7.4; however, as K_m is 1.8, caution must be exercised as the rate of absorption with a heavy oil will probably be so slow as to cause temporary instability on the road.

Taking a case for hot mix plant construction with a graded aggregate having 35 sq. ft. surface area and K_m=1.0 oil ratio calculated at 4.2%, it will be found from chart, **Figure VIII**, that SC-2 will require 4.2%, SC-6 4.7%, 150 penetration asphalt 5.1%, 55 penetration 5.5%. These relative amounts have been used and found suitable in actual practice.

While the foregoing discussion of corrections and special cases may seem to be somewhat involved and complicated, in actual practice the kerosene contrifuge equivalent determination may be performed quickly and is sufficiently accurate except for a few special cases (see correlation on

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Figure IV). There will, of course, remain a few instances wherein no method short of an actual stability test on trial mixes will be adequate. This is due to the fact that any relationship between stability and absorption of a standard liquid or surface measurement calculation is largely fortuitous as in the final analysis the upper limit of permissible asphalt content depends on the degree of lubrication and this can only be positively determined by some test measuring the internal friction of the compacted mass.

All of the foregoing data apply to California asphalts and it should be realized that in using asphalts possessing a more distinct structure, such as Mexican asphalt, for example, the final values indicated herein may need to be increased over the quantity found sufficient for the more truly liquid California product.

In conclusion, the writer wishes to acknowledge the efforts of Mr. Ernest Zube who was responsible for much of the experimental work and to Mr. Robert Carmany who assisted in making the large number of correlation tests and who analyzed the data and developed the mathematical relationships necessary to construct the essential curves and charts.

Since the first printing of the above article in 1942, the C.K.E. method has been applied in the California Laboratory to more than 5,000 samples of bituminous mixtures. A study of the final results demonstrate that the C.K.E. method will indicate the optimum bitumen requirement in approximately 98% of all samples tested. While it is not possible to state definitely that any one particular class of aggregate is responsible for the approximate 2% of "misses," it has been observed that the indicated bitumen ratios are liable to be too high with fine graded aggregates containing limestone dust as a filler. This deviation from the normal trend is probably caused by the high adsorption affinity between limestone and kerosene which causes the sample to retain an undue amount of kerosene after centrifuging.

NOTE: Various models of the centrifuge may require different speeds of rotation in order to develop the desired centrifugal force. Each centrifuge should be checked to determine correct speed of rotation in accordance with the formula on page six.

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