EVALUATION OF A NUCLEAR ASPHALT-CONTENT GAUGE

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The Troxler asphalt-content gauge, model 2226, was evaluated in the laboratory and taken into the field where its results were compared to conventional reflux values. The precision as evaluated in the laboratory was found to be excellent, equivalent to 0.06 percent asphalt with a 45-sec count. The gauge has to be recalibrated for different aggregates and, as a practical matter, should be recalibrated for different mix types. Sample preparation is important, and the samples should be as uniform as possible. The accuracy appears to be as good as that of the reflux extractor.

•THERE have been several reports (1, 2, 3) on the use of nuclear gauges to measure the asphalt content of bituminous mixes. The earliest report (1) was in 1956 and was on research in which experimental equipment was used. That report concluded that, although the theoretical principles involved had been experimentally validated, the variability of the results and the cost of the equipment precluded the use of the apparatus at that time. More recent reports have dealt with the use of commercially available nuclear moisture gauges to measure asphalt content; that is possible because the measurements of both moisture and asphalt content are based on the detection of thermalized neutrons. However, because equipment adaptation is necessary and the variability of the test results is rather large, this equipment has not been widely accepted for measuring asphalt content.

More recently gauges designed expressly for the purpose of measuring asphalt content have become commercially available (4, 5). In 1969 the author (6) reported on the use of such a gauge. It was reported that the precision of the gauge, about 0.20 percent asphalt, was fairly good but that a relatively long counting time, 18 min, was required. Also the accuracy left something to be desired; the correlation between count rate and asphalt content had a standard error of 0.30 percent asphalt. It was suggested that the gauge could be redesigned to improve its accuracy, and this conclusion was generally substantiated by a study done at the University of Southwest Louisiana (7). The manufacturer, Troxler Electronic Laboratories, agreed with this conclusion and made a second-generation gauge available in November 1969.

This report is essentially concerned with an evaluation of the redesigned Troxler gauge, model 2226, shown in Figure 1. The operation of the gauge is similar to that of the original model in that the sample pan is filled and inserted into a drawer for testing. However, it is different in 2 important respects. One is that it operates on the basis of direct transmission rather than backscatter. This means that the sample is placed between the source (300 mCi Am Be) and the He_3 detector tubes, which are much more efficient than the BF_3 tubes previously used. This feature minimizes the influence of the location of the asphalt, a serious drawback in the original gauge. The other difference is the inclusion of a self-standardizing operation (Fig. 2) that converts the count obtained from the scaler into a count ratio. This feature simplifies the gauge operation tremendously by eliminating the requirement for a separate standard count.

PURPOSE AND SCOPE

The purpose of this evaluation was to determine the precision of the Troxler asphalt-content gauge and to evaluate its accuracy under several variables. A laboratory eval-

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uation of the gauge constituted the initial phase of the project. The precision was determined by performing several repeat tests on the same sample, and the accuracy was evaluated by analyzing the effects of several variables. More specifically, in the latter instance, it was necessary to determine for which variables the gauge must be recalibrated. The variables investigated were aggregate type and gradation, asphalt content and asphalt penetration, and producer. On the basis of the author's previous study it was anticipated that different aggregates would produce different count rates, and this expected result was checked by using 4 aggregates: granite, limestone, greenstone, and gravel.

Although the previous study had indicated no effect from gradation, it was thought that gradation should be included as a variable. The gradations studied are given in Table 1. These variables were included in an experimental design to cover an asphalt-content range of 0 to 7 percent as given in Table 2 (all asphalt contents were calculated on a percentage by weight basis); Table 2 also gives the producer and penetration grade. All mixes were of sufficient weight to allow 2 samples of 6,700 grams each to be tested. The laboratory phase of the study was followed by a field-testing program.

NUCLEAR TESTS

The precision of the gauge was established by performing 30 three-minute (1-position) repeat tests on the same sample. On a 6 percent fine limestone mix the standard deviation was 130 counts (equivalent asphalt content = 0.06 percent), which provided a variation coefficient of 0.27 percent. These results are shown in Figure 3, which also shows that count rate is independent of temperature from the normal mixing temperature of 280 F to 140 F. Based on these data and a 45-sec (0.25 test position) count rate, it was determined that for a 45-sec count the precision, or ability of the gauge to repeat a measurement, would have a 95 percent confidence limit of 0.12 percent asphalt.

The accuracy of the gauge under the previously mentioned variables was evaluated by employing 2 statistical techniques. More specifically, these techniques were used to determine which variables would likely require the establishment of separate calibration curves. The first technique employed was a regression analysis of mixes 1 through 48 (Table 2). An indication of the influence of both asphalt penetration and producers was gained by performing an analysis of variance. These analyses, as well as one between design and extracted asphalt content and one dealing with field calibration and testing, are discussed in the following sections.

Sample Preparation

Sufficient material was used in all of the mixes to allow tests on 2 pans for each mix so that an indication of "between-pan" variation could be obtained. The first tests were performed on a fine-gradation mix, and the difference between the 2 test pans was much greater than had been found for the "within-pan," or precision, data that had been obtained. This led to an investigation of the sample-preparation techniques, which revealed much greater reproducibility when a mechanical sample splitter was used than when the sample was split by hand. This difference is given in Table 3. The average values for the difference between pans was about 0.22 percent for hand and 0.04 percent for mechanical splitting. This difference pointed out the necessity for preparing samples with a sample splitter. It also emphasized that differences in asphalt content can be caused by a relatively small amount of segregation, even in a fine-graded mix. Thus, as has been recognized in the past, sample preparation is quite important; because it does cause single test values to vary widely, sample averages should be used as extensively as practicable.

Aggregate Effect

The influence of aggregate type and gradation was determined by performing linear regression analyses on each aggregate for each gradation. All gradations were then pooled, and a regression analysis was made for each aggregate. As mentioned earlier, the initial study had substantiated clearly the theoretical principle that separate cali-

Figure 1. Gauge with sample drawer open.

Table 2. Mixes tested.

Mix[a]	Aggregate	Gradation	Asphalt Content (percent)	Asphalt[b]
1 to 4	Granite	Coarse	0, 3, 4, 5	1 (85 to 100)
5 to 8	Granite	Medium	0, 4, 5, 6	1 (85 to 100)
9 to 12	Granite	Fine	0, 5, 6, 7	1 (85 to 100)
13 to 16	Gravel	Coarse	0, 3, 4, 5	1 (85 to 100)
17 to 20	Gravel	Medium	0, 4, 5, 6	1 (85 to 100)
21 to 24	Gravel	Fine	0, 5, 6, 7	1 (85 to 100)
25 to 28	Limestone	Coarse	0, 3, 4, 5	1 (85 to 100)
29 to 32	Limestone	Medium	0, 4, 5, 6	1 (85 to 100)
33 to 36	Limestone	Fine	0, 5, 6, 7	1 (85 to 100)
37 to 40	Greenstone	Coarse	0, 3, 4, 5	1 (85 to 100)
41 to 44	Greenstone	Medium	0, 4, 5, 6	1 (85 to 100)
45 to 48	Greenstone	Fine	0, 5, 6, 7	1 (85 to 100)
49	Gravel	Medium	5	1 (85 to 100)
50	Gravel	Medium	5	2 (85 to 100)
51	Gravel	Medium	5	1 (60 to 70)

[a] Each mix was split and duplicate samples run for each mix.
[b] 1 = Esso; and 2 = Chevron.

Table 4. Effect of gradation.

Aggregate	Gradation	Slope	Intercept	Standard Error	Correlation Coefficient
Granite	Coarse	1,868	38,544	0.09	0.9994
	Medium	1,896	38,744	0.18	0.9985
	Fine	1,883	38,907	0.13	0.9994
	Pooled	1,902	38,662	0.14	0.9985
Limestone	Coarse	2,026	38,502	0.19	0.9973
	Medium	2,177	37,822	0.20	0.9981
	Fine	2,209	38,213	0.15	0.9992
	Pooled	2,173	38,090	0.20	0.9972
Greenstone	Coarse	1,953	43,366	0.18	0.9976
	Medium	1,873	43,850	0.07	0.9997
	Fine	1,921	44,075	0.17	0.9990
	Pooled	1,940	43,665	0.19	0.9974
Gravel	Coarse	1,885	38,964	0.25	0.9955
	Medium	2,091	38,919	0.39	0.9926
	Fine	1,971	39,797	0.22	0.9984
	Pooled	2,038	39,040	0.33	0.9918

Figure 2. Gauge operation.

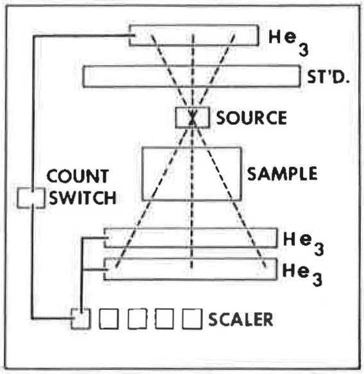


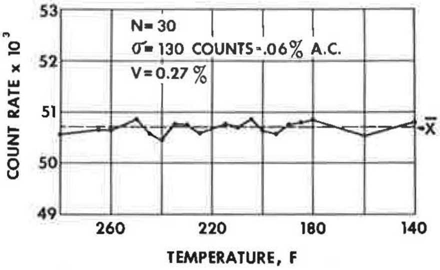
Table 1. Mix gradations.

Item	Coarse (percent passing)	Medium (percent passing)	Fine (percent passing)
Sieve size			
$1\frac{1}{2}$ in.	100		
$\frac{3}{4}$ in.	75	100	
$\frac{1}{2}$ in.			100
$\frac{3}{8}$ in.		70	90
No. 4	40	50	60
No. 8	30	35	45
No. 30			
No. 50		10	15
No. 100		6	10
No. 200	3		6
Asphalt content	0 to 5	0 to 6	0 to 7

Table 3. Effect of type of splitting.

Splitting Method	Pan 1	Pan 2	Difference: Count Rate	Difference: Asphalt Content (percent)
Hand	9,658	9,574	84	0.17
Hand	12,840	12,974	134	0.27
Mechanical	9,543	9,531	12	0.02
Mechanical	12,191	12,214	23	0.05

Figure 3. Precision results and lack of temperature influence on count rate.



bration curves would be needed for each aggregate. Table 4 gives the slopes and intercepts from the linear regression analyses as well as the standard error and correlation coefficient for each gradation and for each aggregate. Of primary importance initially are the very high correlation coefficients obtained under all gradations and aggregates; all are more than 0.990, which indicates that count rate is definitely related to asphalt content. Also of importance is the standard error, which indicates the level of accuracy that can be expected from the prediction. The standard error values are generally 0.20 percent asphalt or less, except in the case of the gravel mixes.

Data given in Table 4 also show that gradations have essentially no effect on calibration or, more precisely, on count rate. The standard errors and correlation coefficients for the individual gradations are not sufficiently improved over those for the pooled values to warrant the use of the former. This same conclusion can be drawn from the graphical representations of the regression analyses shown in Figure 4. There is no discernible difference between the gradation points. This does not mean that there is no gradation effect. As stated previously, the effect of gradation or segregation was apparent from tests on supposedly identical samples. For the limestone gradation, for example, the average difference between pans increased sevenfold: 0.04 percent in the fine gradation, 0.10 percent in the medium gradation, and 0.28 percent in the coarse gradation. The average count-rate difference was 20, 40, and 140 respectively. Naturally, this phenomenon is not unique with nuclear testing. However, the ability to retest the same sample and the speed of testing with the nuclear method make the differences much more apparent.

The results from pooled aggregate analyses (Table 5) show clearly by the variation in intercepts that separate calibration curves are necessary for each aggregate. Although it does not appear that a change in gradation requires a change in calibration, as a practical matter a change in gradation is normally accompanied by a change in aggregate type. This means that as a practical matter a change in gradation should necessitate at least a recheck on the calibration. This subject will be discussed in more detail later.

Because the slopes between aggregates are reasonably close, it was thought it would be possible to use only a 0 percent, or dry aggregate, point and the average slope of 2,013 counts versus percentage of asphalt content to establish a reasonably accurate calibration curve. Predictions based on this method did not compare well with the actual asphalt contents, and this method was dropped from further consideration.

Asphalt Effect

Whether asphalt producer or asphalt penetration affected the count rate was determined by testing 3 mixes (49, 50, and 51). The mixes had a single gradation, aggregate type, and asphalt content and varied only in penetration or producer. An analysis of variance indicated that statistically there was a significant difference between asphalts, and in this case the difference appeared to be due to penetrations. The average count rate and the equivalent asphalt contents measured are as follows:

Mix	Count Rate	Asphalt Content (percent)
49	49,268	5.00
50	49,280	5.01
51	49,024	4.88

Although there may have been some statistically significant difference attributable to penetration, it appeared to be reasonably small and can be accommodated, it is believed, in the field calibration.

CONVENTIONAL TESTS

A basis was established for comparing nuclear asphalt-content values and conventional reflux values by extracting 36 of the first 48 mixes (12 were dry or 0 percent asphalt mixes) by the reflux method and correlating the values with the design asphalt content. Figure 5 shows the regression line and the pertinent statistical information. As expected, the correlation coefficient was high (0.994) and the slope was almost unity (1.02). But the average extracted asphalt content was 0.10 percent lower than the design average, which indicated a bias in the method. That bias in extracted asphalt content was not unexpected because it is quite often found that the amount extracted is not so high as that put into the mix. The bias should be considered whenever it is desired to correlate nuclear values and extracted values because the asphalt content cannot be controlled as well in the plant as in a laboratory.

The standard error of the conventional values versus design values was 0.13 percent as compared to generally less than 0.20 percent for the nuclear correlations given in Table 4. Because of the great speed advantage in the nuclear method, the slight loss in accuracy should be more than compensated for by making more tests.

FIELD CALIBRATION

The primary criteria for establishing a field calibration procedure were that it must be technically sound and be practical. For the first criterion, the following guidelines were established:

1. Each aggregate must be calibrated separately;
2. At least 2 points are necessary to establish a calibration curve;
3. Each mix type must be checked for calibration; and
4. Asphalt type should be checked periodically for calibration.

Guidelines for the second criterion were as follows:

1. The procedure must be one that plant personnel can master; and
2. The calibration procedure must not be lengthy or be required too often.

With these guidelines it was decided to calibrate as soon as possible after starting up a plant. Because moisture variations affect the count rate of the gauge, the ideal sampling point appeared to be the hot bin, where the moisture content should be reasonably stable. This was also advantageous because the aggregate, after it was blended in the proper proportions, could be tested dry to establish the 0 percent point on the calibration curve and then, because it was still hot, could be mixed with an asphalt sample from the storage tanks to produce a second point on the calibration curve near the optimum asphalt content for that mix. With this procedure, about 1 hour is required for establishing a calibration curve; afterward, testing can commence. The main parameter established by this process is the slope of the curve because the intercept will change from time to time depending on the moisture in the aggregate. Therefore, the 0 percent point only should be checked at least once a day and more often if variable moisture conditions exist in the aggregate stockpiles.

INITIAL FIELD TESTING

The procedure just given was used to check 5 plants during the fall of 1970. Table 6 gives the results of the nuclear tests using both 1 and 0.25 position counts and of the corrected reflux tests. The correction values are the differences between the design asphalt content used in making up the calibration sample and the amount extracted by the reflux test. This procedure is in agreement with results of the correlation in the preceding section on conventional tests. The comparison between nuclear and corrected reflux averages is very good; the average difference for all results is only 0.13 percent asphalt for the 1 position and 0.09 percent asphalt for the 0.25 position.

EXTENDED FIELD TESTING

Throughout the 1971 construction season, the asphalt-content gauge was used at an asphalt plant supplying base, intermediate, and surface mixes for an Interstate project. A technician from the Virginia Department of Highways operated the gauge in conjunction with the conventional reflux method used for acceptance purposes. Whenever a conven-

Figure 4. Regression analysis for aggregates.

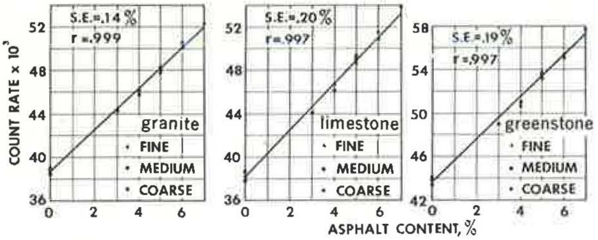


Figure 5. Regression analysis of asphalt.

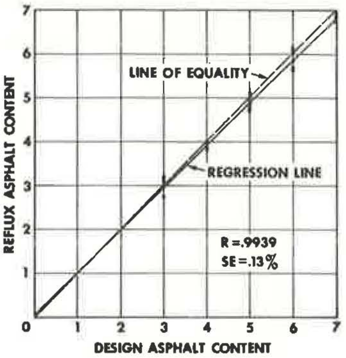


Table 5. Effect of aggregate.

Aggregate	Slope	Intercept	Stand. Error
Granite	1,902	38,662	0.14
Limestone	2,173	38,090	0.20
Greenstone	1,940	43,665	0.19
Gravel	2,038	39,040	0.33
Average	2,013		

Table 6. Results of initial field testing.

				Nuclear				Corrected Reflux (percent)		
				1 Position		0.25 Position				
Plant	Calibration	Mix	Number of Tests	Avg.	Standard Deviation	Avg.	Standard Deviation	Avg.	Standard Deviation	Corrected Asphalt Content (percent)
1	1	Base	10	4.82	0.48	4.87	0.48	4.85	0.40	0.50
1	2	Base	8	5.31	0.71	5.32	0.64	5.19	0.56	0.84
2	1	Surface	10	5.70	0.22	5.69	0.17	5.74	0.14	0.28
2	2	Surface	10	5.86	0.37	5.78	0.28	5.78	0.14	0.16
3	1	Intermediate	10	4.60	0.20	4.57	0.14	4.57	0.12	0.19
3	2	Intermediate	6	4.29	0.15	4.21	0.23	4.43	0.15	0.05
3	3	Surface	6	4.53	0.11	—	—	4.74	0.15	0.17
4	1	Surface	10	5.51	0.44	5.61	0.47	5.72	0.37	0.11
5	1	Base	8	3.96	0.31	—	—	4.16	0.21	0.22
5	2	Intermediate	7	5.12	0.49	—	—	4.96	0.24	0.14

Table 7. Results of extended field testing.

	Nuclear				Corrected Reflux			
Mix	Difference From Job Mix	Standard Deviation	Correction	Number of Samples	Difference From Job Mix	Standard Deviation	Correction	Number of Samples
Base								
Before	0.5	0.4	—	61	0.0	0.3	0.2	37
After	-0.1	0.2	—	67	-0.1	0.2	—	67
Intermediate	0.0	0.4	—	64	0.0	0.4	—	64
Surface	0.2	0.2	—	25	0.2	0.2	—	25

Table 8. Results of hot-bin and washed-sample analyses.

	Sieve (percent passing)								
Mix	1 in.	¾ in.	⅜ in.	No. 4	No. 8	No. 30	No. 50	No. 200	Number of Samples
Base									
Hot bin	100.0	75.7	—	41.8	26.0	—	—	3.4	19
Reflux	100.0	75.1	—	44.0	28.8	—	—	5.3	20
Intermediate									
Hot bin	100.0	84.3	76.2	47.2	28.3	—	6.3	3.8	24
Reflux	100.0	84.6	76.4	46.1	29.1	—	8.0	5.0	26
Surface									
Hot bin	—	—	95.5	61.1	38.7	16.2	9.8	2.9	6
Reflux	—	—	95.1	60.7	41.2	20.9	13.4	4.2	6

tional sample was tested, a comparison nuclear sample was tested. However, because of the speed of nuclear tests, many more of those tests were made. The comparative tests provided an opportunity to evaluate the gauge under everyday plant conditions and by a technician not familiar with it.

From the data obtained under those conditions, it was found that testing the aggregate dry to establish the 0 percent calibration point daily was probably not necessary. The standard deviation determined from samples taken daily during a period of several months was only 190 counts, or approximately equivalent to 0.12 percent asphalt. On the basis of these results, it is anticipated that two 0 percent calibration points per week will suffice.

A sample preparation effect related to aggregate gradation, heretofore not evident, appeared when the base mix was tested; because it was reasonably coarse-graded, it often had a coarse surface texture. Table 7 gives the results for the comparative tests obtained from this project. The "before" data for the base mix are the results before any consideration was given to the surface texture of the sample. The nuclear asphalt contents averaged 0.5 percent more than the job-mix value, and the corrected-reflux results averaged the same as the job-mix value. The standard deviations for the 2 types of tests were comparable, which indicated that the nuclear values were as consistent as those of the reflux. Therefore, the nuclear readings were higher than should be expected.

After it was ascertained that the calibration was accurate and not responsible for the high values, it was noticed that the finished texture in the pan was always coarse when a high value was obtained. Particular attention was then paid to placing most of the coarse aggregate in the sample pan first, thus providing a relatively smooth-finished texture in the pan. The results became lower and consistent with the corrected-reflux values as shown by the "after" data for the base mix.

For the other mix types, it is obvious from the data given in Table 7 that the nuclear results can estimate the job-mix asphalt content as closely as, if not closer than, the reflux method. On this project, there appeared to be somewhat more variability in the nuclear method than was found from previous testing. However, because the method is appreciably faster than the conventional one, many more tests can be run and the testing variability effectively reduced.

QUICK-GRADATION ANALYSIS

The adoption of a rapid-test method for the acceptance of asphalt content requires a reevaluation of the method of acceptance for the gradation of asphalt-concrete mixes. Having to wait for a gradation obtained from a washing process negates some of the advantage of the speed of the nuclear asphalt-content test. It appears that the best way of speeding up gradation tests would be through the use of hot-bin samples. This procedure was used on the field project as a comparison with the gradation values from the reflux tests. The results are given in Table 8.

There appears to be very good agreement between the 2 methods, except in the fine-sieve sizes. Because the preparation of hot-bin samples requires splitting the sample and combining it proportionately, some fines are lost. However, this method still appears to offer some hope for speeding up the gradation analysis.

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