ASPHALT CONTENT DETERMINATION USING NUCLEAR TECHNIQUES

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An evaluation was made of the application of the Troxler nuclear asphalt content gauge, model 2226, to determine the asphalt content of hot bituminous mixes using neutron thermalization. Parallel data were acquired, where convenient, by the use of a Nuclear-Chicago asphalt content gauge, model 9999, previously evaluated. Data were first acquired for variables of mix design (gradation), aggregate types, and asphalt producers for bituminous mixes with various representative asphalt contents. These initial samples were mixed under controlled laboratory conditions. Comparisons were made of design asphalt contents, Immerex extraction values on the same samples, and the values determined with the two nuclear units. Field tests of the Troxler gauge were also conducted at various batch plants with resulting values compared to extracted asphalt content on the same sample.

•DURING the past 15 years, various nuclear techniques and instrumentation have been applied to the task of determining the asphalt content of bituminous concrete mixes in an accurate and swift manner (2-4). The standard reflux extraction is an accepted method for obtaining asphalt content; however, considerable time (as much as 1½ hours) is required for the test to be accurately performed, and the material represented by the tested mix may have been placed and compacted before the extraction results are known. In addition, mixes determined by this method yield a standard deviation of 0.2 percent of bitumen content (ASTM D 2172-65T, Method C). With the evolution of solid-state circuitry and detecting devices of greater sensitivity, studies of nuclear techniques progressed until units were designed specifically for the purpose of determining the asphalt content of hot bituminous concrete mixes while maintaining a sufficient degree of portability such that field use became practical. Initial studies of such a gauge by the department were reported in 1968 (1). Early in 1970, a Troxler asphalt content gauge, model 2226, was purchased, and an investigative study was undertaken to evaluate this new gauge.

THE TROXLER GAUGE

The 16- by 16- by 16-in. Troxler gauge (Fig. 1) consists of a one-piece unit weighing about 125 lb. All components are enclosed within the single unit, and a sliding-drawer arrangement is provided such that stainless steel pans containing the bituminous test sample can be inserted into the gauge. Three He-3 neutron detector tubes were utilized to monitor the thermal neutrons from a test specimen. Two of these tubes were sample detector tubes, positioned beneath the test specimen pan in the sliding drawer. The other tube was situated near the top of the gauge and acted as a reference detector (Fig. 2).

The counts monitored by the reference detector were used as a continuous internal standard count and were electronically compared with the sample count. Thus, any

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electronic drift caused by temperature variation or component aging could be accounted for during the actual test count. Because of this system of continuous standardization, no auxiliary standard was provided.

PRINCIPLE OF OPERATION

The basic principle of operation of an asphalt content gauge of this type relies on neutron thermalization. It is first necessary to produce a sufficient number of neutrons. A convenient source of neutrons is provided when beryllium metal is bombarded with alpha particles emitting from a radioactive source. With this gauge the source consisted of 300 mC of americium-241. This source emits a wide variety of beta and gamma radiation of relatively low energies; in addition alpha particles in the energy range of 5.31 to 5.50 MeV are emitted. These alpha particles are of importance in neutron production because they have sufficient energy to initiate the beryllium-alpha reaction, ${}_4Be^9 + {}_2He^4 \rightarrow {}_0n^1 + {}_6C^{12}$, when they collide with beryllium metal mixed with the americium-241 in the sealed source. In terms of alpha particles with the energy value of 5.3 MeV, about 1 alpha particle in 10^4 produces a neutron; therefore, the number of neutrons from a 300-mC source would be approximately

$$3.7 \times 10^7 \frac{\text{alpha disintegration}}{\text{millicurie}} \times 300 \text{ mC} \times 10^{-4} \frac{\text{neutron}}{\text{alpha disintegration}}$$

$$= 11.1\ (10^5) \text{ neutrons with about 2.5 MeV of energy}$$

When charged particles react with matter, electrostatic forces and radiation emission are most important; however, the emitted neutrons are uncharged, and their interaction with matter consists almost entirely of collisions with nuclei of the matter. Such collisions can be divided into three classes: elastic scattering, where the incident neutron is deflected by the nucleus with a loss of kinetic energy; inelastic scattering, where the incident neutron and nucleus interact such that a new neutron is emitted with a lower energy than the incident neutron; and neutron capture, where the neutron is absorbed by the nucleus with the usual emission of a photon. The two scattering interactions are of importance in the determination of asphalt content in bituminous mixes. With scattering, the nucleus maintains its lowest energy state, and the resulting collisions with nuclei are of the "billiard ball" type and easily analyzed with familiar laws of mechanics, based on the principles of energy and momentum conservation.

Useful data can be obtained from an asphalt content gauge by slowing sufficient numbers of "fast" neutrons (energies from 0.5 to 10 MeV) to "thermal" levels (0.025 eV). Only at thermal levels can the neutrons be successfully counted by the He-3 detector tubes. After a sufficient number of scattering collisions, a neutron's velocity is reduced to where its kinetic energy is the same as that of the atoms of the scattering medium. Thermal neutrons are thus in thermal equilibrium with the atoms of the asphaltic mix under test in a nuclear gauge.

THEORETICAL CONSIDERATIONS

The scattering collisions that occur over a timed counting period are a function of the macroscopic cross section for the number of nuclei of the test material. This is expressed for a single element as

$$\Sigma = \frac{\rho N_a}{A} \sigma_s \tag{1}$$

where

Σ = macroscopic cross section in barns (1 barn = 10^{-24} cm^2),
A = atomic weight of element,
ρ = density of element in g/cm^3,
N_a = number of atoms per gram atom (0.602×10^{24}), and
σ_s = microscopic scattering cross section for a single atomic nucleus in barns.

For a compound consisting of i-elements, the cross section for scattering can be written as

$$\sum_{i} = \frac{\rho N_a}{M} \gamma_i \sigma_{si} \tag{2}$$

where

M = the compound molecular weight, and
γ_i = the number of ith atoms in the compound molecule.

Thus, for a material scattering consisting of a single compound with i atoms, we have

$$\sum_{i} = \frac{\rho N_a}{M} [\gamma_1\sigma_1 + \gamma_2\sigma_2 + \ldots + \gamma_i\sigma_i] \tag{3}$$

If the scattering material consists of several types of various scattering compounds, say, j compounds, the total scattering material cross section is Σ_T and can be written as

$$\sum_{T} = \sum_{1} + \sum_{2} + \ldots + \sum_{j} \tag{4}$$

Thus, the total scattering cross section for a mixture of bituminous material consisting of various types of aggregate and bitumen can be determined, although not easily.

As the asphalt content changes, the number of individual atoms N of asphalt changes or the term $N = \frac{\rho}{A} N_a$ changes. Thus, for an increase of N, the value of Σ_T for the entire mix would increase, resulting in more scattered or thermalized neutrons and a higher count for a counting period. In a typical bituminous mixture, it is the added hydrogen atoms present with an increase of asphalt that produce a higher count. Hydrogen has an elastic scattering cross section as much as 20 barns in the chemically unbounded state, whereas nearly all other elements lie in the range of 2 to 10 barns for neutrons of low or thermal energies (5). Therefore, any increase in the number of asphalt molecules means more hydrogen atoms and thus more scattered thermal neutrons, which results in a higher count rate on the gauge.

GAUGE CALIBRATION

The asphalt content gauge must be calibrated such that a curve of count rate versus asphalt content can be established. A sample pan containing only dry aggregate of the proper mix design (gradation) is first run to establish the zero asphalt content count rate. It was suggested by the Troxler gauge manufacturer that at least four times (24,000 g) the amount of aggregate required to fill a test pan ($\approx$ 6,000 g) be mixed, that it be split with a sample splitter, and that one 6,000-g portion be used to establish the dry aggregate count rate. It is suggested that the remaining 12,000-g splitter portion be mixed with sufficient asphalt at about 300 F to produce a complete mix with a desired asphalt content in the range of the mix to be tested. This sample should be split, a test pan filled and packed, and a count rate obtained for the design bituminous mix. The two established count rates for the respective zero and design asphalt contents can be used to plot a curve that determines asphalt content values.

Calibration of the Nuclear-Chicago gauge leads basically to a similar curve, but here several sample pans of varying asphalt contents about the design mix value are carefully prepared and count ratios established versus the respective asphalt contents. Count ratios are obtained by dividing the average count rate for 10 counts taken on the sample pan by the average count rate similarly obtained on a standard supplied by the gauge manufacturer. No sample splitter is recommended for mix preparation although the manufacturer recommended extreme care in preparing accurate calibration mixes.

The calibration procedure used in this evaluation consisted of preparing a zero asphalt content pan of thoroughly mixed aggregate weighed to the nearest gram and reading it in both gauges. Asphalt was then added to the same aggregate in such an amount by weight to produce the required design percentage of asphalt content. This mixture was thoroughly mixed at about 300 F, and an amount equal in weight to that of the dry aggregate was placed in the test pan and read in both gauges. All asphalt remaining in the mixing bowl and on all mixing utensils was accounted for, and a final, precise asphalt content for the mix was determined (usually a few tenths of a percent lower than the design value).

Similar mixing procedures were performed on other dry aggregate samples until four separate asphalt content count rates and a zero asphalt content count rate were determined with each nuclear gauge for the various mix designs required for the evaluation.

EXPERIMENTAL PROCEDURE

Phase one of the evaluation dealt only with carefully prepared laboratory samples of bituminous mixes.

Phase two of the study consisted of removing the Troxler nuclear gauge to several bituminous mix batch plants. Random samples of various bituminous mixes were tested. All calibration samples for the nuclear gauge were prepared at state facilities after obtaining hot-bin aggregate and asphalt samples from the plant. Extractions were run on the same samples tested in the nuclear gauge by use of laboratory extraction facilities.

Section 1

After nuclear-gauge calibration, two sample pans of each bituminous mix were prepared with the following mix design and percentages of asphalt content (asphalt used was all from the same supplier):

Bituminous Mix Design	Design Percentage of Asphalt Content by Weight
ID-2 wearing	5 to 10
ID-2 binder	4 to 8
FJ wearing	6 to 11

Gradation data for each mix design are given in Appendix A.

Each of the preceding duplicate sample pans was prepared using limestone, gravel, and slag. Each type was obtained from the same supply source for the entire test. Asphalt content determinations were made using the two calibrated nuclear gauges previously described for each sample mix. Immerex extractions (ASTM D2172-65T, method C) were performed on each sample mix at the completion of nuclear determinations.

Section 2

After nuclear-gauge calibration, two sample pans each were prepared with the following bituminous mix designs and asphalt contents using only limestone aggregate (all limestone used was from the same supplier):

Bituminous Mix Design	Design Percentage of Asphalt Content by Weight
ID-2 wearing	5 to 7
ID-2 binder	3 to 6
FJ wearing	6 to 8

Each of the preceding duplicate samples was mixed with four manufactured brands of asphalt different from that used in the earlier test. The asphalt content determinations and Immerex extractions were the same as those used in the earlier test.

EXPERIMENTAL RESULTS AND COMMENTS

In the performance of the section 1 testing, the various representative aggregates and mix designs were accurately prepared in calibration pans of 0 percent asphalt and

Figure 1. Troxler asphalt content gauge, model 2226.

Figure 2. Diagram of Troxler gauge.

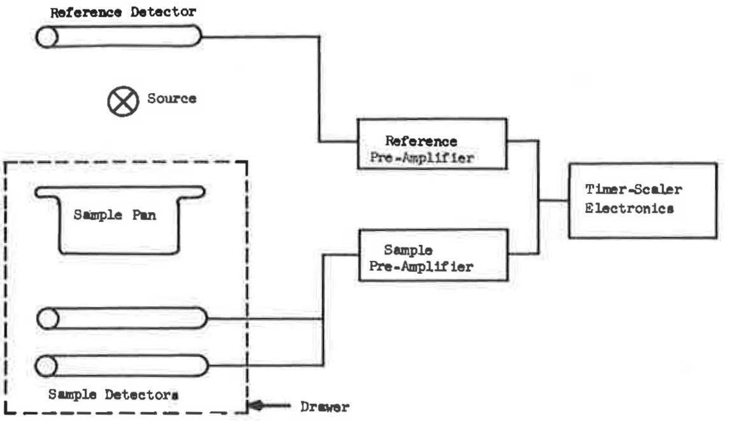


Figure 3. Calibration curves for Troxler gauge (various mix designs and aggregates).

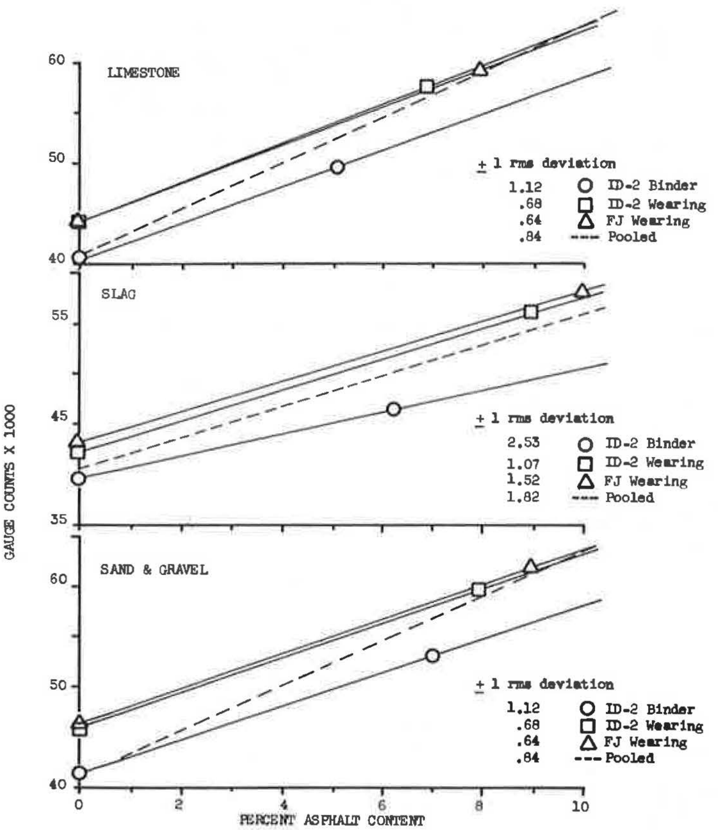


Figure 4. Calibration curves for Nuclear-Chicago gauge (various mix designs and aggregates).

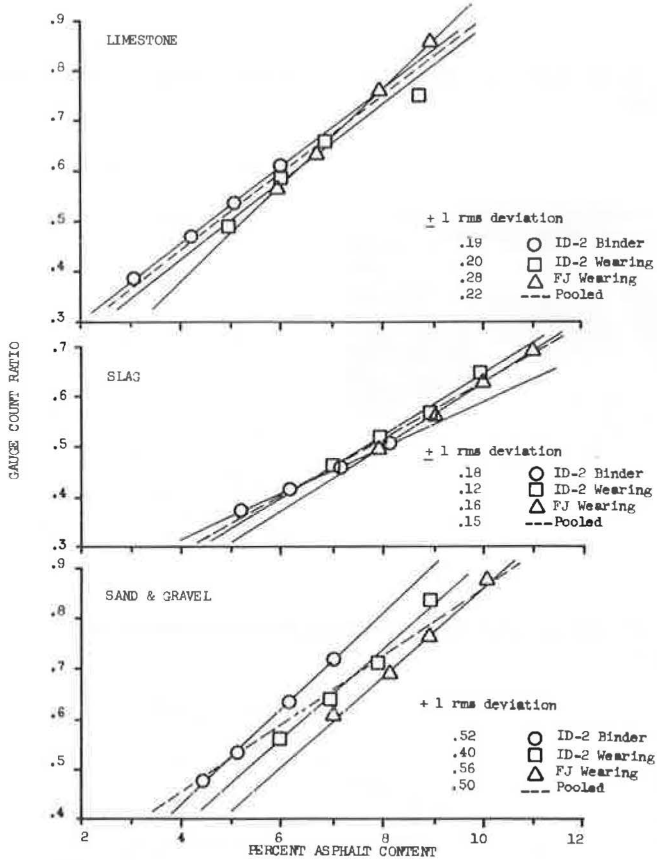


Table 1. One standard root mean square deviation (±) for design versus gauge-predicted asphalt contents by percent.

	Mix Design			
Aggregate	FJ Wearing	ID-2 Wearing	ID-2 Binder	Pooled
Limestone				
Troxler	0.37	0.30	0.43	0.37
Nuclear-Chicago	0.19	0.23	0.14	0.19
Slag				
Troxler	0.47	0.21	0.71	0.51
Nuclear-Chicago	0.20	0.15	0.19	0.18
Sand and gravel				
Troxler	0.37	0.57	0.33	0.44
Nuclear-Chicago	0.22	0.22	0.16	0.20
Pooled				
Troxler	0.38	0.35	0.48	0.41
Nuclear-Chicago	0.20	0.22	0.15	0.19

Table 2. One standard root mean square deviation (±) for extraction versus gauge-predicted asphalt contents by percent.

	Mix Design			
Aggregate	FJ Wearing	ID-2 Wearing	ID-2 Binder	Pooled
Limestone				
Troxler	0.48	0.40	0.54	0.47
Nuclear-Chicago	0.32	0.26	0.28	0.29
Slag				
Troxler	0.46	0.34	0.76	0.55
Nuclear-Chicago	0.33	0.24	0.20	0.26
Sand and gravel				
Troxler	0.24	0.78	0.32	0.51
Nuclear-Chicago	0.22	0.45	0.23	0.32
Pooled				
Troxler	0.44	0.48	0.55	0.49
Nuclear-Chicago	0.31	0.30	0.26	0.29

four additional pans containing design asphalt contents for the desired test range. Readings were taken with both nuclear gauges for each calibration pan. Regression-analysis techniques were used to establish equations for count versus asphalt content for the Troxler gauge and count ratio versus asphalt content for the Nuclear-Chicago unit. All counts on the Troxler gauge were taken in the calibrate position requiring about 11.5 min per test. The Nuclear-Chicago gauge took ten 1-min counts on each pan after establishing an average of 10 standard counts on a sealed Benelex standard provided with this gauge. A ratio of the average standard count divided into the averaged sample count establishes a ratio that is linearly related to asphalt content over successive testing.

Plots of the established calibration equations for each gauge showing the variations with aggregate and mix design are shown in Figures 3 and 4. The lines themselves are established from the regression calibration data.

It may be noted that, with the Troxler gauge, there is little effect of mix design for the ID-2 wearing and FJ wearing for respective types of aggregate, but the ID-2 binder mix curve gives from 2 to 5 percent higher asphalt content for the same gauge value. Definite variation with type of aggregate is apparent as noted on the dashed curve showing pooled data. Slopes of the pooled lines are quite different for each type of aggregate, and the intercept point varies for each type. Appendix B gives respective slope and intercept values for each gauge and test parameter.

Similar analysis of data for the Nuclear-Chicago gauge shows less variation with mix design. The sand and gravel mix have the widest variation, about 1.5 percent asphalt content among the three mix designs. Other aggregates show about 0.5 percent variation in asphalt content among the particular mixes. Again, the pooled data lines show a distinct variation in asphalt content for similar count ratios and different aggregates.

Also noted on each set of curves is the one standard deviation in asphalt content 1σ (assuming that there would be no calibration for mix design with particular aggregate types). As previously mentioned, the ID-2 binder mix in the Troxler gauge had the greatest deviation, about ± 1.77 percent asphalt content averaged for all three aggregates. The Nuclear-Chicago gauge has smaller deviations among mixes, about ± 0.7 percent, and yields a deviation between aggregates of about 0.2 percent for slag and limestone and 0.5 percent for sand and gravel. Better calibration and test results would be obtained if separate calibrations are made for each aggregate type and mix design.

The calibration curves established for each particular type of aggregate and mix design were used to determine the predicted asphalt contents of the design mixes of section 1 with each nuclear gauge. The same pans were then extracted to obtain an extraction asphalt content by percent. Again the one standard 1σ root mean square deviation was calculated for the various measurement techniques. The precisely designed pan values were used as a base in developing Table 1, which gives the standard deviation between design and gauge-predicted asphalt contents. Results obtained with the Nuclear-Chicago gauge were generally better than with the Troxler unit, which showed higher deviations with slag aggregates and an overall standard deviation of ± 0.41 percent asphalt content for the test. The Nuclear-Chicago gauge has an overall deviation of ± 0.19 percent. This was higher than that determined by similar investigations of the Troxler gauge (6) and may have been caused by the use of hand-mixed design pans instead of the mechanical splitter techniques.

Similar analysis was performed for extraction values as a base versus gauge-predicted asphalt contents (Table 2). When compared to the extracted values, both the gauges have a higher deviation about the extract value than does the pan design value. When a standard deviation of the extracted value about the base of designed asphalt content was determined, an overall value of ± 0.25 percent asphalt content was obtained. These data are given in Table 3. A curve of asphalt content by extraction and asphalt content by design is shown in Figure 5. The extracted value is uniformly lower than the design value with an average difference of 0.1 percent from design. This agreed well with similar tests performed earlier (7).

In section 2 of the study, the variation in gauge operation and calibration with dif-

Table 3. One standard root mean square deviation (±) for design versus extraction asphalt contents by percent.

	Mix Design			
Aggregate	FJ Wearing	ID-2 Wearing	ID-2 Binder	Pooled
Limestone	0.27	0.22	0.26	0.25
Slag	0.22	0.25	0.18	0.22
Sand and gravel	0.24	0.27	0.29	0.27
Pooled	0.26	0.23	0.26	0.25

Figure 5. Asphalt content by extraction and asphalt content by design.

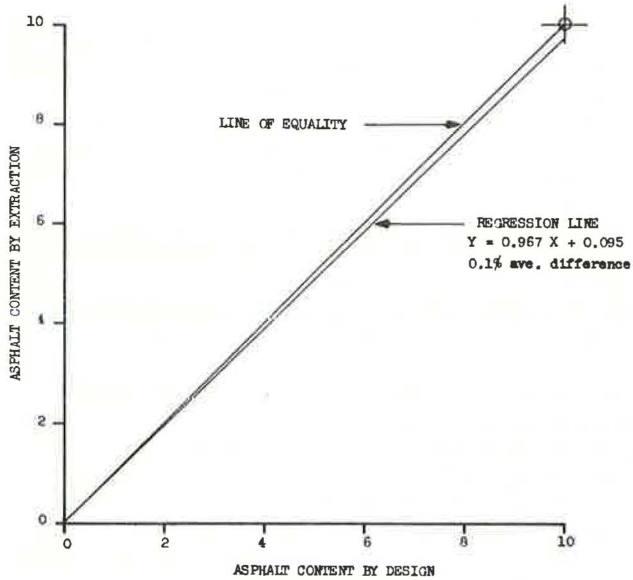


Figure 6. Asphalt-effect calibration curves for Troxler gauge (limestone aggregate), ID-2 binder mix.

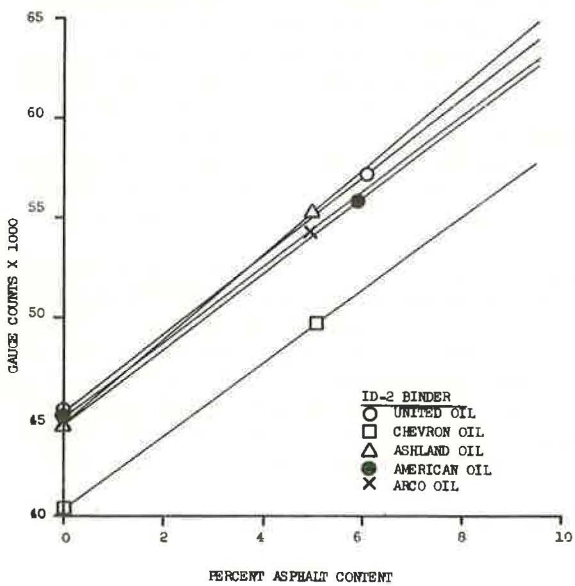


Figure 7. Asphalt-effect calibration curves for Troxler gauge (limestone aggregate), ID-2 wearing mix.

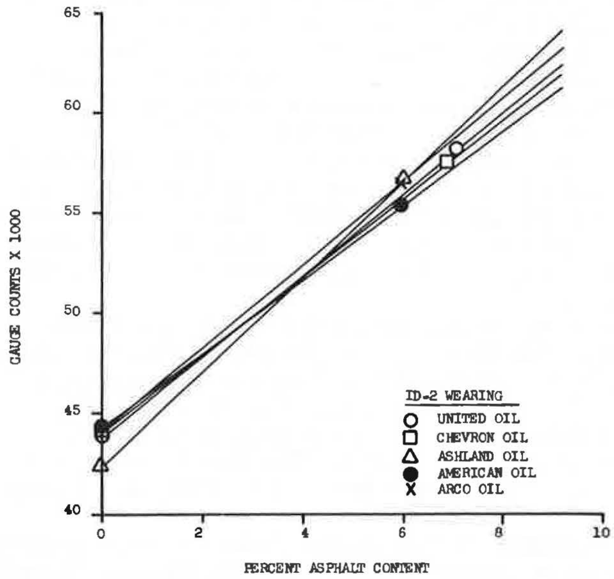
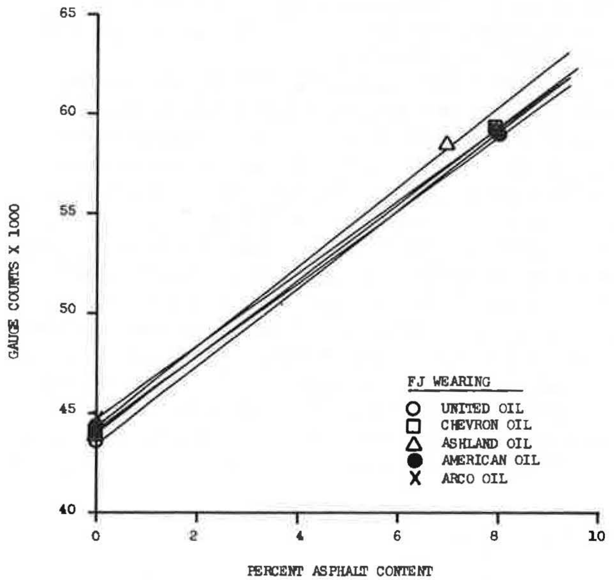


Figure 8. Asphalt-effect calibration curves for Troxler gauge (limestone aggregate), FJ wearing mix.



ferent asphalt manufacturers was examined. Calibration pans were prepared to accurately determined design values as described previously, but only limestone aggregate was used for the three mix designs. Figures 6, 7, and 8 show calibration curve variations for the three investigated mix designs for the Troxler unit. Similar calibration curves for the Nuclear-Chicago gauge are shown in Figures 9, 10, and 11. Neither gauge shows extreme sensitivity to variations in asphalt brand except for the Troxler gauge with ID-2 binder mix and Chevron asphalt. This is consistent with the data shown in Figure 3. Excluding this particular curve, the variation of which is not apparent with the other mix designs used, an average error of about ±0.3 percent asphalt content could be expected without individual gauge calibration for each type of asphalt. This holds approximately true for the Troxler gauge with asphalt content values from 1 to 5 percent and the Nuclear-Chicago gauge with values of 3 to 7 percent. For values of asphalt content in the 8 to 9 percent region, errors in calibration of up to ±0.75 percent asphalt content could be encountered.

After calibration, test pans of various design asphalt contents and types of asphalt were run, and the content was predicted using the previously described calibration curve equations. Table 4 gives the one standard deviation between design asphalt content as a base and the gauge-predicted values. No appreciable variation in gauge accuracy with either gradation or type of asphalt was apparent. Overall gauge deviation was slightly less for the Troxler unit than that found in section 1. This may have been the result of the absence of the aggregate variable and the relative insensitivity of the gauge to various types of asphalt.

During phase two of the testing, the Troxler gauge was used at several field locations to monitor the asphalt content of bituminous material from a typical batch plant. Samples of aggregate, asphalt, and the design gradation of the mix were acquired, and calibration pans were read with the gauge for 0 percent asphalt and an asphalt content slightly above the design value. All calibration pan preparation and readings were performed at state facilities. Samples of a field test mix were taken from various points in a loaded truck, mixed, placed in a sample pan, and run in the gauge. Insufficient time was available for extraction of all tested samples, so the tested material was placed in a sample box and returned to the laboratory for extraction.

Table 5 gives the 1 σ for the gauge-predicted value compared with the extraction value as a base. The pooled data for all field studies yielded a 1 σ of ±0.72 percent asphalt content. It is not felt that this higher standard deviation can be attributed to inaccuracies in the nuclear gauge. The extraction samples were held up to several weeks prior to processing. Also all calibration readings with the gauge were performed in the state laboratory, whereas field test data were taken at the batch plant site, at times in open areas. Differences between standard counts taken with the Troxler gauge in the laboratory and similar counts taken at the field site gave a correction count that was added or subtracted from the field test count to allow for the different background conditions. Without such corrections, a 1 σ for the field tests would have been nearly ± 1.0 percent. A higher overall accuracy and lower standard deviation, more comparable to that obtained in the laboratory phase, could undoubtedly have been obtained if all readings, including calibration tests, field sample tests, and extraction of the test samples, had been performed at the field plant. Such procedures will require services of a skilled technician and necessary equipment to produce accurately designed calibration mixes.

CONCLUSIONS

The following conclusions are supported by test results:

1. The overall results of the calibrated Troxler gauge, disregarding effects of gradation and type of aggregate, showed a standard deviation of about ±0.40 percent asphalt content from design. It is felt that this value might possibly be reduced if the sample splitter technique is applied for calibration sample and test sample preparations, although it would require considerable cleaning and scraping when various mix designs are tested. It has also been suggested by the gauge manufacturer that light compaction with a small plate fitting within the test pan may improve accuracy. Vibration and striking of material in the pan were done manually in this study.

Figure 9. Asphalt-effect calibration curves for Nuclear-Chicago gauge (limestone aggregate), ID-2 binder mix.

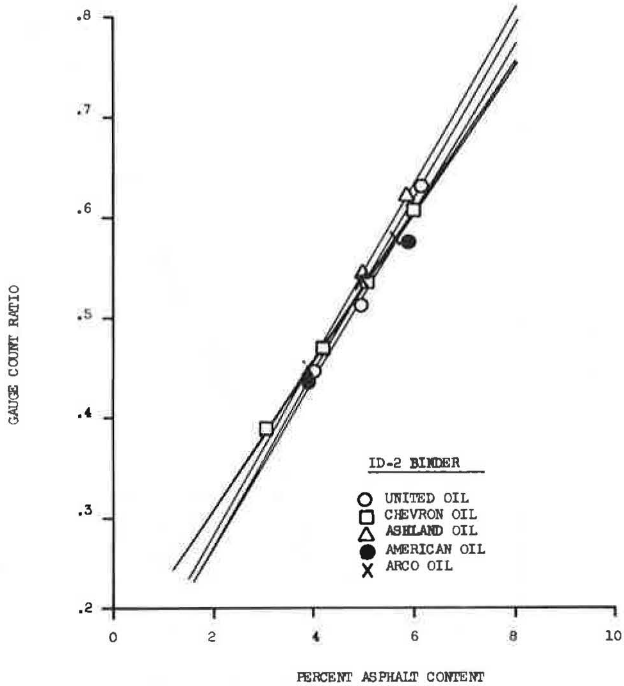


Figure 10. Asphalt-effect calibration curves for Nuclear-Chicago gauge (limestone aggregate), ID-2 wearing mix.

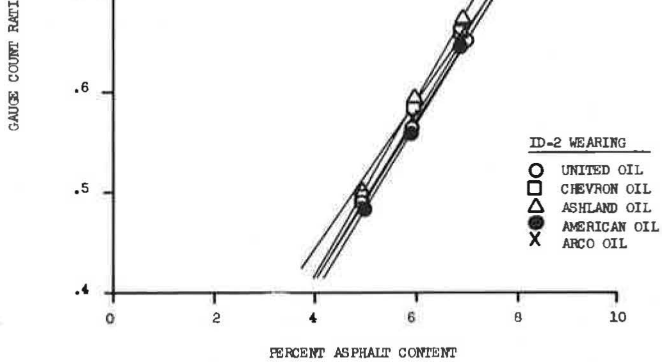


Figure 11. Asphalt-effect calibration curves for Nuclear-Chicago gauge (limestone aggregate), FJ wearing mix.

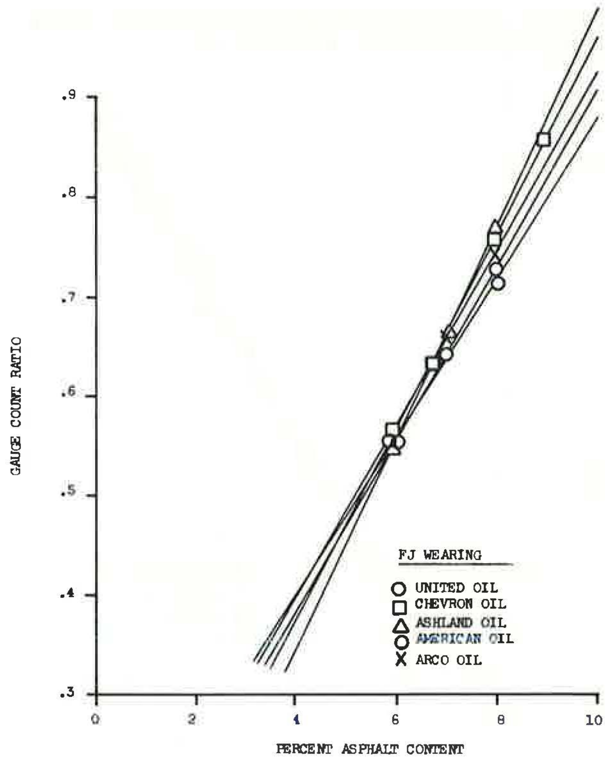


Table 4. One standard root mean square deviation (±) for design versus gauge-predicted asphalt contents by percent (various asphalts).

Asphalt	Mix Design FJ Wearing	ID-2 Wearing	ID-2 Binder	Pooled
Chevron				
Troxler	0.39	0.18	0.62	0.43
Nuclear-Chicago	0.09	0.35	0.10	0.21
Ashland				
Troxler	0.25	0.48	0.17	0.33
Nuclear-Chicago	0.11	0.31	0.15	0.21
United				
Troxler	0.14	0.43	0.24	0.30
Nuclear-Chicago	0.10	0.27	0.14	0.18
American				
Troxler	0.40	0.32	0.34	0.35
Nuclear-Chicago	0.21	0.15	0.19	0.18
ARCO				
Troxler	0.32	0.37	0.52	0.41
Nuclear-Chicago	0.16	0.12	0.17	0.15
Pooled				
Troxler	0.32	0.32	0.30	0.37
Nuclear-Chicago	0.14	0.26	0.15	0.19

Table 5. One standard root mean square deviation (±) for extracted versus gauge-predicted asphalt contents by percent (field testing).

Aggregate	Mix Design BCBC Binder	ID-2 Wearing	ID-2 Binder	Pooled
Limestone	0.63	0.78	0.79	0.74
Sandstone	—	0.47	—	0.47
Pooled	0.63	0.73	0.79	0.72

2. Recalibration of the gauge for each type of aggregate and mix design to be tested is recommended. A study of calibration procedures was made where a zero asphalt content pan and a pan containing asphalt by weight in the design percentage range were used to obtain the regression calibration curve. A similar regression curve was made using only three pans of various asphalt contents about the design percentage range. Better correlation with the sample test values was obtained when the two-point, 0 percent design calibration curve was applied.

3. This study included the application of slag aggregates to nuclear evaluation of asphalt content. These aggregates appeared to produce less reliable determinations of asphalt content. Studies with the Troxler gauge have shown that trace quantities of elements such as iron, boron, manganese, and cadmium in variable amounts between slag samples can vary the absorption microscopic cross section enough to affect the gauge calibration significantly. An increase of 0.05 to 0.60 percent in manganese content of two slag samples caused a decrease in count rate of as much as 5.3 percent. With even smaller content variations of cadmium (where the microscopic cross section is 185 times greater than manganese), serious count rate variations between slag samples could occur.

4. In general, there is only a slight variation in gauge readings between similar test specimens mixed with various brands of asphalt. All brands used in this test were of the viscosity known as AC-2000. For greatest accuracy, however, it is recommended that recalibration be performed for each change in asphalt brand and, if convenient, for each different truck load of similar asphalt brand.

5. Applications of this nuclear asphalt content gauge to field testing would appear to be more successful if the moisture content of the dry aggregate used in the batch mix is as small as possible. Any moisture left in the aggregate appears as added asphalt to the gauge and could account for the usually higher asphalt content than extraction for field samples. The requirements that recalibration be made with each mix parameter change should not be a problem with normal plant use, but the services of a skilled technician are an absolute necessity in calibration pan preparation.

6. In a final statistical analysis of the overall value of the Troxler gauge in providing a quicker determination of asphalt content, the following relation is applied to determine the number of tests required by the gauge to yield the actual asphalt content (plus or minus a desired standard deviation) with 95 percent confidence:

$$\pm t = 1.96\,\sigma/n^{1/2} \text{ or } n = (1.96\,\sigma/\pm t)^2$$

where

$\pm t$ = desired accuracy for overall content determinations,
σ = mean test method standard deviation, and
n = number of tests (where one test consists of an 11.5-min counting period).

For the date gathered in this study

$$\pm t = \pm 0.40$$

that is, 0.4 percent is the accepted accuracy required for 95 percent confidence of an extraction test of an asphalt sample;

$$\pm t = \pm 0.41$$

is the overall standard deviation for all pooled tests performed with the gauge; and

$$n = \left(\frac{1.96 \times 0.41}{0.40}\right)^2 = 4.0$$

Thus, a minimum of 4 tests must be performed with the Troxler gauge to obtain the required degree of accuracy.

Similar analysis of data for the Nuclear-Chicago gauge yielded a requirement of only one test for similar degrees of accuracy.

Thus, it would require a total of about 46 min to test a sample with the Troxler gauge operating in the calibrate test-mode position to obtain the required degree of accuracy. This is still only about one-half the time required to perform an extraction of a similar sample. Although not yielding the degree of accuracy specified by the manufacturer, use of the Troxler gauge can still provide a quick, accurate means of determining asphalt content in either field or laboratory locations.

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The opinions, findings, and conclusions expressed in this paper are those of the author and not necessarily those of the Pennsylvania Department of Transportation or the Federal Highway Administration.

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APPENDIX A

MIX GRADATION

PERCENT PASSING			
SIEVE SIZE	ID-2 BINDER	ID-2 WEARING	FJ WEARING
2-1/2			
2			
1-1/2	100.0		
1	99.1		
3/4			
1/2	63.4	100.0	
3/8		99.3	100.0
4	36.2	67.9	99.0
8	28.5	45.0	79.6
16	20.2	30.2	54.4
30	13.9	20.5	35.7
50	8.9	12.9	21.2
100	5.6	7.9	11.9
200	3.6	4.7	6.9

APPENDIX B

CALIBRATION CURVE SLOPE AND INTERCEPT VALUES

	(TROXLER GAUGE)			(NUCLEAR CHICAGO GAUGE)		
AGGREGATE	MIX DESIGN	SLOPE	INTERCEPT	MIX DESIGN	SLOPE	INTERCEPT
LIMESTONE	ID-2 BINDER ID-2 WEARING FJ WEARING POOLED	2.155 1.949 1.903 2.216	38,925 44,014 44,143 41,297	ID-2 BINDER ID-2 WEARING FJ WEARING POOLED	.0763 .0780 .0972 .0774	0.1482 0.1096 -0.0156 0.1287
SLAG	ID-2 BINDER ID-2 WEARING FJ WEARING POOLED	1.200 1.555 1.504 1.566	38,685 42,036 43,093 40,275	ID-2 BINDER ID-2 WEARING FJ WEARING POOLED	.0457 .0616 .0648 .0576	0.1334 0.0261 -0.0195 0.0545
SAND & GRAVEL	ID-2 BINDER ID-2 WEARING FJ WEARING POOLED	1.688 1.703 1.760 1.907	41,364 46,212 46,016 43,484	ID-2 BINDER ID-2 WEARING FJ WEARING POOLED	.0865 .0910 .0887 .0665	0.1055 0.0074 -0.0264 0.1893