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**State-of-the-Art Guideline Manual
for
Design, Quality Control, and Construction
of
Sulfur-Extended-Asphalt (SEA) Pavements**

by

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TABLE OF CONTENTS

	Page
I. INTRODUCTION	1
II. DESIGN GUIDELINES	2
Structural Design	2
Mixture Design	2
SEA Material Characteristics	2
Mix Design Procedure	7
Standard Marshall or Hveem Procedure Modifications	13
Test Requirements for Sulfur-Extended-Asphalt Mixtures	14
III. QUALITY CONTROL	15
Materials	15
Sulfur	15
Asphalt	15
Aggregates	15
Mix Plant	15
Sampling, Measurements, and Testing	15
Paving Site	16
Sampling, Measurements, and Testing	16
IV. CONSTRUCTION GUIDELINES	16
Recommended Practices	16
Handling Molten Sulfur	16
Storage	16
Cleaning Asphalt Tanks for Sulfur Storage	18
Pumps	18
Piping	25
Valves	25
Preparation of Sulfur-Extended-Asphalt Binder	25
Direct Mixing of Binder Components	25
Preblending of Binder Components	25
Summary	26
Proprietary Considerations	26

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TABLE OF CONTENTS (continued)

	Page
Specifications - Materials and Construction	26
The Sulfur System	26
Storage	26
Pumps	27
Valves	27
Piping	27
Mixing of Binder Components	27
Direct Mixing of the Binder	27
Preblending of the Binder	28
Schematic	28
Test Pavement Section	28
V. SAFETY	28
General	28
Molten Sulfur	29
Sulfur Emissions	29
Temperature Control	29
Regulations Pertaining to Sulfur Emissions	29
OSHA	30
EPA	31
Instruments for Measuring Sulfur Emissions	31
Field Measurements of Emissions	32
Known Hazards	32
VI. REFERENCES	33
VII. APPENDIX A. - Plants for Preparation of Premixed SEA binders	A1
VIII. APPENDIX B. - Tentative Methods for Extraction of Sulfur Asphalt Binder and Determining Sulfur- Asphalt Ratio	B1

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LIST OF FIGURES

Figure	Page
1. Temperature-viscosity chart (mixing-temperature range)	5
2. Influence of compaction temperature on stability level	6
3. Influence of compaction temperature on void levels	8
4. Temperature-viscosity chart (compaction-temperature range)	9
5. SEA justification test data	12
6. Composition of SEA binders as a function of their specific gravity	17
7. Direct-mixing method for production of SEA	19
8. Preblending method for production of SEA	20
9. Sulfur supply system, Henderson, Nev.	21
10. Sulfur supply system, Bryan, Tex.	22
11. Sulfur supply system, Kenedy County, Tex.	23
12. Sulfur system for either method of mixing	24
A-1. SNEA sulfur-asphalt mobile unit	A2
A-2. Gulf Canada Limited sulfur-asphalt module	A4
A-3. Pronk sulfur asphalt binder system	A5
A-4. Texasgulf Inc. portable sulfur-extended-asphalt binder unit	A6

LIST OF FIGURES (continued)

Figure	Page
B-1. Extraction apparatus	B4
B-2. Extractor unit	B9
B-3. Stand for extractor unit	B10
B-4. Extractor unit	B11

LIST OF TABLES

Table	Page
1. Sulfur-extended-asphalt paving trials	2
2. Specific gravity data	3
3. Influence of sulfur substitution on material properties	4
4. Comparison of SEA and A/C paving material costs	11
5. Toxicity levels for sulfur emissions	30
B-1. Size of sample	B2

1. The first part of the document discusses the importance of maintaining accurate records of all transactions and activities. It emphasizes that this is crucial for ensuring transparency and accountability in the organization's operations.

2. The second part of the document outlines the various methods and tools used to collect and analyze data. It highlights the need for consistent and reliable data collection processes to support effective decision-making.

3. The third part of the document focuses on the role of technology in data management and analysis. It discusses how modern software solutions can streamline data collection, storage, and reporting, thereby improving efficiency and accuracy.

4. The fourth part of the document addresses the challenges associated with data management, such as data quality, security, and privacy. It provides strategies to mitigate these risks and ensure that data is used responsibly and ethically.

5. The fifth part of the document discusses the importance of data governance and the role of leadership in establishing a strong data culture. It emphasizes that data should be used to drive innovation and improve organizational performance.

6. The sixth part of the document provides a summary of the key findings and recommendations. It reiterates the importance of data in driving organizational success and provides actionable steps for implementation.

7. The seventh part of the document includes a list of references and sources used in the research. It provides a comprehensive overview of the current state of data management and analysis in the industry.

8. The eighth part of the document contains a list of appendices, including detailed data tables, charts, and additional information that supports the main text. These appendices provide a more in-depth look at the data and analysis presented.

9. The ninth part of the document includes a list of figures and tables, providing a visual representation of the data and analysis. These figures and tables are essential for understanding the results and trends discussed in the document.

10. The tenth part of the document contains a list of footnotes and additional information. It provides further details and context for the data and analysis presented, as well as information about the author and the organization.

STATE-OF-THE-ART GUIDELINE MANUAL
FOR
DESIGN, QUALITY CONTROL, AND CONSTRUCTION
OF
SULFUR-EXTENDED-ASPHALT (SEA) PAVEMENTS

I. INTRODUCTION

Interest in the use of sulfur in highway pavement construction has been stimulated by unpredictable increases in cost and the relative uncertainty as to the future availability of asphalt cement (A/C) along with the potential surplus of sulfur in the near future. These events have led to the development of a new binder: a sulfur-extended-asphalt (SEA) binder. This new binder replaces some of the asphalt with sulfur in conventional asphalt paving mixtures. The binder is easily prepared and can be mixed with aggregate in conventional asphalt paving plants. The mix material can be transported, laid, and compacted with standard paving equipment. Studies of SEA pavements indicate that their properties are comparable and in some cases may prove to be superior to those of conventional asphalt pavements.

Substitution of sulfur for part of the asphalt binder in asphaltic concrete pavements was described by Bencowitz and Boe 1/ in 1938. They reported that stable mixtures of 25 wt-pct sulfur in asphalt could be prepared by mixing the two at 300°F (149°C) for two hours with a stirrer (325 rpm). With some asphalts they achieved stable mixtures containing up to 40 wt-pct sulfur. Their report also indicated that the sulfur in SEA binders lowered the viscosity at the mixing temperature and improved the performance of the paving. Increasing the sulfur content of the binder resulted in increased paving stability of the compacted paving when the sulfur content exceeded 25 wt-pct. Although Bencowitz' work laid the groundwork for SEA pavements, additional development of the process did not take place until the early 1970's. Then, concern over the increasing cost and decreasing availability of asphalt coupled with a forecast of ever-increasing supplies of sulfur revived interest in SEA pavements. Garrigues 2/ in France, and Kennepohl 3/ and Pronk 4/ in Canada, developed methods for preparing premixed SEA binders for mixing with aggregates. McBee 5/, U.S. Department of the Interior, Bureau of Mines, developed a simple, direct-mixing method for preparing uniform SEA paving materials that utilized the high shear mixing action of the pugmill to blend the hot sulfur, asphalt, and aggregate in asphalt paving plants.

The first SEA test pavement on U.S. public roads was placed in Texas 6,7/ in 1975 using a preblended SEA binder. A second test section using the direct-mixing procedure was laid in Nevada 8/ in 1977. Since that time, other test sections of SEA paving have been laid in Arizona, Delaware, Florida, Illinois, Louisiana, Maine, Michigan, Minnesota, Mississippi, New York, Ohio, North Carolina, Washington, and Texas. Additional test sections of SEA paving are scheduled for construction this year by other States. A combined total of 57 SEA test pavements that have been made in the United States, Canada, Europe, and the Middle East through 1979

is shown in table 1.

Table 1. - Sulfur-extended-asphalt paving trials

	<u>Europe</u>	<u>Canada</u>	<u>United States</u>	<u>Others</u>	<u>Total</u>
Before 1977	7	4	1	0	12
1977	4	3	2	2	11
1978	8	2	5	1	16
1979	2	3	11	2	18

The Federal Highway Administration (FHWA) is encouraging highway agencies to construct experimental pavements with SEA binder, so that they may be evaluated in the field, under typical operating conditions. The Bureau of Mines and The Sulphur Institute are cooperating with FHWA in this endeavor. This manual has been prepared to make available to potential users of SEA paving materials, guidelines for the design, quality control, and construction of SEA pavements. These guidelines are based on knowledge and experience gained to date in the United States and Canada.

II. DESIGN GUIDELINES

Structural Design

At present, sufficient inservice performance data for sulfur-extended-asphalt materials containing 20 to 50 wt-pct sulfur in the binder are unavailable for establishing structural design criteria. Therefore, until the criteria are developed, the use of thicknesses of sulfur-extended-asphalt material equivalent to those of conventional hot-mix asphalt concrete is recommended.

Mixture Design

SEA Material Characteristics

Before designing a mixture, the general characteristics of sulfur, asphalt, and SEA binders should be understood by the practitioner. The following terms will be defined and used throughout this manual:

1. Sulfur-Extended-Asphalt Pavement. Pavements composed of mineral aggregates and an SEA binder consisting of a mixture of sulfur and asphalt.
2. SEA Binder Percentage. The wt-pct of sulfur and A/C in the SEA binder. Thus, 30-70 SEA, 40-60 SEA, and 50-50 SEA indicate 30, 40, and 50 wt-pct sulfur in the binder with the remainder A/C.
3. Sulfur Substitution Ratio (R). The weight ratio of sulfur used to replace asphalt in the binder. For example, a conventional mix design required 6.00 wt-pct asphalt binder, and an equivalent SEA pavement used a 6.79 wt-pct 30-70 SEA binder. In this case, 2.05 lbs of sulfur

would be substituted for 1.21 lbs of asphalt. Dividing the sulfur by the asphalt (2.05/1.21) gives a 1.69 to 1 sulfur substitution ratio.

4. Mixing-Temperature Range. 250° to 300° F (121° to 149° C)
5. Compaction-Temperature Range. 185° to 250° F (85° to 121° C)
6. Working-Temperature Range. The temperature span between the mixing temperature and final compaction temperature.
7. Vol-pct. Volume-percent expressed as percentage of total mixture.
8. Wt-pct. Weight-percent expressed as percentage of total mixture.

Sulfur, at standard conditions of temperature and pressure, exists as a friable yellow solid, in contrast to asphaltic cement which exists as a viscoelastic solid. Because of its unique properties, sulfur can significantly alter the basic physical properties of the binder. A thorough knowledge of these effects is essential to provide a cost-effective mix design with good structural integrity. Table 2 contains specific gravity data for sulfur, AR 2000 asphalt, and SEA blends. Sulfur is about twice as dense as asphalt, and therefore a given weight of sulfur occupies one-half the volume of the same weight of asphalt. When combined with asphalt to form SEA binder, the sulfur increases the specific gravity of the binder in proportion to the volume of sulfur added.

Table 2. - Specific gravity data

	Temperature, ° F (° C)		
	60 (16)	250 (121)	300 (149)
Sulfur	2.00	1.80	1.78
AR 2000 asphalt	1.01	.94	.93
15 vol-pct (26 wt-pct) ²	1.16	1.07	1.06
25 vol-pct (40 wt-pct) ²	1.26	1.16	1.14
35 vol-pct (52 wt-pct) ²	1.36	1.24	1.23

¹Average specific gravity of solid sulfur.

²Percentages - based on sulfur in the SEA binder at a sulfur-to-asphalt specific gravity ratio of 2 to 1.

In SEA pavements, sulfur serves a dual purpose, that of a binder and that of a structuring material. In the mixing temperature range, the solubility of sulfur in the asphalt is generally 20 wt-pct or greater, depending on the asphalt used. The solubility of sulfur in the laid pavement at ambient temperature is lower, and some of the originally dissolved sulfur precipitates as sulfur crystals. These crystals can impart a structuring role to the pavement depending on the size of crystals

formed. Minute crystals will act similar to mineral filler (minus 200 mesh) while larger crystals serve as aggregate materials. Experience to the present time indicates there are not essential differences in the performance of pavements made with SEA binders up to the 30-70 level and A/C binders. Above the 30-70 SEA binder level, it may be necessary to adjust the mineral filler content of the aggregate downward to compensate for the additional structuring caused by the sulfur recrystallizing in the laid pavement.

Figure 1 illustrates the temperature-viscosity relationship for the materials over the mixing temperature range. As indicated, between 240° and 310° F (115° - 154° C) sulfur exists as a very low viscosity liquid compared to asphalt. The material solidifies at 240° F (115° C) and above 310° F (154° C) becomes extremely viscous. Blends of sulfur and asphalt exhibit lower viscosities than asphalt with the lowest viscosity of these tested occurring for the 15 vol-pct (26 wt-pct) substitution.

Table 3 illustrates the influence of equal volume substitutions of sulfur for asphalt in a control mix with a volcanic aggregate having a maximum top size of 3/4 inches and 7.0 wt-pct grade AR 2000 asphalt as the optimum design concentration. Equal volume substitutions of sulfur for asphalt were used to maintain a constant volume binder content. At the 15 vol-pct (26 wt-pct) substitution level, Marshall properties are essentially unchanged and the two materials are virtually indistinguishable. Above 15 vol-pct (26 wt-pct) substitution, uniform increases in stability, density, and stiffness (up to 35 vol-pct) are obtained with minor change in flow and void levels through 50 vol-pct substitutions. These data illustrate the potential latitude in stability tailoring which can be obtained through variations of the sulfur replacement percentage, and also the dual role of sulfur as an extender and a structuring agent.

Table 3. - Influence of sulfur substitution on material properties

Composition ¹				Specific gravity	Voids, pct	Marshall		Dynamic stiffness ² psi × 10 ⁶
Sulfur, vol-pct	Sulfur, wt-pct	Asphalt, vol-pct	Asphalt, wt-pct			Stability, lb	Flow, 0.01 in	
0	0	100	7.0	2.288	2.4	2,580	12	.653
15	2.0	85	5.9	2.300	2.8	2,230	10	.980
25	3.4	75	5.2	2.307	3.2	3,080	11	1.542
35	4.7	65	4.4	2.321	3.2	5,520	10	2.040
50	6.7	50	3.4	2.320	4.4	9,600	12	--
75	9.8	25	1.7	2.343	4.9	9,910	6	--

¹Vol-pct refers to the volume-percent in the binder; wt-pct refers to the weight-percent of the total mix.

²Determined using the Schmidt 9/ method at ambient temperature.

Figure 2 illustrates typical stability variations of SEA materials given in table 3 over the entire working range of 185° to 300° F (85° to 149° C). As indicated, the control material is identical to the 15 vol-pct (26 wt-pct) substitution. These materials were mixed at 300° F (149° C) and compacted at successively lower temperatures down to 185° F (85° C). Sulfur replace-

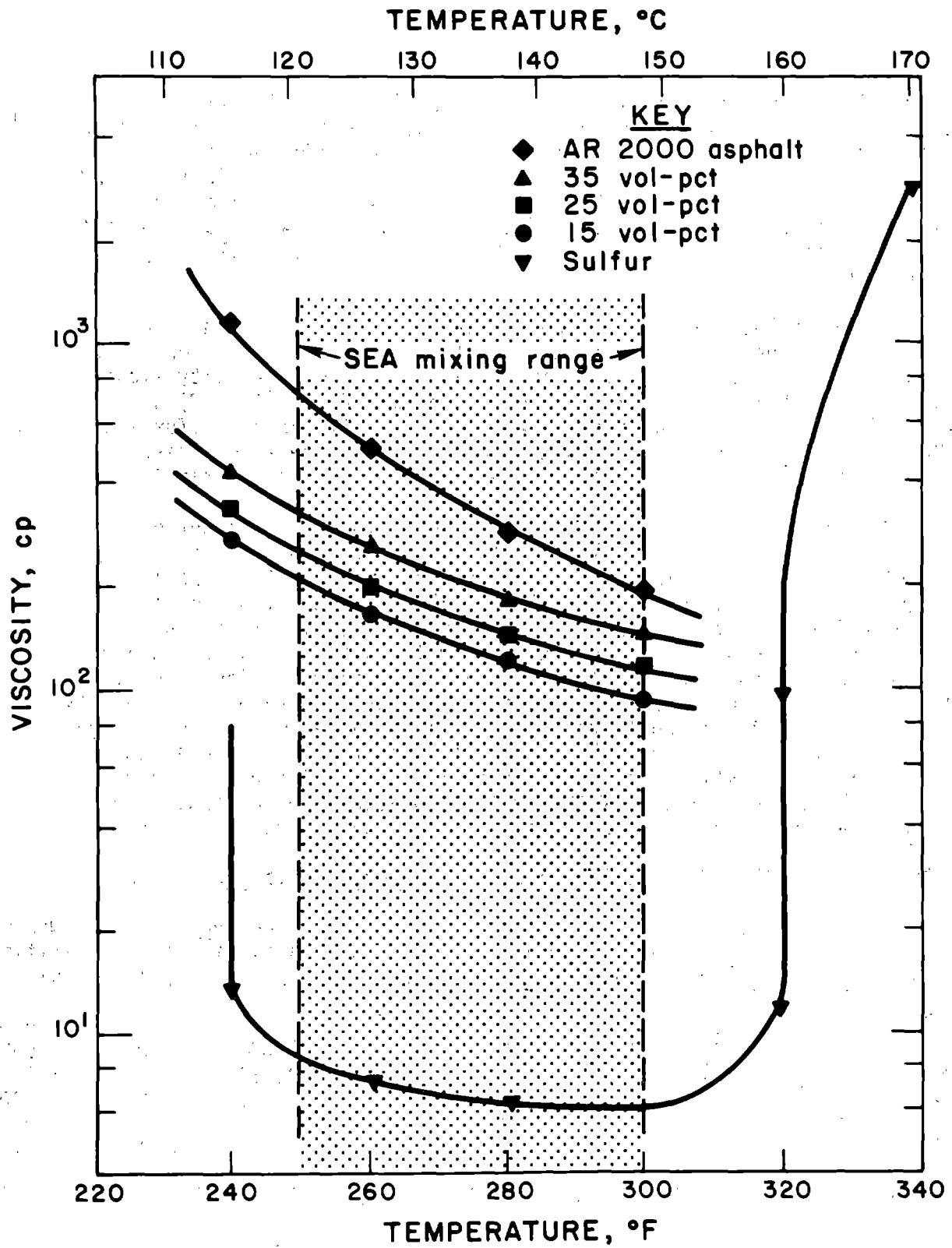


FIGURE 1. - Temperature-viscosity chart (mixing temperature range).

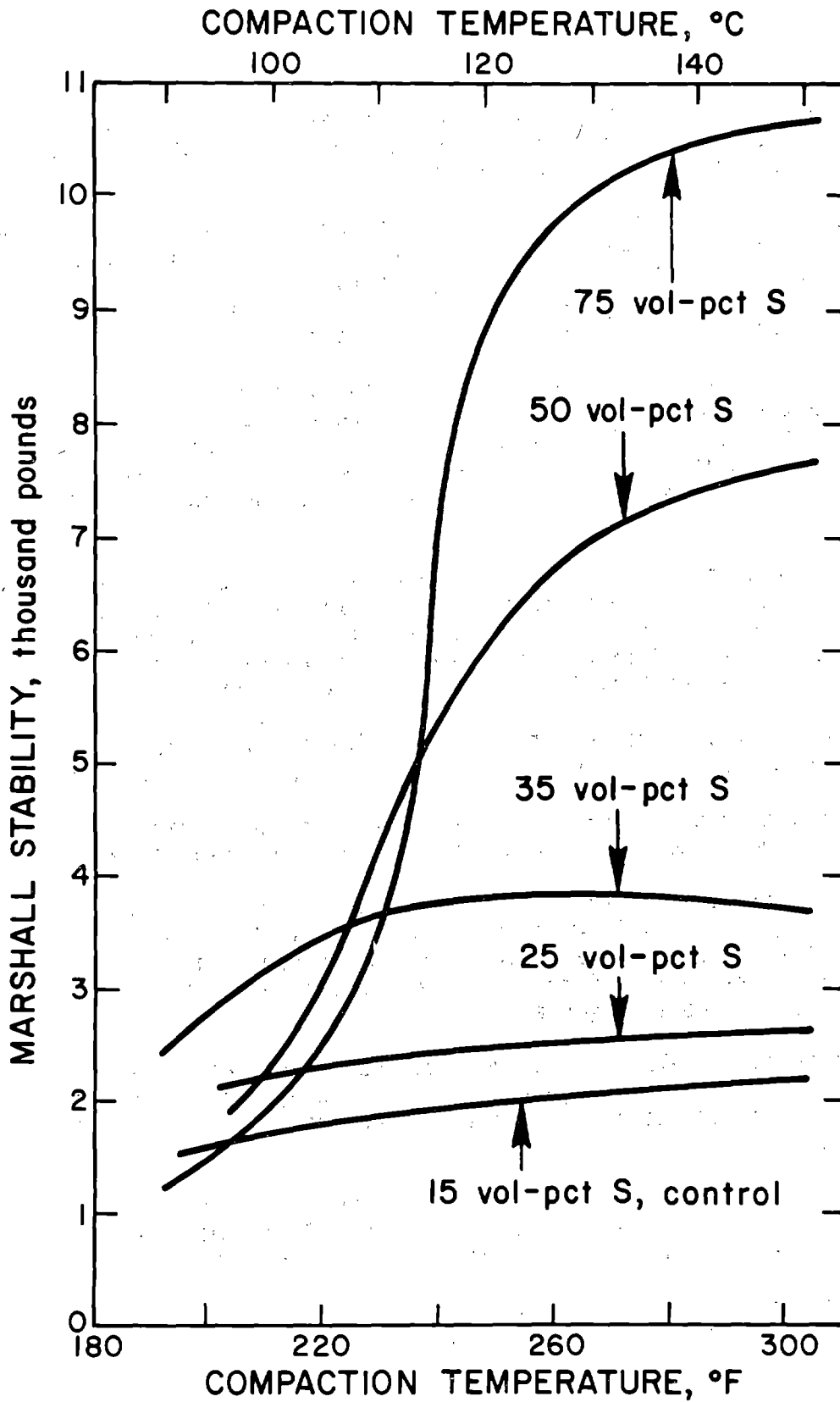


FIGURE 2. - Influence of compaction temperature on stability levels.

ment up to 25 vol-pct (40 wt-pct) produces higher stabilities. Above 25 vol-pct (40 wt-pct) to 35 vol-pct (52 wt-pct) a slight sensitivity to compaction temperature is observed; however, the materials exhibit higher stabilities than the control materials when compacted as low as 185° F (85° C). Above 35 vol-pct (52 wt-pct) substitution the materials are quite sensitive to compaction temperatures below 240° F (115° C), the solidification temperature of sulfur, and sustain tremendous reduction in stability when compacted at the lower temperatures. Figure 3 illustrates the influence of compaction temperature on void levels for the same materials.

These data parallel the stability relationships shown in figure 2 and indicate that the highest potential asphalt replacement using SEA materials is in the range of 25 vol-pct (40 wt-pct) to 35 vol-pct (52 wt-pct). Also, substitution in the range of 25 vol-pct (40 wt-pct) and lower results in materials with essentially the same void levels as the conventional binder.

Figure 4 illustrates the viscosity temperature relationship for typical SEA blends for comparison with asphalt over the compaction temperature range. A similar relationship to figure 1 is apparent, again indicating lower viscosity for the SEA binders over the entire range. These properties allow for enhanced workability for SEA materials in the field.

From these general characteristics, the following conclusions can be made about SEA materials versus conventional asphalt paving materials:

1. Binder viscosities are lower over the mixing and working temperature range, which should allow enhanced workability.
2. Marshall stabilities are a function of sulfur replacement percentage. Materials with around 15 vol-pct (26 wt-pct) substitution are comparable in stability to conventional asphalt mixes, while higher levels of sulfur result in significant stability increases.
3. Substitution levels above 25 vol-pct (40 wt-pct) result in materials sensitive to compaction temperature, with 35 vol-pct (52 wt-pct) indicated as the maximum recommended substitution level.
4. Binder requirements, in weight-percent, for SEA paving are greater than those for A/C paving because of the approximate 2 to 1 specific gravity ratio between sulfur and asphalt.
5. Slightly more SEA material than A/C material by weight will be required to pave a given depth because of the higher specific gravity of the SEA paving materials (table 3).

Mix Design Procedure

The current state-of-the-art for SEA mixture designs utilizes conventional Marshall or Hveem design methods with well-graded aggregates conforming to each particular State's specifications. Marshall and Hveem

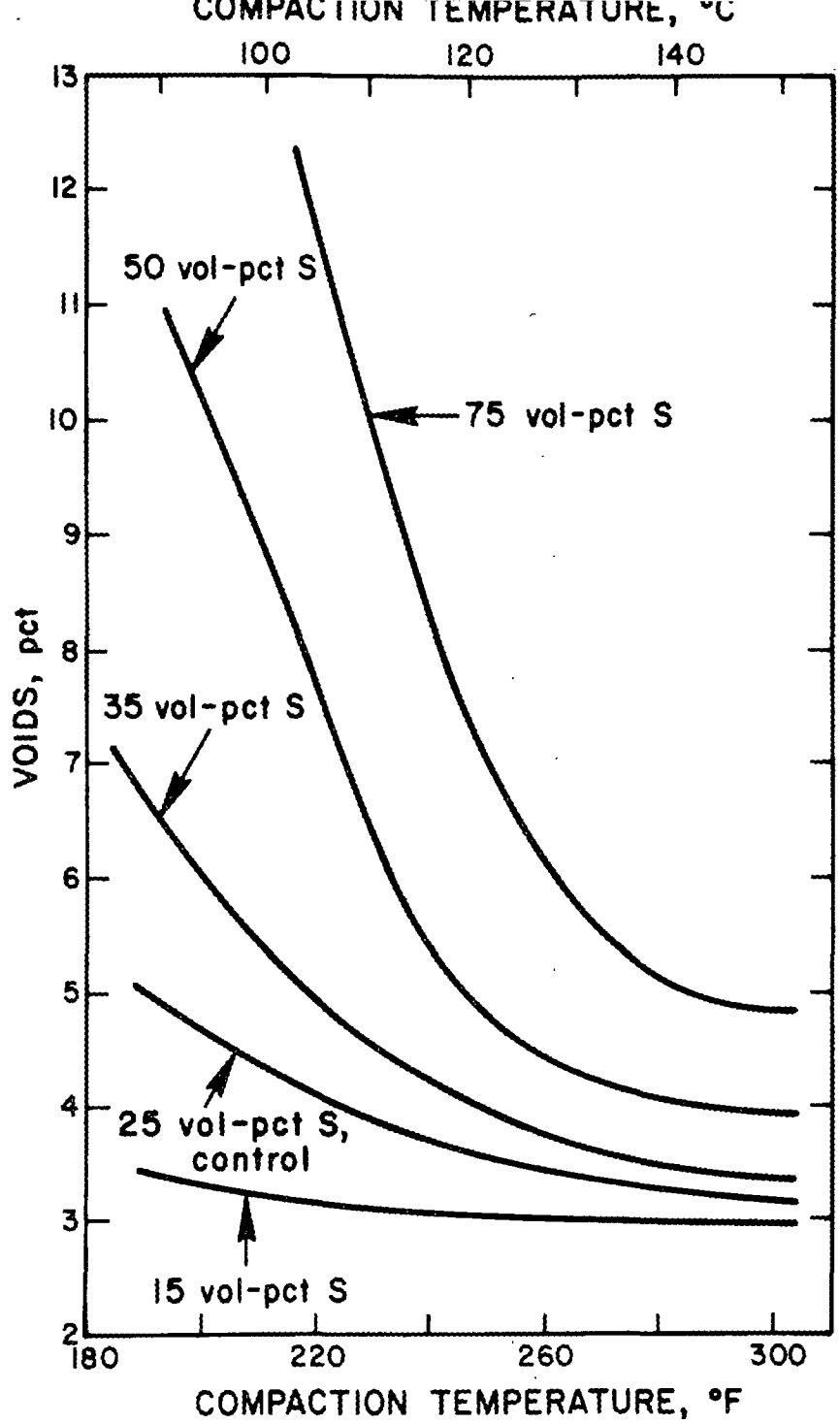


FIGURE 3. - Influence of compaction temperature on void levels.

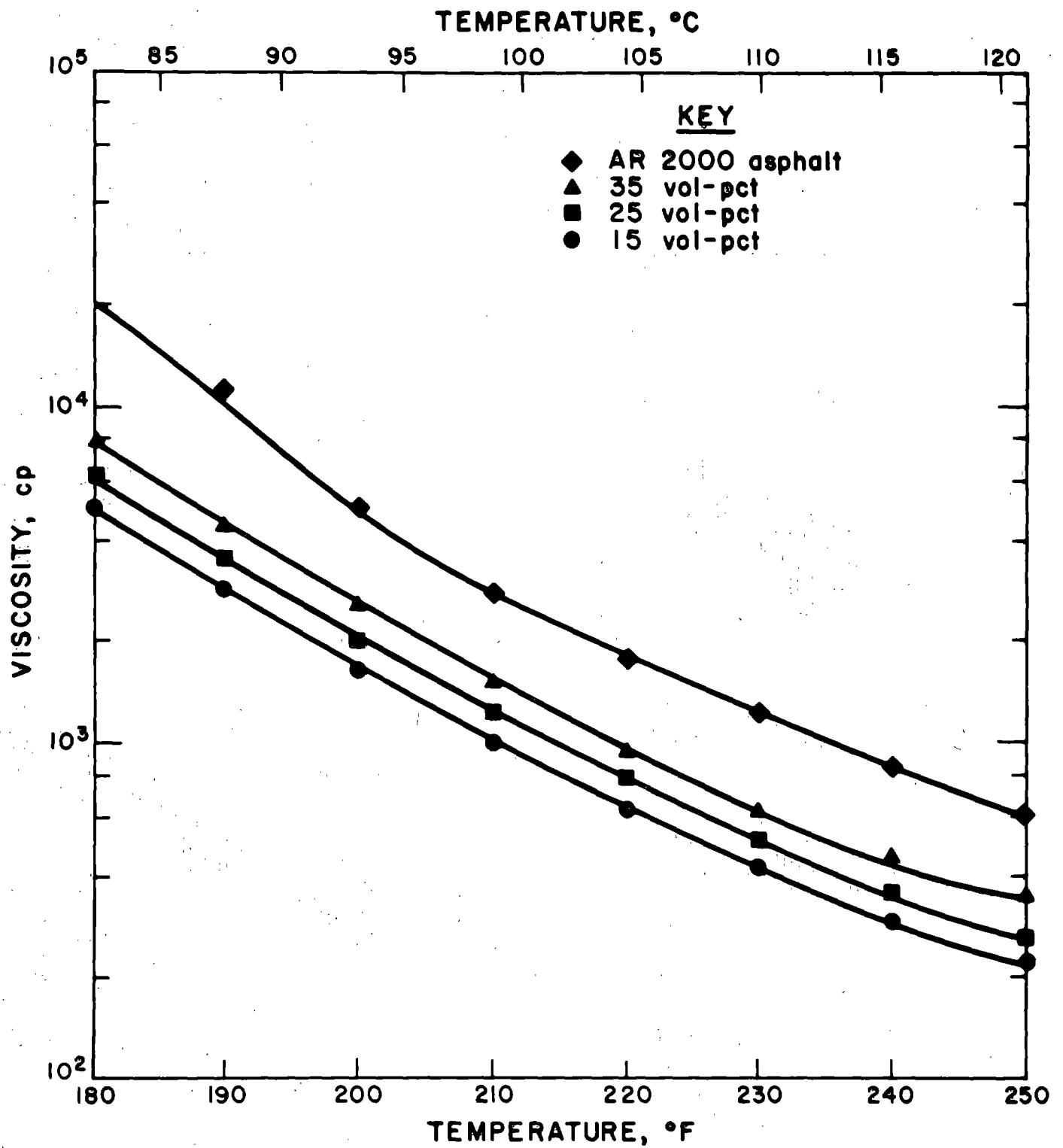


FIGURE 4. - Temperature-viscosity chart (compaction temperature range).

design procedures are fully described in the Asphalt Institute Manual series No. 2 (MS2) 10/ and in the ASTM standards part 15 11/. Optimum SEA binder levels may readily be determined as follows:

1. Determine the optimum asphalt content of a mix with an asphalt binder. Note that this value will represent the lower binder concentration feasible for SEA.
2. Select a sulfur substitution level (i.e. 20-, 30-pct, etc.) and calculate the SEA binder content in a mix in which an equal volume of SEA binder replaces the asphalt in the optimum asphalt mix of step 1 above using equations 1 or 2 below. Note that this is the upper SEA binder concentration feasible and represents a 2 for 1 weight substitution of sulfur for asphalt.
3. Using the values obtained in steps 1 and 2 above as maximum and minimum parameters, establish intermediate points at uniform increments for use in laboratory justification tests.
4. Perform Marshall or Hveem justification tests and determine the optimum SEA binder concentration.

The SEA binder content in step 2 may be calculated using either of the following formulas:

$$(1) \text{ SEA (Equal volume replacement) wt-pct} = \frac{10000 \cdot AR}{10000R - 100P_s(R-1) + AP_s(R-1)}$$

$$(2) \text{ SEA (Approximate equal volume replacement) wt-pct} = \frac{200A}{200 - P_s}$$

Where: A = Weight percent A/C in conventional design,
 R = Sulfur substitution ratio,
 and P_s = Weight percent sulfur in the SEA binder.

Equation (1) will produce the mathematical equivalent volume replacement of asphalt with sulfur when $R = \frac{G_s}{G_a}$.

Where: G_a = Specific gravity of asphalt at ambient temperature,
 and G_s = Specific gravity of sulfur at ambient temperature.

It should be noted here that construction experience in the U.S. and Canada indicate R values as low as 1.4 are feasible. As a general rule, the R values may run from approximately 1.4 with 20-80 or 30-70 SEA binders and increase to approximately 2.0 with 50-50 SEA binders. These binders have a considerable impact on economics for the SEA materials.

Equation (2) is the simplest formula, which may be used to obtain an "approximate" SEA binder content for step 2. Laboratory personnel may prefer to use this formula.

The following example will illustrate how the formulas are used to obtain the SEA binder in step 2 equal volume replacement. Consider a conventional asphalt mix with pure asphalt in which the mix design asphalt content is 6.0% (A=6.0); the specific gravity of the asphalt is 1.03 ($G_a=1.03$) and the specific gravity of sulfur is 2.00 ($G_s=2.00$). The SEA design is for a 30-70 sulfur asphalt mixture ($P_s=30$, $P_a=70$), replacing an equal volume of conventional asphalt.

Using formula 1: $R = \frac{2.00}{1.03} = 1.94$

$$\text{SEA (wt-pct)} = \frac{10000(6.00)(1.94)}{10000(1.94) - (100)(30)(1.94-1) + 6.00(30)(1.94-1)}$$

$$= 6.95$$

Using formula 2:

$$\text{SEA (wt-pct)} = \frac{200(6.00)}{200-30} = 7.06$$

After obtaining the SEA binder content for step 2 equal volume replacement, establish intermediate points for the design as indicated in step 3 and implement step 4. Typical data for a 30-70 SEA binder are plotted in figure 5 along with control data for a 6.0 pct conventional design. As shown in figure 5, an optimum SEA binder content of 6.6 pct yields a material with properties such as voids, in the same range as the conventional asphalt mix and stabilities equivalent or greater than the control. This 6.6 pct binder content corresponds to a sulfur substitution ratio of about 1.5 to 1 (i.e., only 1.5 pounds of sulfur were needed for each pound of asphalt saved when substituting an SEA binder for asphalt. Almost 2 pounds sulfur per pound of asphalt would have been needed for an equal volume replacement). By minimizing the optimum SEA binder content -- and thus, the substitution ratio -- optimum economic benefits will be achieved as shown in table 4. These values are based on a conventional 6.0 wt-pct A/C mix using 1979 costs on the west coast of the United States.

Table 4. - Comparison of SEA and A/C paving material costs¹

<u>Binder</u>	<u>A/C</u>	<u>Sulfur substitution ratio (R)</u>		
		<u>2</u>	<u>1.7</u>	<u>1.4</u>
100 A/C	\$8.59	-	-	-
30-70 SEA	-	\$8.59	\$8.41	\$8.17
40-60 SEA	-	8.59	8.34	8.01
50-50 SEA	-	8.59	8.26	7.84

¹In dollars for pavement volumes equal to a ton of 6.0 wt-pct A/C conventional mix with material costs of \$100 per ton of asphalt, \$50 per ton of sulfur, and \$2.75 per ton of aggregate.

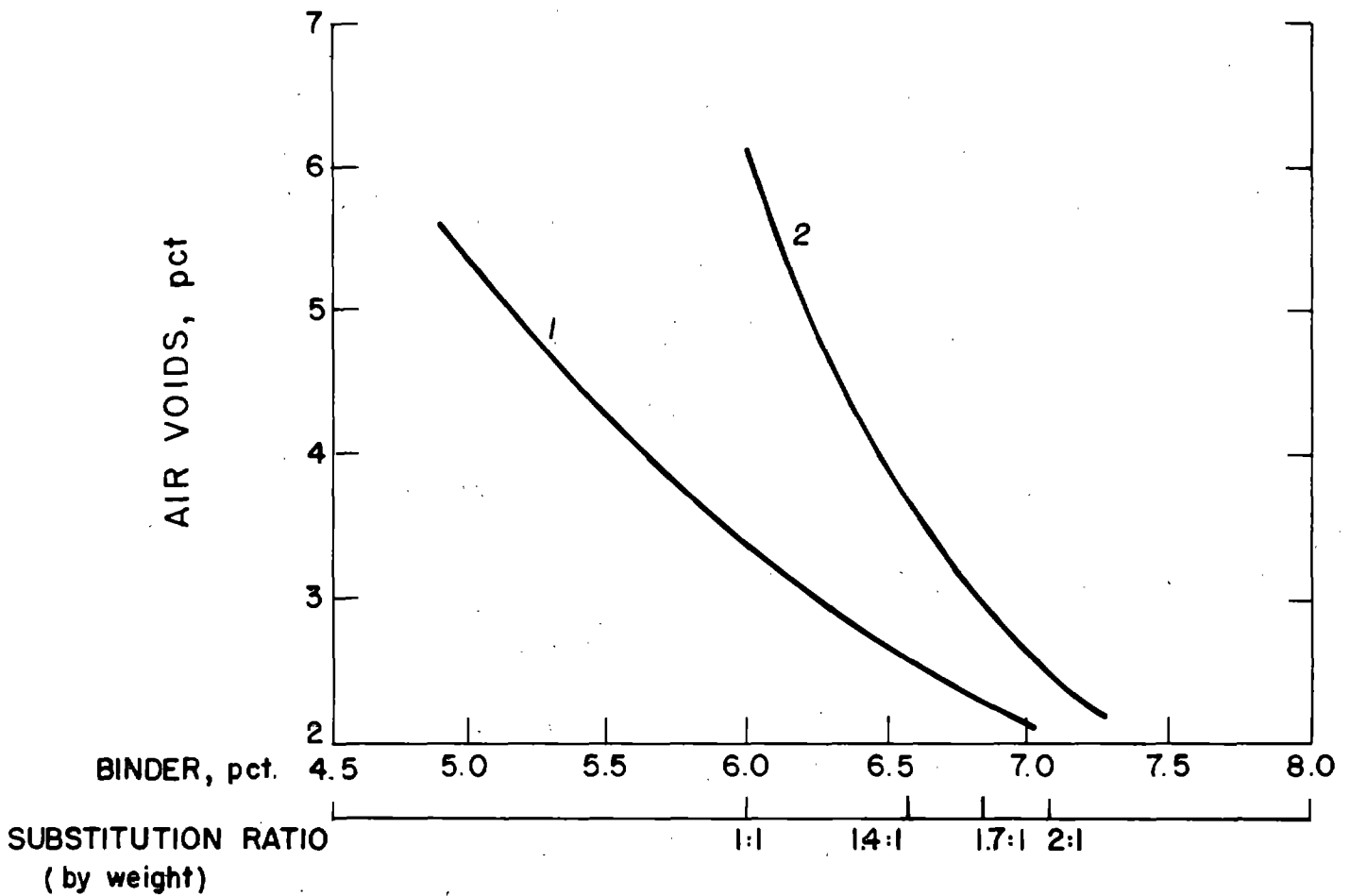
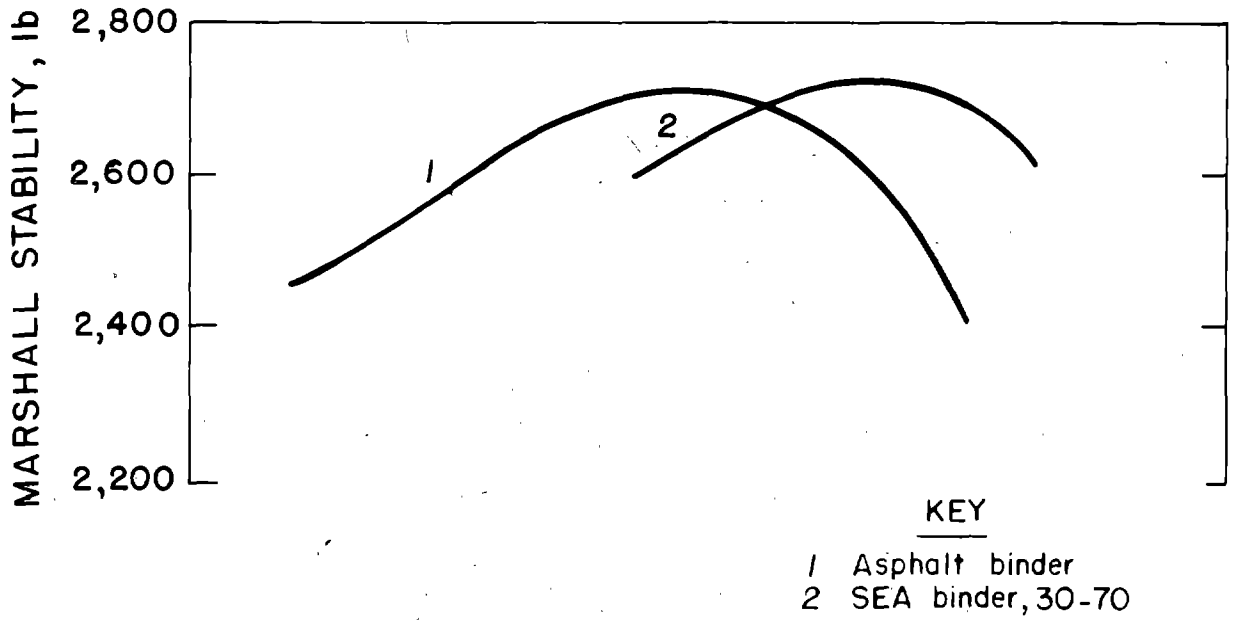


FIGURE 5.— SEA justification test data

FIGURE 5. - SEA justification test data.

Standard Marshall or Hveem Procedure Modifications

Most State and Federal highway agencies currently utilize Marshall or Hveem mixture design methods or variations of these methods. This section of the manual is designed to acquaint the practitioners with the unique characteristics of SEA materials to allow their successful design.

Mixture design of SEA paving materials can be accomplished using slightly modified Hveem or Marshall design procedures. Necessary modifications, which are minor in nature, are described below.

(1) Stability and Flow Using the Marshall Apparatus:

The methods of preparing testing specimens and determination of Stability and Flow shall conform to ASTM D 1559-76, "Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using the Marshall Apparatus," with the following modifications:

1. Scope

- 1.1 Delete the second sentence and add, "This method is for use with mixtures containing sulfur asphalt and aggregate up to 1-in (254-mm) maximum size." Note: Unless otherwise stated in these modifications, references to asphalt and to asphalt cement in the test method shall apply to sulfur-extended asphalt.

3. Test Specimens

3.3 Determination of Mixing and Compacting Temperatures:

- 3.3.1 Delete and insert, "The temperature at which the hot asphalt, molten sulfur, and hot aggregate are mixed shall be within a range of 270° to 300° F (132° to 149° C)."
- 3.3.2 Delete and insert, "The compacting temperature range shall be within a range of 250° to 280° F (121° to 138° C)."
- 3.3.3 Delete.
- 3.3.4 Delete.

3.4 Preparation of Mixtures:

- 3.4.1 Delete entire paragraph and insert, "Weigh into a pan the amount of each size fraction required to produce a batch that will result in triplicate compacted specimens 2.5 ± 0.05 in (63.5 ± 1.27 mm) in height (about 3600 g). Place the pan on the hotplate or in the oven and heat to a temperature not exceeding the mixing temperature established in 3.3 by more than approximately 20° F (7° C). Charge the mixing bowl, which also has been heated to the mixing temperature, with the heated aggregate and dry mix thoroughly. Weigh the required amount of preblended sulfur-extended asphalt or the individual amounts of sulfur and asphalt into a 250-ml stainless steel beaker and heat in the oven at 280° to 300° F (148° to 149° C) for five minutes. Add the sulfur-extended-asphalt mixture to the premixed hot aggregate in the mixing bowl, and mix for a period of 2.0 minutes."

(2) Specific Gravity:

Specific gravities of specimens shall be determined by ASTM Designation D 2726-73, "Standard Test Method for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface Dry Specimens." Test specimens shall be prepared using methods outlined in (1) Stability and Flow Using the Marshall Apparatus.

(3) Stabilometer Value Using Hveem Apparatus:

The method of preparing and testing specimens and determining the stabilometer value shall conform to ASTM Designation D 1560-76, "Standard Test Methods for Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus" with the following modifications:

2. Apparatus

2.9 Sample Mixing Apparatus:

Delete second sentence and insert, "Mechanical mixing of the aggregate and sulfur extended binder is required."

3. Test Specimens

3.3 Preparation of Mixtures:

Change first sentence to read "Combine the moisture-free aggregates into 3600-g batches." Change sentence 4 to read, "For mixtures employing sulfur-extended asphalt, the temperature of the aggregate and the sulfur-extended asphalt at the time of mixing shall be within a range of 270° to 300° F (132° to 149° C) regardless of grade of asphalt used. Mix for a period of 2.0 minutes with the mechanical mixer. Divide the mixed material into 3 equal portions for compaction." Delete last 3 sentences.

3.5 Compaction of Specimens:

Change first sentence to read, "Test specimens shall be formed and compacted in accordance with Method D 1561-76, 'Standard Test Method for Compaction of Bituminous Mixtures by Means of California Kneading Compactor,' except that the compacting temperature for the sulfur-extended-asphalt mixture shall be within a range of 250° to 280° F (121° to 138° C)."

(4) The Effects of Water on the Mixture:

The effects of water shall be determined by ASTM D 1075-76, "Standard Test Method for Effect of Water on Cohesion of Compacted Bituminous Mixtures," except that the test specimens shall be prepared and tested in accordance with ASTM D 1559-76 as modified herein.

Test Requirements for Sulfur-Extended-Asphalt Mixtures

Test samples prepared and tested in conformance with these methods shall conform to the agencies' criteria for light, medium, and heavy traffic for the following:

Marshall

- a. Stability at 140° F, 1b
- b. Flow value, 0.01 in
- c. Air voids, pct in mix
- d. Stability after immersion, 1b

Hveem

- e. Stabilometer value
- f. Swell
- g. Air voids

III. QUALITY CONTROL

Materials

Sulfur

Sulfur shall be elemental sulfur in the free state conforming with the following specification requirements in accordance with the Association of Pulp and Paper Industries (TAPPI), Tentative Standard T161 m-61, with revisions 12/.

<u>Characteristic</u>	<u>Value</u>
Purity, dry basis, pct ¹	97.5 Minimum
Moisture, solid sulfur, pct ²	1.00 Maximum
Ash, pct ¹	1.00 Maximum
Carbon content, pct ¹	1.00 Maximum
Acidity (as H ₂ SO ₄), pct ²	.05 Maximum

¹Primary tests.

²Supplementary tests as needed.

Samples representative of the source from which the sulfur is to be obtained shall be furnished at least 30 days prior to the time the materials will be needed. Samples of at least 1 lb of solid sulfur, crushed to pass a standard No. 10 sieve, shall be provided for determining specification requirements. Additional samples of not less than 50 lbs, broken up into lumps generally smaller than 2 in, shall be supplied for determining the job mix formula. All samples shall be packaged in clean containers in contact with plastics or glass.

Asphalt

Asphalt shall meet existing State criteria for acceptance.

Aggregates

Aggregates shall meet quality and gradation specifications for dense-graded materials.

Mix Plant

Sampling, Measurements, and Testing

In addition to normal quality control sampling and testing, the following procedures should be used:

1. A record should be maintained of the production temperature of the SEA materials exiting the mix plant. Mix temperatures should be between 250° and 300° F (121° and 149° C).
2. Binder composition may be determined by several methods. These include determining their density by hydrometer, pycnometer, or nuclear density methods. From the density, the composition of sulfur and asphalt in the binder may be calculated to read from a chart such as figure 6, which gives the percentage composition of SEA binders as a function of their density at given temperatures. The figure also shows the variation in binder content with specific gravity of the asphalt cement used.
3. Total binder content may be determined by hot, solvent extraction of the SEA material. Solvents reportedly used include benzene, trichloroethylene, and methylene chloride. A tentative method is given in appendix B. Total binder content may also be calculated when using mix plants equipped with automatic printouts.

Paving Site

Sampling, Measurements and Testing

Quality control at the paving site is similar to that at the mixing plant with the addition of the following:

- .1 A record of the compaction temperature of the SEA paving. Compaction should be accomplished by rolling at paving material temperatures exceeding 200° F (107° C).

IV. CONSTRUCTION GUIDELINES

Recommended Practices

Handling Molten Sulfur

Useful handbooks on handling molten sulfur are available from most major sulfur suppliers and safety concerns 13-15/.

Storage. The tank, or tanks, for sulfur storage may consist of a clean asphalt tank or similar vessel. The tank and the underpinning must be strong enough to contain the sulfur, which is about twice as heavy as asphalt for equal volumes. The tank must be fully insulated and equipped for heating the sulfur between 255° and 310° F (124° and 154° C).

The sulfur tank must be electrically grounded. It should be vented to prevent the concentration of gases in the air spaces from reaching hazardous limits. Temporary venting has been done by partially opening the manhole, taking care to prevent the entrance of moisture. Vent pipes rising above the tank, installed at each end of a horizontal tank and on opposite sides of a vertical tank, are recommended for air circulation. The filling line should discharge near the bottom of the tank to minimize

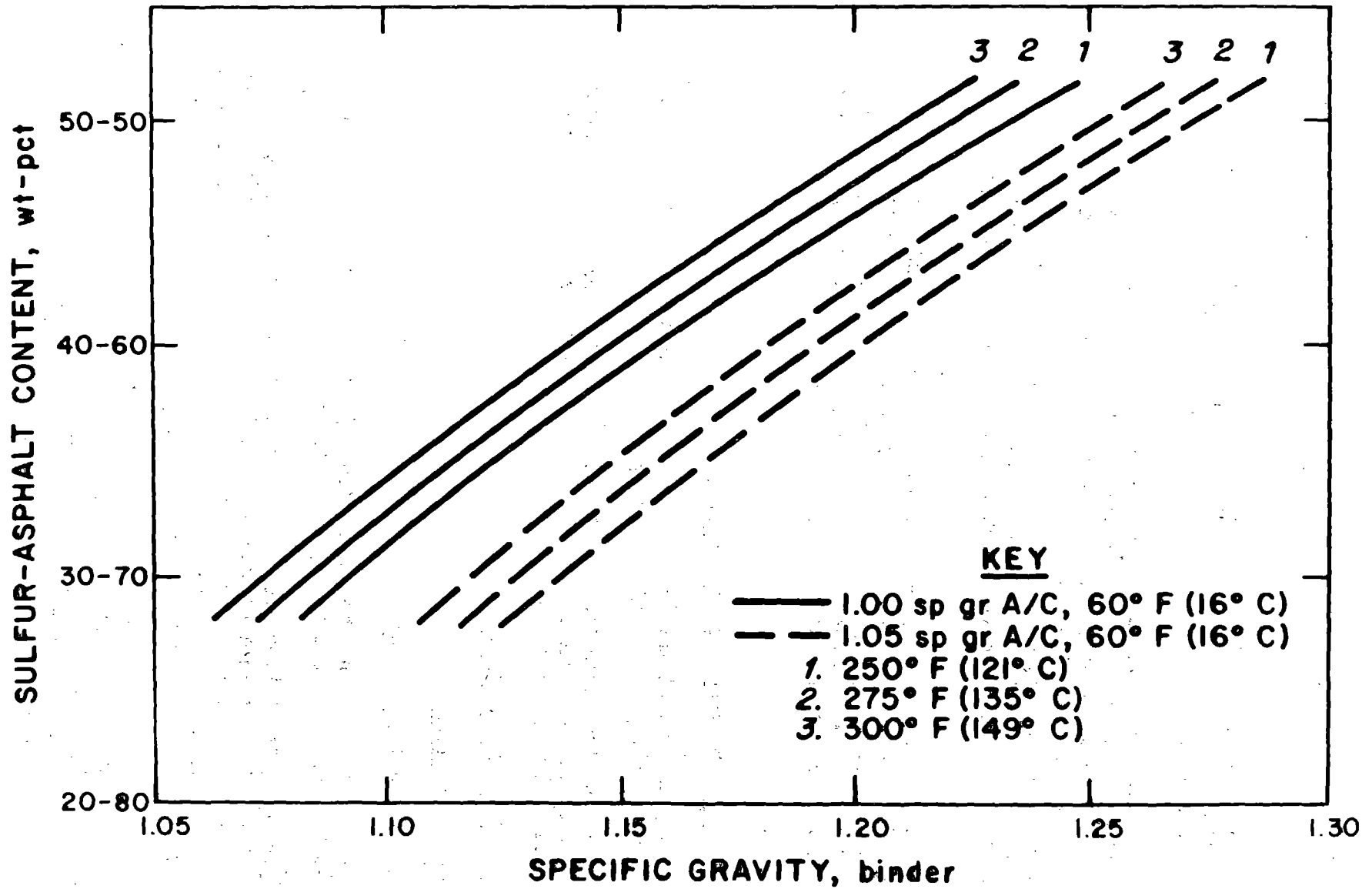


FIGURE 6. - Composition of SEA binders as a function of their specific gravity.

the agitation of the sulfur.

In view of the progress being made in extending asphalt with sulfur, a well-constructed auxiliary sulfur system may be desirable. Generalized systems are shown in figures 7 and 8. Metering pumps are not necessary on batch plants equipped with weighing systems when using the method illustrated in figure 7. Schematics of several temporary sulfur systems that have been used on SEA paving projects are shown in figures 9 through 12. These are for orientation only and do not preclude other equipment or arrangements that may be suitable.

Cleaning Asphalt Tanks for Sulfur Storage. An asphalt tank, placed in sulfur service, must first be completely drained and free from residual asphalt, water (emulsions), or cutbacks. Normal clingage from paving asphalt cement should be removed by appropriate cleaning techniques to avoid the possibility of dangerous emission of hydrogen sulfide gas.

Before returning to asphalt service, the tank must be thoroughly drained, taking care to remove any sulfur trapped below the outlet flange. The dome and vent pipes must be open when the tank is refilled with asphalt. The sulfur clingage mixing with asphalt can form volatile sulfur compounds dangerous to workers.

Quantities of sulfur remaining in the tank, at completion of the project, may be drained into a temporary earth pit. After cooling, the solid sulfur can be hauled to a suitable disposal area. Molten sulfur, placed in a pit, will cool quickly at the surface to form a crust with hot liquid sulfur below. Care must be taken to prevent workers from walking on the crusted sulfur.

Pumps. Pumps should be selected on the basis of the manufacturer's recommendations for handling the liquid sulfur. In any case, several sulfur characteristics must be kept in mind. The sulfur will solidify below about 245° F (118° C). Sulfur is a good insulator and cannot be melted easily. Unlike asphalt, it will not soften gradually.

A wide range of centrifugal, gear, and piston pumps are used in the sulfur trade. Centrifugal pumps are favored for medium to high volumes, 25 to 1500 gpm, and a wide range of pressures; gear and piston pumps are favored for low volume over wide pressure ranges and where precisely controlled rates are required. Although widely used without bypass valves, the centrifugal pump in stop-go operation can heat the contained sulfur to over 320° F (160° C), above which the viscosity of the contained sulfur increases abruptly.

Although most sulfur pumps are "steam jacketed," many can be heated with either steam or hot oil. Asphalt positive displacement (gear) pumps have been used successfully on SEA projects for hot asphalt and, in turn, for hot sulfur and hot SEA binder. The pump should be fully heat jacketed. If partially jacketed, it must be heat traced and insulated. This type of pump requires a safety release valve, either built-in or installed in the discharge line.

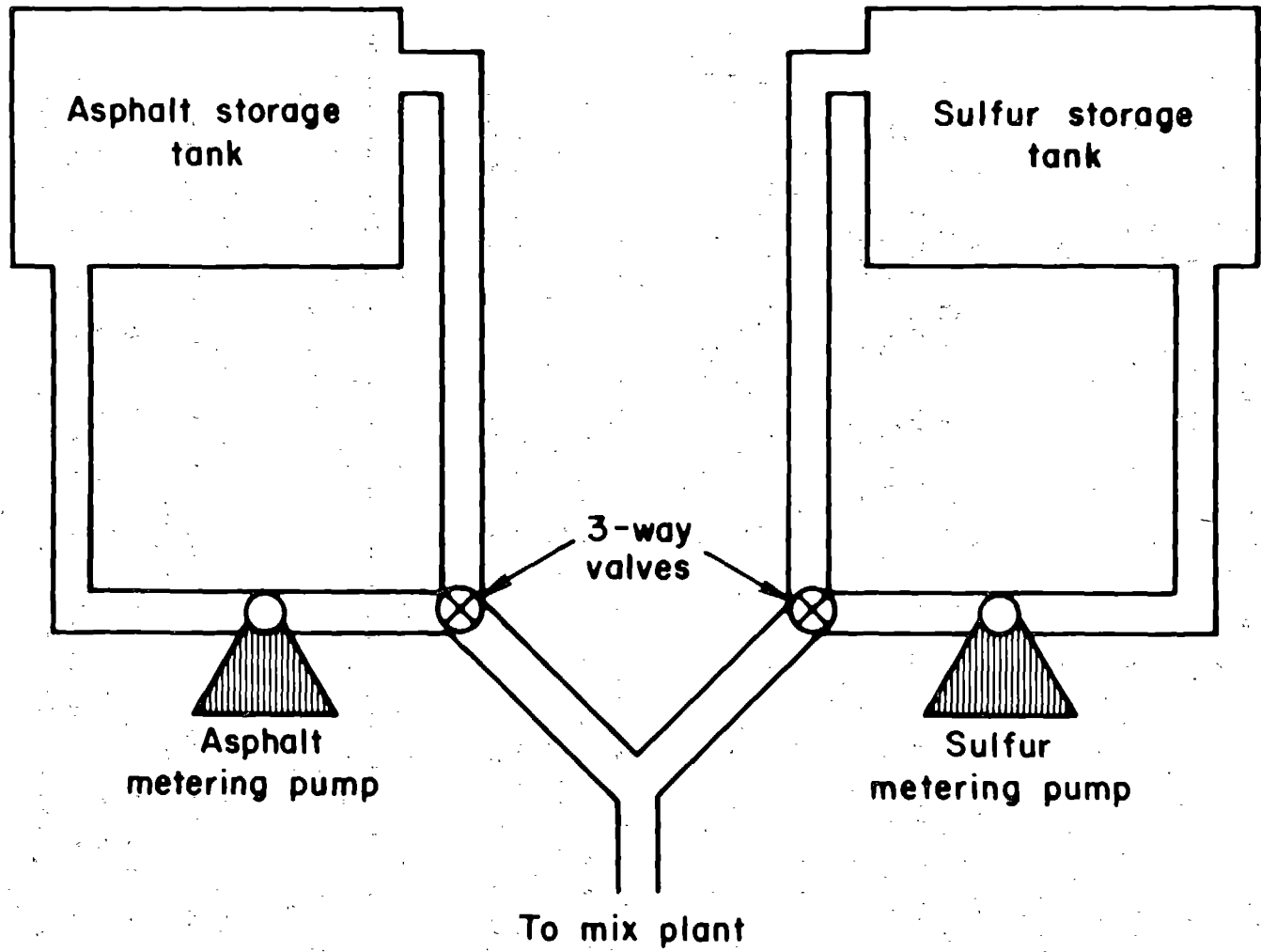


FIGURE 7. - Direct mixing method for production of SEA.

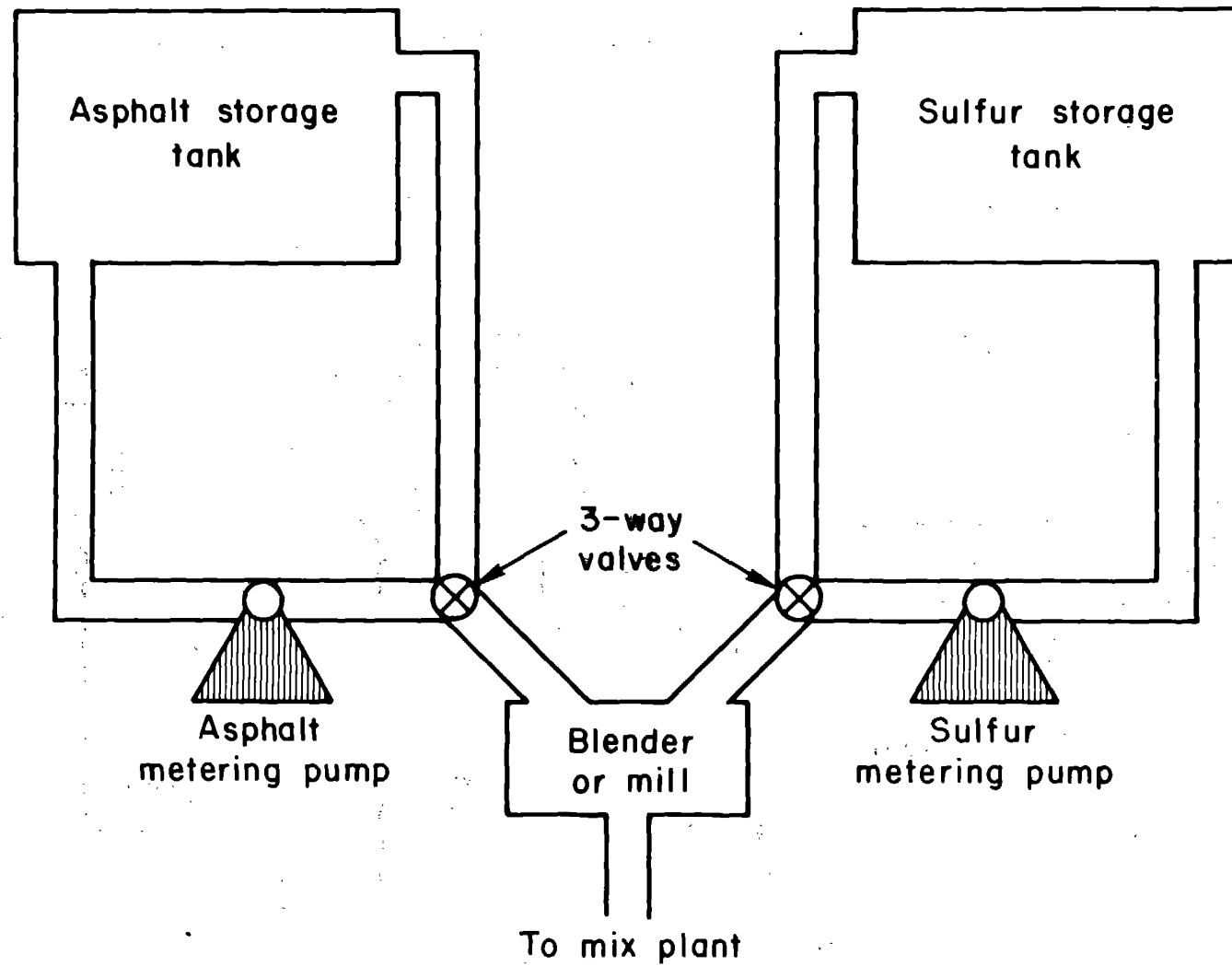
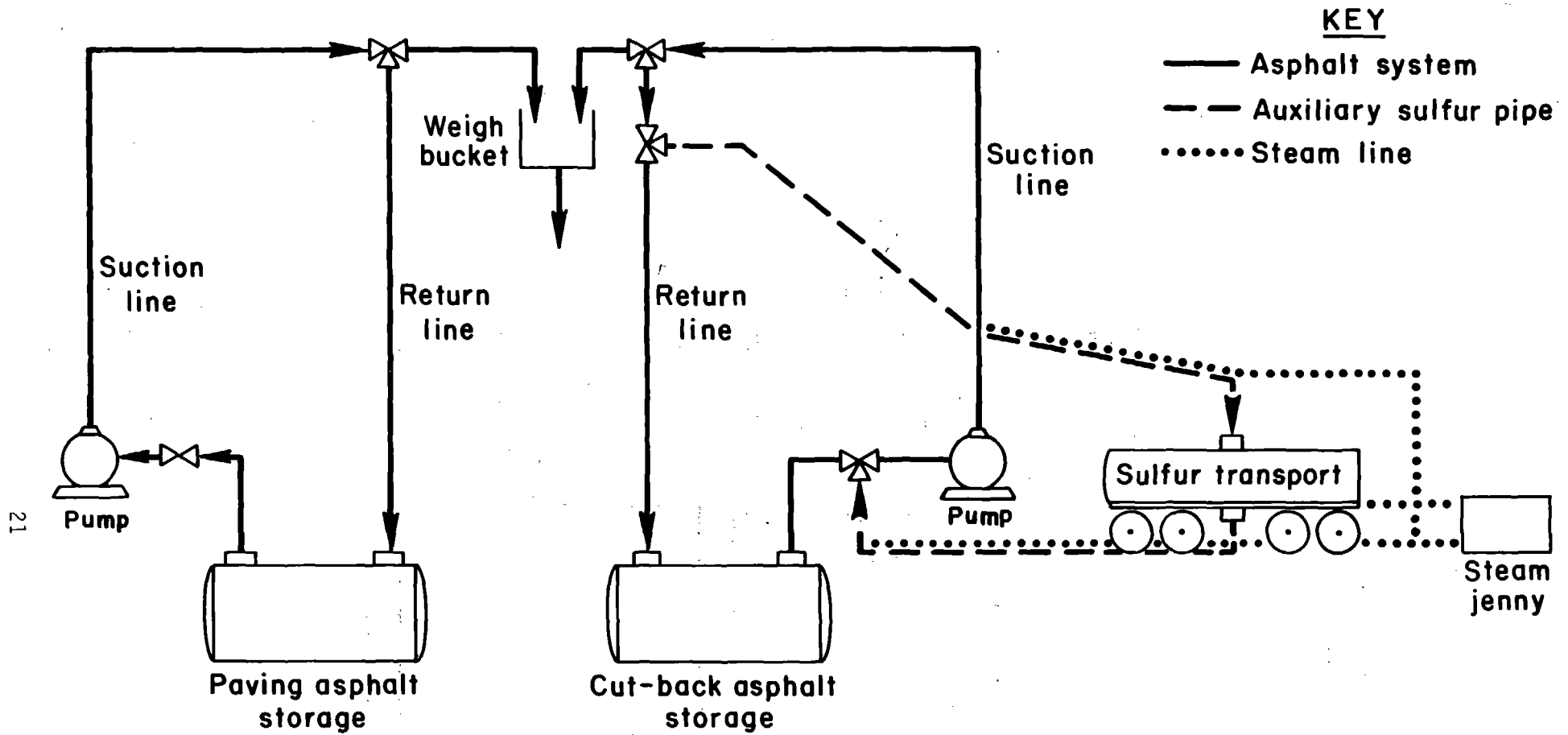


Figure 8. - Preblending method for production of SEA



21

Figure 9. - Sulfur supply system, Henderson, Nev.

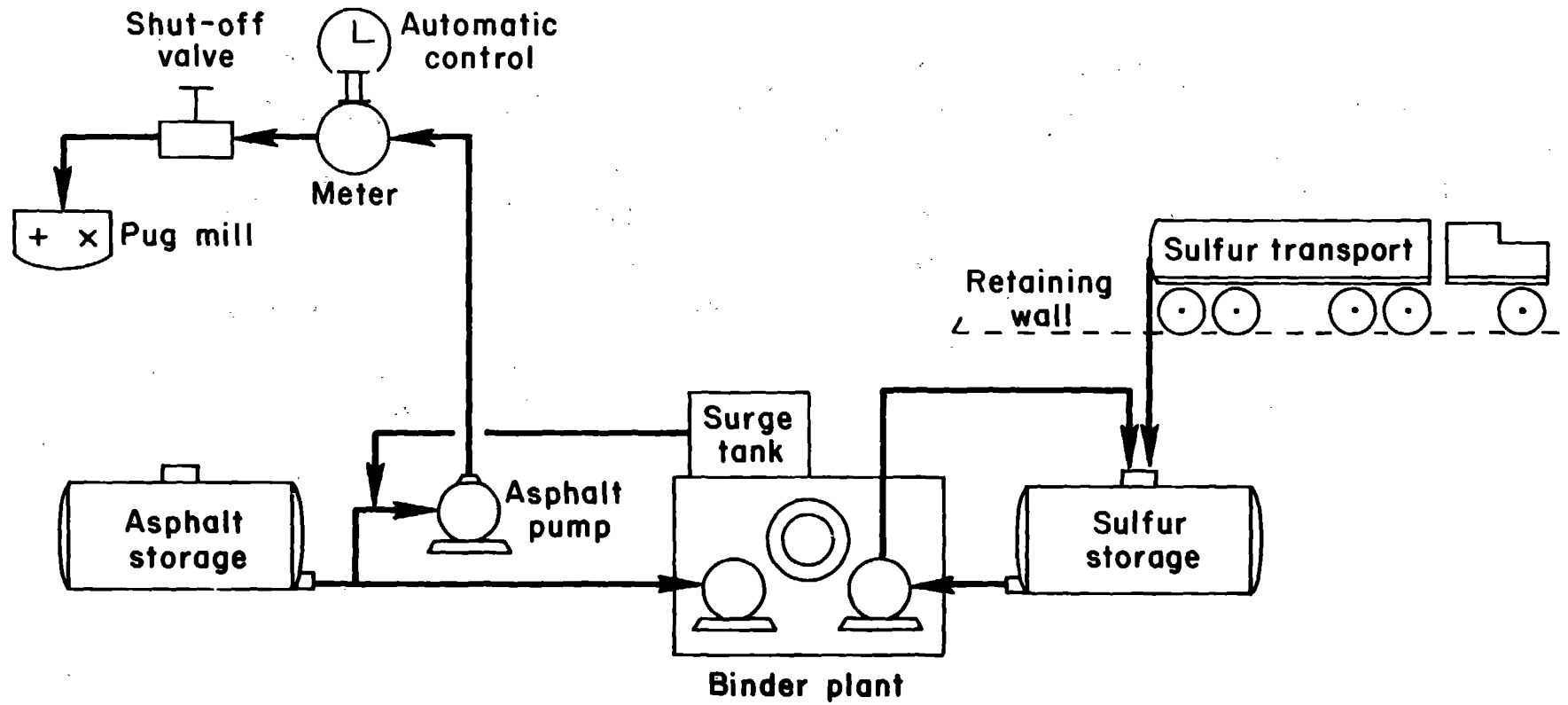
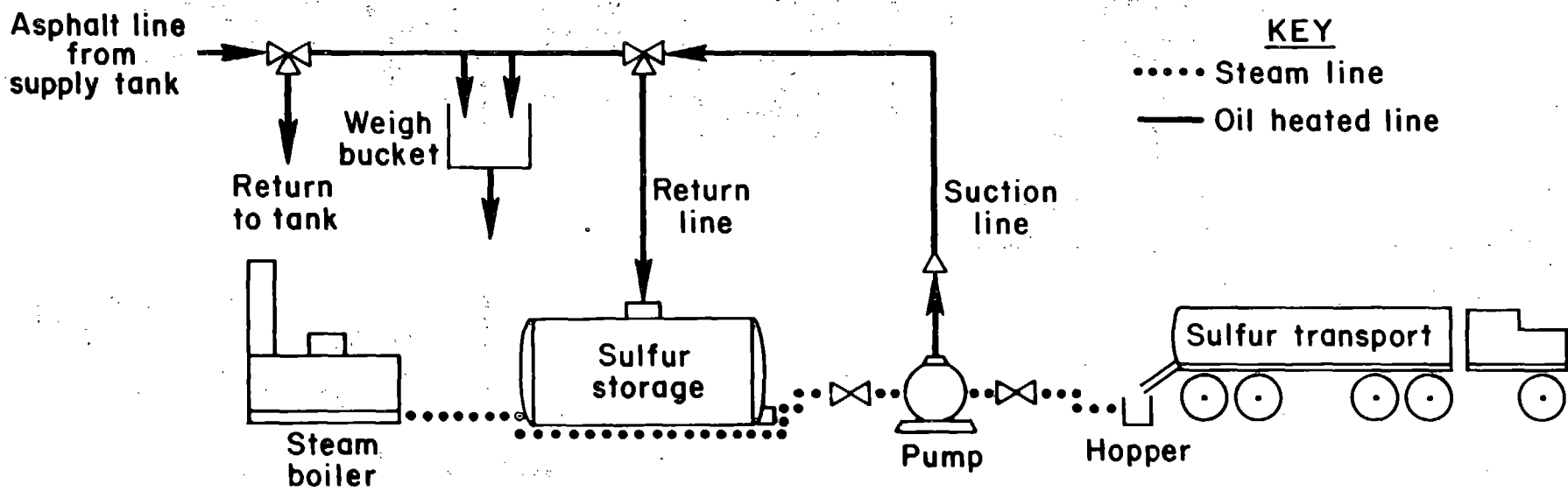


Figure 10. - Sulfur supply system, Bryan, Tex.



23

Figure 11. - Sulfur supply system, Kenedy County, Tex.

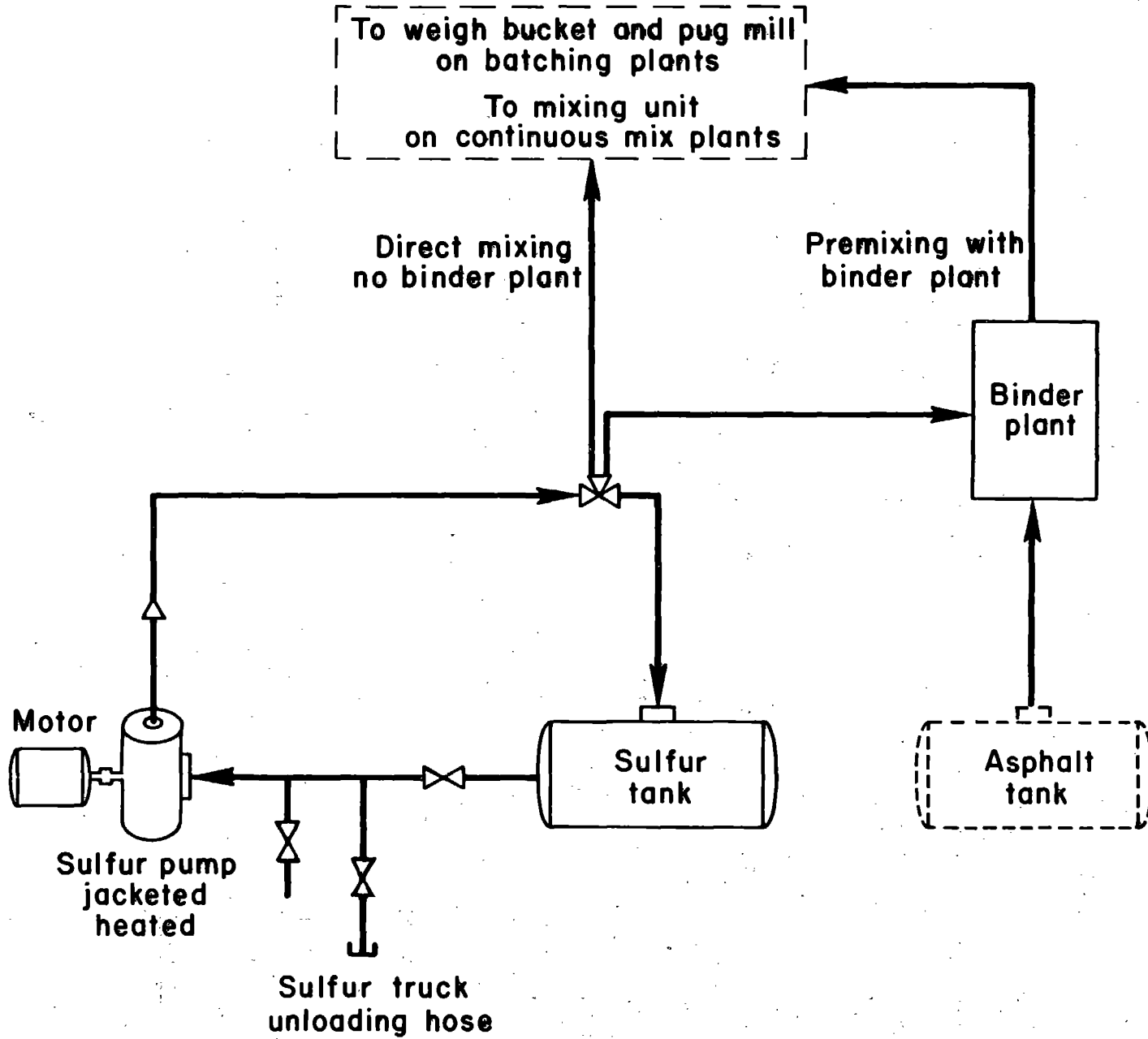


Figure 12. - Sulfur system for either method of mixing

Piping. All pipe, pipe fittings, and valves must be insulated and heated. Mild steel, galvanized iron, alloy steel, aluminum, or other corrosion-resistant pipe is suitable. Mild steel and galvanized iron pipe are commonly used. Prefabricated mineral wool or fiberglass with sheet aluminum cover or similar insulation is used. Foil-backed insulation mats, burlap sacking covered with roofing paper, or similar materials are suitable for temporary use.

Three general types of pipe heating are employed: jacketed pipe lines, "gut" lines, and heat-traced lines.

In a jacketed pipe line, the molten sulfur is carried in an internal pipe surrounded concentrically by a larger pipe. Joints and fittings require workable assemblies. The space between the pipes is supplied with steam under pressure at 35 to 75 psig. Hot oil has also been used successfully with temperatures targeted at 290° to 320° F (143° to 160° C). A typical size used in the sulfur system on SEA projects has been 3- by 4-inch jacketed.

A small pipe, inside a larger pipe, carrying steam or hot oil, is called a gut line. These lines are used only in pipe of 2 inch diameter or larger. A 3 inch pipe with a 3/4 inch gut line may be suitable. Steam, hot oil, or electrical tracer lines are attached to sulfur lines, wound around pumps and valves, and insulated.

Valves. A wide variety of jacketed valves of all patterns and shapes is available for sulfur service. Copper and bronze fittings should not be used in contact with sulfur.

Two-way manually operated jacketed valves can be used in the sulfur-unloading and sulfur storage outlet lines. Jacketed check valves and jacketed vents are employed. One or more three-way valves may be needed in the sulfur-circulating system, as shown in figures 9, 10, 11, and 12. These valves are likewise jacketed. They are normally fast-acting with remote controls.

Preparation of Sulfur-Extended-Asphalt Binder

Direct Mixing of Binder Components. The binder can be prepared by direct mixing of the hot components of sulfur and asphalt with the hot mineral aggregates as shown in figure 9. The pugmill provides the necessary mixing action to prepare the SEA mixture.

Preblending of Binder Components. The binder can also be prepared by preblending in an in-line blender of the hot components of sulfur and asphalt and transferred immediately, or following a short period in transitory storage, into a pugmill or dryer drum mixer for mixing with the hot mineral aggregates.

The premixed hot binder should be stored only for short periods (minutes) to avoid sedimentation of the heavier sulfur component as well as emission of hazardous gases.

Differences in Material Performance Characteristics resulting from the use of premixing versus direct mixing of the binder have not been determined; both methods merit consideration in setting up the sulfur system at the hot-mix plant.

Summary. The use of sulfur to improve asphalt paving material is an old art. During the past decade, many papers describing sulfur asphalts have been published by government, academic, and private groups. Many patents describing the preparation and use of sulfur asphalts under a variety of conditions have been issued. Some of these patents have not expired, and presumably applications for other patents are pending. These patents should not discourage groups from investigating and placing experimental SEA pavements. However, each organization should determine whether licensing of the technology is indicated prior to initiating commercial usage of SEA pavement binders.

Proprietary Considerations

In some cases, the binder properties have been related to the methods of binder preparation and, in turn, to a particular plant or mill, several of which have been used successfully for measuring and premixing the binder components. Emphasis was placed on the solubility of sulfur in asphalt together with the amount and particle sizes of the sulfur dispersed in the sulfur-asphalt mixture. More detailed information on these systems is included in appendix A.

Specifications - Materials and Construction

Existing State or Federal agencies' specifications for materials and construction of A/C paving shall be used with the following additions.

The Sulfur System

Liquid sulfur will be delivered to the contractor at the job site in truck transports or railroad tank cars at a temperature range of not less than 250° F (121° C) nor more than 300° F (149° C). The hauling equipment and procedures for heating, unloading, storage, handling, and safety shall be in accordance with the practices commonly used in the sulfur industry.

The contractor shall provide a sulfur system for storing and handling sulfur at the hot plant. The system shall consist of (1) a storage tank or tanks, together with a pump, valves, and pipe for transferring sulfur from transport to storage, and (2) a full circulating system, from storage to binder proportioning plant, or alternatively, directly to the weigh bucket or mixer unit on the hot-mix plant.

Storage. The tank or tanks for storage of sulfur shall consist of an asphalt tank or similar vessel, suitably cleaned and ventilated and strong enough to contain and support the sulfur, which is twice the weight of asphalt for equal volumes. Alternatively, a transport on standby may be used as storage. In any case, storage capacity shall be sufficient to provide sulfur for a full day's paving operation. The tank shall be electrically grounded and vented to prevent concentration of gases in the

air spaces from reaching explosive limits. Venting shall include pipe, rising above the tank, as necessary for air circulation.

Sulfur storage shall be so equipped that the sulfur can be heated under effective and positive control at all times, to the temperature requirements specified herein. Heating shall be accomplished by steam coils, hot-oil coils, or other means that will not permit a flame to come in contact with the storage tank nor permit surface temperature in contact with the sulfur to exceed 315° F (157° C). An armored thermometer or thermocouple with a range of 200° to 400° F (93° to 204° C) shall be fixed in the sulfur storage to enable accurate temperature measurements at all times.

Sulfur storage shall be fully insulated to maintain the temperature of the hot material in the absence of applied heat to a loss of not more than 2° F per hour.

Pumps. The sulfur pump or pumps in the sulfur system shall be of the types and sizes recommended by the manufacturer for handling the low-viscosity, hot sulfur, and shall be equipped with a safety release bypass valve. Alternatively, when approved by the contracting agency, an asphalt pump of the positive displacement type, fully jacketed, may be used.

Valves. The sulfur system shall include two-way manually operated jacketed valves in the sulfur unloading line and storage outlet lines, jacketed check valves, and jacketed vent valves, all as required to insure directional flow, together with an automatically controlled three-way valve at the binder plant, weigh bucket, or mixer unit, as the case may be. When the quantity of sulfur delivered is controlled by metering, the meter shall be certified and an approved means provided whereby the amount of sulfur delivered through the meter can be readily checked by weight.

Piping. All pipe shall be heated and insulated. Typical 3- by 4-inch jacketed pipe, 3 inch pipe fitted with 1/2 to 3/4 inch gut line, steam or hot-oil tracer lines, electrical tracers, or other approved methods shall be used.

Mixing of Binder Components

The SEA binder shall be prepared either by direct mixing or by pre-blending methods for batching plants and continuous-mixing plants, as specified by the contracting agency.

Direct Mixing of the Binder. The molten sulfur may be added directly to the hot asphalt in the weigh bucket or directly to the hot asphalt and hot mineral aggregates in the pugmill on batching plants and directly to the hot asphalt and hot aggregates in the mixing unit on continuous-mixing plants. A satisfactory means, incorporating either weighing, metering, or volumetric measurements, shall be provided to obtain the required percentages of the molten sulfur and hot asphalt for the type of SEA binder and within the tolerances specified.

Preblending of the Binder. When preblending of the binder is employed, the SEA binder shall be prepared in a binder plant designed and constructed for accurate proportioning of the molten sulfur and hot asphalt and the intimate mixing of these hot components. Use of the binder plant by the contractor shall not involve the contracting agency in any encumbrances of a proprietary nature whatsoever.

The basic plant shall consist of two material feed systems, one each for molten sulfur and for hot asphalt, each system complete with a pump, meter, and valves as required to deliver the specified amount of the component to a colloid mill, in-line blender, or other device for the intimate mixing of components and discharge to the hot plant. Plant instrumentation and controls shall enable a positive rate of flow for each binder component and the finished product at a temperature within the specified range of 255° to 300° F (124° to 149° C).

All piping, valves, pumps, meters, tanks, and other devices shall be heat traced and insulated as necessary to keep the contained liquid sulfur, hot asphalt, and finished SEA binder at a temperature above 255° F (124° C).

The capacity of the binder plant shall exceed the amount of binder required by the hot-mix plant when operating at full capacity.

Schematic. Schematics of sulfur systems showing direct mixing and premixing of the molten sulfur and hot asphalt are shown in figures 7 and 8; these do not preclude the use of other equipment or arrangements designed for the project and approved by the contracting agency.

Test Pavement Section

At startup of paving operations, the contractor shall prepare a quantity of mixture as required and construct a trial pavement section at least 50 ft long and one traffic lane in width, and of a thickness corresponding to the thickness of the course as shown in the plans and specifications. The purpose of this section shall be to check on the adequacy of mixing, placing, and compaction equipment and of temperature and emissions control. Measurements of temperature and emissions shall be made, and samples of the pavement shall be taken, all as directed by the contracting agency. The operation or operations shall be adjusted as required to assure that the provisions for safety and the finished pavement meet specification requirements. If the test section does not conform to requirements, the pavement shall be removed as directed at no expense to the contracting agency. Full production of SEA pavement mix shall not be started without approval.

V. SAFETY

General

Sulfur is not considered a hazardous material by the Interstate Commerce Commission. About 90 pct of the elemental sulfur used in the United States, approximately 13 million long tons annually, is shipped in the liquid state. Truck transports are widely used, with the typical 18-wheeler hauling 20 to 25

tons. Practices for heating, hauling, and storage together with safety are well established in the trade.

Molten Sulfur

Hot sulfur poses the same dangers as hot asphalt or any other hot liquid. Sulfur will burn if ignited. As with handling asphalt, and in particular liquid asphalt, all sources of ignition such as smoking, open flames, and sparks are not permitted near liquid sulfur.

Sulfur Emissions

Emissions of hydrogen sulfide, sulfur dioxide, and sulfur vapor may be present during the preparation and placement of SEA pavement mixes. The concentrations of these emissions are usually low or nonexistent when SEA paving is produced at temperatures below 300° F (149° C). Above this point, gaseous emissions may increase rapidly.

Gaseous emissions may be high in the dome of sulfur transports similar to asphalt transports or in the top of improperly ventilated sulfur storage. Care must be taken to avoid breathing these fumes.

Vapor containing small amounts of elemental sulfur may be given off during the preparation and placement of the sulfur-asphalt pavement mix. As the vapor cools, the sulfur crystallizes into small particles which are carried in the air like dust. Sulfur is virtually nontoxic, and there is no evidence that systemic poisoning results from the inhalation of sulfur dust. The dust can irritate the inner surfaces of the eyelids and may also irritate open cuts of the skin. Goggles and disposable filter masks are provided to workers in those areas where the sulfur dust might be objectionable.

Temperature Control

Temperature control is the most important factor in the production of SEA paving materials for controlling sulfur emissions.

Regulations Pertaining to Sulfur Emissions

Sulfur emissions are normally measured and monitored during startup of the SEA paving operations for assurance that allowable concentrations are not exceeded. The magnitude and importance (severity) of the emissions will be gaged by the regulations of the recognized authorities in the area. Two authorities are outstanding: The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA), establishing, either directly or indirectly through Region and State organizations, requirements (standards) for the workplace; and the Environmental Protection Agency (EPA), establishing, either directly or indirectly through Region and State organizations, requirements (standards) for air, water, and solid wastes.

OSHA

The requirements of OSHA prevail in the work areas "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources." OSHA regulations apply to three general areas: 1) in the laboratory, where the sulfur-asphalt mixes are designed and tested, 2) at the hot-mix plant, where the raw materials are stored and where the pavement mixes are prepared, and 3) in the haul truck and at the paver site where the pavement mix is placed.

The maximum allowable concentration of hydrogen sulfide, for prolonged exposure, is 10 ppm. The maximum allowable concentration of sulfur dioxide, for prolonged exposure, is 5 ppm 16/. This and other applicable information on sulfur emissions is contained in table 5 for ready reference.

Table 5. - Toxicity levels for sulfur emissions

<u>Concentration, ppm</u>	<u>Effect</u>
<u>TOXICITY OF HYDROGEN SULFIDE 17/</u>	
0.02	Odor threshold.
0.10	Eye irritation.
5-10	Suggested maximum allowable concentration for prolonged exposure.
70-150	Slight symptoms after exposure for several hours.
170-300	Maximum concentrations that can be inhaled for 1 hour without serious consequences.
400-600	Dangerous after exposure for 1/2 to 1 hour.
700	Fatal with 1/2 hour exposure.
<u>TOXICITY OF SULFUR DIOXIDE 18/</u>	
0.3-1.0	Detected by taste.
More than 1.0	Injurious to plant foliage.
3	Noticeable odor.
5	Immediate irritation to nose and throat.
6-12	Irritation to eyes.
20	Suggested maximum allowable concentration for 30 to 60 minutes' exposure.
400-500	Immediately dangerous to life.

EPA

In general, EPA regulations start at the property line, "over-the-fence." They are reflected in the well-known State requirements for clean air control of hot-mix plants. State regulations also encompass the control of air pollution from sulfur compounds. A typical requirement limits hydrogen sulfide emissions to a net ground level concentration of 0.08 ppm averaged over any 30-minute period if the downwind concentration of hydrogen sulfide affects a property used for residential, business, or commercial purposes. Similarly, typical requirements may limit sulfur dioxide emissions to net ground level concentrations of 0.28 to 0.4 ppm.

In most cases, property line air sampling will suffice for determining the concentrations of these sulfur gases. However, provisions are also made for plant stack gas sampling and the calculating of ground level concentrations.

Instruments for Measuring Sulfur Emissions

Many instruments are suitable for measuring and monitoring sulfur gases. The following have been widely used for sulfur asphalt experimental paving projects in the United States:

1) A three-component unit for continuous measuring:

Hydrogen Sulfide Analyzer, Model 850
Houston Atlas, Inc., Houston, Tex.

Rustrak Recorder, Model 288
Rustrak Industries, Inc., East Greenwich, R.I.

Bellows Remote Sampling Device, Model MB 4-1
Mattel Bellows Co., Sharon, Mass.

2) Portable units for continuous monitoring and transitory measurements:

Interscan portable, direct-reading analyzers for H₂S, and
Interscan portable, direct-reading analyzers for SO₂,
Interscan Corp., Chatsworth, Calif.

3) Portable instruments for transitory measurements:

Drager Multi-Gas Detector with tubes (SO₂, H₂S)
National Mine Service Co., Pittsburgh, Pa.

Rotorod Gas Sampler, Model 721
Metronics Associates, Inc., Palo Alto, Calif.

4) Detector cards for multiuses:

Colortec Hydrogen Sulfide Detector Cards
Metronics Associates, Inc., Palo Alto, Calif.

High-volume-type air samplers, each assembled with motors, air suction pumps, and cages, have been used to monitor sulfur dust in the ambient air. The total matter collected may be analyzed by following ASTM Standard E 30-47.

Field Measurements of Emissions

Hydrogen sulfide and sulfur dioxide emissions, monitored and measured on several SEA binder projects, have shown no occupational problems.

Typically, the concentrations of sulfur gases in the personnel areas around the hot-mix plant and at the paver have been found to be nonmeasurable or very low, from a trace to 2 ppm. A slight odor of sulfur dioxide is usually present, but it can be detected at concentrations of 0.03 ppm, far below the tolerance level of 5 ppm.

Measurements in nonpersonnel areas have been higher. In the paver hopper as new mix was being dumped, and at the paver screed level while it was being preheated, momentary levels of H₂S from 1 to 20 ppm have been recorded. Such concentrations decrease rapidly with distance from the source.

Known Hazards

Hazardous concentrations of sulfur gases have been measured in the domes of sulfur transports and asphalt transports upon arrival at the hot-plant site, in the top of poorly ventilated sulfur storage tanks containing some asphalt, and in transitory storage of SEA binders.

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APPENDIX A

Plants for Preparation of Premixed SEA Binders

Preblending units or methods that have been used in the U.S. include -

1. Société Nationale Elf Aquitaine's Sulfur-Asphalt Mobile Unit.
2. Gulf Canada Ltd's Sulfur-Asphalt Module (SAM).
3. Sulphur Development Institute of Canada's Pronk Sulfur-Asphalt System
4. Texasgulf, Inc.'s Sulfur-Extended-Asphalt Binder Plant and Sulfur System.

An early effort in the preparation of sulfur in asphalt mixtures, "--at a temperature sufficiently high to permit the production of a substantially homogeneous mixture, but not high enough to cause a chemical reaction to take place--" is described by Bacon et al. in U.S. Patent 2,182,837, dated December 12, 1939, and assigned to Texas Gulf Sulphur Co.

Some more recent U.S. patents of interest are listed below:

No. 3,738,853, dated June 12, 1973, Kopvillem et al., assigned to Shell Oil Co.

No. 3,970,468, dated July 20, 1976, Garrigues et al., assigned to Société Nationale des Pétroles d'Aquitaine.

No. 4,154,619, dated May 15, 1979, Pronk et al., assigned to Sulphur Development Institute of Canada.

No. 4,155,654, dated May 22, 1979, Kennepohl et al., assigned to Gulf Canada Ltd.

Preblending Units

Société Nationale Elf Aquitaine (SNEA)

Sulfur Asphalt Mobile Unit. The SNEA sulfur-extended-asphalt mobile unit is schematically illustrated in figure A-1. Both the sulfur flow and the asphalt flow into the system are controlled by proportioning pumps. The hot components then pass through an in-line blender and next through a homogenizer turbine into transitory storage (surge tank). The blended SEA mixture is then pumped to the pug mixer on demand. The sulfur-to-asphalt mixture is adjustable up to 50 wt-pct sulfur. A Type 1 unit has a capacity of up to 6 tons of binder per hour. A Type 2 unit has a capacity of 6 to 15 tons of binder per hour. A hot oil heater provides hot oil for heating the pumps, mixer, and turbine. A steam boiler provides the steam necessary to heat the standby sulfur transports. All of the equipment is trailer mounted to give a compact unit.

A2

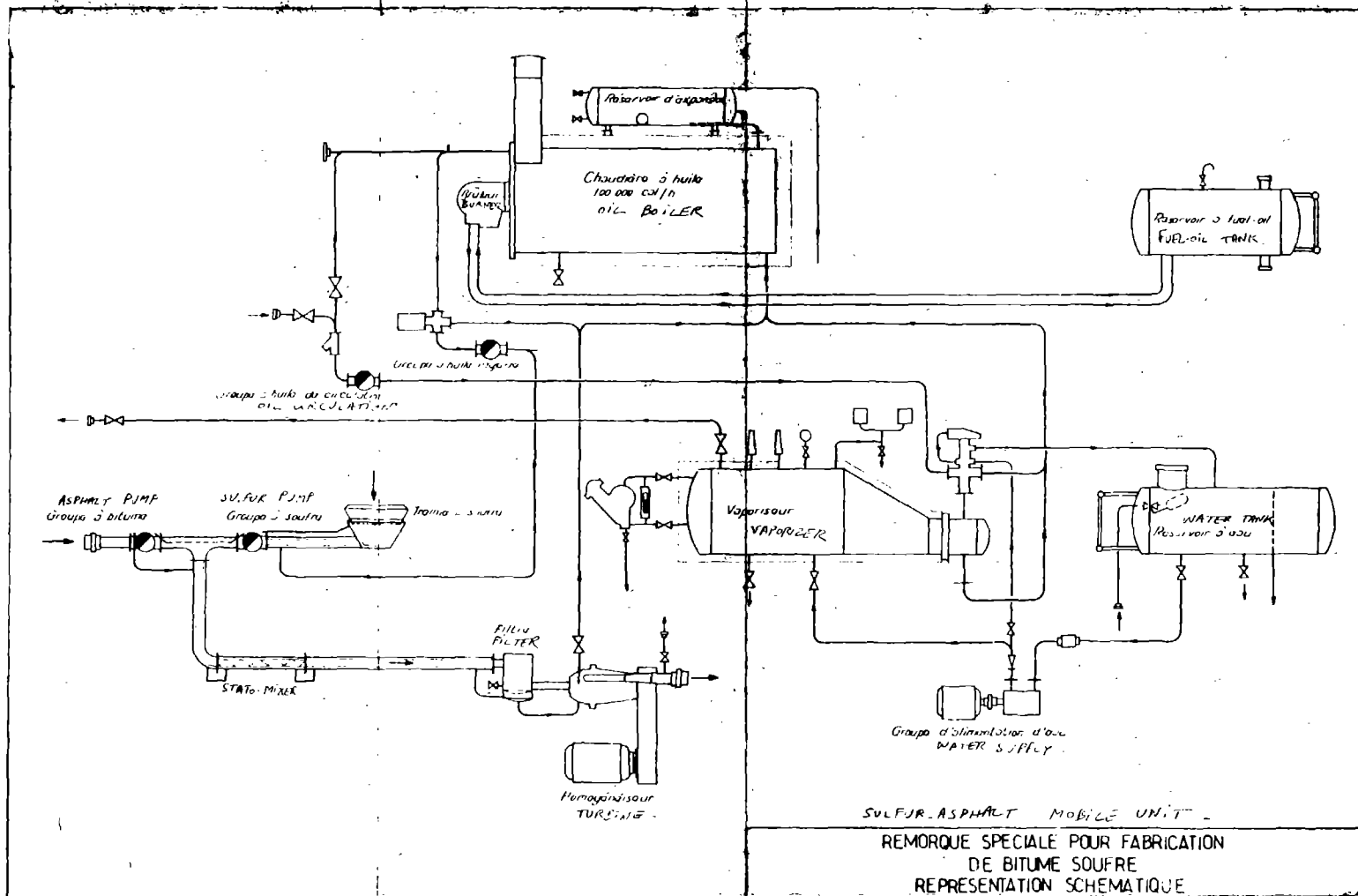


FIGURE A-1. - SNEA sulfur asphalt mobile unit.

Gulf Canada Ltd.

Sulfur Asphalt Module (SAM). The Gulf Canada Ltd. SAM unit is manufactured by Barber Greene Co. for them. The module is schematically illustrated in figure A-2. Items 1 and 2 are hot storage for sulfur and asphalt, respectively. Variable pumps, items 3 and 5, deliver measured amounts of sulfur and asphalt to y-connection 4 and then to a high-shear-type mixer (8) from which the SEA binder flows to the pug mixer. The entire system is heated by hot oil from heater B. The sulfur-asphalt ratio may be adjusted for 25 to 60 parts sulfur per 75 to 40 parts asphalt by weight. The sulfur and asphalt lines can be assembled with fast-acting, three-way valves between the respective pumps and the y to return the material through storage in two independent full-circulating systems. Binder can be delivered as required directly to the pugmill or uniformly to a continuous mixer and in intervals as short as a few seconds from the mixer (8).

Sulfur Development Institute of Canada (SUDIC)

Pronk Sulfur Asphalt System. There is no specific Pronk binder plant. The Pronk sulfur-asphalt system is shown in figure A-3. A binder-handling system such as that illustrated is tailored to the particular asphalt plant being used. For example, on a batch plant which uses a positive displacement pump for transferring asphalt, the components A, B, C, D, and E, an in-line blender, and a sulfur storage tank would be required. Pump A would be a positive displacement type which functions as a meter. For a continuous-mix plant, other arrangements are necessary. A skid-mounted unit with both an asphalt and a sulfur pump has been used. Variations of sulfur and asphalt and total binder were achieved using two varidives mechanically interlocked. The sizing, positioning, and configurations of the static mixer are important.

Texasgulf Inc.

Sulfur-Extended-Asphalt Binder Plant and Sulfur System. A schematic diagram of the sulfur-extended-asphalt binder plant and sulfur system is given in figure A-4. It consists of a full-circulating sulfur and asphalt system, each equipped with pumps, volumetric meter, and three-way valves. The metered sulfur and asphalt are combined and passed through an in-line blender to a continuously stirred, transitory storage tank and from there to the hot-mix plant. The plant and two 18-long-ton sulfur storage tanks are mounted on a single trailer for easy mobility. Duplicate pumping systems for the sulfur and asphalt are provided, and the lines, pumps, meters, and blender are all hot-oil-heated. The complete binder plant and storage system can be easily positioned and hooked into the asphalt and hot-oil lines at a hot-mix plant. Any desired sulfur-asphalt ratio binder can be prepared. Capacity is about 40 tons per hour maximum for 30-70 SEA binder.

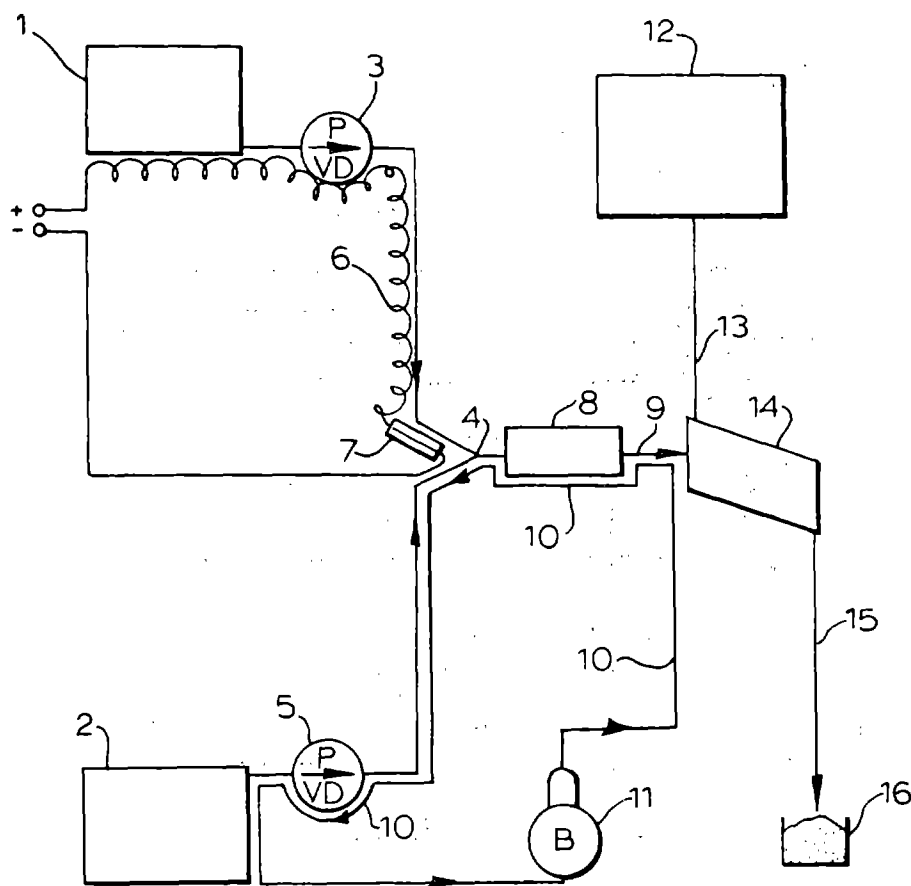


FIGURE A-2. - Gulf Canada Limited Sulfur asphalt module.

PLANT SCHEMATIC FOR SULPHUR/ASPHALT BINDER PRODUCTION

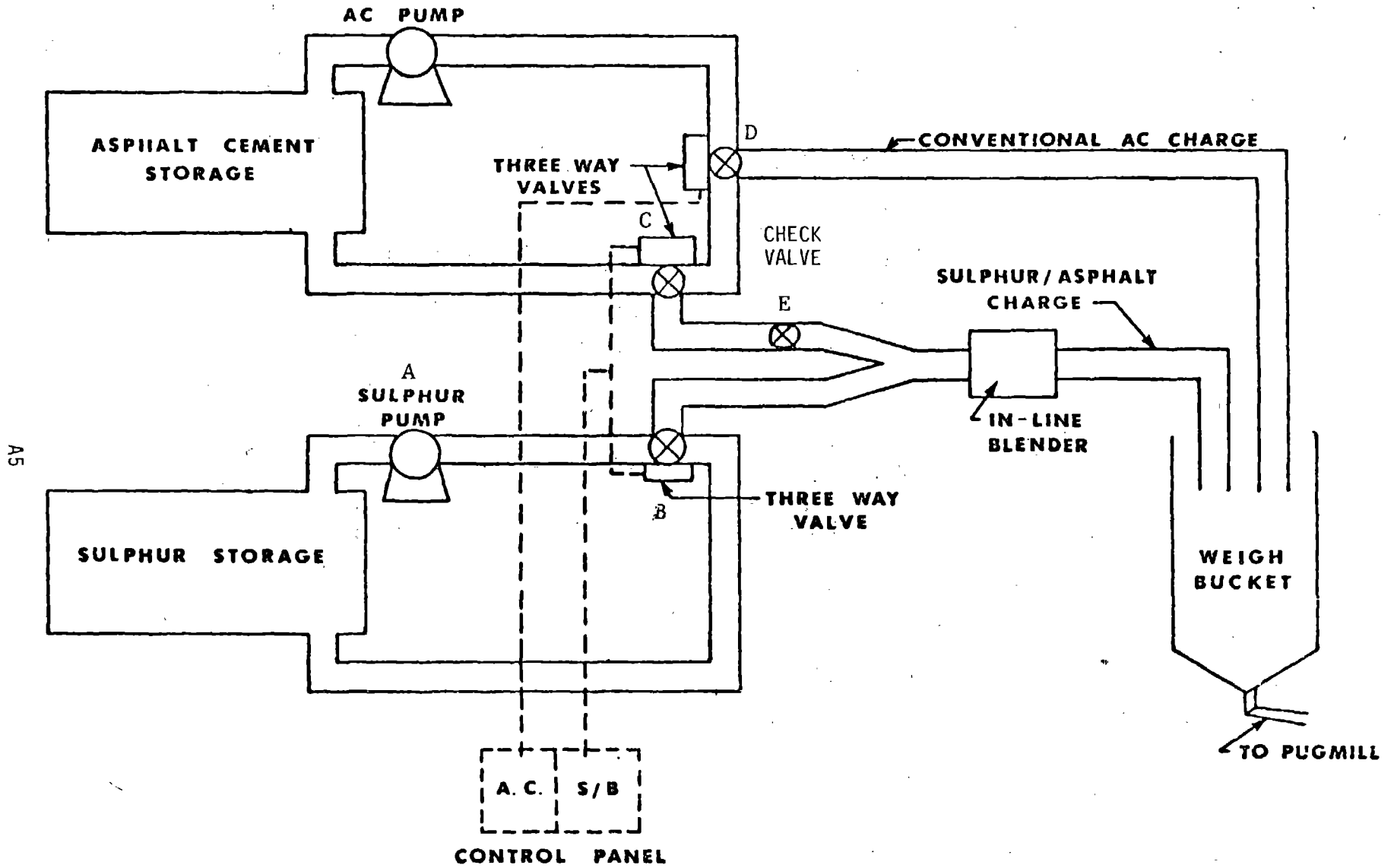
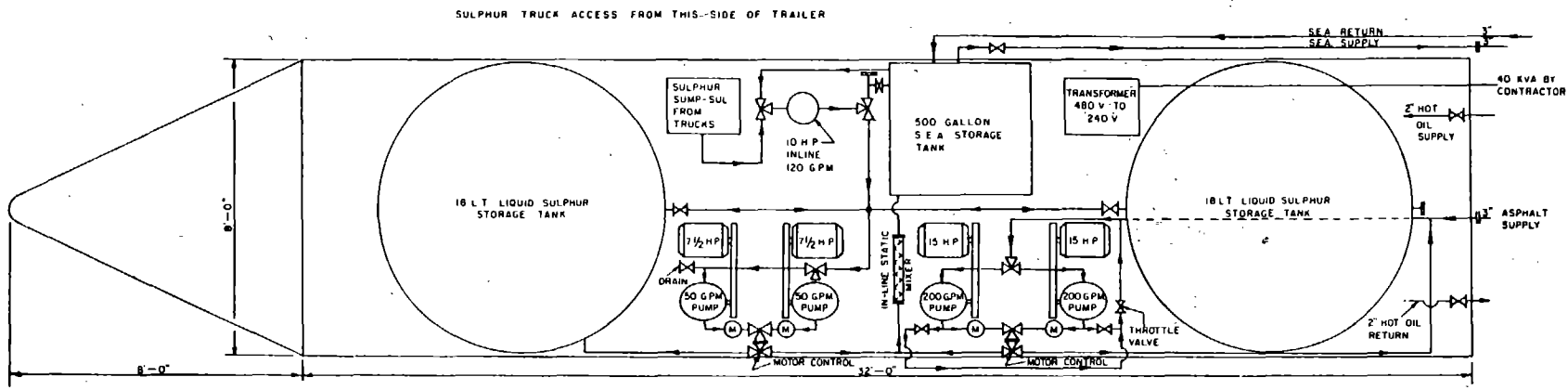
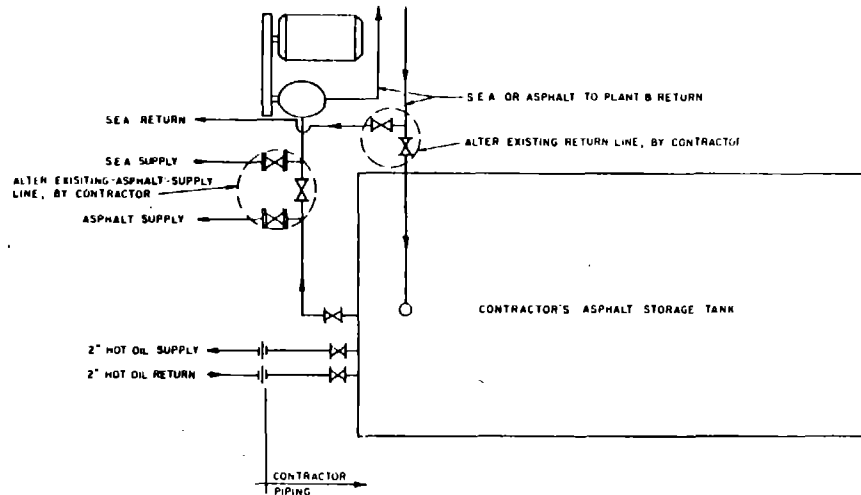


FIGURE A-3. - Pronk sulfur asphalt binder system.



PIPING SCHEMATIC



NOTE : CONTRACTOR TO FURNISH ADEQUATE HOT OIL TO KEEP TRAILER MOUNTED EQUIPMENT ABOVE 275°F

A PORTABLE SULPHUR/ASPHALT (S.E.A.) EMULSIFICATION UNIT			
NEWGULF, WHARTON CO., TEXAS			
Texasgulf Inc. ENGINEERING DEPARTMENT NEWGULF, TEXAS			
DESIGN	WMB	CHECKED	APPROVED
	8-1-79		<i>[Signature]</i> 8-21-79
DRAWN	VDP	CHECKED	DRAWING NUMBER
	8-20-79		2-58-93

REV	DATE	BY	REMARKS

FIGURE A-4. - Texasgulf Inc. portable sulfur-extended-asphalt binder unit.

APPENDIX B

Tentative Methods for Extracting SEA Binder

The following methods using either trichloroethylene or methyl chloride as the solvent for extracting SEA binder from paving materials are being evaluated for determination of binder content of SEA materials. Warm solvents (approximately 150° F) should be used throughout to assure complete solubility of sulfur.

METHODS OF TEST FOR QUANTITATIVE EXTRACTION OF BITUMEN FROM BITUMINOUS PAVING MIXTURES¹

1. SCOPE

1.1 This method covers procedures for the quantitative determination of bitumen and sulfur-extended bitumen in hot-mixed pavement mixtures and pavement samples.

1.2 The aggregate remaining may be used for sieve analysis according to AASHTO T 30, Mechanical Analysis of Extracted Aggregate.

Note: Although bitumen, by definition, is material soluble in carbon disulfide, trichloroethylene is used in this method for safety reasons. Methylene chloride may also be used.

2. SUMMARY OF METHODS

2.1 The paving mixture is extracted with a suitable reagent using the extraction equipment applicable to the particular method. The bitumen content is calculated by difference between the mass of the original sample and the mass of the extracted aggregate, its moisture content, and the mass of the mineral dust filtered from the extract. The sulfur-asphalt ratio is determined on the filtered extract.

3. APPARATUS

3.1 Oven, capable of maintaining the temperature at 110° ± 5° C (230° ± 9° F).

3.2 Pan, flat, 12 in (300 mm) long, 8 in (200 mm) wide, and 1 in (25 mm) deep.

3.3 Balance, conforming to the requirements of AASHTO M 231, class D.

3.4 Balance, conforming to the requirements of AASHTO M 231, class E, capacity 15 kg or more.

3.5 Hotplate, electric, with adjustable heating rate.

¹Based on AASHTO T 164-76.

- 3.6 Graduated cylinder, 1000- or 2000-ml capacity.
- 3.7 Pycnometer, 1000- or 2000-ml capacity.
- 3.8 Desicator.
- 3.9 Gelman filter membrane, 1.2 micron.
- 3.10 Vacuum filtration funnel.

4. REAGENTS

4.1 Trichloroethylene, Technical Grade, Type 1, Federal Specification 0-T-634, latest revision. NOTE: Trichloroethylene should be used only under a hood in a well-ventilated area; since it is toxic to some degree. According to data from Accident Prevention Manual for Industrial Operations, 4th Edition, National Safety Council, the maximum acceptable concentration for 8-hour exposure is 200 ppm.

5. PREPARATION OF SAMPLE AND GENERAL REQUIREMENTS FOR WEIGHING

5.1 If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan and warm until it can be handled to a maximum temperature of $110^{\circ} \pm 5^{\circ} \text{C}$ ($230^{\circ} \pm 9^{\circ} \text{F}$).

5.2 The test sample should normally be the end result of splitting or quartering a larger sample conforming to AASHTO T 168 (Sampling Bituminous Paving Mixtures). The size of the test sample shall be governed by the nominal maximum aggregate size in the mixture and conform to the mass requirement shown in the table B-1.

Table B-1.- Size of Sample

<u>Nominal maximum aggregate size</u>		
<u>Standard,</u> <u>mm</u>	<u>Alternate,</u> <u>in</u>	<u>Minimum mass of sample,</u> <u>kg</u>
4.75	No. 4	0.5
9.5	3/8	1
12.5	1/2	1.5
19.0	3/4	2
25.0	1	3
37.5	1-1/2	4

NOTE: When the required minimum mass of sample is greater than the allowable maximum mass for the method used, divide the sample into equal portions for testing. The masses for calculations will then be the sum of like masses of the test portions.

5.3 Weighing of extraction test apparatus and/or samples shall be done on a balance meeting the requirements of 3.3 when the capacity is sufficient; otherwise, a balance meeting the requirements of 3.4 shall be used.

6. WATER DETERMINATION

6.1 Determine the water content of a representative portion of the mixture according to AASHTO T 110 Test for Moisture or Volatile Distillates in Bituminous Paving Mixtures.

6.2 Calculate the mass of water in the sample, W_2 , by multiplying the moisture content by the mass of the sample.

7. APPARATUS

7.1 In addition to the apparatus listed in Section 3, the following apparatus is required for extraction using Method 1. Two commonly used alternate configurations of equipment are described in 7.1.1.1 through 7.1.2.5. Other apparatus differing in dimensional details may be used provided it is otherwise in substantial conformity.

7.1.1 Extraction apparatus, alternate No. 1, similar to figure B-1.

7.1.1.1 Glass jar, cylindrical, plain, 6-in (152-mm) OD, 18 in (457 mm) high, made of heat-resistant glass.

7.1.1.2 Cylindrical metal frame, 6-3/4-in (171-mm) OD, and 13-1/2 in (343 mm) high. The frame shall contain a 2.00- to 1.70-mm (No. 10 to 12) mesh metal cone with a base 6-1/2 in (165 mm) upper frame shall have stub legs that fit in recesses provided in the top rim of the lower frame or an equivalent method of support. Both frames shall contain 2.00- to 1.70-mm (No. 10 to 12) mesh metal cones having a base approximately 4-1/2 in (114 mm) in diameter and side length of approximately 6-3/4 in (171 mm), mounted inside the top rim of each frame. A bail handle may be provided on the inside of the top rim of each frame.

7.1.1.3 Condenser, 6-1/4 in (159 mm) in diameter with a truncated hemispherical condensing surface. It shall be equipped with 1/4-in (6.4-mm) ID tubing inlet and outlet assembled so that no lead-soldered joint comes in direct contact with the condensing solvent vapor.

7.1.1.4 Filter paper, medium grade, fast filtering, 330 mm in diameter.

7.1.1.5 Asbestos-coated wire, 1/8 in (3.2 mm) thick, or similar insulating pad.

7.1.2 Extraction apparatus, alternate No. 2.

7.1.2.1 Glass jar, cylindrical, plain, 8-3/4-in (222-mm) OD, 18 in (457 mm) high, made of heat-resistant glass.

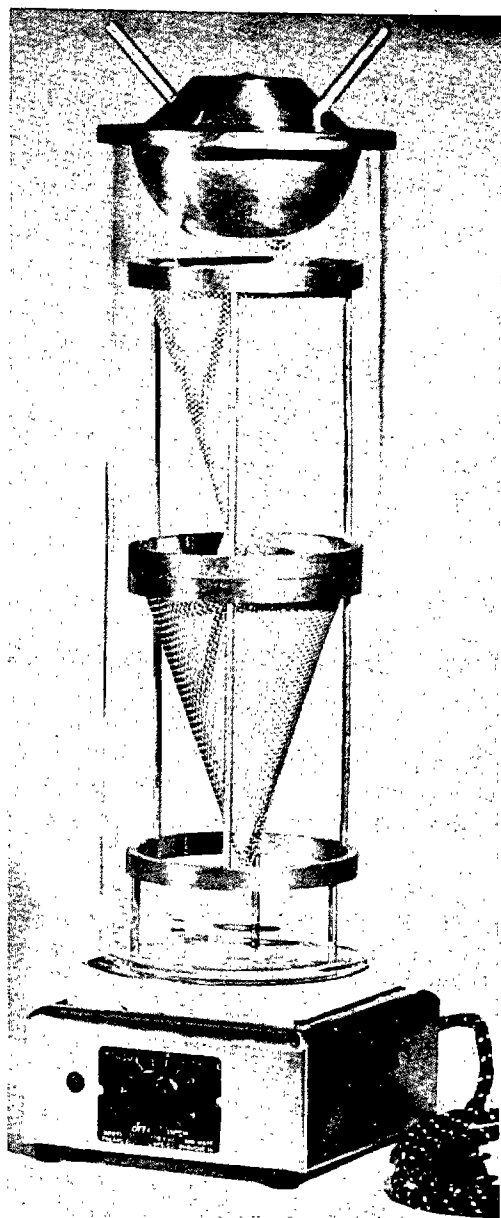


Figure B-1. - Extraction apparatus.

7.1.2.2 Cylindrical metal frame, 6-3/4-in (171-mm) OD and 13-1/2 in (343 mm) high. The frame shall contain a 2.00- to 1.70-mm (No. 10 to 12) mesh metal cone with a base 6-1/2 in (165 mm) in diameter and 10 in (254 mm) side length, mounted inside the top rim of the frame. A bail handle may be provided on the inside of the top rim of the frame. A similar setup using two frames with cones having shorter side lengths and mounted one above the other may be used.

7.1.2.3 Condenser, 9 in (229 mm) in diameter, with a truncated hemispherical condensing surface. It shall be equipped with 1/4-in (6.4-mm) ID tubing water inlet and outlet assembled so that no lead-soldered joint comes in direct contact with the condensing solvent vapor.

7.1.2.4 Filter paper, medium-grade, fast-filtering, 500 mm in diameter.

7.1.2.5 Asbestos-coated wire, 1/8 in (3.2 mm) thick, or similar insulating pad.

8. PROCEDURE FOR BITUMEN CONTENT

8.1 Determine the moisture content of the sample in accordance with Section 6.1.

8.2 Dry and weigh filter paper(s) to nearest 0.1 g. Fold filter on its diameter and fold twice again, one fold being made over the other to make three segments. Open to form a hollow three-ply cone with a single one-ply seam.

8.3 Select the test sample size in conformance with Section 5 and determine its mass, W_1 . Determine the mass of the water in the sample, W_2 , in accordance with Section 6.2.

8.4 Deposit the sample in the filter-paper-lined cone(s).

8.5 Pour approximately 600 ml (more or less as required by jar size), of trichloroethylene into the glass jar and place the cone(s) and frame(s) with supporting legs in the jar. The solvent level must be below the tip of the lower cone.

8.6 Place the loaded jar on the electric hotplate and cover the jar with a condenser. Circulate a gentle steady flow of cold water through the condenser. Adjust the heat so that the solvent boils gently and a steady, light flow of condensed solvent runs into the sample in the cone. Take care to adjust the heat so that the filter cone does not overflow. Continue extraction until the solvent running from the tip of the cone appears a very light straw color when viewed against a white background. Shut off the heat but not the condenser water, and allow to stand until cool enough to handle. Direct contact between the glass jar and the hotplate should be avoided by the use of an appropriate insulating pad.

8.7 Remove the frame(s) with filter paper(s) and extracted aggregate from jar. Dry in air, and then remove filter paper containing sample and place in a tared pan. Dry to a constant mass in an oven at $110^{\circ} \pm 5^{\circ} \text{C}$ ($230^{\circ} \pm 9^{\circ} \text{F}$). Subtract mass of tared pan and original mass of filter paper(s) and record the difference as the mass of extracted aggregate, W_3 .

NOTE: If desired, under 8.2, the mass of filter paper(s) and frame(s) may be determined together, then under 8.7 the frame(s), filter(s), and aggregate may be dried without separating. Subtract the mass of the frame(s) and filter(s) to determine the dry mass of the aggregate.

8.8 Dry and weigh a Gelman membrane filter capable of filtering 1.2 micron mineral matter and larger (or equivalent). Place membrane in a vacuum-type filtration funnel and filter the entire quantity of extract, taking care not to lose any. Dry the filtering system in air; then remove the filter membrane and place in a tared pan. Dry to a constant mass in an oven at $110^{\circ} \pm 5^{\circ} \text{C}$ ($230^{\circ} \pm 9^{\circ} \text{F}$). Subtract mass of tared pan and original mass of the membrane filter and record the difference as the mass of the filtered mineral matter, W_4 .

NOTE: This step is similar to the ash correction test and accomplishes same result, but without using any extract that must be saved for determination of sulfur-asphalt ratio.

9. CALCULATIONS FOR BITUMEN CONTENT

9.1 Calculate the percentage of bitumen in the sample as follows:

$$\text{Bitumen Content (by weight of dry mix, pct.)} = \frac{(W_1 - W_2) - (W_3 + W_4)}{W_1 - W_2} \times 100,$$

where W_1 = mass of sample,

W_2 = mass of water in sample,

W_3 = mass of extracted mineral matter,

and W_4 = mass of mineral matter filtered from extract.

10. PROCEDURE FOR SULFUR-ASPHALT RATIO

10.1 Pour all the filtered extract obtained from 8.8 above into a tared pycnometer which is large enough to hold all the extract and any solvent needed to wash clean any devices, etc., used in the transfer process. Fill any remaining unused volume in the pycnometer with additional solvent. Weigh the pycnometer and its contents after it has been brought to a constant temperature of 77°F , at which temperature the exact volume of the flask, and hence its contents, is known. Subtract mass of tared pycnometer and record the difference as the mass of the filtered extract, W_6 .

11. CALCULATIONS FOR SULFUR CONTENT (S/A RATIO)

11.1 Calculate the combined mass of sulfur and asphalt (W_5) in the original sample:

$$W_5 = W_1 - W_2 - W_3 - W_4$$

11.2 Calculate the combined volume of sulfur and asphalt in the original sample, (V_1).

11.2.1 Using the mass (W_6) of the extract in the pycnometer as determined in 10.1:

$$V_1 = V_2 - \frac{(W_6 - W_5)}{S_1}$$

where V_1 = combined volume of sulfur and asphalt in original sample at 77° F,
 V_2 = volume of flask at 77° F,
 W_6 = mass of extract containing sulfur, asphalt, and solvent,
 W_5 = mass of sulfur and asphalt,
and S_1 = specific gravity of solvent at 77° F.

11.3 Calculate the mass of sulfur (W_7) in original sample:

$$\frac{W_7 = W_5 - V_1 S_2}{\left(1 - \frac{S_2}{S_3}\right)}$$

where S_2 = specific gravity of asphalt at 77° F,
and S_3 = specific gravity of sulfur at 77° F.

11.4 Calculate the mass of asphalt (W_8) in original sample:

$$W_8 = W_5 - W_7$$

11.5 Calculate sulfur content of binder:

$$\text{Pct sulfur content (S)} = \frac{W_7}{W_5} (100)$$

$$\text{Pct asphalt content (A)} = \frac{W_8}{W_5} (100) = 100 - S$$

11.6 Sulfur-asphalt ratio = S/A

METHOD 2

12. APPARATUS

12.1 In addition to the apparatus listed in Section 3, the following apparatus is required for Method 2:

12.1.1 Extraction apparatus, consisting of a metal container, condenser lid, and stand similar to that shown in figures B-2 and B-3.

12.1.2 Basket, for sample as shown in figure B-2. A 4.75-mm or heavier screen shall be placed in the basket to support the sample.

12.1.3 Filter Cloth* of approximately 185 mesh, placed over the 4.75-mm screen and shaped to cover the inside of the basket completely.

13. PROCEDURE

13.1 Determine the moisture content of the sample in accordance with Section 6.

13.2 Weigh 3500 to 11,000 g of sample in tared basket assembly to the nearest 1 g and place in extractor. Pour 1150 to 1250 ml of trichloroethylene over the sample. Place extractor lid tightly in place and allow water to circulate freely in top. Apply heat from either a gas burner or an electric hotplate.

13.3 Reflux the sample from 1.5 to 3 hr until all bitumen is extracted from the aggregate. Shut down the extractor after 1.5 hr and inspect the sample. Mix the sample with a trowel and continue extraction to completion.

NOTE: The sample is completely extracted when, upon inspection, no discoloration is found either on the aggregate or on the surface of the trowel which has thoroughly mixed the sample.

13.4 Drain the extract from the extractor and wash clean with fresh solvent. Combine the extract and the washings in a 2000-ml graduate. Remove sample basket, dry in air and then to constant mass on a hotplate at $110^{\circ} \pm 5^{\circ} \text{C}$ ($230^{\circ} \pm 9^{\circ} \text{F}$), then follow rest of procedure as described in Sections 8.7 through Section 11.

METHOD 3

14. APPARATUS

14.1 In addition to the apparatus listed in Section 3, the following apparatus is required for Method 3:

14.1.1 Extraction Apparatus, figure B-4, consisting of an extraction kettle of metal or borosilicate glass, fitted with a perforated basket and a condenser top. The underside of the condenser shall be covered

*A 16xx Swiss Stencil Cloth, available from the Atlas Screen Supply Co., 1733 Milwaukee Ave., Chicago 47, Ill., is suitable for this purpose.

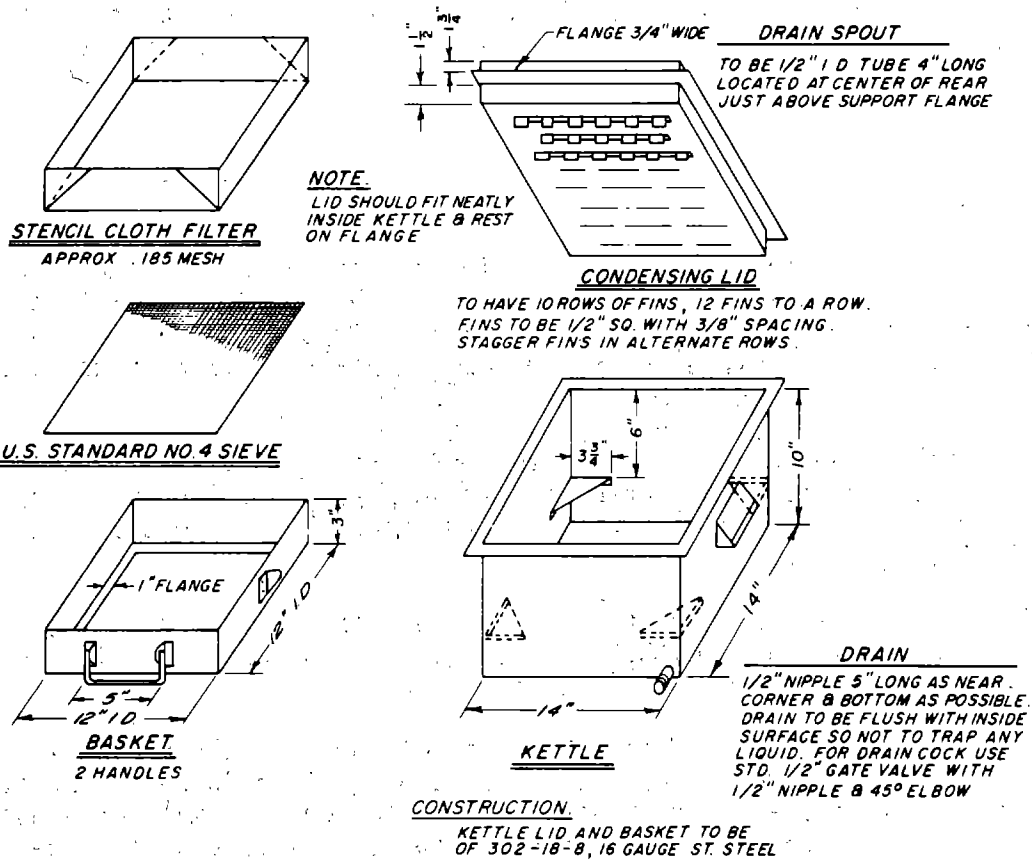
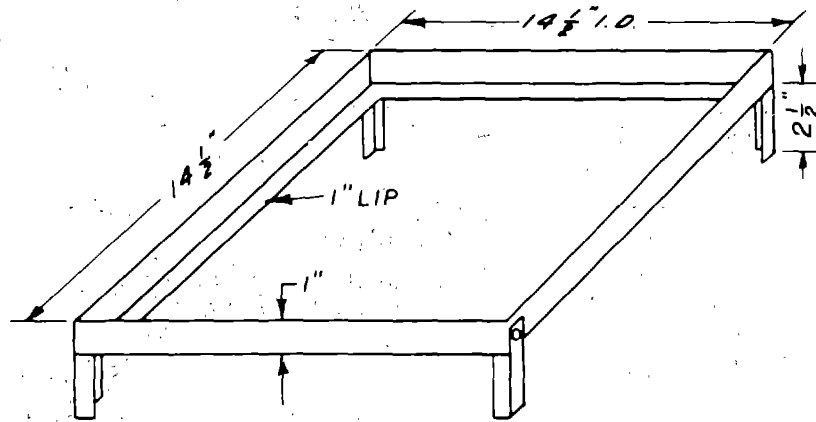


Figure B-2. - Extractor Unit

STAND MADE FROM 1" X 1" X 1/8" ANGLE IRON



FRONT LEGS FIXED WITH SINGLE PIN
TO ALLOW LEGS TO FOLD BACK WHEN
DRAINING THE EXTRACTOR.

Figure B-3. - Stand for extractor unit

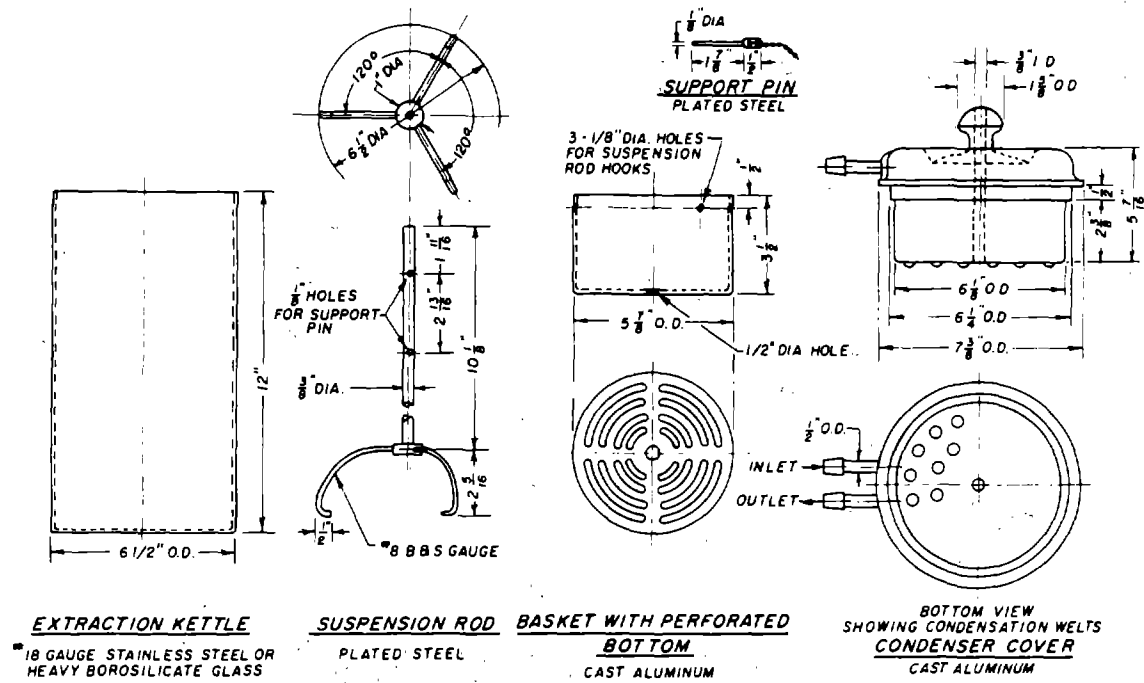


Figure B-4. - Extractor Unit

with numerous rounded knobs to distribute the condensed solvent uniformly over the surface of the sample. The suspension of the basket shall be arranged to support the basket 1/2 in (12.7 mm) above the bottom of the kettle, for immersion of sample in the solvent, and 4 in (102 mm) above the bottom of the kettle for refluxing.

14.1.2 Cloth Filter Sacks, with an elastic hem for lining the basket.

15. PROCEDURE

15.1 Determine the moisture content of the sample in accordance with Section 6.

15.2 Insert a filter sack in the extraction basket and weigh these with the tare pan to determine the total tare weight. Weigh into the filter sack a 500-g representative portion of the paving mixture if the maximum aggregate size is less than 1/2 in (12.5 mm). For larger size aggregate, use a 1000-g sample.

15.3 Attach the suspension rod to the loaded basket and set the assembly into the extraction kettle. Pour approximately 600 ml of trichloroethylene over the sample. Set the condenser cover in place on the kettle. Provide a flow of cold water through the condenser lid. Raise the basket to immersion level, for example 1/2 in above the bottom of kettle, by inserting the support pin through the upper hole of the suspension rod. Place the extractor on the hotplate and adjust the heating rate so that solvent is maintained at a gentle boil, avoiding vigorous boiling which might wash fines over sides of basket.

15.4 Continue heating with the sample in immersion position for 15 to 30 min and then raise basket to refluxing level. Increase the heat and maintain active boiling until solvent dripping from basket appears light straw in color when viewed against a white background. If a stainless steel kettle is used, lift out the basket and the condenser cover assembly for examination of the solvent.

15.5 Remove the extractor from the hotplate and allow to cool for several minutes. Lift out the basket and condenser assembly. Cover the kettle. Remove the filter sack, and distribute its contents onto the tared pan in which the sample was originally weighed. Place the filter sack and basket on top of recovered aggregate. Dry on a steam bath and then in an oven at $110^{\circ} \pm 5^{\circ} \text{C}$ ($230^{\circ} \pm 9^{\circ} \text{F}$) to constant mass. Transfer extract to 1000-ml graduate. Wash extractor clean with solvent and add washings to extract. Then follow rest of procedure as described in Section 8.7 through Section 11.

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16. Abstract Sulfur-Extended-Asphalt (SEA) binders save asphalt, a potential energy source, by replacing some asphalt in conventional flexible pavement mixes with sulfur. These new binders appear to possess properties comparable to asphalt. The guideline manual provides the highway community in both public and private organizations with the most definitive state-of-the-art guidelines extant for using these binders. Information on design, construction, quality control, equipment, mixing plants, specifications, and safety is included. Administrators and professionals in pavement construction, design, maintenance, and materials testing will be the personnel who are most interested in the manual.			
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