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Current Refining Practices for Paving Asphalt Production

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Abstract

A study titled, "Survey of Available Asphalts and Current Refinery Practices for Asphalt Production," was initiated in 1988 by The Asphalt Institute as Task B3 of Strategic Highway Research Program (SHRP) contract SHRP-87-A-001 with the University of Texas at Austin.

The study objectives were: 1) to survey the current state of the art of paving asphalt production in the United States and Canadian petroleum refining industries; and 2) to examine how refining methods and crude oil sources may affect the physical and compositional characteristics of paving asphalt. This report presents the results of the study germane to the first objective. At the time of this writing, work related to accomplishment of the second objective is continuing; these results will be reported at a later date.

This report provides an abundance of information about the production, sources, distribution and marketing of paving asphalt in the United States and Canada. Forty-one refining firms representing seventy-two asphalt refineries responded with detailed answers to a lengthy technical questionnaire. These refineries accounted for eighty-five to ninety percent of the paving asphalt produced in the United States and Canada in 1987. In addition, another thirteen independent asphalt marketing firms operating twenty asphalt terminals in the United States responded to a separate questionnaire on their distribution and marketing practices.

A general picture of the paving asphalt production industry has been drawn from this information, and the main features of the U.S. and Canadian asphalt refining industries are presented. This information was also utilized in the selection of the paving asphalts incorporated in the SHRP Materials Reference Library (MRL) at the University of Texas. The MRL provides a common set of materials for use by all the research agencies participating in the SHRP asphalt research program.

Executive Summary

A study titled, "Survey of Available Asphalts and Current Refinery Practices for Asphalt Production," was initiated in 1988 by The Asphalt Institute as Task B3 of Strategic Highway Research Program (SHRP) contract SHRP-87-A-001 with the University of Texas at Austin.

The study objectives were: 1) to survey the current state of the art of paving asphalt production in the United States and Canadian petroleum refining industries; and 2) to examine how refining methods and crude oil sources may affect the physical and compositional characteristics of paving asphalt.

This report presents the results of the study germane to the first objective, the refinery survey. At the time of this writing, work related to accomplishment of the second objective is continuing; these results will be reported at a later date.

The principal purpose for undertaking this refinery survey was to compile information on current refinery methodology as practiced on the North American continent and, if possible, to assess whether the recent changes in paving asphalt manufacture and crude oil supply influence the properties of the materials. Searching for possible sources or causes for the alleged inferior or inadequate performance of some paving asphalts was also a consideration in the study.

This refinery survey provided an abundance of information about the production, sources, distribution, and marketing of paving asphalt in the United States and Canada. Industry response to the survey must be termed as excellent: forty-one refining firms representing seventy-two asphalt refineries responded with detailed answers to a lengthy technical questionnaire. It is estimated that these refineries accounted for eighty-five to ninety percent of the paving asphalt produced in the United States and Canada in 1987. In addition, another thirteen independent asphalt marketing firms operating twenty asphalt terminals in the United States responded to a separate questionnaire on their distribution and marketing practices.

A general picture of the paving asphalt production industry has been drawn from this information. The following statements are important highlights of the results:

- Total paving asphalt tonnage produced at the seventy-two responding refineries was estimated at 27.1 million tons, or about ninety-two percent of the 1987 paving asphalt consumption (independently reported) in the United States and Canada.

- More than seventy percent of the paving asphalt reported produced in the United States and Canada in 1987 conformed to the AC-viscosity grading system (AASHTO specification M226, Tables I and II). Of this total, about sixty-five percent was produced to meet the AC-20 grade requirements.

- The well-known and long-established atmospheric and vacuum distillation petroleum refining processes, or a combination of the two, account for the majority of the paving asphalt produced in the United States and Canada.

- Solvent refining and air blowing are still of secondary importance in terms of paving asphalt production volume.

- The ROSE process appears to be the only significant new method adopted for paving asphalt production in the last decade. The use of this process is increasing.

- Integrated refineries manufacturing a wide variety of petroleum products dominate total paving asphalt production. For seventy-two percent of the responding refineries, paving asphalt production represents twenty-five percent or less of their annual crude oil throughput; for only one refinery does it represent seventy-five percent or more.

- Significant changes in the crude oils employed in paving asphalt production have occurred over the past fifteen years, and continue to occur. Alaska North Slope, Mexican, and heavy Canadian crude oils such as Peace River, Bow River, and others that were virtually unknown as sources for paving asphalts in a 1979 survey, now represent the starting materials for a very large percentage of paving asphalt production, especially at large-capacity integrated refineries. U.S. Mid-Continent and Middle Eastern crude oils significant as sources a decade ago are considerably less important now. Venezuelan crude oils still play an important role in U.S asphalt production.

- Paving asphalt is widely distributed throughout the United States from the refineries themselves, as well as through a secondary distribution system of refinery-operated and independent terminals. More than seventy percent of the individual states and Canadian provinces are served by five or more competitive sources of paving asphalt.

- Only one of the forty-one responding asphalt refining firms reported that it imported finished paving asphalt into the United States (from a source other than Canada) in 1987. By contrast, the majority of the responding independent asphalt marketing firms reported significant imports in 1987. Together with the one refining firm, these marketers account for almost forty percent of the independently reported 1987 paving asphalt imports.

- Quality control practices generally appear very stringent in all phases of paving asphalt production and distribution from refineries. While thirty-five percent of the refineries reported some specification compliance problems during the 2 years prior to the survey, the majority reported that these occurred only once or twice a year or represented a failure rate of less than 0.5 percent of the loads shipped from the refinery. Moreover, in many instances, it appeared that the specific problems arose from conditions or factors to which the asphalt was exposed after it left the refinery.

The information gathered during the course of this survey was also used in the selection of the paving asphalts incorporated in the SHRP Materials Reference Library (MRL) at the University of Texas. An important goal of the MRL is to make available to researchers in the SHRP Asphalt Program a common set of paving asphalts that represents the widest possible variety of performance histories, crude oil sources, and refining processes.

1

Introduction and Background of the Survey

Introduction

The study titled, "Survey of Available Asphalts and Current Refinery Practices for Asphalt Production," was conducted in 1988 by the Asphalt Institute as Task B3 of Strategic Highway Research Program (SHRP) contract SHRP-87-A-001 with the University of Texas at Austin.

The study objectives were as follows: 1) to survey the current state of the art of paving asphalt[1] production in petroleum refining industries in the United States and Canada; and 2) to examine how refining methods and crude oil sources may affect the physical and compositional characteristics of paving asphalt.

The information gathered during the course of this survey and study was also utilized in the selection of the paving asphalts incorporated in the SHRP Materials Reference Library (MRL) at the University of Texas. An important goal of the MRL is to make available to researchers in the SHRP asphalt research program a selection of paving asphalts that represents the widest possible variety of performance histories, crude oil sources, and refining processes.

Many petroleum refineries which produce paving asphalts intended for hot-mixed pavement construction which meet AASHTO specifications M 226, Viscosity Graded Asphalt Cement, and M 20, Penetration Graded Asphalt Cement, also produce related products, including emulsified asphalt and asphalt cutbacks used in highway construction and maintenance, and also roofing, and other industrial grades of asphalt. This study,

[1] The term "Paving Asphalt" is employed in this report to denote the viscosity or penetration-graded asphalt cement as produced at the petroleum refinery.

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however, concentrated solely on paving asphalts, and this report will discuss only these materials. In Europe and a majority of other areas, the term "bitumen" or "petroleum bitumen" is employed to identify this material. It is also anticipated that this survey of refinery practices will provide realistic background information to users and researchers of asphalt materials that will be helpful in the primary goal of the SHRP asphalt study, namely, the development of performance-based specifications for asphalt binders and asphalt paving mixtures. This, it was anticipated, would lead to more rational and economical application of bituminous materials.

An asphalt refinery survey was the principal source of information on U.S. and Canadian petroleum refining industries used in the preparation of this report. The survey was divided into three work elements:

1. A detailed technical questionnaire on refinery practice sent to each refining firm producing paving asphalt at refineries in the United States and Canada, supplemented by information from an independent questionnaire sent to firms operating as brokers or resellers for asphalt in the secondary distribution market;

2. On-site visits by the study personnel to approximately one-half of the refineries responding to the questionnaire, during which production processes and unit operations were closely scrutinized; and

3. A limited review of the current technical literature of petroleum refining with emphasis on paving asphalt manufacture.

During the course of the refinery visits, samples of current production of paving asphalt were gathered, and a comprehensive set of laboratory tests evaluated their physical and chemical characteristics. However, this report will deal only with the survey of refinery practices for paving asphalt production. A companion report, dealing with properties of paving asphalt cements sampled during the SHRP refinery survey, will present the test results on the asphalt production samples, and will discuss their correlation to relevant factors, such as the refining process and crude oil sources.

Background

Petroleum-derived paving asphalt (bitumen) is by far the most widely used binder in pavement construction. In the United States and Canada, an annual total of twenty-five million or more short tons of asphalt cement are mixed at elevated temperatures with mineral aggregates to produce on the order of 0.5 billion tons of asphalt hot-mix for paving. It is estimated that this quantity is about four times that used in Western Europe, and more than two times that employed in the entire world outside of the United States.

This great usage suggests that sizable savings could be realized from improvements in asphalt pavement technology, including improvements in paving mixture components, mixture and pavement design, and construction processes. Improvement of the characteristics of materials and better utilization of paving asphalt, principally through the development of performance-based specifications for asphalt binders and asphalt-aggregate mixtures, are the overall purposes of the SHRP asphalt research program and also of this study of refinery practices.

The physical and chemical properties of paving asphalts are determined by two factors: the compositional characteristics of the crude oil employed in their production, and the method of crude oil processing or refining. Since, in most cases, paving asphalt manufacturing processes do not appreciably change the chemical makeup of the asphaltic compounds present in the crude oil, the chemical composition of the crude oil is probably the more important factor in determining paving asphalt properties.

A great variety of crude oils is used to manufacture paving asphalt by more than eighty asphalt-producing refineries in the United States and Canada. And, in the majority of cases, crude oils are blended to optimize the production of selected petroleum products, including paving asphalts. It has been reported in the past that more than one hundred crude oil "slates" (either single crude oils or combinations of two, three, or, in a few instances, four or more crude oils) have been employed for paving asphalt manufacture.

Overall, paving asphalt represents three to four percent of total annual crude oil throughput in the United States and Canada. However, individual crude oils may vary widely in their percentage of bituminous materials; some crude oil may contain as much as eighty percent asphalt, while others contain only a trace of this material. Furthermore, it must be recognized that, besides the amount of asphalt, the physical and chemical characteristics of the crude oils and, therefore, of the bituminous materials from different sources, may vary substantially. These differences are the cause for the empirical or descriptive classifications of crude oils such as sweet, sour, paraffinic, naphthenic, and asphaltic.

The amount and composition of crude oil from different fields varied over the span of years. This prompted the development of various methods for the efficient separation and processing of different crude oil fractions varying in molecular weight and chemical makeup. These same refinery processes are used for the separation of the unaltered asphaltic (bituminous) material, a petroleum fraction composed of a variety of hydrocarbon and organic hydrocarbon-like molecules having the highest average molecular weights and the most diverse chemical composition. These chemical compounds, besides major elements of carbon and hydrogen, include variable amounts of nonmetallic elements such as sulfur, oxygen and nitrogen, and a score of metallic elements such as vanadium, nickel, and iron.

The separation of asphalt from crude is prompted by several important considerations. First, the lighter refinery products, such as petrochemical feedstocks, gasoline, distillate fuels, lubricants, and gas oils cannot tolerate contamination by the asphaltic compounds. Second, refinery processes utilizing catalytic conversions, such as catalytic cracking or catalytic hydrocracking and hydroprocessing, generally do not employ asphalt-contaminated streams because of premature and irreversible poisoning of expensive catalysts. And, finally, asphalts are needed and are indispensable for the construction of all types of pavements and for use in various roofing, waterproofing, and other industrial applications. At this point, however, it should also be recognized that, if needed, the asphaltic refinery streams could be subjected to thermal cracking, coking, or could even be used as a feed for the catalytic hydrocracking process to produce lighter hydrocarbon fractions. Such use, of course, would decrease the availability of paving asphalt, an essential engineering material for highway construction and maintenance.

The sources and characteristics of crude oil available for processing tend to change continually as new crude oil from different fields become available. Also, characteristics of crude oil even from a given field may change measurably with the continuing exploitation of that field. It is well known that within the last fifteen years, new crude oil sources, such as those from the Alaska North Slope, the Bay of Campeche region in Mexico, and Africa have been introduced and are used extensively for the manufacture of paving asphalt. Additionally, new or modified refinery processes, such as ROSE (trademark symbol, Residual Oil Supercritical Extraction) have been developed. Because of changes in crude oil and its characteristics, other refinery processes utilized in asphalt manufacture such as fractional distillation, solvent refining, and air blowing may have been significantly modified.

The main purposes and goals of this study were to determine, as fully as possible, whether the types of changes pointed out previously have had significant impact on the manufacture of paving asphalt; and, if so, what, if any, changes in paving asphalt properties were caused by these variations in crude oil and refining processes. Finally, it is anticipated that some judgment on whether these changes might be critical in regard to asphalt pavement performance could also be made. This report will attempt to address these questions.

2

Survey Methodology

The survey of asphalt refinery practices was the principal means employed to develop information on the North American asphalt refining industry. The survey consisted of four work elements:

1. A critical review of the current technical literature dealing with the production of paving asphalt in the petroleum refining industry;

2. A comprehensive and detailed questionnaire on refinery practice sent to eighty-seven known primary paving asphalt producers in the United States and Canada;

3. On-site visits to approximately one-half of the asphalt refineries responding to the survey, during which selected production processes and unit operations were intensively studied and asphalt samples obtained for the laboratory test program; and

4. A detailed, complementary questionnaire on asphalt distribution practices sent to forty-one independent asphalt suppliers (terminal operators) located in the United States.

This part of the report presents, primarily in narrative form, the results obtained from the questionnaires and refinery visits. The production of paving asphalt is described in sequential order, beginning with crude oil source and supply; progressing to the different process methods and refinery units employed in its production, storage, and transport; to the consumer; and ending with a discussion of how quality control is maintained during all phases of the process. Detailed analyses of the questionnaire responses are contained in Appendixes I and II.

Each of the four work elements described above required a different means for its accomplishment. This part relates the procedures employed for each work element, including the compilation and analysis of data.

Search of Current Technical Literature

The chemical engineering and petroleum refining technical literature for the period 1968 to the present was searched for references to the following:

1. General methods for paving asphalt production employed throughout the world;

2. The impact of new petroleum refining technology and processes on asphalt production; and

3. Correlations among asphalt properties, refining methodologies, and crude oil sources.

The search was conducted principally in the computer data bases contained in the Science and Technology Network (STN) operated in the United States by Chemical Abstracts Service, Columbus, Ohio. This network provides access to data bases operated by scientific organizations in Europe and Japan, as well as in the United States and Canada, allowing a relatively rapid review of the worldwide technical literature.

STN is accessed through a personal computer and modem, and an on-line search and retrieval is made in each data base of interest through the use of a series of search terms or key words, which are matched by the network with words and phrases in the titles and abstracts of articles contained in the data bases.

Two or more search terms may be concatenated to facilitate the location of references with very specific subject matter, or a search term may be narrowed by joining several terms with "NOT" connectors. Alternatively, the search may be directed by reference to specific authors, chemical compounds, or technical journals. Searches may also be limited to specific periods of time and specific data bases.

Complete bibliographical information, including detailed abstracts on selected references may be captured in a computer file or printed out as the search progresses. Some data bases contain the complete texts of the references which may be scrolled through on the computer monitor.

The following data bases contained in STN were searched as part of this work element: the American Chemical Society Chemical Abstracts (STN filenames CA and CAOLD); the American Petroleum Institute technical literature data base (APILIT); Chemical Hazards in Industry (CHI); Dechema Chemical Engineering and Biotechnology Abstracts Data Bank (DECHEMA); and the Computerized Engineering Index (COMPENDEX). Table I presents the search terms employed to identify pertinent references contained in the STN data bases.

Technical references identified through the on-line search of STN were reviewed at the Engineering and Physical Sciences Libraries of the University of Maryland system, the American Petroleum Institute library located in Washington, D.C., and the library of the Asphalt Institute at College Park, Maryland (presently located in Lexington, Kentucky). In addition, several technical monographs, texts, and articles not identified through the computer search were "manually" located and reviewed in these libraries.

A bibliography of references so identified and subsequently employed in the preparation of this report is presented in Chapter 10 of this report. It must be noted, however, that the search turned up relatively little of importance in terms of new processes, relationships of crude oil sources to properties and performance, and so on.

TABLE I. TERMS EMPLOYED IN ON-LINE SEARCH OF STN DATA BASES

The main answer set was defined by search term 1. All other search terms were applied to answer set 1 to generate subsidiary, more specific answer sets in each data base searched.

1. (Asphalt or Bitumen) not roofing not patent
2. (Manufacture or production) or petroleum refining
3. Visbreaking or coking or hydrorefining or air blowing
4. Steam distillation or straight run or thermal cracking
5. Vacuum distillation or oxidation or solvent precipitation
6. Propane (Extraction or Deasphalting) or PDA or fractionation

Survey Questionnaires

Two survey questionnaires were prepared and distributed: a refinery survey and a survey of independent asphalt terminal operators. Their purpose was to gather timely, factual data from which to form a detailed picture of the paving asphalt production and distribution systems in the United States and Canada.

The first questionnaire was intended for firms that are primary producers of asphalt cement, for example, those which produce paving asphalt from crude oil; the second for firms that operate independent distribution terminals for asphalt, for example, those not affiliated with primary producing firms.

The refinery survey questionnaire was developed in two parts, and both parts are presented in Appendix I. Part A, GENERAL INFORMATION, was intended to elicit information from each responding firm on the following topics:

1. The location and general operating characteristics of each asphalt refinery;
2. Asphalt marketing patterns of refinery, including exchanges and imports.

Each responding firm was asked to complete Part B of the questionnaire, REFINERY OPERATIONS, for each of its active asphalt refineries. Part B deals with the technical aspects of asphalt production and distribution, including information on crude oil slates, production processes, blending, quality control, storage, and transport.

Insofar as possible, the questions in each part were presented in multiple choice format, both to encourage complete responses, and to make the responses amenable to descriptive statistical analysis. However, where a multiple choice response was inappropriate, sufficient space was provided for a narrative response or, in the case of Question 9 in Part B, space was provided for a production process diagram or flow chart.

The initial mailing list for the refinery surveys was developed from the membership list of the Asphalt Institute and from the list of nonmember asphalt-producing firms that participated in the annual Asphalt Institute survey of paving asphalt supply and demand. Additional potential respondents were identified from the entries for United States and Canadian petroleum refiners in the Midwest Oil Register and the annual refining survey issue of the Oil and Gas Journal.

Each firm was mailed a single Part A and sufficient copies of Part B to accommodate the number of asphalt refineries that it operates. The accompanying instructions urged a complete response to all applicable questions; however, partial responses were acceptable and encouraged whenever the marketing policy of a particular firm would not permit specific information to be divulged.

To maintain the strict confidentiality of the responses, neither part contains an entry for the name of the firm, and all parts are coded with a five-digit random number used exclusively for identification throughout the survey process. A single computer file, requiring a password for access known only to the two Asphalt Institute staff members responsible for the survey, contained the code numbers employed for each firm. Pre-addressed Asphalt Institute envelopes were provided for return of the completed survey questionnaires.

Answers from completed surveys were entered into a computer data base written with the dBASE III+ program. All entries in the data base were coded with the five-digit code numbers discussed above, so that the complete data base presents a composite picture of asphalt refining in the United States and Canada, without reference to any of the specific firms engaged in asphalt production.

Parts A and B of the independent asphalt supplier survey (marketer or broker) questionnaire are presented in Appendix II. As may be seen, both parts were adapted from the refinery survey questionnaire to elicit general information on the following:

1. The location and general operating characteristics of each firm's asphalt terminals;

2. Asphalt marketing patterns including exchanges and imports; and

3. The technical aspects of asphalt distribution, including blending, quality control, storage, and transport.

The mailing list for the asphalt marketer survey was compiled from two sources. The seventeen district engineers of the Asphalt Institute provided a list of marketers distributing asphalt in their respective areas of the United States. This list was supplemented by those firms identified in the refinery survey responses as major customers of the asphalt refineries.

Marketer survey questionnaires were similarly coded with five-digit random numbers to protect the confidentiality of the responses. All answers from completed surveys were entered into data bases written with the dBASE III+ program to facilitate further analysis.

Refinery Visits

Visits were made to thirty-six refineries, including thirty-one in the United States, four in Canada, and one in Venezuela. Thirty-three of these refineries responded to the survey.

Each visit served three main purposes:

1. To discuss with refinery personnel the details of asphalt production at the refinery, including crude oil selection and variability, process and quality control operations. and marketing and distribution;

2. To view all process units employed for asphalt production, as well as quality control laboratories, storage and blending tanks, and transport loading facilities; and

3. To arrange for sampling of the primary and, if available, secondary grades of asphalt produced at the refinery for inclusion in the laboratory testing program.

Selection criteria for the refinery visits were several:

1. Need to obtain asphalt samples produced from a large variety of crude oils;

2. Diversity of size and geographical location of refinery;

3. Detailed examination of all types of asphalt production processes, including air blowing and solvent refining; and

4. Sampling of asphalts from refineries which have been included in earlier studies of this type.

Generally, the duration of refinery visits was of three to four hours, depending upon the size of the refinery and the complexity of the asphalt production process. In all cases, arrangements for the visits were made in advance, principally through the contact persons listed in the survey questionnaire responses.

Detailed notes were taken during each visit, with particular attention to recording the operational parameters (temperature, pressure, and so on) of the process units; the crude slate employed for the sampled asphalts; distribution and marketing patterns; specification-related problems; and any factors peculiar to asphalt production at the refinery. This information was employed to supplement and enhance the discussion of the survey responses presented in following sections of the report.

3

Asphalt Refinery Statistics

Refinery Statistical Data

The discussion in this section is principally based upon the data obtained through the refinery survey questionnaires, complemented and supported by information acquired during the refinery visits. Responses were obtained from forty-one refining firms; four other firms indicated they no longer produce asphalt cement. A general picture of paving asphalt production was developed from the survey responses of seventy-two asphalt refineries in the United States and Canada.

Refinery survey questionnaires were sent to eighty-seven U.S. and Canadian firms that were known or believed to produce paving asphalt cement. Of these eighty-seven firms, forty-one replied with completed questionnaires, giving detailed data on seventy-two refineries that were producing paving asphalt cement at the time of the survey. An additional sixteen firms replied that they did not produce paving asphalt cement at the current time. The remaining thirty firms did not respond in any fashion.

A general picture of paving asphalt production was developed from the survey responses of seventy-two asphalt refineries in the United States and Canada. As discussed in greater detail below, it is estimated that these seventy-two refineries represent between eighty-five and ninety percent of all paving asphalt produced in North America in 1987, excluding domestic Mexican production. Approximately ten to fifteen of the thirty nonresponding firms are thought to have produced paving asphalt in 1987; the majority of these are small-capacity refineries that market in their immediate geographical areas.

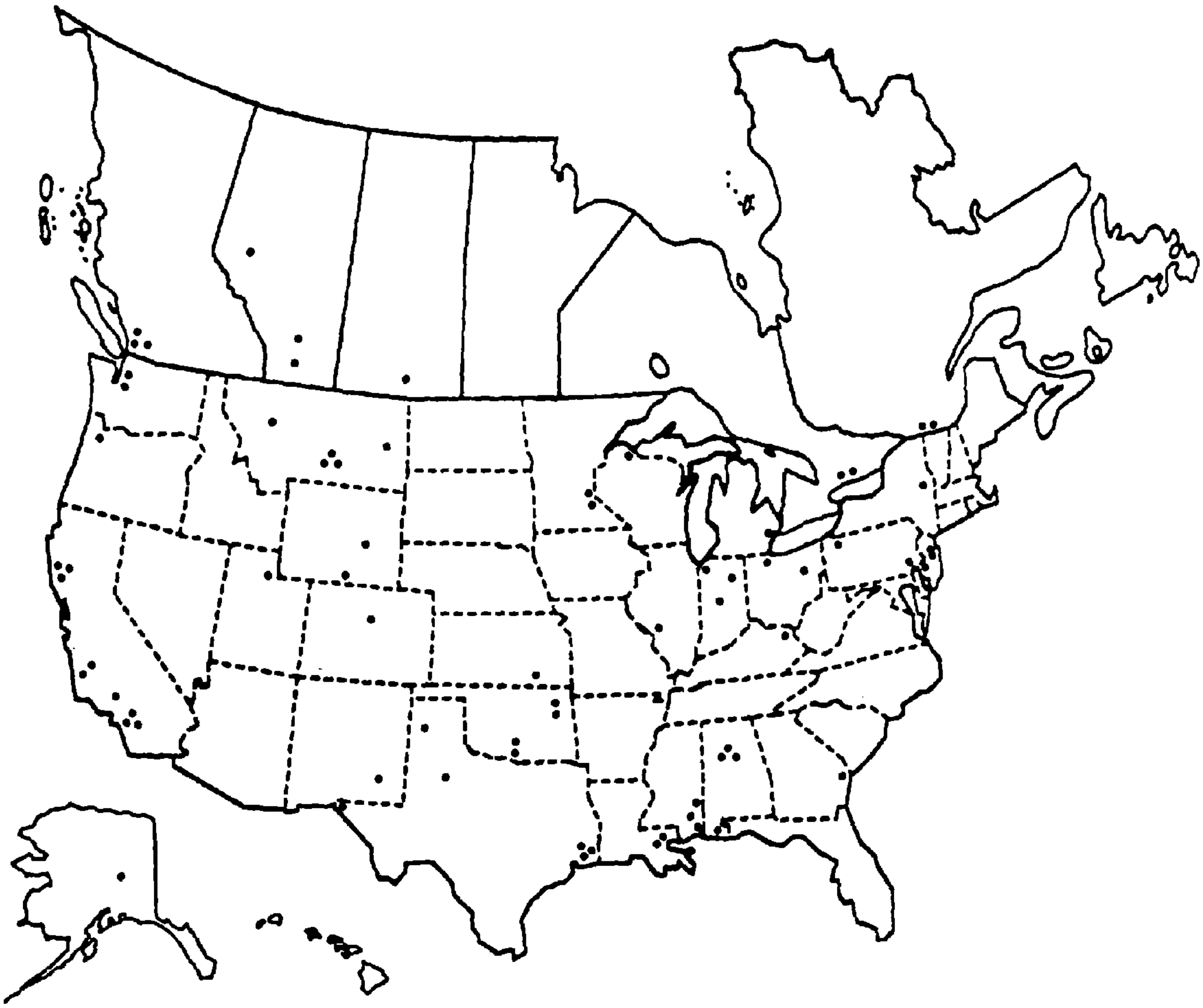

Figure 1. Geographical Location of Refineries Responding to the SHRP Refinery Survey Questionnaire.

Geographical Distribution

The approximate geographical locations of the seventy-two refineries responding to the refinery survey are shown in Figure 1.

In the United States, these are clustered in important crude oil-producing regions, for example, Alaska, California, the Rocky Mountain states, the Gulf Coast region, and the Texas-Oklahoma area. Alternatively, the refiners are located in areas with high population density, such as the upper Midwest, where crude oil is predominately supplied either by pipeline from oil-producing regions, or the Middle Atlantic region where it is imported by tanker from Mexico, Venezuela and, to a lesser extent, the Middle East.

The responding Canadian refineries are generally located close to the border with the United States. They also are grouped in either the western oil-producing provinces or in the population centers of Ontario and Quebec.

Crude Oil Throughput and Asphalt Output

Asphalt is produced in two types of petroleum refineries:

1. *Integrated refineries* are operated primarily to produce transportation and heating fuels in large volumes, as well as petrochemical feedstocks. For such refineries, asphalt represents a small percentage of the total crude throughput;

2. *Asphalt refineries* at which asphalt is the major or the primary product, and which produce relatively small volumes of blending components for transportation and heating fuels and petrochemical feedstocks.

This division of function is usually, but not always, reflected in the size of the refineries. Integrated refineries tend to have daily crude oil throughputs of hundreds of thousands of barrels. For comparison, 100,000 barrels of crude oil is equivalent to more than four million gallons of gasoline, or about 18,000 short tons of paving asphalt. Asphalt refineries commonly are small- or medium-size facilities with crude oil throughputs less than 50,000 barrels per day (bpd).

Figure 2 presents the breakout of crude oil throughput of the responding refineries. Total estimated throughput of the responding United States refineries from the data in Appendix I was 4,937,000 bpd, while that for Canadian refineries was 548,000 bpd.

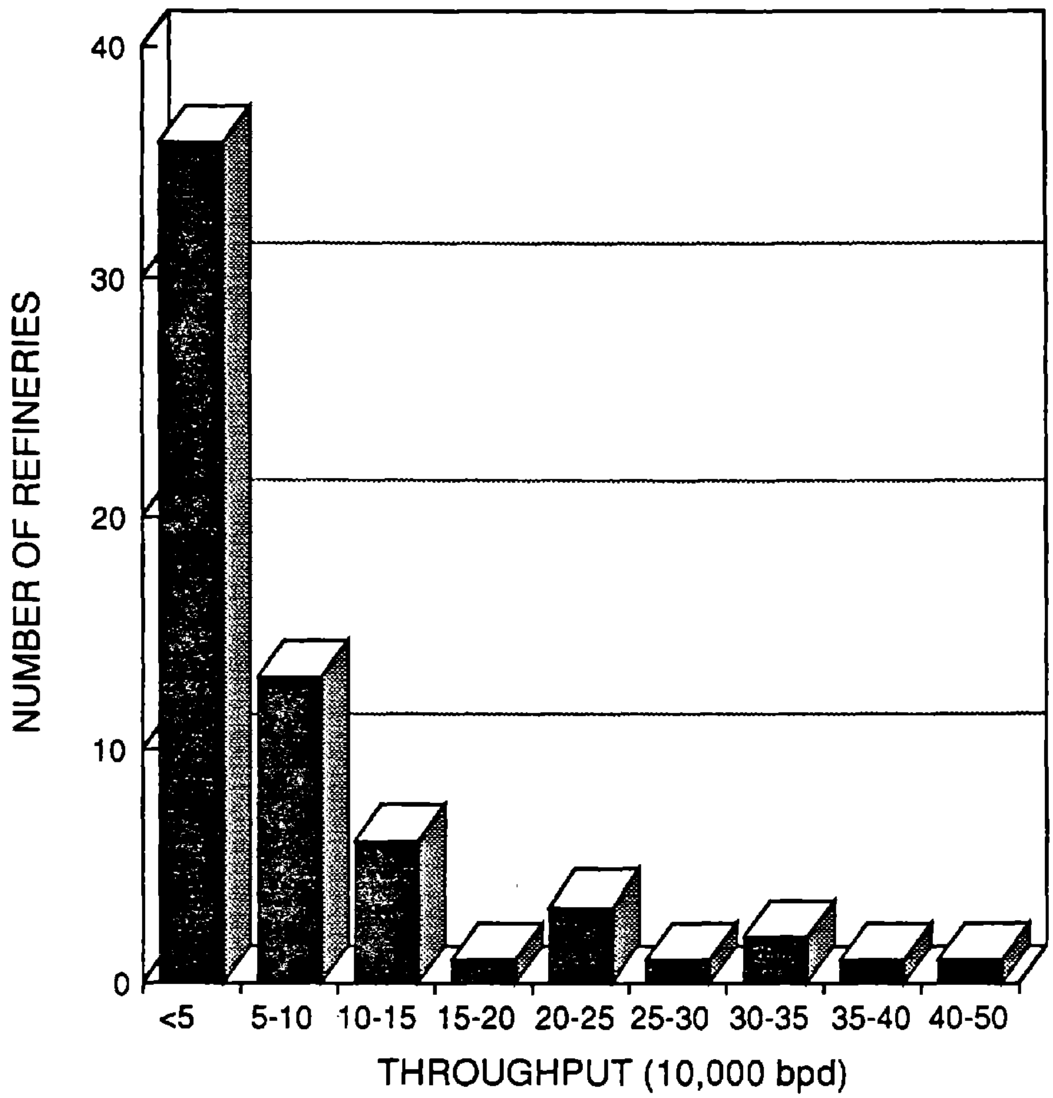

Figure 2. Crude Oil Throughput of Refineries Responding to the SHRP Refinery Survey Questionnaire.

Fifty-six percent of the refineries have a crude oil throughput of 50,000 bpd or less. Twenty-four percent had throughputs greater than 100,000 bpd, while fourteen percent had the capacity to process more than 200,000 bpd of crude oil. By comparison, the Oil and Gas Journal[2] annual United States refinery survey lists twelve percent (23 of 188) of refineries with a crude oil throughput of greater than 200,000 bpd and forty-eight percent (90 of 188) capable of handling no more than 50,000 bpd.

Figure 3 presents the distribution of asphalt production capacity[3] among the responding refineries. Approximately one-half of the refineries had a capacity of 1,000 tons per day (tpd) or less while only fifteen percent could produce more than 5,000 tpd.

Total capacity in 1987 for these refineries was estimated from the data in Appendix I at 149,000 tons per day or about 53,640,000 tons per standard (360-day) year (tpy). This estimate for the United States and Canada combined compares favorably with the total United States asphalt production capacity of 49,365,000 tpy contained in the latest Oil and Gas Journal U.S. refinery survey.

When these two categories of data are compared, it is found that the annual asphalt production capacity of fifty-three million tons represents approximately fifteen percent of the crude oil throughput of the responding refineries. This is in contrast to a value of approximately 4.7 percent for the U.S. refining industry as a whole, and suggests that the responding refineries tend to specialize in asphalt production.

In this regard, specific data were solicited to compare the actual asphalt production at each refinery as a percentage of its crude oil throughput. Seventy-two percent reported that asphalt represents twenty-five percent or less of their annual crude oil throughput. Only one percent reported that paving asphalt production accounted for seventy-five percent or more of their throughput.

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[2] Oil and Gas Journal, March 20, 1989, p. 68ff.

[3] The term "capacity" denotes the practical upper limit to daily production of asphalt (or another petroleum product) at the refinery. It is based upon operation of all process units at their maximum rates. In practice, refineries will run at seventy to ninety percent of their capacity, based on factors such as seasonal product demands, maintenance downtime, etc.

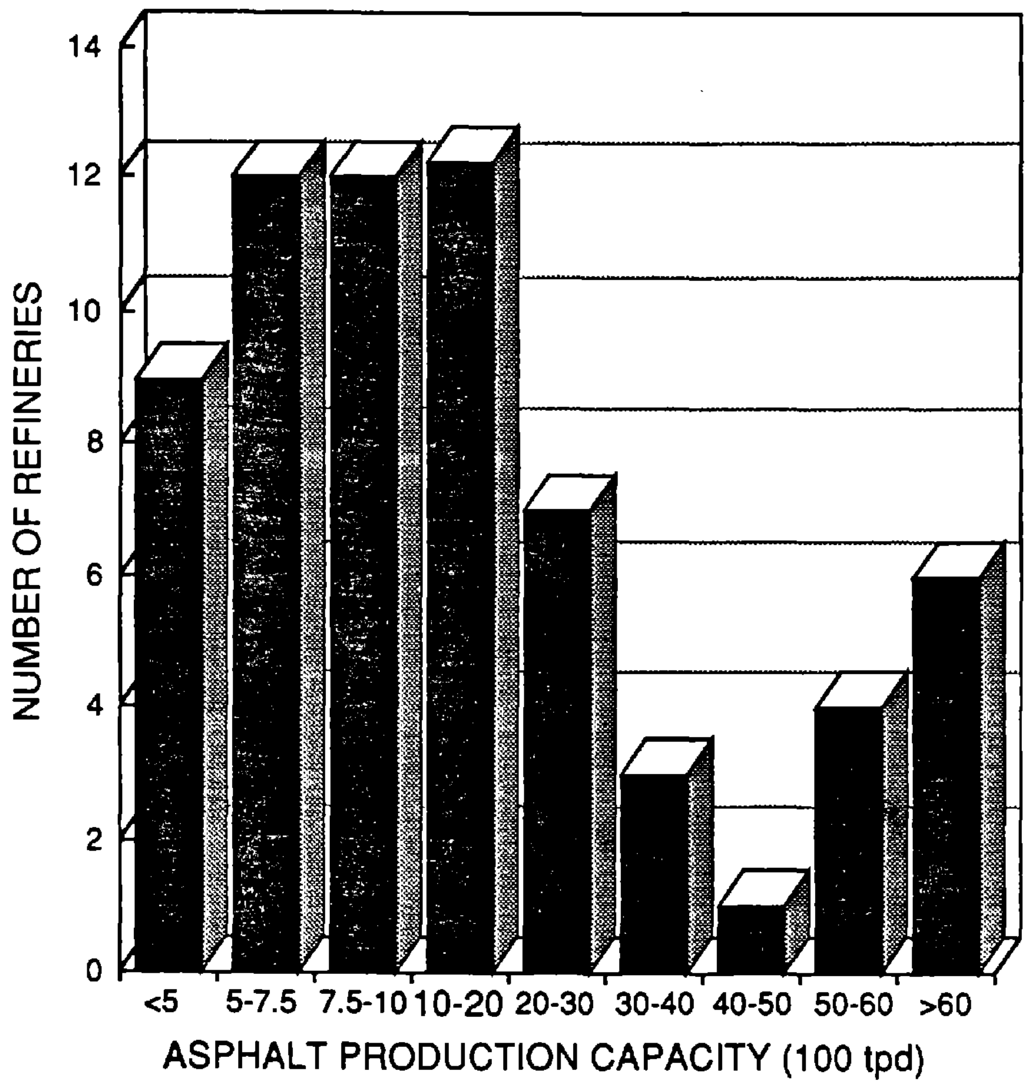

Figure 3. Paving Asphalt Production Capacity of Refineries Responding to the SHRP Refinery Survey Questionnaire.

Asphalt Production Volume, 1987 and Earlier

Table II presents the actual asphalt production of the responding refineries in the years 1985, 1986, and 1987.

TABLE II. REPORTED ASPHALT PRODUCTION

	NUMBER OF REFINERIES IN		
TONS PER YEAR	1985	1986	1987
<200,000	31	33	29
200,000-1,000,000	31	30	34
1,000,000-1,500,000	3	3	3
>1,500,000	2	2	2

These data suggest that actual asphalt production increased slightly over the period 1985 to 1987, with a net increase in refineries producing in the range 200,000 to 1,000,000 tons per year compared to those in the <200,000 tons per year range. This trend is commensurate with the 4.7 percent increase of asphalt cement usage reported by the Asphalt Institute for this period[4].

A production level of 1,000,000 tons per year is equivalent to an average daily production of about 2,800 tpd. Although fourteen refineries reported that asphalt production capacity greater than 3,000 tpd, only five refineries operated at or above this level in the period 1985-1987. By comparison, in 1987, twenty-nine refineries produced less than 200,000 tons or 550 tpd, although only nine refineries were limited to a production capacity at or below this level.

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[4] Asphalt Usage, 1987, United States and Canada, The Asphalt Institute, College Park, Maryland, April 1988.

Distribution of Asphalt Grades

Table III presents the actual tonnage of all specification grade paving asphalt cements produced in 1987 by the responding refineries. (As indicated in Appendix I, fifty-eight of seventy-two refineries answered this question in detail.)

TABLE III. SPECIFICATION-GRADE PAVING ASPHALT PRODUCED IN 1987

GRADE	AMOUNT (TONS)	GRADE	AMOUNT (TONS)
AC-2.5	335,524	AC-5	633,011
AC-10	1,963,739	AC-20	8,962,446
AC-30	1,817,222	AC-40	45,850
	TOTAL FOR AC-GRADED ASPHALTS:		13,757,792
AR-1000	30,560	AR-2000	26,348
AR-4000	1,332,459	AR-8000	420,484
AR-16000	6,477		
	TOTAL FOR AR-GRADED ASPHALTS:		1,816,328
40-50	9,000	60-70	109,301
85-100	1,467,216	120-150	1,140,289
150-200	202,850	200-300	151,222
	TOTAL FOR PEN-GRADED ASPHALTS:		3,079,878

Total reported asphalt tonnage produced in 1987 was 18,653,998 tons. Of this total, seventy-four percent were AC-viscosity graded (AASHTO M226, Tables I and II), ten percent were AR-viscosity graded (AASHTO M226, Table III), and the remainder, sixteen percent, were produced to the penetration grading system (AASHTO M20).

AC-20 viscosity-graded asphalt is the most common grade used; it represents forty-eight percent of the reported production in 1987. The most common Table III grade is AR-4,000 which represents seventy-three percent of the total AR-graded production, but only seven percent of the total reported 1987 production. In the case of penetration-grade asphalt cement, 85-100 was the most commonly used grade.

The viscosity grading (AC) system for paving asphalts is employed by thirty-five states and the District of Columbia. The Rolling Thin Film Oven residue viscosity-grading (AR) system is employed only by California, Nevada, Oregon, and Washington. The penetration grading system is used by four states and all the Canadian provinces. Seven states employ both the viscosity-grading and the penetration-grading systems.

Twenty-three refineries also reported production of special grades of asphalt in 1987. These generally represent the following:

1. Grades not common to the geographical area where the refinery is located or in which its products are distributed;

2. Grades produced to state or other specifications not covered by the standard AASHTO or ASTM specifications; and

3. Modified asphalts.

Total reported production of these special grades was 1,684,095 tons. The special grades of unmodified asphalts reported were as follows: AC-3, AC-3.5, AC-7.5, AC-8, and AC-15; AR-2000W and AR-4000W, specified by the state of Washington; AR-6000; HMA-1, specified by the state of Florida for recycling; and 150, 65-80, 80-90 and 110-160. The reasons for use of these special grades were not entirely clear in most cases.

Combining these specific data with the reported 1987 production ranges for the fourteen refineries that did not answer this question (refinery survey Part B, Question 12), total unmodified paving asphalt production for 1987 by all seventy-two refineries was estimated at 27.1 million tons, or about fifty percent of the available production capacity. Moreover, this total represents approximately ninety-two percent of the total asphalt consumption of 29.5 million tons reported for the United States and Canada in 1987 by the Asphalt Institute[5].

[5] Ibid., p. 17.

4

Crude Oils Employed for Asphalt Production

Introduction

One of the primary goals of the refinery survey was the identification of the crude oil types and streams employed in the United States and Canada for asphalt production. The SHRP asphalt program is particularly concerned with the elucidation of relationships between the physicochemical properties of asphalt and its performance in asphalt-aggregate mixtures and, ultimately, pavements. The crude oil(s) from which the asphalt is produced is a prime determinant of its chemical composition and behavior. As mentioned previously, the processes employed in most refineries for asphalt production do not induce chemical changes in those crude oil components, which after refining constitute asphalt cement. An exception to this is the air-blowing process which, in general, is used sparingly.

Crude oil is produced on every continent except Antarctica. Approximately 30,000 oilfields with the potential to produce "commercial" quantities of crude oil have been discovered in different parts of the world in the past century. Of these, 26,000 are located in the United States and 1,500 in the U.S.S.R.[6]. The number of oilfields actually in production at present is considerably smaller, however. On a worldwide basis in 1981 and 1982, there were only 1,500 oilfields producing at the rate of 1,000 bpd or more, and only seventy (of which twenty-five were located in the Middle East) producing more than 100,000 bpd. However, even this smaller number is sufficient to complicate attempts to relate crude oil type to asphalt types and behavior.

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[6] E.N. Tiratsoo, "Oilfields of the World," 3rd Edition, Gulf Publishing Co., Houston, Texas, 1986, p. 20.

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Crude oils are commonly classified into four types on the basis of their gross chemical composition: light paraffinic, paraffin-naphthenic, naphthenic, and aromatic. Generally, naphthenic and aromatic crude oils contain significant amounts of asphalt, and so crude oils of these types are favored for asphalt production. They also are the least likely to contain high levels of paraffin waxes which are undesirable in crude oils selected for asphalt production. Moreover, crude oils favored for asphalt production may generally be described as "heavy," that is, they will have American Petroleum Institute (API) gravities in the range of ten to twenty, and in many cases they will be "sour," containing a relatively high mass percent of sulfur-containing compounds. Light, sweet crudes are ideally suited for the refining of transportation fuels so they command premium prices on the world market, but their availability has steadily declined over the last two decades. Because of this, the general trend is to use "heavier" crudes, even for the production of lighter products.

The selection of crude oils by any refinery will always be governed by economic factors. The majority of refineries are "integrated" and produce a wide range of fuels and other petroleum products. These refineries will typically utilize a blend of crude oils that allows the supply of all products, including asphalt, to be maintained in balance with their demand at the lowest unit cost. The smaller number of refineries that produce asphalt as their primary product may have the ability to use a narrower range of crude oils, or even a single crude oil which is particularly suited for asphalt production. Even in these cases, final selection must meet severe economic tests.

Frequency of Crude Oil Use

It would be ideal if only a limited set of crude oils chosen for their well-defined composition and behavior could be employed for asphalt production, but this is seldom possible. Generally, a refinery will have access to a number of crude oils which may be used in several different combinations, depending on their relative cost at any point in time and on specific product demand. These facts imply that the number of crude oils used for asphalt production will be large and variable in proportion, making the investigation of relationships between their physical and chemical properties and asphalt pavement performance difficult.

The seventy-two refineries that responded to the refinery survey identified 123 individual crude oils that were available for use in asphalt production in early 1988. Table IV presents the name of each identified crude oil, the number of refineries that reported its use and, where appropriate, its reported blending range for asphalt manufacture. In preparing the survey, it was recognized that many refineries, because of product demand, change their crude oil slates or feed on a regular basis. The survey questionnaire (see Appendix I) was structured to elicit information on the most probable slates which might be

TABLE IV. CRUDE OILS EMPLOYED IN ASPHALT PRODUCTION IN THE UNITED STATES AND CANADA

CRUDE OIL	NO. OF REFINERIES	BLENDING RANGE (%)
Alaska North Slope	11	20-65
Amdel Sour	1	1
Amoco Pipeline	1	6
Arabian Heavy (Saudi Arabia)	5	20-100
Arabian Light (Saudi Arabia)	2	25-50
Bachaquero (Venezuela)	4	5-26
Baxterville (Mississippi)	2	
BCF-17 (Venezuela)	1	36
BCF-21 (Venezuela)	1	
Belridge Light (SJV[1])	1	24
Bonanza	1	
Boscan (Venezuela)	3	25-50
Boundary Lake (Canada)	3	95
Bow River (Canada)	8	60
Byron Garland (Wyoming)	1	
B-West	1	
C	1	
Canadian	1	
Canadian Light and Heavy Sour	3	
Canadian Mixed Sweet	1	
Canadian Sweet	2	
Cat Canyon (California Coastal)	1	
Central Montana Sour	1	
Chauvin (Canada)	1	
Circle Ridge	1	
Coalinga (SJV)	1	15
Coastal Mix	1	
Cold Lake (Canada)	10	50-70
Cottonwood (Wyoming)	1	
Cushing Pipeline (Oklahoma)	1	

TABLE IV. (CONTINUED)

CRUDE OIL	NO. OF REFINERIES	BLENDING RANGE (%)
Cymric Heavy (SJV)	1	20
Donkey Creek General Sour	1	
East Howard	1	24
Elk Basin Heavy (Wyoming)	1	
Elk Hills (SJV)	3	50-60
Elwood (California Coastal)	3	10-40
Escalante	1	
Frannie/Elk Basin (Wyoming)	1	
Grass Creek (Wyoming)	1	
Gulf Alberta (Canada)	1	
Halsey Canyon	1	10
Hawkins (Texas)	1	30
Heidelberg (Mississippi)	1	
Hondo (Ventura Basin Offshore)	4	10-80
Howard Glasscock (Texas)	1	35
Illinois Basin	2	15
Isthmus (Mexico)	3	25-50
Kansas/Oklahoma Local	1	
Kern Ridge (SJV)	1	88
Kern River (SJV)	2	27
Kirkuk (Iraq)	1	20
KLM CA (SJV)	1	12
Lagotreco	1	
Lagunillas (Venezuela)	1	
Leona (Venezuela)	1	
Light Sour Blend	1	
Lloydminster (Canada)	8	
Local Sweet (Oklahoma-Kansas)	1	11
Louisiana Sweet Light	1	30
Manyberries (Canada)	1	30
Maya (Mexico)	12	5-80
Menemota	2	
Merey (Venezuela)	1	

TABLE IV. (CONTINUED)

CRUDE OIL	NO. OF REFINERIES	BLENDING RANGE (%)
Mesa Semi	1	29
Mexican	2	
Michigan Heavy/Cass City	1	
Michigan Sweet	1	
Middle East	2	
Midway-Sunset (SJV)	2	15
Milk River	1	10
Mixed Blend Sour	1	
Montana Mix	1	30
Mount Poso (SJV)	1	85
Myton	1	9
New Mexico/West Texas Sour	1	
North Dakota Sour	2	
NW Montana/Central Montana	2	
Oklahoma Domestic	1	
Oklahoma Mixed	1	
Oklahoma Select	1	
Oregon Basin (Wyoming)	1	
Peace River (Canada)	5	5
Pilon (Venezuela)	3	35
Placerita Canyon Heavy	1	10
Rangeland (Canada)	2	
Rangely (Colorado)	1	71
Raspo Mare (Italy)	1	
Red Wash (Utah)	1	13
Redwater (Canada)	1	
Rimbey Condensate (Canada)*	1	15
San Ardo (Central CA Basin)	1	
San Joaquin Valley (California)	6	5-80
Santa Maria (California Coastal)	2	

*Natural gas liquid

TABLE IV. (CONTINUED)

CRUDE OIL	NO. OF REFINERIES	BLENDING RANGE (%)
Signa Special (SJV)	1	
Slick Creek	1	
South Alabama	1	
South Carlton	1	
South Kaybob Condensate (Canada)*	1	15
South Mississippi Heavy Sour	1	
South Saskatchewan (Canada)	1	
Southwest Wyoming Sweet	1	
Stevens	1	14
Stockbridge	1	
Sunniland (Florida)	1	36
Sweet Oklahoma Mix	1	
Synthetic Crude	1	
Texas Panhandle	1	
Tia Juana Pesado (Venezuela)	1	
Torchlight (Wyoming)	1	
Trinidad	1	
Vacuum Field Sour (New Mexico)	1	
Venezuelan	1	
Ventura Mix (Ventura Basin)	1	10
West Texas Intermediate	6	55
West Texas Mixed Sour	1	25-65
West Texas Sour	3	50
Wilmington (Los Angeles Basin)	2	5
Wynot	1	
Wyoming	1	25
Wyoming Asphalt Sour	1	
Wyoming Sour	2	
Y (Casper)	1	
Y (Freeman)	1	

*SJV = San Joaquin Valley (California)

employed during the year, rather than the crude oil or slate in use at the time the survey response was prepared. Conversely, many refineries employ a rather stable crude oil slate, and their response would clearly indicate this fact.

As may be noted in Table IV, the majority (sixty-nine percent) of the identified crude oils are from oilfields in the United States. Canadian and Venezuelan oilfields represent the source of another fourteen and nine percent, respectively. The remaining crude oils (eight percent) are from oilfields in the Middle East, Mexico, Trinidad, and Europe.

Fifteen of the seventy-two refineries reported that they employ the Universal Oil Products (UOP) K factor[7] to characterize crude oils. The mean K factor reported in the survey was 11.7 with a standard deviation of 2.0. This indicates that for asphalt production the crude oils tend on average to be naphthenic in character.

Of the 123 identified crude oils, the majority are employed by only one or two refineries in the United States and Canada. However, there are eight crudes which are very widely used, and these are presented in Table V. Taken together, these eight appear seventy-five times in survey responses as either single crude oils or as components of crude oil blends used in asphalt production. On a regional basis, Alaska North Slope (ANS) and San Joaquin Valley (SJV) crude oils are employed by refineries primarily in the western United States; Maya and West Texas Intermediate are used extensively in the Midwest and Gulf Coast areas. The four Canadian crude oils are used largely in the upper Midwest and Canada.

TABLE V. CRUDE OILS MOST FREQUENTLY EMPLOYED IN ASPHALT PRODUCTION

CRUDE OIL	NO. OF REFINERIES
Alaska North Slope	11
Arabian Heavy	5
Bow River	8
Cold Lake	10
Lloydminster	8
Maya	12
Peace River	5
San Joaquin Valley	20
West Texas Intermediate	6

[7] A factor, K, is used to characterize (crude) oils. It is a ratio of the cube root of average boiling point T_B (°R) to a specific gravity at 60°F. $K = T_b /$ Sp Gr at 60°F.

The survey was not structured to elicit information on the volume of each crude oil utilized for asphalt production. However, the responses did allow each refinery's asphalt production to be categorized. Using this information, the crude oils employed by the fourteen largest refineries, those with an asphalt production capacity of 3,000 tons per day or greater, were segregated, and are presented in Table VI with the number of these refineries using each crude oil. All were used as components of crude oil slates rather than a single crude oil. Maya crude oil is employed by seven of these large refineries, while three each use Alaska North Slope, Arabian Heavy, Bachaquero, and Boscan. On this basis, it may be deduced that these five crude oils represent important components of a large amount of the asphalt produced in the United States and Canada.

It must be recognized that named crude oils in many instances represent the combined output of several distinct oilfields gathered together for transport to markets. For example, Alaska North Slope crude oil represents the output of several oilfields in the Prudhoe Bay area of Alaska which is transported to market via the Alyeska pipeline. The term "San Joaquin Valley" may represent crude oil from a single oilfield in the San Joaquin Valley of California, that is, Midway Sunset, Belridge, or Elk Hills, but it may also represent a pipeline blend of crude oils from several different oilfields in this large geographical area.

Similarly, the important Mexican crude oil designated as Maya is representative of the combined output of the Reforma fields located offshore of Tabasco State in the Bay of Campeche. In such cases, it is expected that the properties of the crude oil will change with time as the production of older oilfields decline and new fields come on stream. Also, seasonal variation in properties will occur with the heavy crudes such as the Maya used for asphalt production; in the winter, pipelines will blend substantial amounts of lighter crude in with the heavy material in order to maintain its pumpability at low or even ambient temperatures.

On the other hand, there are several crude oils used for asphalt production which represent the stable, well-defined output of a single oilfield which has been in production for many years. Good examples of this situation are several well-known California oilfields including Wilmington, Midway Sunset, and Cat Canyon, as well as oilfields such as Baxterville and Heidelberg in Mississippi.

Use of Single Crudes

For a researcher, the ideal situation in which to study the effect of crude oil source on asphalt properties is that of the refinery that employs a single crude oil for asphalt production. Survey responses indicate that in practice this is the exception rather than the rule.

Of the seventy-two refineries responding to the survey, only eighteen reported the use of a single crude oil for asphalt production. Table VII presents the single crude oils so identified and the number of refineries which employed each. Of these crude oils, only Alaska North Slope and Lloydminster were crude oil utilized by more than one refinery.

TABLE VI. CRUDE OILS USED BY REFINERIES WITH ASPHALT PRODUCTION CAPACITY GREATER THAN 3,000 TONS/DAY

CRUDE OIL	NO. OF REFINERIES
Alaska North Slope	3
Arabian Heavy	3
Arabian Light	1
Bachaquero	3
BCF-17	1
Boscan	3
Bow River	1
C	1
Cold Lake	2
Hawkins	1
Isthmus	2
Lagunillas	1
Leona	1
Maya	7
Menemota	1
Montana Mix	1
North Dakota Sour	1
Peace River	1
Pilon	2
Raspo Mare	1
Sunniland	1
Tia Juana Pesada	1
West Texas Mixed Sour	1
Wilmington	1
Y (Casper)	1
Y (Freeman)	1

TABLE VII. SINGLE CRUDE OILS USED IN ASPHALT PRODUCTION

CRUDE OIL	NO. OF REFINERIES
Alaska North Slope	4
Baxterville	1
BCF-17	1
Boundary Lake	1
Bow River	1
Canadian Light and Heavy Sour	1
Cold Lake	1
Lloydminster	2
Oklahoma Domestic	1
Peace River	1
San Joaquin Valley	1
South Carlton	1
S. Mississippi Heavy Sour	1
Wilmington	1

Therefore, the majority of the responding refineries (seventy-five percent) ordinarily produced asphalt from a slate of blended crude oils.

Common Crude Oil Slates For Asphalt Production

The survey responses identified thirty-nine crude oil blends utilized for asphalt production. Fifteen of the blends employed two crude oils, twelve used three crude oils, and six each represented blends of four and five crude oils, respectively. All were examined for evidence that one or more "common" blends were employed by a variety of geographically diverse refineries for this purpose.

Maya crude oil was present in sixteen of the thirty-nine blends in proportions varying from five to eighty percent of the total. Maya crude oil was most frequently used in combination with Arabian Heavy, Arabian Light, and Boscan, but no two refineries employed exactly the same Maya blends. Therefore, as the term was defined in the previous paragraph, there were no common Maya blends found.

Similarly, generically designated "San Joaquin Valley" crude oil or crude oils from specific fields in the San Joaquin Valley was present in eleven blends. San Joaquin Valley crude oil was found almost exclusively in blends with crude oils from the Coastal, Los Angeles Basin, and Ventura Basin oilfields of California.

Alaska North Slope crude oil was present in seven of the thirty-nine blends, but none of these showed any commonality with respect to the other components of the blend.

Geographical Distribution Patterns

Table VIII presents the crude oils reportedly used for asphalt production by the responding refineries in each of the four SHRP Long-Term Pavement Performance (LTPP) project regions. These regions include the states and Canadian provinces shown in the map in Figure 4.

As would be expected based from the previous discussion, Alaska North Slope crude oil was reported to be utilized in asphalt production in all four LTPP regions, while Bow River, Cold Lake, and Maya were each employed in three. Numerically, the Western Region refineries employed the greatest variety of crude oils, but these were predominately crude oils from oilfields in California and the Rocky Mountain Area. Venezuelan crude oils are found only in the North Central and Southern regions, while Canadian crude oils are found in use in all regions but the Southern. Crude oils of Middle Eastern origin were represented in all regions but the Western.

Stability of Crude Slates

Question 44 of Part B of the survey questionnaire (Appendix I) was structured with the goal of estimating the variability of the crude oil slates employed for asphalt production over several past periods of time.

Figure 5 presents as a bar graph the results of that question. About forty percent of the responding refineries had changed their crude oil slate in the previous six months; more than sixty percent in the previous five years; and more than eighty percent in the past fifteen years, the period coinciding approximately with the Middle Eastern oil embargo and the Iranian revolution in the 1970s, and the collapse of OPEC oil production and prices in the early 1980s. Obviously, significant changes in the physicochemical properties of asphalts may be possible when present production is compared even with that of the recent past at many refineries.

Changes in Crude Slates in the Last Decade

In 1977 the Asphalt Institute initiated a study to survey the properties of paving asphalts to assess their conformance with AASHTO and ASTM specifications. More than two hundred asphalts were obtained from seventy-eight refineries and the results of extensive testing of physical and chemical properties were reported.[8]

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[8] V.P. Puzinauskas, Properties of Asphalt Cements, Research Report 80-2, the Asphalt Institute, College Park, Maryland, 1980.

TABLE VIII. CRUDE OILS EMPLOYED FOR ASPHALT PRODUCTION IN EACH SHRP LTPP REGION*

LTPP NORTH ATLANTIC REGION

Alaska North Slope
Bachaquero (Venezuela)
BCF-17 (Venezuela)
Boscan (Venezuela)
Bow River (Canada)
Menemota (Venezuela)
Tia Juana Pesado (Venezuela)
Venezuelan

LTPP NORTH CENTRAL REGION

Alaska North Slope
B-West
C
Canadian Light and Heavy Sour
Canadian Mixed Sweet
Canadian Sweet
Chauvin (Canada)
Coastal Mix
Cold Lake (Canada)
Cushing Pipeline
Illinois Basin
Isthmus
Kansas/Oklahoma Local
Lloydminister (Canada)
Louisiana Light Sweet
Maya (Mexico)
Mexican
Michigan Havy/Cass City
Michigan Sweet
Middle East
Montana Mix
North Dakota Sour
Peace River (Canada)

LTPP NORTH CENTRAL REGION (contd.)

South Saskatchewan
Stockbridge
Synthetic Crude
Trinidad
West Texas Intermediate
Wynot
Wyoming Sour
Y (Casper)
Y (Freeman)

LTPP SOUTHERN REGION

Alaska North Slope
Amdel Sour
Arabian Heavy
Arabian Light
Bachaquero (Venezuela)
Baxterville (Mississippi)
BCF-21
Boscan (Venezuela)
East Howard
Hawkins (Texas)
Heidelberg (Mississippi)
Howard Glasscock (Texas)
Kirkuk (Iraq)
Local Sweet
Maya (Mexico)
Merey (Venezuela)
Mesa Semi
New Mexico/West Texas Sour
Oklahoma Domestic
Oklahoma Mixed
Oklahoma Select
Pilon (Venezuela)
South Alabama

* See Figure 4.

TABLE VIII. (continued)

LTPP SOUTHERN REGION (contd)

South Carlton
Sweet Oklahoma Mix
Texas Panhandle
Vacuum Field Sour (New Mexico)
West Texas Intermediate
West Texas Sour
Wyoming

LTPP WESTERN REGION

Alaska North Slope
Amoco Pipeline
Belridge Light (SJV)
Bonanza
Boundary Lake (Canada)
Bow River (Canada)
Byron Garland
Canadian Sweet
Cat Canyon (Ca Coastal)
Central Montana Sour
Circle Ridge
Coalinga (SJV)
Cold Lake (Canada)
Cottonwood (Wyoming)
Cymric Heavy (SJV)
Donkey Creek General Sour
Elk Basin Heavy (Wyoming)
Elk Hills (SJV)
Elwood (Ca Coastal)
Escalante
Frannie/Elk Basin
Grass Creek (Utah)
Gulf Alberta (Canada)
Halsey Canyon
Hondo (Ca Coastal)
Kern Ridge (SJV)
Kern River (SJV)
KLM CA
Lloydminster
Manyberries
Midway Sunset (SJV)
Milk River

LTPP WESTERN REGION (contd)

Mount Poso (SJV)
Myton
NW Montana/Central Montana
Oregon Basin (Wyoming)
Peace River
Placerita Canyon Heavy
Rangeland
Rangely (Colorado)
Red Wash (Utah)

Redwater (Canada)
Rimby Condensate
San Ardo (Ca Coastal)
San Joaquin Valley
Santa Maria (CA Coastal)
Slick Creek
South Kaybob Condensante (Canada)
Southwest Wyoming Sweet
Stevens (SJV)
Torchlight (Wyoming)
Ventura Mix (CA Coastal)
Wilmington (LA Basin)
Wyoming Asphalt Sour
Wyoming Sour

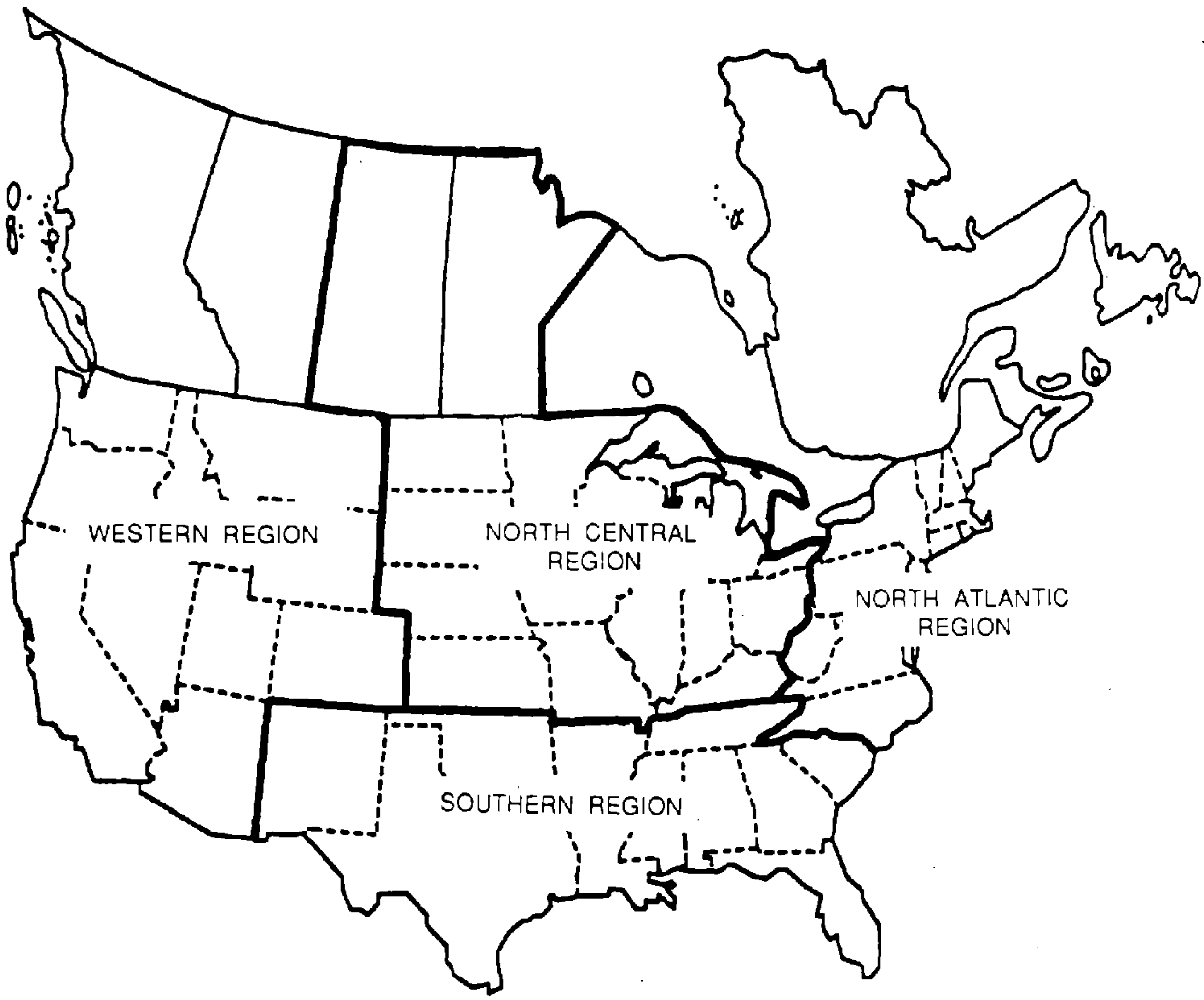

Figure 4. SHRP Long Term Pavement Performance (LTPP) Regions.

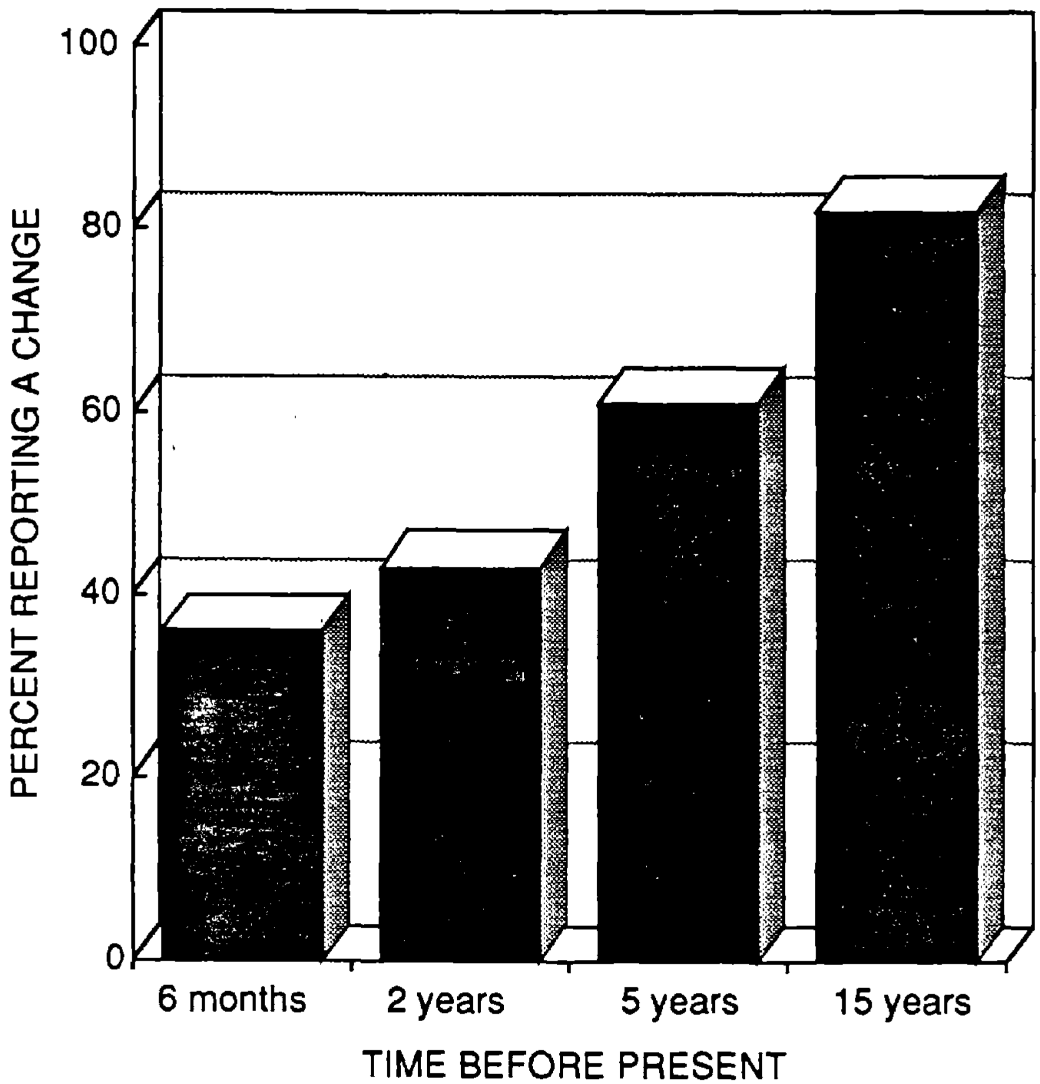

Figure 5. Refineries Reporting a Change in Crude Oil Slate for Paving Asphalt Production During the Indicated Time Period.

Unpublished information on the crude oil slates used for asphalt production was obtained for eighty-one asphalts produced by thirty-three refineries. The crude oils and the number of refineries employing them in 1977 for asphalt production are presented in Table IX. A comparison of this table with previous Table IV shows that approximately twenty of the crude oils in the 1977 list are also found on the list of 123 crudes in use in 1987.

When Table IX is compared with Table VI, which presents the crude oils in use by the largest refineries producing asphalt in 1987, it was found that only four of the 1977 crude oils, namely, Arabian Light, Cold Lake, West Texas Sour, and Wilmington, are still represented on the list of crude oils utilized by large capacity refineries. Moreover, the 1977 list does not contain several crude oils, including Alaska North Slope, Arabian Heavy Bachaquero, Lloydminster, and Maya, which are at the present time very important in the overall picture of U.S. and Canadian asphalt production.

This information independently confirms the conclusion of the previous section that crude oil slates employed by refineries producing asphalt have changed substantially in the past fifteen years.

Sulfur, Vanadium, and Nickel Contents

Questions 34, 35, and 36 of Part B of the survey questionnaire requested information from each refinery on the sulfur, vanadium, and nickel content of the single crude oils and crude oil blends which they employ in asphalt production. The intent was to determine the general character of the crude oils used, and to estimate to what extent these elements are concentrated in asphalt during the refining process. This latter goal would be reached through comparison of the survey responses to elemental contents measured on asphalts obtained in the refinery survey.

Figures 6, 7, and 8 summarize these responses through presentations of the percentage of refineries reporting the sulfur, vanadium, and nickel contents of the crude oils and crude oil blends used in asphalt production within each of four approximate numerical ranges.

As expected, the sulfur content of most crude oils is greater than one percent, corresponding to the usual definition of a "sour" crude oil. In many instances, it would be advantageous for a refinery with access to the less expensive sour crude oils to produce asphalt as part of its product slate. The sulfur may be concentrated in the asphalt without known adverse effects on its performance and the burden of removing the sulfur from the refinery stream through desulfurization processes is reduced.

TABLE IX. CRUDE OILS AND REFINERIES IDENTIFIED AS SOURCES OF ASPHALT CEMENTS SAMPLED FOR ASPHALT INSTITUTE RESEARCH REPORT RR-80-2

CRUDE OIL	NUMBER OF REFINERIES
Alberta	1
Arabian Light	1
Basrah	1
Canadian	1
Cat Canyon	1
Cessford	2
Ceuta	1
Coastal West Texas	1
Cold Lake	1
Colorado	1
East Texas	2
Gulf Alberta	1
Kansas	2
Lloydminister	3
Midcontinent	3
Montana	2
North African	1
North Louisiana	1
Oklahoma Mixed	1
Oxnard	1
Redwater	1
Russian	1
San Joaquin Valley	3
Smackover	2
South Alabama	1
S. Mississippi	2
S.E. Mississippi	1
S.W. Alabama	1
Texas	1
Utah	1
West Texas	1
West Texas Sour	1
Wilmington	1
Wyoming	7

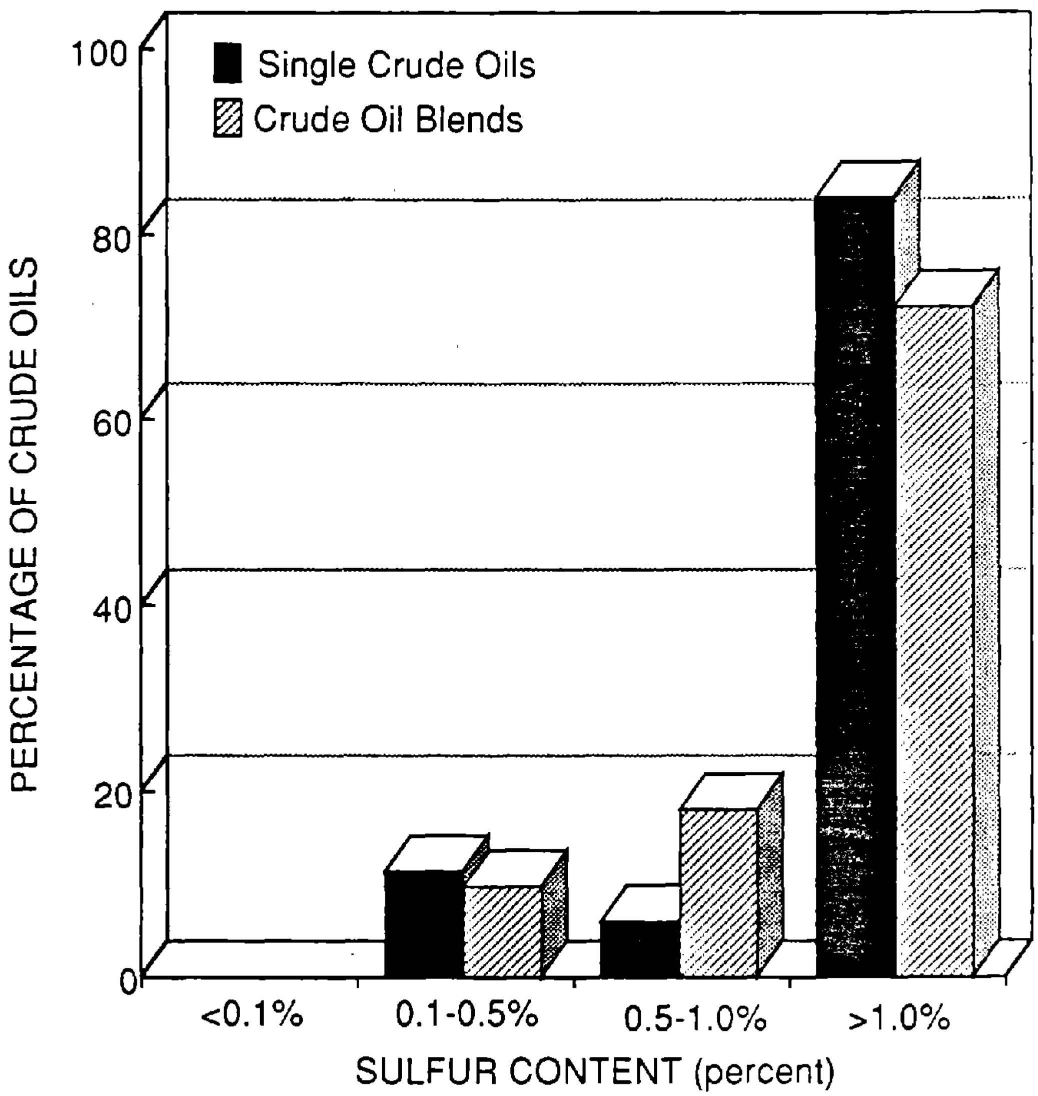

Figure 6. Sulfur Content of Crude Oils Used in Paving Asphalt Production.

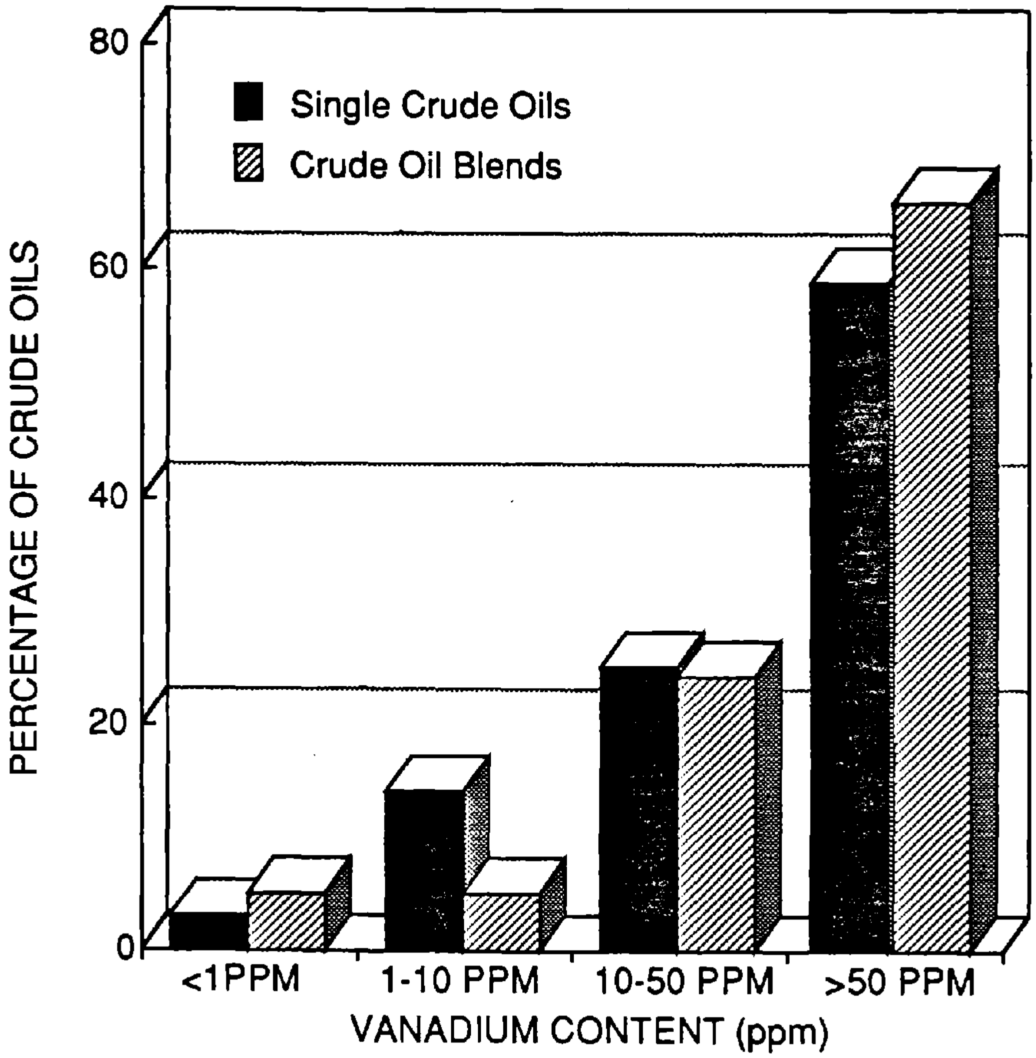

Figure 7. Vanadium Content of Crude Oils Used in Paving Asphalt Production.

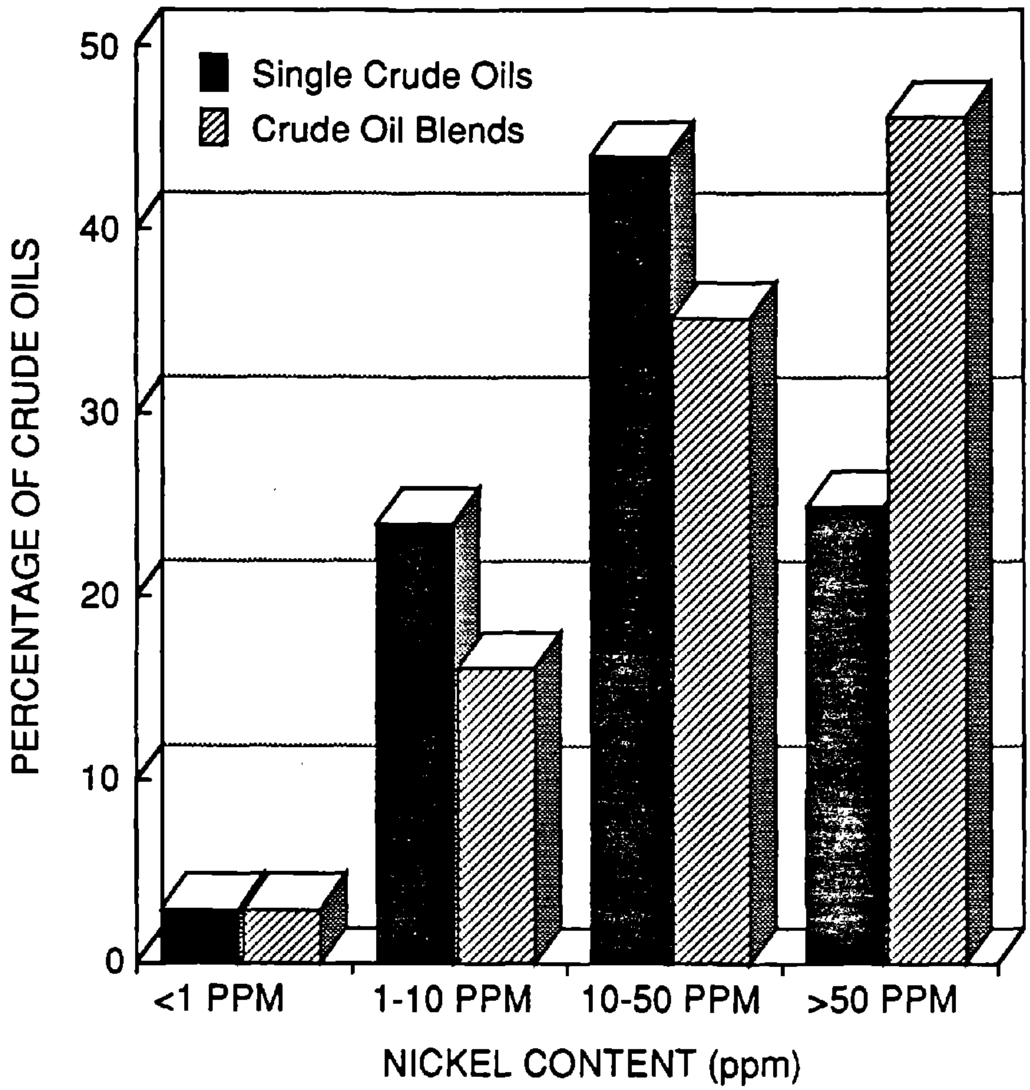

Figure 8. Nickel Content of Crude Oils Used in Paving Asphalt Production.

Conversely, this predominance of sour crude oils supports the observation that sour, heavy crude oils are most suitable and most frequently used for asphalt production.

The vanadium and nickel contents of the crude oils were predominately reported to be ten parts per million (ppm) or greater, with a significant percentage reporting greater than fifty ppm. Crude oils with high heavy metal concentrations are troublesome to refiners because the metals often act as "poisons" to the expensive catalysts used in the reforming processes which boost the production of transportation fuel components from crude oils. Concentration of these trace metals in asphalt is an efficient method to remove them from the refinery stream at an early stage and prevent catalyst poisoning. The effects of vanadium, nickel, and other trace metals on asphalt performance are being studied in the SHRP asphalt program.

5

Refinery Processes for Asphalt Production

General Considerations

Four primary crude oil refining processes are utilized to manufacture paving asphalt as follows:

1. Fractional crude oil distillation under atmospheric pressure with steam;
2. Topped crude distillation under vacuum conditions with or without steam;
3. Solvent refining; and
4. Air blowing.

The first three of these methods involve the recovery of asphaltic materials as they exist in the unprocessed crude oil. The air-blowing process, on the other hand, involves chemical and physical changes to the asphaltic material. Blending of high-viscosity asphalt with softer asphalt or with low-viscosity and low-volatility refinery streams, such as heavy gas oil to produce paving asphalt of the desired properties and grade is an auxiliary, but widely used refinery operation.

Information on current use of these manufacturing operations was sought in this study through the questionnaire (Appendix I), refinery visits, and review of the literature. An attempt was made to highlight those production and manufacturing aspects which it was believed would influence most directly the chemical and physical properties of the paving asphalt.

Crude oils, depending upon their properties, are classified descriptively as paraffinic, naphthenic, asphaltic, or mixed base. Some, because of their high aromatic compound content, are called aromatic base crude oils. Because of the optimization of selected petroleum product yield at integrated refineries, crude oils are often blended to obtain a desired feedstock. However, it should be noted that paraffinic base would seldom be blended with an asphaltic base crude oil.

Assay tests are normally conducted to determine whether a given crude oil is suitable for paving asphalt production. Such tests involve distillation of the crude oil to obtain the 750°F mean average boiling point residue, followed by determination of the API gravity[9] and Universal Oil Products K, or Watson characterization factor of this residue to establish whether it is suitable to produce a paving asphalt of the desired properties.

Production and Delivery of Crude Oil to Refineries

Crude oil pumped from the ground is associated with water containing a variety of salts, natural or man-made mud, and other suspended mineral particles. Often, water and oil form emulsions which must be broken and the water removed before delivery of the crude oil to the refinery. Separation of water and oil is accomplished in a settling tank. Silicone-type surface-active agents may be used for breaking water-in-oil emulsions. Separated oil is pumped into the crude storage tanks before delivery to the processing units at the refinery.

Pipelines, tankers, and barges are the most common delivery means for crude oil, although some refineries surveyed also receive deliveries of particular crude oils needed for asphalt production by railcar or by tank truck, especially in cases where the refinery lies in close proximity to the producing field.

Most crude oil is delivered by pipeline at ambient environmental temperatures. Occasionally, heating or dilution of heavy, or viscous crude oil, with a lighter refinery product or crude oil is needed to facilitate the oil pumping process when ambient temperatures are low. As a rule, to prevent corrosion, the water content of a crude oil must not exceed two percent before it is accepted for pipeline transportation. At the refinery, crude oil is pumped into storage tanks before processing.

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[9] The API gravity is an arbitrary scale expressing the gravity or density of a crude oil or crude oil products and is calculated by the empirical equation:

$$\text{Deg API} = (141.5/\text{Sp Gr } 60°\text{F}/60°\text{F})$$

Desalting and Dewaxing of Crude Oil at the Refinery

In the multiple product or integrated refinery, desalting of crude oil is a routine processing step. In an asphalt refinery, on the other hand, if the water and salt contents are low, desalting may not be practiced.

The purpose of desalting is to reduce the deposition of salt (principally sodium chloride) on and the corrosion of the refining equipment. Removal of other suspended particulate matter is a secondary effect of desalting. Refinery desalting involves mixing the crude oil with wash water at moderately elevated temperatures to dissolve the salt. Water and oil are then separated in settling tanks, often using either chemical or electrostatic methods to effect separation. In the former method, chemical agents are employed to break the formed emulsions; in the latter, a high-voltage current is applied to coalesce and separate water droplets in water-in-oil emulsions.

Eighty-four percent of the responding refineries reported that they employed desalting of crude oil before paving asphalt production was accomplished. Thirty-seven refineries provided detailed information on the desalting process they employed. Of these, twenty-eight used electrostatic separation only, while the other nine used a demulsification (chemical) process in combination with electrostatic separation. For example, one refinery reported that desalting was carried out by mixing wash water and crude oil in the feedline of a large cylindrical desalting vessel in which separation subsequently took place, enhanced by the use of surfactants and an induced electrostatic field.

The use of paraffinic-type crude oils in paving asphalt production raises the possibility for incorporation of paraffin, and microcrystalline wax with the potential for adversely affecting the adhesion, cohesion, temperature susceptibility, and other properties of the asphalt. However, only four of sixty-six responding refineries (six percent) reported the need to dewax the crude oil used in paving asphalt production.

Atmospheric Fractionation

General Description

After desalting, or directly from the storage tank, the crude oil is pumped through a heat exchanger, where its temperature is raised typically to 500 to 600°F. Then, it is heated to approximately 750°F by pumping it rapidly through a coiled tube exposed to direct heat in a pipe still or furnace heater. It is then continuously delivered to a flashing zone of the atmospheric fractionation tower where the most volatile components are stripped off overhead, while the less volatile components are drawn off as side streams.

Fractionating towers are vertical, cylindrical vessels varying widely in size at different refineries. They are equipped with bubbler cap trays at different levels of the tower. These trays aid in refluxing, with the lower trays facilitating the condensation of liquids and the efficient separation of straight-run petroleum fractions that boil in different temperature ranges.

Atmospheric fractionation produces the material termed "topped crude" which is typically delivered to a vacuum fractionation tower for further processing. However, in the case of heavy crude oils, such fractionation will directly result in paving asphalt that is often called "straight-run asphalt." Boscan (Venezuela), and Lloydminster (Canada) crude oils are some examples of such heavy asphaltic crude oils.

Survey Results

Survey responses from sixty-eight refineries discussed the use of atmospheric fractionation (or distillation, as it was termed in the survey questionnaire). Of those sixty-eight refineries, only eight (twelve percent) indicated that atmospheric fractionation was not employed during paving asphalt production. Thirteen of these refineries employed superheated steam at temperatures ranging from 320 to 750°F to facilitate the fractionation process by reducing process temperature and facilitating the transport of the petroleum fractions in the tower. Interestingly, pounds of steam consumed per ton of asphalt produced ranged from a low of 0.14 up to 170, depending strongly upon the characteristics of the crude oil processed.

Of those refineries reporting the use of atmospheric fractionation, only five (seven percent) used this process exclusively to produce paving asphalt. They reported a maximum transfer line temperature, for example, the temperature of the crude oil as it was introduced into the fractionation tower, in the range of 590 to 740°F. For these refineries, this represents the temperature to which the crude oil must be heated to allow sufficient light fractions to be removed to produce residua (for example, residual oil) acceptable as paving asphalt cement meeting appropriate specification requirements.

Vacuum Distillation

General Description

Distillation under vacuum, coupled with atmospheric distillation, is the most widely used unit operation in petroleum refining and also in paving asphalt production. Asphalts produced by atmospheric distillation alone and by atmospheric and vacuum distillation combined are often termed as "straight-run asphalts." Topped crude, a material produced as a residual fraction in the atmospheric distillation tower, contains high boiling, heavy petroleum fractions, such as gas oils, lube oil stocks, and asphalts. These materials cannot be distilled off in the atmospheric tower without severe thermal degradation or cracking. Such materials have to be separated under vacuum or reduced pressure which, in effect, decreases their boiling temperature ranges and thereby minimizes exposure to destructively high temperatures.

Topped crude is fed through a pipe furnace where it is rapidly heated to approximately 730 to 850°F. Temperature of the feedstock depends upon the volatility of the gas oils and on the desired degree of separation. Superheated steam is often used to maintain temperature and increase the feed rate. Partial steam pressure also increases volatility, minimizes thermal cracking, and aids separation of feedstock components. Hot feed from the pipe furnace is introduced into the flash zone of the vacuum tower where light and heavy gas oils are flashed off and asphalt, the highest boiling range petroleum fraction, is continuously removed from the bottom of the tower. Again, a copious amount of superheated steam is injected at the tower bottom to aid fractionation and separation of the gas oils.

Asphalt is the only petroleum fraction that is not volatilized during refinery processing, and because of this it is often referred to as the residual fraction or crude oil residua. Thus, it is reasonable to assume that the high-molecular-weight asphalt constituents are nearly the same as those existing in the parent crude oil of the asphalt. It should be recognized, however, that in the case of asphalt, these high-molecular-weight and highly polar molecules are in close proximity to each other. This leads to molecular associations that, in turn, cause the high viscosity and complex rheological behavior of the asphalt.

The amount and molecular makeup of asphaltic materials in different crude oils varies substantially. This means that different refineries using crude oils from different sources have to adjust their operating conditions to produce paving asphalts having the desired properties. Temperature, pressure, amount of steam, and rate of crude throughput must be properly varied for that purpose. It should be noted that in an integrated refinery producing a wide variety of petroleum products, the main purpose of atmospheric and vacuum distillation is to obtain "clean" petroleum fractions to be used for further processing into fuels, lubricants, and feedstocks for a variety of other refinery processes and products. Asphalt may be only a minor product in such a refinery. However, in a number of smaller refineries, paving asphalt may be the principal product with its chemical and physical properties primarily dependent on the type of crude oil used, and on the uniformity of the refinery feed. In such refineries, depending on the crude oil source, asphalt often is a major component of topped crude which is fed to a vacuum tower or fractionator. Thus, since asphalt is not volatilized during the refining operation, the refining process itself, and the refinery's ability to adjust these processes with changing crude oil feed, although important, appear to be only secondary in importance to the type of crude oil used to manufacture paving asphalts with the desired properties.

Survey Results

Sixty-four of sixty-nine responding refineries (ninety-three percent) reported that they employ vacuum distillation in the production of paving asphalt. Of this total, fifty-three indicated that the feedstock for the vacuum distillation unit was topped crude prepared at temperatures ranging from 440 to 750°F in an atmospheric fractionation tower (although one refinery reported 1,000°F). Based on fifty-five survey responses, the topped crude was transferred to the vacuum distillation unit at temperatures ranging from 366 to 820°F; and the operating vacuum in the distillation units varied from five to three hundred mm Hg. Taken together, these data reflect the wide variety of crude oils employed for paving asphalt production in the United States and Canada; topping and transfer line temperatures and operating vacuums differ greatly in order to accommodate the great range of physical and chemical properties of the crude oils employed.

Solvent Refining

General Considerations

Before discussing petroleum refining processes by solvent extraction, the basic difference between separation of asphalt from other crude oil components by distillation and by solvent refining should be recognized. The distillation process separates various products or components based upon differences in their boiling temperature or vapor pressure. These properties, as a general trend, relate to the molecular weight or molecular size range of the distilled petroleum fraction. It should be noted that generally, the aromaticity tends to increase with the increasing molecular weight of the petroleum fraction. In the solvent extraction process, on the other hand, the solubility characteristics of different molecular species in the crude oil components also play an important role in their separation. Thus, in deasphalting with propane or with any other low-molecular-weight aliphatic solvent, besides molecular-size separation, the paraffinic components are separated from the naphthenic (for example, cycloparaffinic) and aromatic fractions. The latter fractions constitute asphaltenes and asphaltic resins of paving asphalt or bitumen.

There are several different versions of asphalt manufacture by solvent precipitation. Basically, however, these methods may be regarded as similar. Generally, they process crude oils containing relatively low asphalt content and, in all cases, the degree of sharpness of the separation depends on factors such as solvent type, solvent-to-feed ratio, operating temperature, and pressure and the rate of crude oil throughput. In most cases, the recovered asphalt must be blended with softer materials to obtain products with desired properties meeting specification requirements.

Propane Deasphalting Process

Extraction and recovery of asphalt from vacuum tower residua by means of low boiling temperature paraffinic solvents constitutes one version of paving asphalt manufacture by solvent extraction. This method, often referred to as deasphalting or solvent precipitation, involves the continuous countercurrent liquid-liquid extraction and separation of bituminous materials from valuable lubricating oil blend stocks, and from catalytic or hydrocracking feedstocks having low content of undesirable sulfur, heavy metals, and asphaltic materials. Solvent extraction invariably produces hard, high-viscosity bitumens that must be blended with softer materials to obtain paving asphalts.

In this process, the asphaltic residue from the vacuum tower is pumped to the upper section and the solvent is introduced at the bottom of the extraction tower. Propane or propane-butane mixtures are the most frequently used solvents in this process. This means that these gases must be liquified by the use of pressure which, depending upon the processing conditions, may range from 300 to 500 psi. Solvent-to-feedstock volumetric ratios from four to six are commonly used. However, it has been recorded that, depending upon the operating conditions, this ratio may exceed a value of ten.

Normally, temperatures at the bottom of the extraction (or fractionating) tower are about 120°F, and are largely controlled by the temperature of the entering liquid propane. At that temperature, paraffinic oils are readily soluble in liquid propane or propane-butane blends. Some of the naphthenic and aromatic components may also dissolve in the solvent. At the top of the tower, the temperature of approximately 200°F is typically controlled by steam coils. This temperature is close to a critical temperature for propane above which hydrocarbons or hydrocarbon-like molecules become insoluble in the solvent. And at this temperature, dissolved naphthenic and aromatic oils separate from the solution and flow down the tower. Such refluxing aids in the effective and sharp separation of asphaltenes and resins present in the feedstock.

The asphaltene and resin suspension in solvent is removed at the bottom and the paraffinic solution at the top of the extraction tower. Solvent is recovered normally using high- and low-pressure flash towers or drums. Often steam is used to strip the remaining traces of solvent from the asphaltic material. As mentioned above, these highly viscous materials are blended with the selected softer blending stocks to obtain paving asphalts meeting specification requirements. Needless to say, both blending components affect physical and chemical properties of final asphalt cements.

ROSE--Residual Oil Supercritical Extraction and Other Supercritical Processes

This version of the deasphalting of petroleum residual oils obtained after distillation was developed in the late 1970s and early 1980s. It is a multistage process separating asphaltenes, resins, and oils. The oil fraction is used either as lubricating oil blending stock or as a feedstock for the catalytic cracking unit.

Propane, butane, and pentane, or mixtures of these hydrocarbons, may be used as solvents and the selection of solvent depends upon the properties of the feedstock and the desired properties of the final product.

In this process, a mixer is used to blend residual oil with liquid solvent at an elevated temperature and pressure. The blend is then pumped to the first-stage separator where, through countercurrent flow of solvent, the asphaltenes, consisting of high-molecular-weight naphthenic and aromatic compounds, are precipitated. The asphaltenes, after additional heating, are stripped of solvent in a flash tower. The overhead solution from the first-stage separator is heated and pumped into the second-stage separator where, because of higher temperature, the resins are separated. After solvent stripping, the resins are recovered from the bottom of a second flash vessel. The overhead from the second-stage separator is heated to a supercritical temperature of solvent at which the oil becomes insoluble and separates in the third-stage separator. Again, solvent is stripped off and oils are removed from the third-stage solvent stripper. Solvent collected from all three flash towers is recycled with relatively low solvent losses.

The ROSE is a rather flexible process. For example, the whole second-stage separation could be shunted out converting the system to a two-stage operation. Also, different solvents can be used and operating conditions adjusted to yield oil with properties needed for further processing. It is evident that this and similar supercritical processes are growing in usage, and that they provide an economical route to good quality feedstocks for refinery downstream processing. They also yield components for blending into asphalts having desirable properties.

Survey Results

Only thirteen of sixty-nine responding refineries (nineteen percent) reported that they employ some form of solvent refining in the production of paving asphalt. Of these thirteen, only three indicated that they employed a supercritical extraction process, such as the ROSE process described in the solvent refining step. A large majority of responding refineries (eighty percent) employs the residua from the vacuum distillation unit as the charge to the solvent refining unit; the others used either asphalt flux or short waxy residua.

The operating parameters of the solvent refining units were described in some detail. Propane is the usual solvent, but a small number of refineries employ propane with a slight admixture of butane or other light hydrocarbon. Unlike fractionation or distillation processes where the temperature of the feedstock must be raised to high levels to effect separation, the typical operating temperature of the solvent refining units was reported to be below 200°F, but the pressure in the unit was very high, typically ranging between 450 and 500 psi, or more than thirty times greater than atmospheric pressure. Besides temperature, pressure, and solvent type, the main operating parameter is the volumetric solvent-to-charge ratio, typically found to be in the range of six volumes of solvent to one volume of feed. The bottoms from solvent refining are usually, but not always, a hard, viscous material that must be blended with a softer material to produce a specification-grade paving asphalt. Several different materials are employed for blending, including low-viscosity asphalt flux, high-viscosity flux, and vacuum gas oil. In one instance, the solvent-refined bottoms are co-reduced with topped crude to grade in a vacuum distillation unit, while two refineries reported that they employ the solvent-refining unit to produce paving asphalt to grade.

Air Blowing

General Description

Blowing air through a selected bituminous stock or flux at elevated temperature with the purpose of increasing its viscosity and changing other properties to desired levels constitutes paving asphalt manufacture by the air-blowing process. Air blowing is used with crude oils or crude oil residues that normally are not conducive for processing directly to paving asphalt by atmospheric or vacuum distillation. Air blowing is a chemical conversion process that is fundamentally different from either distillation or solvent refining processes where an attempt is made to preserve the physical and chemical properties of the asphalt, a natural constituent of petroleum. By air blowing at an elevated temperature, the chemical makeup of asphaltic molecules is intentionally altered by inducing reactions such as dehydrogenation, with a subsequent condensation polymerization, some oxidation, and also volatilization of lighter feedstock components. All or most of these reactions tend to increase the average molecular size of the blowing flux with the resultant increase in viscosity. Often air-blown asphalts are referred to as oxidized asphalts, but such reference is misleading since oxidation, if at all occurring during the blowing process, is at a rather low level.

Sufficient evidence exists in the literature to indicate that air blowing converts asphaltic resins to asphaltenes and forms harder resins from softer materials. These conversion reactions are exothermic and normally must be tempered by steam or water spray.

Occasionally, particularly in the case of continuous air blowing, the reaction temperature may be controlled by the addition of cooler feed (for example, flux material). It should also be noted that the air-blowing process is used solely for treating asphaltic fractions of crude oil and is not employed with any other petroleum fractions or products.

Manufacture of asphalt by air blowing may be a batch or continuous process. Because of the higher flexibility of the process, the use of batch type air blowing predominates. In the batch process, the blowing flux, such as vacuum tower residua or a soft asphalt, is preheated in a tube furnace and charged into a blowing drum or convertor, often referred to as a blow still. Air, supplied by means of air blowers or compressors, is injected at the bottom of the charge through a vertical pipe equipped with a sparge at the bottom end. Fine air bubbles rising through the asphaltic liquid provide an intimate gas-liquid contact. After injection of air, because of the exothermic reaction, the temperature of the liquid gradually rises to a desired level such as 475 to 520°F. At this point, water is sprayed into the top of the charge to moderate and control the air-blowing temperature. The end of the air blowing is usually determined by intermittent testing for softening point or other properties of the air-blown material. After the proper level is reached, air injection is discontinued and the batch is quenched with water for quick cooling. This prevents or decreases degradation of polymers formed during air blowing. Such degradation tends to occur if the air-blown asphalt is stored at the high air-blowing temperature.

Flow of materials and the process of the continuous air-blowing operation is similar to that of the batch type. In some cases, two blowing drums or convertors are connected in series to facilitate the conversion process. Regardless of the higher initial costs, the continuous process may be more economical or provide better control of the product. However, the continuous process becomes less practical if a great variety of air-blown products is to be made. This may require frequent adjustments in the operating conditions and changes in feedstock or blowing flux which may not be practical in a continuous air-blowing plant.

A number of factors affect the properties of the final product produced by air blowing: source and type of blowing flux, air feed rate, blowing time, and, most importantly, the blowing temperature. These factors must be carefully balanced and controlled by the operator to produce the desired finished product.

In the case of paving asphalts, normally only mild air blowing is used. Process conditions and feed or flux are rigorously controlled so that paving asphalt of the desired grade is obtained. Material is also often blown to a harder grade, then blended with softer straight-run asphalt or flux to obtain a product of the desired grade and quality.

Survey Results

Nine of the sixty-nine responding refineries reported the capability to employ air blowing in the production of paving asphalt. Based upon information obtained during the refinery visit phase of the study, it appears that the number of refineries that actually employ air blowing at present is considerably smaller than this number, perhaps no more than two or three refineries in the United States and Canada. A far greater number actively utilize this process for the production of roofing and industrial grades of asphalt.

Eight of the nine refineries air blow paving asphalt to grade, but four also report blowing to a hard material that must be blended to a specification grade with a low-viscosity material, typically vacuum distillation residua, asphalt flux, or unblown paving grade asphalt. Blending is controlled by monitoring viscosity, penetration, or occasionally, ductility or softening point. When the paving asphalt is air blown to grade, process control is provided by strict adherence to an established time and temperature schedule. Only one refinery reported the use of a catalyst, ferric chloride, in the air blowing of paving asphalt.

Blending of Residues From Other Refining Operations

A major point of interest for many user agencies is the question of the blending of residues from petroleum refining processes such as reforming, thermal cracking, catalytic cracking, and hydrocracking into paving asphalts. In these processes, the bottoms from atmospheric fractionation or vacuum distillation or distillation side streams such as heavy vacuum gas oils are subjected to severe conditions of temperature and pressure in order to break apart large, naturally occurring molecules to form higher-value materials to use in transportation fuels or petrochemical feedstocks.

Historically, the blending of residues from early cracking processes into paving asphalts in the 1930s led to apparent performance problems that subsequently discouraged this practice on any appreciable scale. Several state highway agencies still employ the spot test (AASHTO T102-83, Spot Test of Asphaltic Materials) in their specifications for paving asphalt to prevent the blending of cracked residues into paving asphalt by suppliers. However, there has been little published research[10] to indicate whether such a prohibition is necessary for the residues of modern refinery operations, and indeed there is no specific restriction by either AASHTO or ASTM for the incorporation of these residues in paving asphalt if the applicable specification requirements can be met.

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[10] G.L. Oliensis, The Oliensis Spot Test ASE Quality Test, Proceedings of AAPT, Vol. 26, 1957, p. 82.

Ninety percent of the refineries responding to the survey indicated that they never employed the residues from other refinery operations, for example visbreaking, thermal cracking, or catalytic cracking, in their paving asphalt production stream. When those affirmative responses which report the use of solvent refining or vacuum distillation residua are eliminated, only one refinery (of sixty-eight) remains that reported the occasional use of visbreaking residua at a blending level of two percent or less. Thus, it would appear that in the United States and Canada, the blending of residua from severe petroleum refining processes into paving asphalt is uncommon.

Examples of Paving Asphalt Production Processes at U.S. and Canadian Refineries

As discussed in Chapter 2, thirty-six refineries in the United States, Canada, and Venezuela that produce paving asphalt, or about one-half of those responding to the survey questionnaire, were visited to obtain more detailed information and a better understanding of specific production processes. The breakout of refining processes employed for paving asphalt production is shown in Table X:

TABLE X. ASPHALT PRODUCTION PROCESSES IN VISITED REFINERIES

REFINING PROCESS	NO. OF REFINERIES
Atmospheric fractionation only	1
Vacuum distillation of topped crude oil	24
Vacuum distillation followed by solvent refining	8
Vacuum distillation followed by solvent refining and air blowing	1
Vacuum distillation followed by air blowing	1
Blending of products from another refinery	1

In this section, specific discussion of the paving asphalt production operations at several of these refineries are described in order to provide a picture of the diversity of process type, equipment, and scale of operations.

Atmospheric and Vacuum Distillation of Crude Oil

Example 1

At a modern, midsized asphalt refinery, crude oil stored at 130°F is heated[11] to 500°F before flashing in an atmospheric fractionation tower to remove naphtha and kerosene. The bottoms from the atmospheric tower are then heated to 700°F and passed to a vacuum distillation column operating at 28 mm Hg where gas oils are removed. The grade of the paving asphalt obtained as the vacuum residua is controlled by the depth of gas oil removal and by the blending of finished products.

Example 2

A large integrated refinery passes desalted crude oil heated to 200°F to an atmospheric fractionation tower where steam is employed to help flash off naphtha condensates boiling between 200 and 400°F on vapor equilibrium flash trays. The residua from this tower are heated to 700°F as it moves to a second atmospheric fractionation tower where steam again is used to facilitate the removal of all materials with an equivalent atmospheric boiling point up to 825°F as gas oil. The bottoms are then pumped to a vacuum tower through a heat exchanger to restore the temperature to 700°F. Steam is used to reduce the partial pressure in the vacuum tower; the paving asphalt is reduced to grade in the vacuum tower by adjusting the partial pressure of the steam to control the depth of removal of vacuum gas oil.

Example 3

Another large asphalt refinery employs two crude units[12] each of about 20,000 bpd capacity wherein naphtha, kerosene, distillate oils, and atmospheric gas oil are produced in an atmospheric fractionation tower. The atmospheric bottoms go to a vacuum tower where light and heavy vacuum gas oils are removed to produce paving asphalts to grade. The

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[11] In general, heating of crude oil is accomplished through the use of tube furnaces, while heating of topped crude, vacuum residua, or "bottoms," etc. is done with heat exchangers that capture process heat and recycle it to the heating of feedstock. Efficient operation of refineries requires that as little fuel as possible be employed for heating of raw materials.

[12] A crude unit is a modular refinery unit composed generally of atmospheric and vacuum distillation units that produces a variety of light and heavy petroleum products and feedstocks for other specialized process units such as reformers, cat-crackers, etc. Many refineries have two or more crude units of varying size.

temperature at which the vacuum tower operates controls the grade of the asphalt produced. Interestingly, the vacuum tower can operate as low as 30 mm Hg by using steam aspiration to produce the vacuum; this arrangement is termed a "wet" vacuum system. All heat required for operation of the crude unit is provided by the incoming charge of crude oil by use of heat exchangers (see Footnote 10).

Example 4

A small asphalt refinery combines light and heavy crude oils from local fields to produce a blend particularly suited for paving asphalt production. Water is added to the (blended) crude oil, which is then sent to a settling tank where more water is introduced to facilitate electrostatic desalting. The salt is removed with the separated water from the settling tank. The crude oil is then passed through heat exchangers to raise its temperature from 110°F to 390°F and then through a crude heater where its temperature reaches 650°F.

The heated crude oil is then introduced into an atmospheric flash tower where naphtha and kerosene cuts are removed with the aid of steam. The atmospheric bottoms are transferred to a vacuum tower operating at about 30 mm Hg with steam where gas oil fraction is removed. The paving asphalt is produced as the vacuum residua. The tower temperature and the proportion of gas oil reflux (for example, the degree to which gas oil is cycled back into the asphalt rather than drawn off the tower) control the properties and hence the grade of the asphalt produced.

Solvent Refining Processes

A variety of solvent refining[13] units were available at the nine refineries visited that employ this process in their paving asphalt production operations. As discussed above, the major distinction among these units is between those that operate in a supercritical mode and those that do not. While the ROSE supercritical fluid technology of which Kerr-McGee Corporation is the licensor is perhaps the best recognized example of supercritical solvent refining technology, other non-ROSE supercritical processes are presently in use for paving asphalt production. Examples of both types of operations, including one employing ROSE technology, are discussed below.

[13] Generically, solvent refining is often termed solvent deasphalting, abbreviated "SDA." When the solvent employed is propane, as is commonly the case, the process is referred to as propane deasphalting, abbreviated "PDA."

Example 1

A large integrated refinery produces paving asphalt from a single crude oil not amenable to asphalt production through distillation processes only, by blending solvent deasphalting (SDA) bottoms with vacuum bottoms to prepare a material meeting specification requirements. The crude oil is first desalted and dewatered, then subjected to atmospheric fractionation followed by vacuum distillation. Some vacuum residua are sent to the SDA unit, while the remainder is put in storage for blending with the SDA bottoms to form specification-grade paving asphalt.

Example 2

A midsized integrated refinery employs low-severity propane deasphalting directly for asphalt production. Crude oil is introduced into an atmospheric fractionation tower where light and heavy naphtha, kerosene, diesel oil, and atmospheric gas oil are removed as overhead streams. The atmospheric bottoms go to a vacuum distillation tower operating at 28 mm Hg for removal of light and heavy gas oils as overhead streams.

The vacuum bottoms are sent to the PDA unit where the propane solvent dissolves light paraffinic compounds, and the PDA bottoms are transferred to a stripper for removal of all traces of propane. There are two routes to paving asphalt from the PDA bottoms. First, the PDA unit may be operated to produce "zero" penetration bottoms which are blended with vacuum gas oil to produce specification-grade paving asphalts. Alternatively, the operating temperature of the PDA unit may be adjusted to produce specification-grade material right in the unit. Essentially, variation in the operating temperature controls the amount of light, paraffinic material retained in the PDA bottoms.

Example 3

A midsized integrated refinery employs solvent deasphalting to prepare hard, zero-penetration residua from sweet crude oil. This residua is then blended with a low-viscosity flux oil prepared from a sour crude oil blend to produce specification-grade paving asphalt. Properties of the SDA bottoms are controlled by varying the operating temperature of the SDA unit and the composition of the solvent, typically sixty-five percent propane and thirty-five percent butane. The flux oil production is carried out as a block operation, (that is, the appropriate process units are operated exclusively to produce sufficient flux oil to support paving asphalt production for a fixed period of time).

Example 4

A large integrated refinery combines vacuum distillation and a supercritical extraction process to produce paving asphalt. Vacuum residua are fed to a large extractor tower that is charged with 60,000 barrels (bbl) of butane. The residua are cut into three fractions: deasphalted oil (DAO), resins, and bottoms. The bottoms are essentially paving asphalt; the viscosity and softening point of the bottoms are controlled by varying the operating temperature of the extractor tower. Variation of the operating temperature determines how much of resins and DAO are retained in the bottoms.

The bottoms are moved to a stripper where all traces of butane are flashed off. The overhead from the extractor, a mixture of butane, resin, and DAO (which is similar in properties to conventional gas oil) is introduced into a resin settler unit where the solvent is removed by distillation and the resin separated from the DAO. The inlet temperature of the resin settler is controlled to maintain sharp separation of the resin and DAO.

The resin is then moved to a steam stripping unit where all traces of solvent and DAO are removed and blended back into the process stream. Finally, the DAO stream is passed into another stripper where all remaining butane is flashed off. Generally, the resins and DAO are used as feedstocks for other refinery operations; however, the properties of the paving asphalt may be further adjusted to specification requirements, as needed, by proportional addition of resins or DAO.

Example 5

A large integrated refinery produces paving asphalts to grade as bottoms from a propane deasphalting unit operating in a supercritical mode. The PDA unit takes a charge of approximately 15,000 bpd and contains two extractors that employ propane with about one to two percent butane as the solvent.

The PDA unit is operated to maximize the production of gas oil which is used as feedstock for a fluid catalytic cracker (FCC) to produce gasoline blending components. The PDA unit concentrates the metals present in the crude oil in the PDA bottoms so that catalysts used in the FCC and other processes are not poisoned. Typically, 80,000 bbl of propane is circulated through the unit, with propane being blended with the vacuum-reduced crude oil and also introduced as makeup solvent at the bottom of the tower.

Vacuum-reduced crude oil is moved to intermediate storage and next to the PDA unit. Solvent is in-line blended with the reduced crude in external piping at a ratio of seven parts solvent to one part reduced crude. In the extractor unit, a mixture of solvent and deasphalted gas oil (DAGO) rises to the top, while the asphalt is rejected and drawn off the bottom. The DAGO is transferred to flashers where the propane is removed and recycled to the PDA. The asphalt also goes to a flasher to remove all traces of solvent.

The PDA unit operates under supercritical conditions at 120°F and 460 psi. The charge to the PDA unit is introduced at 150°F and the bottoms exit at 290°F after flashing to remove solvent. As the operating temperature of the extractor is raised, the viscosity of the asphalt produced decreases because the solubility of the DAGO in the propane decreases with increasing temperature under supercritical conditions. Thus, to produce AC-10 asphalt, the unit is operated at higher temperature than for AC-20 production. Alternatively, lower-viscosity asphalt grades may also be produced by blending PDA bottoms with vacuum-reduced crude oil.

Example 6

The final example in this section is a medium-sized refinery that operates a ROSE unit to produce blending components for paving asphalt. The heavy and intermediate ROSE products, termed "asphaltenes" and "resins," respectively, are blended in varying proportions with a lower-viscosity flux to yield specification-grade paving asphalts.

Crude oil is processed through a crude unit containing atmospheric and vacuum distillation towers to yield the least amount of vacuum residua feasible for processing by the ROSE unit. Typically, less than ten percent of the original crude oil charge reaches the ROSE unit; this vacuum residua has about a three hundred penetration. The vacuum tower operates without steam; the operating parameters are 40 mm Hg of vacuum and 670 to 700°F in the flash zone with a vacuum of about 15 mm Hg at the top of the tower. Vacuum tower operation is controlled only by adjusting the operating temperature.

The vacuum residua are transferred to a surge tank where the temperature drops from about 600°F to 300°F and then on to the ROSE unit. This unit employs n-butane rather than n-pentane as the solvent. Although pentane gives a cleaner separation than n-butane, this is not critical for this refinery as the heavy and intermediate components are used together. However, it is reported that n-butane is more difficult to strip off the ROSE components than pentane.

The ROSE unit has a rated throughput of 5,000 bpd. Fifty percent of the vacuum residua charge comes off the ROSE unit as a light deasphalted oil that is further processed for gasoline-blending components.

Physically, the ROSE unit consists of six towers, paired in three stages, each consisting of a separator and a stripper. The n-butane and the vacuum residua are blended together and charged to the first stage at 650 psi, with the same pressure being maintained in all the separators. The strippers operate at constant conditions of 40 to 60 psi and 450°F.

The temperature in the separators is varied to control the separation of the ROSE components. Typically, the asphaltenes fall out in the first stage at 235°F, the resins in the second stage at 300°F, and the DAO in the last at 360°F. All components are transferred from the respective separator to the paired stripper where the n-butane is flashed off and recycled. As mentioned above, the resins and asphaltenes are then reblended in varying proportions with an asphalt flux to produce different specification-grade paving asphalts.

Air-Blowing Process

Two refineries were visited at which air blowing is routinely employed to produce paving asphalt. Both refineries employ predominately sweet, non-asphaltic crude oil slates. Air blowing is required to increase asphalt viscosity and change other properties to the ranges required to meet specifications.

Example 1

A moderately sized integrated refinery employs two crude units, one running sweet and the other sour crude oil at a ratio of about one to ten. Vacuum residua from the two crude units are preblended and pumped to air-blowing stills from intermediate storage tanks in 800 bbl batches or charges. Air is introduced into the stills at a rate of about 6,000 cfm, and air blowing is conducted for a fixed time period to attain approximately the paving asphalt grade needed, anywhere from 2.5 to 3.5 hours depending on the target viscosity. This compares with the eight to ten hour blowing time needed for roofing and industrial asphalts.

The air-blowing reaction is exothermic so that no process heat is required other than the heat of reaction. Typically, the asphalt temperature will rise to about 435°F during air blowing. The reaction is quenched by the introduction of water into the blowing still, with the time of water injection determined by the grade of asphalt being produced. Since the properties of the vacuum residua feedstock can vary from day to day due to variations in crude oil supply, adherence to specifications is achieved by blending of succeeding batches in storage after their properties are determined by laboratory testing.

The air-blowing reaction produces a substantial volume of vapor containing water and various hydrocarbon materials. In order to control air quality, the vapor is passed to a knockout tank where water condenses and drops out; the hydrocarbon gases and liquids with some water go to an incinerator where they are burned for process heat.

Example 2

The other refinery is a large integrated refinery that employs solvent refining as an intermediate step between vacuum distillation and air blowing to produce paving asphalt. The crude oil slate employed contains a significantly higher percentage of sour crude oil than that used by the refinery discussed in Example 1 above.

Crude oil is passed through an atmospheric fractionation tower where light fractions are drawn off for liquid fuel and liquid natural gas production. The bottoms pass to the first of two vacuum towers where lube stock cuts are removed. The vacuum bottoms then go to a second vacuum tower where lube stocks are taken as overhead and middle cuts, leaving a very heavy vacuum bottom that represents about fifteen percent of the original charge to the tower.

The bottoms from the second vacuum tower are passed to a propane deasphalting (PDA) unit in which the solvent extracts lube stock or gas oil from the vacuum bottoms. The PDA bottoms are sent to either of two air-blowing stills for paving asphalt production or to a coking unit when asphalt demand is low. One still is employed for production of low-viscosity, specification-grade paving asphalt, the other for a high-viscosity grade.

Production to grade is controlled by varying the blowing time and volume of air passed through the still. Each air-blown batch is tested for adherence to specification as is material in storage. Batch-to-batch variations are smoothed out by blending in storage. Intermediate grades are custom blended to order from the two grades in storage at the truck-loading rack.

6

Quality Control For Asphalt Production and Storage

Quality control is the procedure employed in a refining (or any manufacturing) process to confirm that the product consistently meets established specifications. The production of asphalt requires a sequence of quality control steps to assure that refining, blending, storage, and transport-loading operations do not adversely affect the quality.

In general, refiners cease to have practical control over asphalt quality when it is loaded into the customer's transport. However, as discussed below, many refiners take steps to minimize the possibility of changes in material properties after the asphalt leaves the refinery gates.

In the United States, asphalt quality is judged by its adherence to state highway agency specifications. These generally are adapted from those established by the American Association of State Highway and Transportation Officials (AASHTO). The AASHTO specifications, in turn, are based upon asphalt specifications promulgated and published by American Society for Testing and Materials (ASTM), but with several significant differences.

AASHTO specifications M20 and M226 govern penetration and viscosity-graded paving asphalt cements, respectively, and require conformance to a set of physical property requirements, for example, viscosity at 140F and 275°F, penetration at 77°F, ductility, thin film oven loss, changes after heating, and so on. There are no chemical composition requirements established for asphalt in contrast to the specifications for most other petroleum products.

Current asphalt cement specifications assure consistent, predictable behavior of asphalt during the production and laydown of asphalt paving mixture. The flash point is specified to maintain safety during these operations. Specifications are not directly linked to any pavement performance factors, such as rutting, low temperature, and fatigue cracking. However, the choice of penetration or viscosity grade, with limits on temperature susceptibility and heat sensitivity present in the viscosity-graded asphalt specifications, allow the engineer to maintain a certain degree of control over construction practices and expected pavement performance.

Test Methods Employed

The tests employed for asphalt quality control are primarily those used in the AASHTO and ASTM specifications for paving asphalts and the variations on those specifications developed by the individual state highway agencies.

Two testing regimes may be discussed. First, all refineries employ testing during the refining process to monitor asphalt quality as it is produced. The common tests reported for this purpose are the measurement of the viscosity at 140 and 275°F or the penetration at 77°F. These test parameters are used by virtually all of the refineries responding to the survey. The flash point test is less frequently used (by approximately forty percent of the responding refineries) during production monitoring. Other tests, such as the thin film oven test, ductility, and specific gravity, are used routinely by only a few refineries.

The second testing regime is that employed for quality control of the finished asphalts maintained in storage prior to the delivery to customers. The principal tests employed for this purpose and the number of responding refineries using them are presented in Table XI.

TABLE XI. QUALITY CONTROL TESTS FOR FINISHED ASPHALTS

ASPHALT PROPERTY	NO. OF REFINERIES
Penetration at 77°F	64
Viscosity at 140°F	60
Flash point	58
Ductility at 77°F	52
Viscosity at 275°F	51
Thin film oven test	45
Solubility in trichloroethylene	45
Spot test	25
Rolling thin film oven test	24

(Additional information is contained in the response to question 46 of Part B of the refinery survey, Appendix I).

Comparison of the frequency with which these tests are utilized to the complete requirements contained in AASHTO specifications M20 and M226 suggests that the main determinants of the quality of finished asphalts are the viscosity at 140°F and the penetration at 77°F. Of course, these are the asphalt properties used to grade asphalt cements. It appears that a number of refineries have sufficient experience with crude oil sources and refining processes to be able to maintain control over all specification requirements simply by monitoring the main grading requirements. If a new crude oil or crude oil blend is introduced in the refinery stream, the properties of asphalt from this crude are established in either laboratory bench assay or, occasionally, in small-scale pilot plant operation.

Testing During Production and Storage

The frequency of quality control testing is an important factor in determining its effectiveness. Testing may be conducted by lot for materials produced in batches, as is the case when asphalts are air blown to grade or blended to grade in storage. Similarly, testing may be conducted for a given volume of material produced. This frequency would be applicable, for example, in refineries where asphalts are produced to grade by atmospheric or vacuum distillation in a continuous process.

Alternatively, testing may be conducted at periodic time intervals. This frequency would also lend itself best to continuous production processes or to monitoring of the quality of stored asphalt.

Finally, testing may be conducted at random, based on time or material quantity. This frequency would be applicable to continuous or batch production processes, or to monitoring the quality of asphalt held in storage.

Seventy-five percent of the responding refineries conduct quality control testing on a "By Lot" or "By Volume" basis. Only twenty-two percent of the refineries use testing of samples taken at fixed time periods, and just three percent rely on testing at random intervals.

Specific Quality Control Strategies

Refinery visits provided insight into the details of asphalt production quality control strategies at several refineries. Some typical quality control practices are described in the text that follows.

At one medium-sized asphalt refinery, the asphalt product stream is tested every two hours, around the clock. Each storage tank is tested every fourth day.

One medium-sized integrated refinery employs on-line, quality control by monitoring the viscosity of the asphalt as it is produced by distillation in a vacuum tower. Storage tanks of the finished product are also sampled and tested to verify adherence to specifications. Another medium-sized asphalt refinery measures the viscosity of asphalt every two hours during production and daily in storage.

A very large integrated refinery maintains asphalt quality control during production by measuring product viscosity and penetration every four hours. Asphalt is shipped from this facility primarily by barge, and each barge load is sampled to measure viscosity, penetration, and flash point. Since barges take appreciable time to load, the viscosity of the asphalt is measured every two hours during the loading.

A small asphalt refinery employs routine measurement of asphalt viscosity and penetration to control the production process. A medium-sized integrated refinery uses a viscosity analyzer in the vacuum tower bottoms stream to monitor asphalt production.

Another medium-sized integrated refinery where asphalt is produced to grade by blending hard PDA (propane deasphalting) bottoms with vacuum gas oil, the tanks employed for storage at the truck-loading facility are tested and sealed upon filling. The refinery laboratory also tests the properties of all process unit streams and finished products as produced and as stored.

Another small asphalt refinery that reduces asphalt to grade on the vacuum tower maintains production control by sampling the product every two hours and measuring its penetration and softening point. If the production drifts out off specification, the blend of light and heavy crude oils is adjusted to move the properties back into the required ranges.

Another very large integrated refinery that produces large volumes of asphalt by blending vacuum tower residua with heavy flash distillate controls the finished asphalt production to very tight internal specifications to allow for mistakes and contamination after the asphalt leaves the refinery or its terminals. The vacuum tower residua are sampled once every eight hours, and its penetration and viscosity are measured to monitor production control. When an asphalt storage tank has been filled with blended asphalt, the tank is sampled and certified to meet applicable specifications. Shipping tanks located at the transport-loading facility are also sampled and tested for penetration and viscosity to satisfy state highway agency requirements.

Another large integrated refinery that produces asphalt by vacuum distillation in block operations certifies each asphalt production period by sampling and testing for viscosity, penetration, ductility, flash point, and thin film oven test parameters. Samples are taken at random times each day at the truck transport and railcar-loading facilities.
At a medium-sized integrated refinery which produces asphalt by air blowing PDA residua, each batch from the air-blowing still is sampled and tested for adherence to applicable specifications.

Similarly, a refinery that produces asphalt by reduction to grade of PDA bottoms, samples the PDA bottoms around the clock, and adjusts the operating parameters of the PDA unit as needed.

Finally, at a medium-sized integrated refinery that produces asphalt to approximate grade in batches by air blowing vacuum tower residua, finished asphalt is made by blending successive batches on the basis of their tested properties. Finished asphalts then are transferred to storage tanks where they are tested daily. The air-blowing operation is continually tuned on the basis of test results to maintain or achieve required specification properties.

Testing of Retained Samples

One manner in which a refinery may maintain some control over the quality of its asphalt products after they leave the refinery is by the use of retained samples. These are samples taken from storage tanks or, more commonly, from transports at the time of loading, and retained at the refinery for varying periods of time, generally not exceeding one year. They are tested only if a specification compliance problem is identified during the use of the material.

Retained samples allow a refinery to determine the reasons for specification failures reported for its asphalt. Such reasons may be as follows:

1. Caused by testing error;

2. Originated at the refinery;

3. Resulted from contamination or poor handling practices during transport

or in storage and handling at an independent terminal or paving contractor's facility.

Since several state highway agencies hold the asphalt producer (the refinery) responsible for specification failures that occur even after the asphalt leaves its control. Retained samples provide a means of pinpointing the source of problems that occur and, if needed, allocating penalties for noncompliance to the appropriate parties.

The use of retained samples was raised during the refinery visits. One large refiner with many asphalt refineries and terminals requires that all incoming truck transports be inspected for cleanliness. Of most concern is contamination of the transports by fuel oil; this would severely affect the viscosity and flash point of any asphalt introduced into the transport. The refiner has found that most problems typically arise after the products are sold and are no longer under the refiner's control.

Another large integrated refinery retains a sample from every transport load shipped from the refinery. The first retained sample taken each day is tested to assure that the asphalt in storage meets the required specifications. Subsequent samples are retained for a year and then disposed of. This refinery, which in peak paving months will ship as many as 250 twenty-two-ton truck transport loads a day, generally has to test about twenty retained samples a year because of problems.

Similarly, one relatively small asphalt refinery makes a daily check of the penetration of retained samples taken at the transport loading rack. Another refinery of medium size takes a sample from every transport and tests it for adherence to specifications before the transport is released to the customer. These samples are further retained for three months in the event that problems arise during subsequent storage and use of the asphalt.

Another large integrated refinery retains a sample from the last load taken from each storage tank (the asphalts are typically blended to specification in the storage tanks) until the tank is refilled. It also retains for one year samples taken from every truck, barge, and railcar load leaving the refinery. Finally, a medium-size integrated refinery retains a sample from every truck transport shipped from the refinery, and tests every fifth retained sample for specification compliance.

Self-Certification vs. State Agency Testing

The state highway agencies (SHA), which are the main purchasers, directly or indirectly, of paving asphalts, require affirmation that purchased asphalt comply with applicable specifications. Traditionally, compliance has been determined by SHA testing of check samples taken from refinery storage tanks or from transports. Recently, reductions in SHA work forces have caused some movement toward self-certification of asphalt by the producer.

Still, the refinery survey indicated that only twenty-eight percent of the respondents are permitted by SHA policy to self-certify the compliance of their paving asphalts with applicable specifications. At the majority of refineries, asphalt samples are provided to SHA inspectors and tested at a central laboratory for specification compliance. In some cases, the samples may also be sampled by the inspectors, either from storage tanks or from transports destined for specific highway construction projects.

In contrast to the quality control testing conducted by the refineries themselves, SHA sampling relies more on random sampling and testing. Specifically, thirty-nine percent of the responding refineries reported that SHA samples were taken at random (compared to just three percent for quality control testing) and another forty-nine percent on a "By Lot" or "By Volume" basis.

A large petroleum refiner, in an effort to avoid compliance problems, regardless of their source, produces asphalt cements to tighter requirements than those included in state specifications. As stated, this policy allows for the product to become contaminated during shipping or at the customer's facility, and still meet state specifications.

A large integrated refinery is required to self-certify asphalt compliance with state specifications, but the SHA also has an inspector at the refinery who tests all product batches separately. Another large integrated refinery is required to self-certify all loads of asphalt; however, split samples must also be provided to the SHA for separate confirmation of the test results. Similarly, a small asphalt refinery self-certifies SHA specification compliance, but a SHA inspector takes samples weekly from storage tanks for testing as an independent check on the self-certification.

Type and Frequency of Specification Compliance Problems

Thirty-five percent of the responding refineries reported that within the two years previous to the survey, they had experienced a problem with asphalt failing to meet applicable specification requirements.

The majority reported that problems occurred no more than once or twice a year, or that the failure rate was less than 0.5 percent of the loads shipped.

Most failures involved noncompliance of the asphalt viscosity or penetration with the specified values. In two reported cases, the failure was attributed to contamination of the asphalt after it had left the refinery. In another instance, the failure was found to have been caused by improper sampling technique during sampling by the inspector, allowing the samples to comprise a blend of two different grades.

For noncompliant asphalt still within the control of the refinery, corrective action usually involved reblending of the stored asphalt to specified limits or adjustment of the refinery operation to eliminate the problem. One refinery reported the need to change crude slate to achieve the viscosity-penetration relationship required by SHA specifications.

Once the asphalt has left the refinery, the latitude for corrective action is small, and settlement usually involves monetary penalties. In such situations, it is in the refinery's best interests to determine the exact point in the path from refinery to customer at which the problem arose.

7

Asphalt Refinery Storage, Loading Facilities, and Transport

Storage Facilities

All petroleum refineries, regardless of their size, must maintain extensive tankage for storage of crude oils and all the intermediate and finished products that make up their product slates, including asphalt. At any refinery, the land area devoted to tank farms rivals, and generally exceeds, the area devoted to production units.

Seventy-five percent of the refineries that responded to the survey estimated that it takes between three and twenty days for asphalt to leave the refinery after it is produced. Since the median reported asphalt production capacity is between 1,000 and 2,000 tpd, a typical refinery needs anywhere from 20,000 to 225,000 bbl of storage volume just to handle minimum operational requirements.

Management of refinery storage space is a complex operation that must take into account large seasonal swings in demand for major products like transportation fuels. With the exception of California, Arizona, Florida, and parts of Texas and the southeastern United States, asphalt paving is not possible for significant periods of the year in the United States and Canada. Thus, asphalt production and storage requirements are also subject to large seasonal variations.

Asphalt Storage Tank Types and Sizes

Asphalt storage tanks may be divided for convenience into three functional types: primary storage, blending, and loading. A given asphalt refinery may employ separate units of each type or may utilize the same tankage to meet all three requirements.

Primary storage tanks are employed for the bulk storage of finished asphalts and are generally the largest asphalt tankage available at the refinery. Smaller blending tanks are employed at certain refineries to facilitate the production of intermediate asphalt grades by blending two finished grades or a finished grade and a flux, such as vacuum gas oil. Loading tanks, which are generally comparable in size to blending tanks or smaller, are located at the transport-loading facility and hold enough finished product to meet one or two days demand.

The majority (eighty-four percent) of the responding refineries maintain at least four tanks for asphalt storage. Storage tanks are primarily (eighty-five percent) greater than 10,000 bbl in capacity. Indeed, primary asphalt storage tanks are usually far larger in size than 10,000 bbl capacity.[14] (A flaw in the questionnaire is that the range of sizes utilized for asphalt storage was grossly underestimated.)

Based upon data collected during the refinery visits, primary storage tanks range in size up to the 300,000 bbl (54,000 ton) capacity noted at two refineries. Other common sizes are 30, 50, 80, 90, and 150 thousand bbl. The usual capacity of blending and loading tanks appears to be in the range of 10,000 to 30,000 bbl, but one small asphalt refinery was visited that conducts blending in tanks of 35,000 bbl and greater capacity.

The total asphalt storage capacity available at various refineries also differs greatly, and does not appear to be proportional only to their asphalt production capabilities. One medium-sized asphalt refinery for which asphalt represents fifty percent of the product line has a total of 240,000 bbl of asphalt storage in four tanks: two 80,000 bbl, one 50,000 bbl, and one 30,000 bbl. However, a medium-sized integrated refinery maintains 110,000 bbl of primary asphalt storage, supplemented by several small tanks at the transport-loading facility.

A small southeastern asphalt refinery has 30,000 bbl of primary asphalt storage capacity while a similar-sized facility in the same region has 135,000 bbl of primary storage, as well as five smaller loading tanks.

A very large integrated refinery in the northern United States maintains a primary asphalt storage capacity of 800,000 bbl, with another 200,000 to 400,000 bbl available if the need arises. By contrast, a comparably sized integrated refinery in a mild climate maintains only 90,000 bbl of asphalt storage. Thus, similar refineries may have significantly different

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[14] An accepted conversion factor in the industry is that one short ton of paving asphalt takes up a volume of approximately 5.56 barrels (bbl) where a barrel of petroleum contains forty-two gallons. Thus, a 10,000 bbl storage tank holds about 1,800 tons of paving asphalt.

storage tank facilities, depending upon diversity of products, product demand cycles, climate, and the number of terminals supplied.

Physical Characteristics of Asphalt Storage Tanks

Asphalt storage tanks invariably are of the familiar cylindrical configuration employed for the storage of all petroleum products except compressed and liquefied gases at refineries.

Information gathered during refinery visits indicates that the asphalt tanks, regardless of specific function, are insulated to reduce temperature loss. In many cases, the tanks, particularly primary storage tanks in mild climates, have no heating system; rather, they depend upon the process heat imparted during asphalt production to maintain the asphalt at a temperature that permits pumping.

Heated tanks generally employ a circulating hot oil, hot water, or steam system fired by natural gas or refinery product gas to control temperature. Heated tanks are necessary, particularly in cold climates where asphalt is stored in bulk over the winter; such tanks may be allowed to cool naturally until late winter when the heating system is turned on to raise the temperature to the 300°F+ level at which it is sold. The refinery survey responses indicated that during the paving season asphalt is maintained at a mean temperature of 326°F, although specific refineries reported that product is stored at temperatures as high as 400°F and as low as 240°F.

Asphalt storage tanks have agitation systems to maintain a homogeneous temperature while asphalt is continually pumped in and drawn out. Positive agitation is provided by three methods: 1) large, electric motor-driven pitched-blade agitators mounted at the base of the tank, usually in pairs at a ninety-degree separation; 2) bubbling of compressed air through the stored asphalt; or 3) continual circulation of asphalt in and out of the tank through associated transfer lines. Six of the sixty-seven responding refineries indicated that they employ inert gas (for example, nitrogen or carbon dioxide) blanketing of the asphalt storage tanks; this would be done either to reduce the likelihood of oxidation or, primarily, as a safety measure.

Winter Storage

Refineries located in areas where asphalt paving cannot be conducted in the winter generally continue to produce asphalt at a reduced rate throughout all or part of the winter season. They build up a stockpile to meet the high initial demand in the spring, as production is brought up to the normal level for the paving season. This type of seasonal production cycle is analogous to those well known for gasoline and fuel oil.

Twenty-nine of sixty-six responding refineries (forty-four percent) typically store three or more months of asphalt production over the winter season. Those that reported storing three months or less production over the winter are generally found in mild climates where paving operations may be conducted for most or all of the year.

By comparison, seventy-one percent of the refineries reported that they produce asphalt for ten months or more out of the year, and another twenty-three percent produce for seven to nine months a year. The five percent that produce asphalt for six months a year or less are typically found in locations with extremely short paving seasons. Eighteen refineries reported that asphalt is stored over the winter at ambient temperatures. Another forty-four maintain heated storage; the mean temperature reported was 293°F, but temperatures ranged as low as 100°F.

Asphalt Transport Methods

The refinery very often represents the "retail" point of sale for paving asphalt. This is in contrast to many petroleum products that are moved in bulk from the refinery by pipeline, barge, or railcar to a secondary distribution system. Accordingly, asphalt refineries typically have transport-loading facilities for servicing their retail customers, the paving contractors, and the independent terminal operators.

In the United States and Canada, the principal transport methods for asphalt are tanker-trailers, barges, and railcars. The standard tanker-trailer in the United States has a twenty-two-ton capacity; in Canada, the standard unit holds thirty-five to thirty-seven metric tons, and is sometimes operated in a double trailer configuration with a smaller "pup" unit. Asphalt barges typically carry 2,500 to 3,000 ton loads, while the standard asphalt railcar has a forty-ton capacity.

Ninety-six percent of the responding refineries reported that asphalt is routinely transported from the refinery by tanker-trailer, while barge and railcar are used routinely by only twenty-six percent and forty-two percent, respectively. By comparison, the proportion of refineries from which asphalt is never transported by tanker-trailer, railcar, and barge was four, thirty-two, and sixty-one percent, respectively.

Interestingly, sixteen of sixty-nine refineries (twenty-three percent) related that asphalt is occasionally or routinely shipped to paving contractors in transport (presumably, tanker-trailers) owned by the refining company. By contrast, transport owned by independent transport companies and highway paving contractors routinely takes delivery of asphalt at ninety-six and seventy-eight percent of the refineries, respectively.

Truck-Loading Facilities

Loading facilities for asphalt tanker-trailers ("trucks") are a common feature at almost every asphalt refinery. All have three common components: a truck scale, a loading rack, and a control unit.

The first is a truck scale that measures the weight of the tanker-trailer before and after loading. The weight of the asphalt is then calculated manually or, in most cases, automatically. A copy of a loading ticket is given to the truck driver that shows the quantity of asphalt being purchased. Most firms buying asphalt appear to have standing accounts with the refining company that allow consolidated, periodic billing. However, payment may be required at the time of purchase in cases where the purchaser is a new customer or has a poor credit history.

The second component is the loading rack at which the tanker-trailers are physically loaded. A loading rack consists of two or more loading arms that are positioned over the top hatch of the tanker. Asphalt is commonly moved from the storage tanks by pumps, but gravity flow of hot asphalt may occasionally be used for loading.

The third component is the control unit. These vary in complexity and technical sophistication from a simple, electrically actuated valve for control of the gravity-induced flow from a loading tank, to a computer-controlled blending and loading system that can tailor the grade of asphalt delivered by in-line metering of materials from several loading tanks.

Typically, several loading and blending tanks (discussed previously in this chapter) are associated with transport-loading facilities. At refineries where asphalt is produced to grade on the process units, there may be a loading tank dedicated to each asphalt grade sold from the refinery. Alternatively, if only one or two grades are marketed, the loading facility may be directly connected to the primary storage tanks. No specific provision for blending is required in such instances.

At refineries where intermediate grades of asphalt are produced by blending low- and high-viscosity-graded materials, or a high-viscosity asphalt and a flux such as vacuum gas oil, two loading tanks interconnected by an in-line blending unit may be used to produce specification-grade asphalt at the loading rack.

It was found during refinery visits that a twenty-two-ton capacity tanker may normally be loaded with asphalt pumps in fifteen to thirty minutes, depending upon the specific equipment used at the loading rack. Interestingly, a small asphalt refinery that employs gravity loading can fill a tanker in about twelve minutes.

All the refineries visited in this study have truck-loading racks that can accommodate the simultaneous loading of two or more tankers; four or five loading arms appear to be the norm. The largest refineries may load anywhere from one hundred to two hundred truckloads a day during the peak of the paving season, completely turning over the contents of a 10,000 or 20,000 bbl loading tank daily. In many instances, the number of trucks handled is limited mainly by access to the truck scales, and several refineries have installed two scales to speed up operations.

Self-Service vs. Full-Service Facilities

Like the retail sale of gasoline, the trend in the operation of asphalt tanker-truck loading facilities is from full-service, in which all operations are accomplished by refinery personnel, toward self-service, in which most loading and blending operations are accomplished by the truck driver.

A major difference between an asphalt refinery and the local gasoline station is that a truck driver using a self-service asphalt loading rack has been trained and certified in its proper and safe operation. This is particularly important at those refineries that blend to grade at the loading rack.

Self-service facilities generally have at least one refinery employee at the loading facility to operate the truck scales and issue loading tickets. Several facilities have another employee at the loading rack to operate or assist drivers with the blending control unit, take truck samples for testing, and inspect incoming trucks for cleanliness and the absence of contamination in the tanker.

Railcar-Loading Facilities

Many of the refineries visited also have loading racks for filling railcars with asphalt. These also employ multiple loading arms and draw asphalt from loading tanks or through in-line blending units. These, as would be expected, are operated exclusively by refinery personnel.

At a medium-sized asphalt refinery that was visited, a railcar can be loaded in thirty minutes, and another similar-sized refinery handles six to eight railcars per day. Another of this type has the capability to load eight railcars simultaneously with asphalt.

A large integrated refinery for which asphalt is a major product has a railcar-loading facility that handles two seven-car strings at the same time, loading two or four cars simultaneously.

Barge-Loading Facilities

Several large integrated refineries located on or near navigable bodies of water have major installations for the loading of barges. Barge shipments are used to supply bulk deliveries to terminals operated by the refining company, franchisees, or independent operators.

Barge-loading facilities are operated by refinery personnel, but much of the actual loading is conducted by barge personnel. In plan, equipment, and operation, barge-loading facilities are similar to those already discussed for tanker-trucks and railcars, but the scale of operations is considerably larger.

For example, a large integrated refinery in the southeastern United States that ships most of its asphalt products to terminals by barge has a barge-loading facility with a capacity of 8,000 bbl (about 1,440 tons) per hour.

Another large integrated refinery maintains 250,000 bbl of asphalt storage exclusively for its barge-loading facility; two barges can be loaded with asphalt simultaneously at a rate of 2,000 bbl per hour each, completely loading a barge every 8.5 hours. Barge shipments are made to terminals throughout the eastern and midwestern United States.

8

Asphalt Distribution Systems

Introduction

There is a strong, constant demand for paving asphalt throughout the United States and Canada, and it is interesting to examine the asphalt distribution patterns from the refineries and their associated terminals.

Each refining company that responded to the refinery survey was asked to identify the number and location of asphalt terminals that it operates. Terminals are secondary distribution points for petroleum products such as gasoline and asphalt. They are often, but not exclusively, in locations remote from any refineries and are usually supplied by bulk shipments through pipelines or in the case of asphalt, railcar, or barge. There are also independent terminal operators that buy asphalt and other petroleum products from refining companies and resell them in the secondary distribution market or directly to users. These will be discussed later in this chapter.

Sixty-seven refineries reported information on company-operated terminals that market paving asphalt. Of these, forty-three do not operate off-site terminals; the remaining twenty-four operate eighty-seven off-site terminals. Table XII presents a summary of the distribution of terminal operations among the responding refineries.

While the majority of responding refineries (sixty-four percent) do not serve any company-operated terminals, six refineries supply by themselves more than fifty percent of the terminals identified. This suggests that a substantial portion of paving asphalt used in the United States and Canada is supplied by "local" refineries, and that only a few refining firms market asphalt over large geographical areas.

TABLE XII. FREQUENCY OF ASPHALT TERMINAL OPERATIONS

NUMBER OF ASPHALT TERMINALS OPERATED	NO. OF REFINERIES
0	43
1	7
2	3
3	4
4	4
5	2
7	1
9	2
11	1

Figure 9 is a map illustrating the number of refineries that market asphalt in a given state or Canadian province, either directly from the refinery or through company-operated terminals. Figure 10 displays the frequency distribution of refineries in the form of a bar graph. As may be seen, more than seventy percent of the states and provinces are served by five or more asphalt refineries; only one state, Maine, is served by only one of the responding United States and Canadian refineries. Illinois, on the other hand, is served by a maximum of ten different refineries.

Information on company-operated asphalt terminals operating in the United States is summarized in Figures 11 and 12. As may be seen, Maine was the only state identified in which no asphalt was marketed from any terminal. Five or more refining company-operated terminals market asphalt in twenty of the fifty states, and all but six of the states are in the marketing area of two or more terminals.

These data, when considered together, suggest that user agencies in most areas of the United States and Canada have access to asphalt from a substantial number of competing sources.

Sale of Asphalt to Other Distributors

Independent terminal operators represent a secondary distribution system for asphalt, as well as many other petroleum products. These operators, as will be discussed later in this chapter, obtain asphalt both by purchase from domestic refiners, as well as by the importation of finished asphalt from foreign sources.

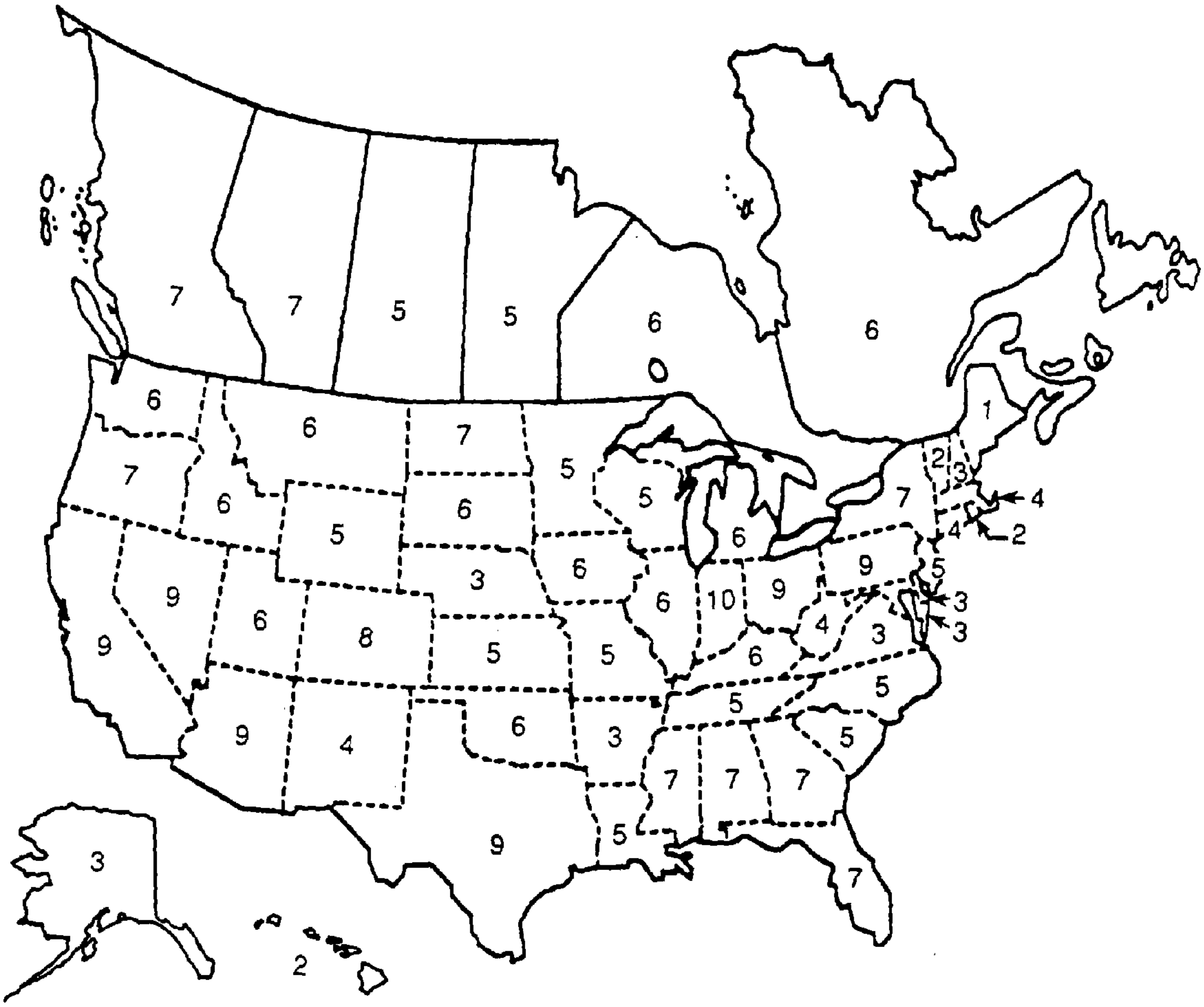

Figure 9. Number of Refineries Marketing Paving Asphalt in Each State and Province.

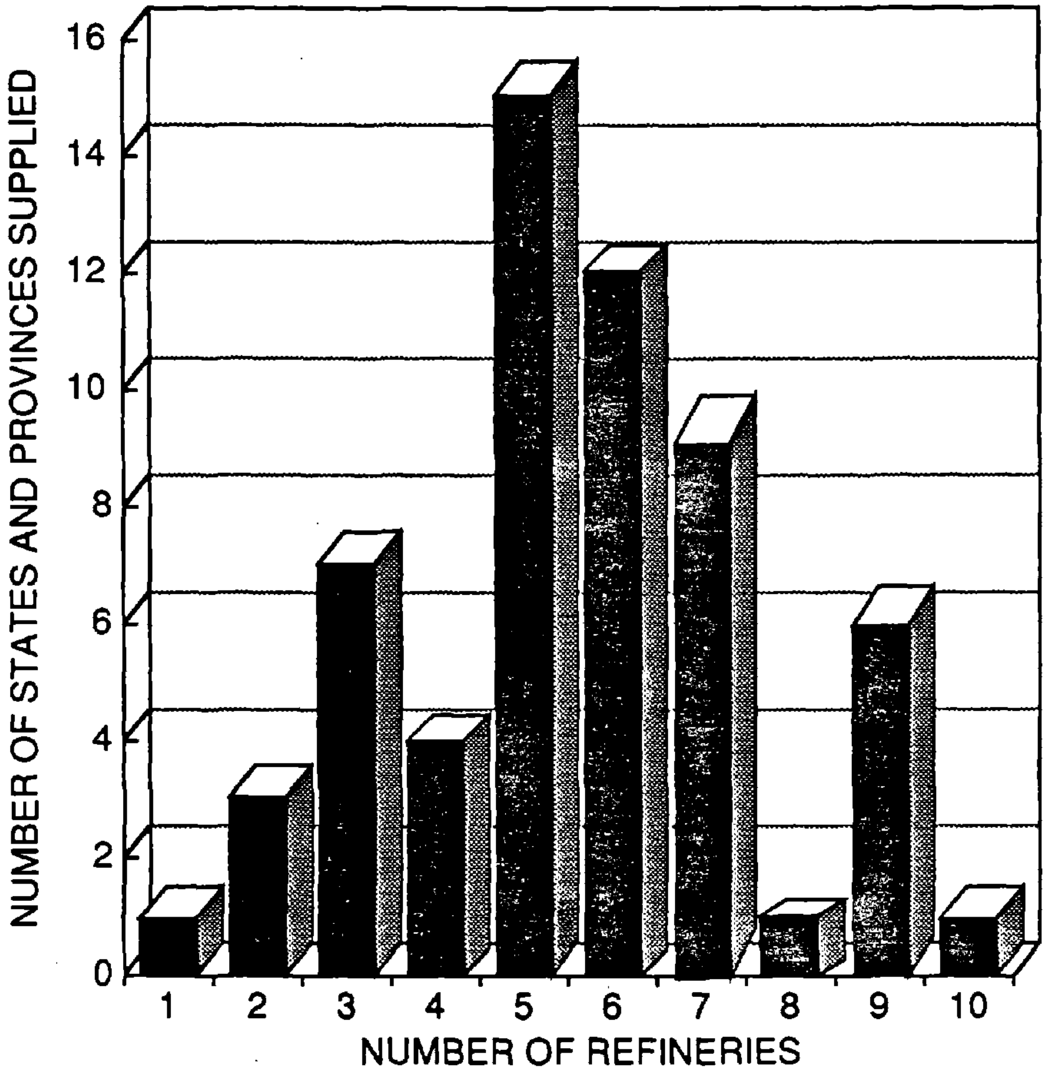

Figure 10. Frequency Distribution of Refineries Marketing Paving Asphalt in the United States and Canada.

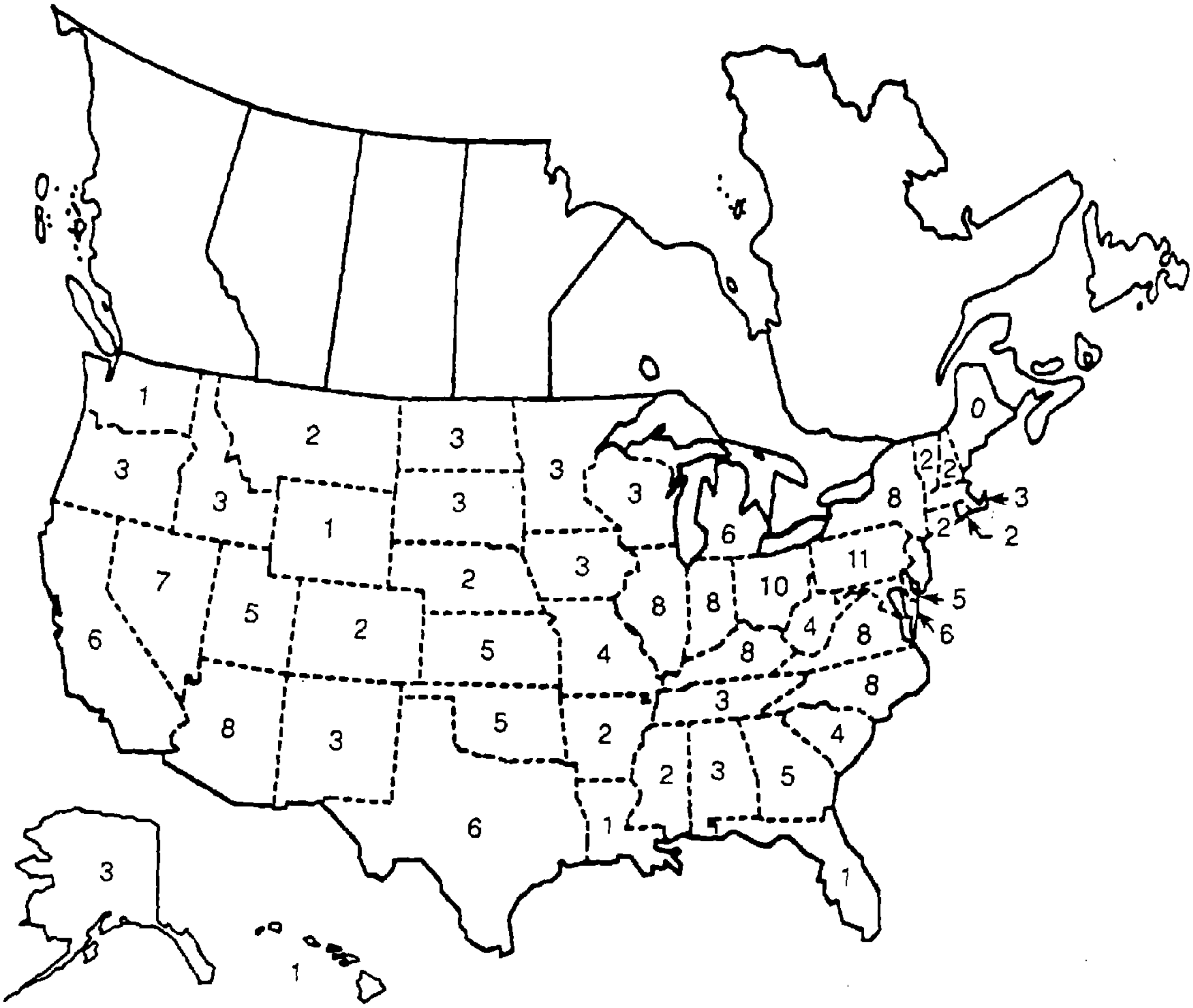

Figure 11. Number of Terminals Marketing Paving Asphalt in Each State.

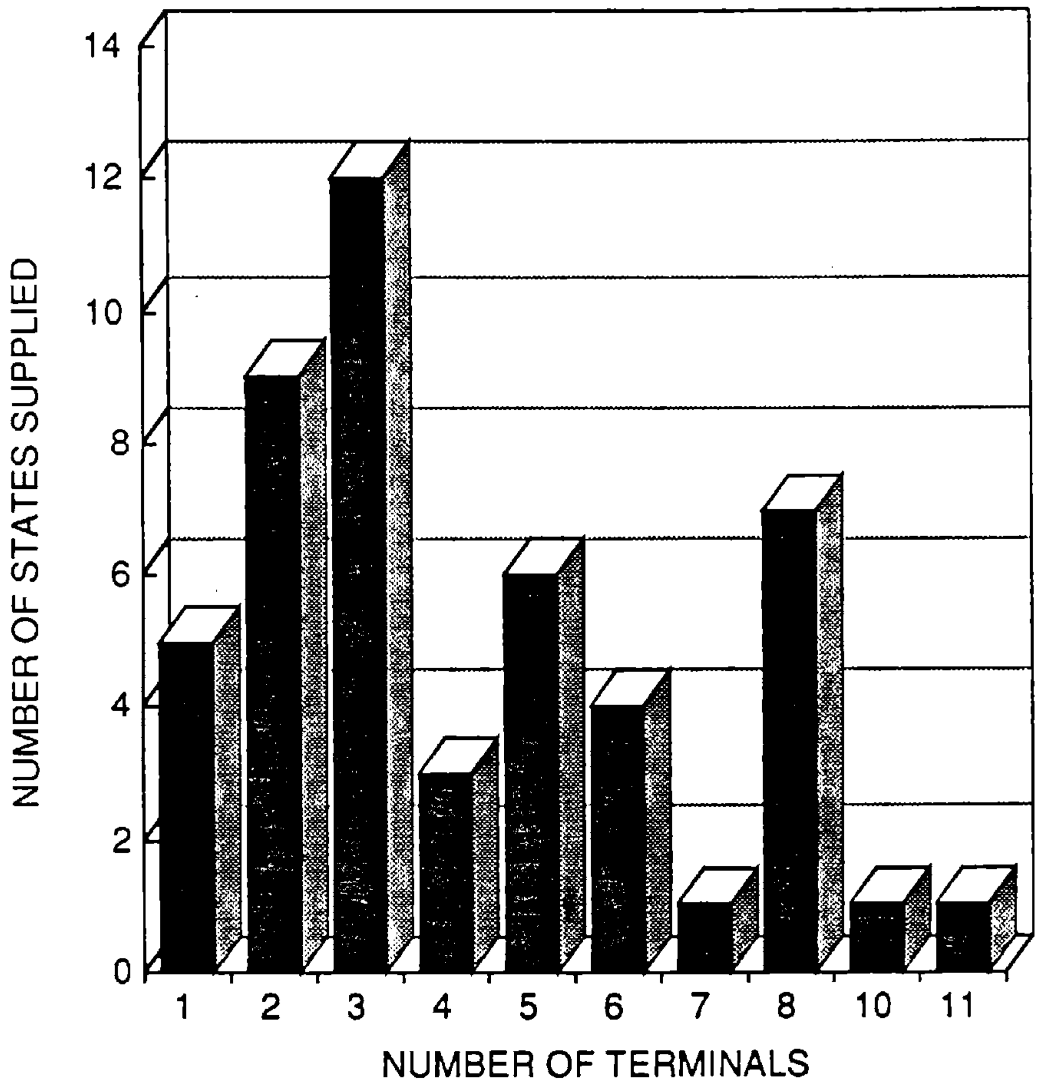

Figure 12. Frequency Distribution of Terminals Marketing Paving Asphalt in the United States and Canada.

Only nineteen percent of the refining companies responding to the refinery survey indicated that they do not sell paving asphalt to independent distributors. Fourteen firms (thirty-eight percent of the respondents) do this on a routine basis. These firms reported that they sold a total of 2,548,520 tons of asphalt to other distributors in 1987; this figure represents approximately eight percent of the total paving asphalt consumption reported for the United States and Canada in 1987.

Another sixteen firms reported that they occasionally sell to independent distributors, but these firms did not provide tonnage figures for 1987. However, the data indicate that the independent, secondary distribution system for paving asphalt may account for as much as ten to fifteen percent of the asphalt sold in the United States and Canada. Obviously, the refining companies do not exert direct control on the quality of this product after it leaves the refinery gate.

Exchange of Asphalt With Other Producers

It is a common practice for refining companies to exchange shipments of gasoline and fuels to balance local variations in supply and demand. On a small scale, a similar exchange practice is also employed with paving asphalt.

Eleven of thirty-nine responding refining companies (twenty-eight percent) reported that they never exchange asphalt with other producing companies to meet a need dictated by local variations in demand. Five companies (thirteen percent) indicated that this practice occurred on a routine basis; in 1987, the total tonnage exchanged was reported to be 383,000 tons of paving asphalt, little more than one percent of the total United States and Canadian consumption in that year. These data suggest that insofar as it is purchased by "brand name" (and this is probably not the usual custom), most paving asphalt is "as advertised."

Importation of Finished Asphalt

The Asphalt Institute has reported[15] that 2,500,153 tons of paving asphalt were imported into the United States in 1987, exclusive of 290,130 tons of Canadian imports. More than fifty-five percent of this total came from Venezuela, with another forty-three percent about equally divided among Mexico, the Netherlands Antilles, and Spain.

[15] Ibid., p. 17.

Independent terminal operators are expected to be the major importers of paving asphalt; however, refining companies responding to the survey were asked if they imported asphalt in significant quantities to supplement their own production. Only one company responded affirmatively; it reported importing 400,000 tons from Venezuela in 1987. These data confirm the supposition that domestic asphalt refiners are not the major importers of asphalt into the United States.

Additive and Modifier Use

There has been great interest in recent years in the use of additives or modifiers to enhance the performance of asphalt pavements. Additives such as organic antistrip agents have been routinely used for more than forty years, and silicone oils have been extensively employed as antifoaming agents, or as "paving mixture workability promoting" agents in asphalt pavement construction. More recently, modifiers such as natural and synthetic rubbers, carbon black, sulfur, and polyethylene, to name but a few, have been extensively evaluated and, in a few instances, placed in operational use.

Most additives and modifiers share a single common feature: they are ordinarily introduced into the paving mixture by blending them with the asphalt. Thus, the introduction of additives into the asphalt at the refinery might be thought to be a common occurrence, at least for materials that have been accepted into routine use.

Surveyed refineries were asked whether any of five additives are routinely blended with asphalt at the refinery, namely, antistrip agents, silicone oil, elastomers (such as SBR, SBS, or SB rubbers), polymers such as polyethylene, ethylene vinyl acetate (EVA), and anti-oxidants. Only fifteen percent of the responding refineries routinely blend antistrip agents; the other four additive types are routinely introduced by only ten percent of the refineries or less. Such blends are prepared in response to requests from user agencies.

No refinery routinely blends anti-oxidants. Fully fifty-three percent of the respondents never blend antistrip agents into their asphalt. The proportion that never blends the other four types is substantially higher: from eighty-four percent for polymers to ninety-seven percent for the anti-oxidants.

In summary, only antistrip agents appear to have any substantial routine or occasional use, but at only a minority of the responding refineries. The presence of silicone oils in asphalt, which has been suggested as a source of certain pavement problems, including tender mixes, appears to be mainly attributable to handling of the asphalt after it leaves the refinery. However, silicone oils are occasionally used as antifoaming agents at crude oil storage, and through this use may be present in asphalt cement.

Several visited refineries added antistrip agents to asphalt at the loading rack when it is required by the cognizant state highway agency. Two others indicated that they have silicone oil available, but it is added (at a rate of four fluid ounces per twenty-two tons of asphalt) only when requested by the purchaser. One Canadian refinery added SBS elastomer also upon request by purchaser.

Several refineries that market in Texas produce and supply large quantities of latex-modified asphalt for state highway agency projects, particularly surface treatments on interstate and primary system routes. No other specific instances of asphalt modifier use were noted during the refinery visits.

Independent Asphalt Suppliers (Brokers)

An important component of the asphalt distribution system is the independent asphalt suppliers. These include terminal operators, known colloquially as resellers or jobbers, who buy paving asphalt from domestic producers or import it in bulk quantity and resell it mainly to asphalt paving contractors. Also included are firms that broker asphalt; these do not operate terminals or physically take delivery of asphalt.

Asphalt suppliers are efficient, competitive sources for asphalt and many other petroleum products in areas remote from any refineries. They provide a significant adjunct to the refiner-operated asphalt distribution system considered in the previous sections.

As described in Chapter 2, a supplier survey questionnaire, structured along the lines of the refinery survey, but significantly abbreviated in scope, was prepared and sent to thirty firms. Thirteen responses were received; eight firms indicated that they operate a total of twenty asphalt terminals in the United States. The other five firms do not operate terminals, but evidently act as brokers for paving asphalt. The detailed answers to the questionnaire are summarized in Appendix II.

The twenty terminals reported marketing asphalt in eighteen states; the data are summarized in Figure 13. The responding firms do business primarily in the Pacific Northwest, Middle Atlantic states, and New England. These are areas of significant demand; however, they have relatively few asphalt refineries, and are generally far removed from domestic crude oil supplies.

Seven of the thirteen responding firms presented information on their asphalt sales volumes in 1985, 1986, and 1987. Each reported selling in excess of 15,000 tons in each of those three years. Table XIII shows the breakout of sales by asphalt grade in 1987

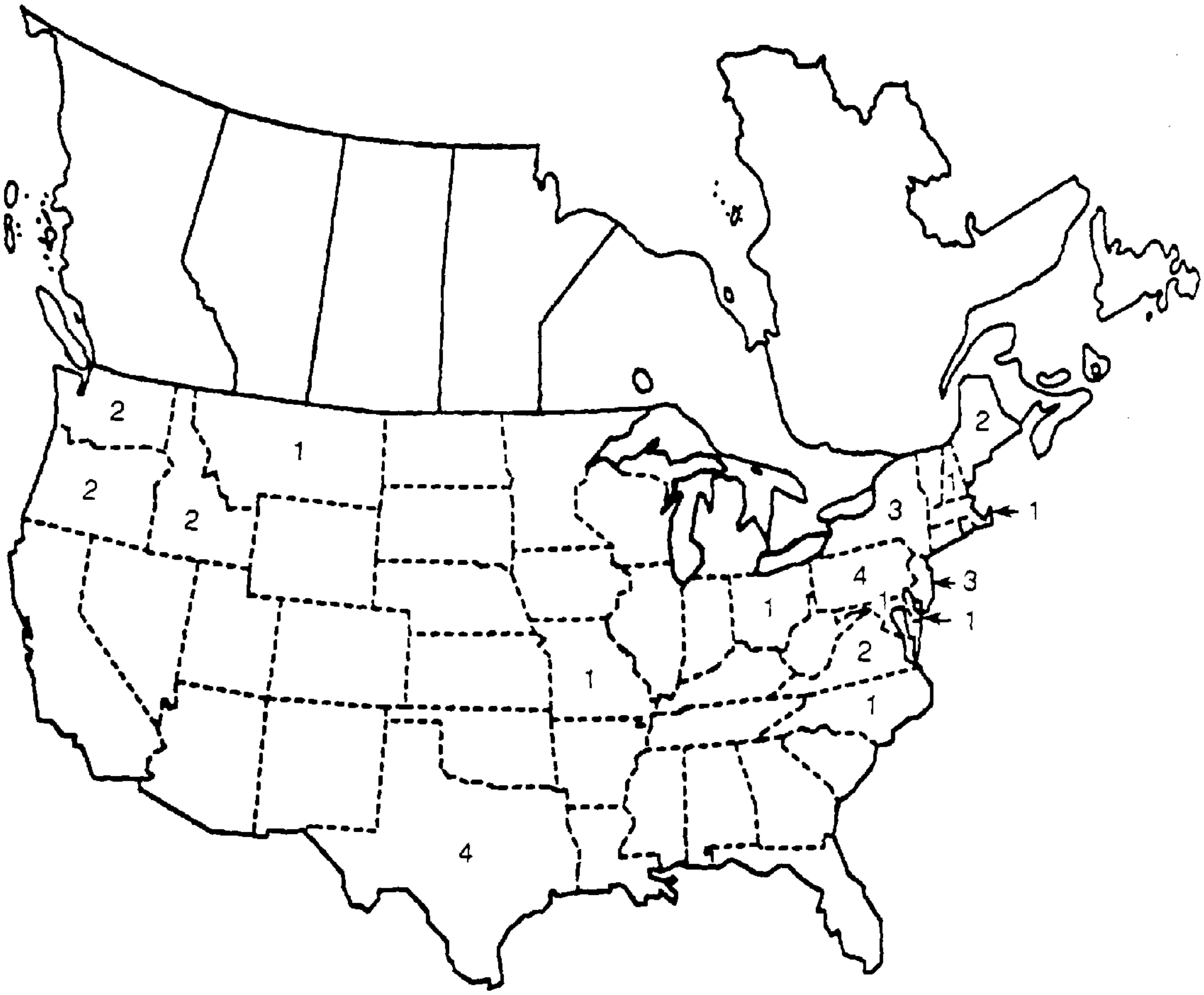

Figure 13. Number of Independent Jobbers Marketing Paving Asphalt in Each State and Province.

reported by only three firms.

TABLE XIII. 1987 JOBBER ASPHALT SALES BY GRADE

GRADE	AMOUNT (TONS)
AC-2.5	20,100
AC-5	66,100
AC-10	101,400
AC-20	783,500
AC-30	4,000
AC-40	1,000

Sales of 20,500 tons of special asphalt grades were also reported; 100 tons of AC-20 with a penetration between 85 and 100; 400 tons of AC-20P, an AC-20 modified with polymer or elastomer; and 20,000 tons of AC-LTX, an asphalt modified with rubber latex. The total for the three firms was 996,600 tons, seventy-nine percent of which was AC-20 grade.

This total represents approximately 3.6 percent of the reported 1987 paving asphalt demand in the United States[16]. If the other ten firms had similar sales volumes, these data suggest that jobbers account for a significant percentage of the "retail" paving asphalt sales (to paving contractors) in the United States, perhaps ten to fifteen percent or higher.

Blending Operations

Although terminal operations necessarily lack the process complexity found in asphalt refineries, production of various grades by blending is a common feature.

Sixty percent of the responding terminals produce intermediate asphalt grades on-site by blending hard (high-viscosity) and soft (low-viscosity) grades. In-line blending is the most common method reported, with the two materials drawn from storage tanks through a blender, presumably at the loading rack. However, one terminal reported that the two grades were blended by combining proper proportions with agitation in a third storage tank.

[16] Ibid., p. 17.

These same terminals also reported the capability to blend a hard asphalt grade with a flux (a soft material not meeting the requirements for the softest asphalt grades) using the same blending methods discussed previously. Four specific flux types were described: Hydroline 90; a high-flash vacuum gas oil; a high-flash vacuum residua; and material with a viscosity equivalent to an AC-5, but not meeting other asphalt specifications. No doubt, these different materials or fluxes may affect significantly properties of finished asphalt cement.

Quality Control

The supplier survey examined the quality control practices of the independent terminal operators. Table XIV presents the asphalt tests most frequently employed at independent terminals for quality control of finished asphalts.

TABLE XIV. QUALITY CONTROL TESTS FOR FINISHED ASPHALTS

ASPHALT PROPERTY	NO. OF TERMINALS
Viscosity at 140°F	15
Penetration at 77°F	15
Viscosity at 275°F	14
Flash Point (COC)	13
Thin Film Oven Test	12
Ductility at 77°F	12

Of the responding terminals, eighty-seven percent conduct quality control testing on a "By Lot" basis; this is also the prevalent frequency for testing in refineries (see section 6). All of the terminals also reported that they routinely test asphalt after prolonged storage, principally over the winter months.

All the responding terminals indicated that acceptance testing of asphalt is performed by state highway agency personnel at their facilities. At about fifty percent of the terminals, this testing is conducted "By Lot;" the frequency at the remaining terminals is divided between "By Time" (twenty-seven percent) and "Randomly" (twenty percent).

Only one terminal reported problems meeting specification requirements within the two years previous to the survey. In one instance, the asphalt had too low a penetration value. This was corrected by a switch to a different crude oil slate by the refiner. In the second case, the asphalt, as delivered from the terminal, had too low a viscosity value. No problem was identified at the terminal, and it is suspected that the asphalt was contaminated in transit after it left the terminal.

Asphalt Storage

Terminals may be expected to principally maintain primary storage tanks for asphalt that usually serve as loading tanks. As discussed above, only one terminal reported producing intermediate asphalt grades by blending in tanks, suggesting that terminals do not commonly keep blending tanks distinct from those used for storage.

Seventy-three percent of the responding terminals have four or more storage tanks for asphalt; one terminal reported that it required only two. The mean storage tank capacity was 50,000 bbl; the size range ran from 18,000 bbl to 150,000 bbl. Thus, terminals, as might be expected, have fewer and smaller storage tanks than refineries.

Average residence time for asphalt in storage was less than twenty days in all cases; and twenty percent of the terminals reported a residence time less than ten days. Interestingly, this is comparable to the average residence time reported by the refineries; this implies that asphalt could spend forty days or more after production in storage and transport during the paving season.

Typically, terminals will maintain less than a three-month supply in storage over the winter, in contrast to refineries, one-half of which almost store three months' or more production over the winter months. Obviously, terminals are severely limited by available storage capacity in this respect.

During the paving season, the mean temperature range at which independent terminals store asphalt is 290 to 330°F. The minimum and maximum reported temperatures were 230 and 350°F. When asphalt is stored over the winter, the majority (eighty percent) of the terminals maintain it heated within a mean range of 250 to 315°F.

An independent terminal can, of course, buy asphalt during the paving season from any producer that it chooses, based upon cost, ease of supply, and other related factors. This means that it is likely for asphalts of the same grade from different producers to become commingled at the terminal unless separate storage is provided. The consequences, if any, of such commingling on asphalt behavior and performance has not been established. Although some information is available that blending of two asphalts cements from different crudes may result in a material with unexpected consistency.

More than fifty percent of the responding terminals reported that such commingling was done routinely or at least occasionally, in agreement with the opinion expressed in the refinery survey results. Most of the responding terminal operators are of the opinion that their asphalts are further commingled with those of other producers at paving contractors' facilities. These facts strongly suggest that specific instances of good or poor early pavement performance must be carefully examined before they are related to the as-produced physical and chemical properties of the asphalt delivered from the refinery.

Asphalt Transport

All the responding terminals routinely ship out asphalt in tanker-trucks; one-third also ship out by railcar on a routine or occasional basis. No terminals employ barges.

In contrast to the refineries surveyed, the majority of the independent terminals employ their own transport, at least on an occasional basis, to ship asphalt. All reported routinely loading into equipment owned by independent transport companies and highway paving contractors.

Marketing Practices of Independent Asphalt Suppliers

The majority of the responding terminals (fifty-six percent) reported that they ship asphalt for ten to twelve months of the year. Only nineteen percent ship during six months or less.

Four suppliers of seven that responded to the question indicated that they at least occasionally exchange asphalt with other distributors in their marketing area to alleviate local variations in demand. One firm reported exchanging 200,000 tons in a typical year; two other firms reported exchanges totalling only 1,000 tons annually.

Unlike the refining companies, the major part of the independent asphalt suppliers import asphalt for sale in the United States. Total quantity of imported asphalt reported for 1987 was 543,200 tons; more than half was received from Venezuela. Together with the one refining firm discussed earlier in this chapter, these suppliers account for almost forty percent of the reported asphalt imports in 1987. Furthermore, imports account for fifty-four percent of the asphalt sales reported by the suppliers in 1987. Clearly, the results of the two surveys indicate that independent asphalt suppliers are the major source of imported asphalt used in the United States.

Additive Use by Independent Asphalt Suppliers

Only a minority of the responding terminals blend any additive routinely with asphalt; of the six that do, five blend antistrip agents, while the others reported producing and marketing latex and polymer-modified asphalts.

Another minority occasionally blend antistrip agents, silicone oils, and modifiers such as rubbers and polymers. None blend anti-oxidants with asphalt.

9

Summary and Closure

Summary

This refinery survey provided an abundance of information about the production, sources, distribution, and marketing of paving asphalt in the United States and Canada. Industry response to the survey must be termed as excellent: forty-one refining firms representing seventy-two asphalt refineries responded with detailed answers to a lengthy technical questionnaire. It is estimated that these refineries account for eighty-five to ninety percent of the paving asphalt produced in the United States and Canada in 1987. In addition, another thirteen independent asphalt marketing firms operating twenty asphalt terminals in the United States responded to a separate questionnaire on their distribution and marketing practices.

A general picture of the paving asphalt production industry has been drawn from this information, and in the opinion of the authors, the following statements are important highlights of the results:

- The well-known and long-established atmospheric and vacuum distillation petroleum refining processes, or a combination of the two, account for the majority of the paving asphalt produced in the United States and Canada.

- Solvent refining and air blowing are still of secondary importance in terms of paving asphalt production volume.

- The ROSE process appears to be the only significant new method adopted for paving asphalt production in the last decade. The use of this process is increasing.

- Integrated refineries manufacturing a wide variety of petroleum products dominate total paving asphalt production. For seventy-two percent of the responding refineries, paving asphalt production represents twenty-five percent or less of their annual crude oil throughput; for only one refinery does it represent seventy-five percent or more.

- The distribution of crude oil throughput in bpd among the refineries responding to this survey is very similar to the distribution reported for the U.S. refining industry as a whole.

- Significant changes in the crude oils employed in paving asphalt production have occurred over the past fifteen years, and continue to occur. Alaska North Slope, Mexican, and heavy Canadian crude oils such as Peace River, Bow River, and others that were virtually unknown as sources for paving asphalts in a 1979 survey, now represent the starting materials for a very large percentage of paving asphalt production, especially at large-capacity integrated refineries. U.S. Mid-Continent and Middle Eastern crude oils significant as sources a decade ago now are considerably less important. Venezuelan crudes still play an important role in U.S asphalt production.

- Paving asphalt is widely distributed throughout the United States from the refineries themselves, as well as through a secondary distribution system of refinery-operated and independent terminals. More than seventy percent of the individual states and Canadian provinces are served by five or more competitive sources of paving asphalt.

- Total paving asphalt tonnage produced at the seventy-two responding refineries was estimated at 27.1 million tons, or about ninety-two percent of the 1987 paving asphalt consumption (independently reported) in the United States and Canada.

- More than seventy percent of the paving asphalt reported produced in the United States and Canada in 1987 conformed to the AC-viscosity grading system (AASHTO specification M226, Tables I and II). Of this total, about sixty-five percent was produced to meet the AC-20 grade requirements.

- Only one of the forty-one responding asphalt refining firms reported that it imported finished paving asphalt into the United States (from a source other than Canada) in 1987. By contrast, the majority of the responding independent asphalt marketing firms reported significant imports in 1987. Together with the one refining firm, these marketers account for almost forty percent of the independently reported 1987 paving asphalt imports.

- Quality control practices generally appear very stringent in all phases of paving asphalt production and distribution from refineries. While thirty-five percent of the refineries reported some specification compliance problems during the two years prior to the survey, the majority reported that these occurred only once or twice a year, or represented a failure rate of less than 0.5 percent of the loads shipped from the refinery. Moreover, in many instances it appeared that the specific problems arose from conditions or factors to which the asphalt was exposed after it left the refinery.

Closure

The principal purpose for undertaking this refinery survey was to compile information on current refinery methodology as practiced on the North American continent and, if possible, to assess whether the recent changes in paving asphalt manufacture and crude oil supply influence the properties of the materials. Searching for possible sources or causes for the alleged inferior or inadequate performance of some paving asphalts was also a consideration in the study.

Refinery practices described in this phase of the report indicate that paving asphalts are produced from well over one hundred crude oil streams using atmospheric and vacuum distillation, solvent precipitation, and air-blowing processes. Combinations and modifications of these principal processes are necessary to accommodate continuous changes in crude oils and crude oil blends available to the refineries. The relatively recent widespread introduction of Alaska North Slope, Mexican Maya, and some Canadian crude oils, and the general trend toward heavier, either old or new crude oil sources in United States refineries, are well documented.

Asphalt, the heaviest petroleum fraction, is composed of hydrocarbon and hydrocarbon-like heteroatom-containing compounds of the highest molecular mass and greatest chemical complexity. Besides carbon and hydrogen, asphalt contains heteroatoms such as sulfur, nitrogen, oxygen, and a number of heavy metals such as vanadium, nickel, iron, and others, all bound in large molecular-size organic compounds. These chemical compounds are undesirable and unacceptable for other refinery products and processes. Thus, they are left in the asphalt, or alternatively, the refinery streams containing such compounds are subjected to destructive refinery processing for their removal.

Probably the single most common reason for change or fluctuations in asphalt properties is the change in crude oil supply. A refinery crude oil slate may be changed because of variable or seasonal demand for different refinery products or simply because of variable availability and the cost of a given crude oil. It is reasonable to expect that the chemical makeup of asphalts derived from different crude oils would vary substantially. And differences in asphalt chemistry, as caused by the chemical variation of crude oil, could influence markedly the performance and behavior of asphalt cement in a paving mixture. For example, a change in crude oil type could increase the amount of paraffinic compounds in the paving asphalt with a subsequent decrease in naphthenic and aromatic compounds which compose asphaltenes and asphaltic resin fractions of asphalt. The amount and type of microcrystalline wax in paving asphalt could also change with the crude oil, as well as the amount of heteroatoms and heavy metals. All these differences undoubtedly will influence the adhesive and cohesive properties of paving asphalt which may lead to differences in pavement performance.

The natural and variable chemical complexity of paving asphalt causing changes in its physical properties possibly could be further augmented by the presence of extraneous materials associated with crude oil production, its processing, and with asphalt manufacture. For example, such materials could be silt, clay, and inorganic salts, invariably present with crude oil, surface-active agents used in crude oil desalting, silicone-type oils used as defoamers, and possibly other materials. Residues or wastes derived from other refinery processes could possibly also find a pathway to either the asphalt itself or to the asphaltic production stream. This is not to say that such extraneous materials are present or were found in paving asphalt; rather, it is merely to point out the possibility of their presence, which could affect the properties and performance of the paving asphalt.

Another unlikely but conceivable reason for drastic change in asphalt properties could be inadvertent error in the refining process not identified by quality control tests before delivery of the material. Overheating and cracking of the paving asphalt or faulty proportioning in the blending process would be examples of such errors leading to marginal or faulty material. None of the above errors have been encountered during the refinery survey and refinery visits. Again, they are mentioned only as a possible source for drastic changes in paving asphalt properties.

Another possible source for inadvertent change in asphalt properties, although not associated with the refining process, deals with the material after it leaves the refinery. Paving asphalt may be delivered by truck, railcar, or barge. The asphalt may be delivered directly to hot-mix plant storage tanks, or it may first be consigned to the storage tanks of an independent marketer or jobber before delivery to hot-mix plants. Thus, the paving asphalt may be repumped as many as four or more times before it is finally incorporated in a paving mixture. Reheating of the paving asphalt to pumping temperature may be required several times during this process. More importantly, at each transfer point, the possibility exists for contamination of the original asphalt with asphalts from other sources, with cleaning solutions, with other petroleum products, or even with materials not derived at all from petroleum refining. Undoubtedly, repeated and prolonged heating and contamination during delivery and subsequent prolonged storage could affect substantially the properties and quality of the paving asphalt.

Because of these enumerated influences, a certain variability in asphalt properties may be expected and is accepted. The problem of the refiner and user alike is to contain this variability within ranges allowed by specification limits established by the user segment of the paving industry.

Current specifications contain requirements controlling viscosity of the paving asphalt, changes in viscosity, and ductility with temperature and with heating. Furthermore, tests to control volatility, purity, and safety aspects are also included in paving asphalt specifications. Such an array of requirements appears to be more than adequate to ascertain whether the properties of the material delivered from the refinery changed to an unacceptable level, and to judge whether such changes would critically affect pavement performance.

The SHRP asphalt program was predicated upon a seeming increase in incidents of poor pavement performance or premature, sometimes catastrophic, pavement failures, allegedly related to inferior quality and an inadequate knowledge of asphalt cement, a binder used for nearly a century in some ninety-five percent of the paved surfaces in the United States and worldwide. Through this program it is planned to develop comprehensive, performance-based specifications for asphalt binders and asphalt-aggregate mixtures that will permit selection of materials tailored to resist stresses of expected traffic loading and environmental conditions, and also capable of accommodating the marginal aggregate sources and deviations from recommended specification or established construction specifications or practices.

Regardless of frequent claims of poor quality and deteriorating performance of paving asphalts, case histories evaluating and documenting rigorously the reasons for such asphalt-related pavement performance problems are lacking and are sorely needed. Collection of such information through the long-term pavement performance (LTPP) and asphalt research programs of SHRP, and by other interested agencies, will close the gap. This will certainly lead to engineering and economic improvements which, in turn, will benefit all segments of the paving industry and the general public.

10

Selected Bibliography

Introduction

As discussed in Chapter 2, an extensive search of scientific and engineering data bases was conducted to aid in the assessment of the current practice in paving asphalt cement production. Emphasis was placed upon the identification of technical references dealing with the following:

1. General methods employed for paving asphalt production throughout the world;

2. The impact of new petroleum refining technology and processes on paving asphalt production; and

3. Correlations among paving asphalt properties, refining methodologies, and crude oil sources.

Although this effort yielded well over 150 possible references from the period 1960-1989, none, in the judgment of the authors, shed any significant light on these three listed items. Therefore, no attempt has been made to incorporate a listing of these references in this report. However, interested readers wishing to expand their knowledge of paving asphalt, its production practices and uses are referred to the following list that includes standard, and in several cases, "classic" texts in the field.

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Appendix I

Refinery Survey Results

Responses to the refinery survey questionnaire were received from forty-two firms in the United States and Canada, which reported on a total of seventy-two refineries producing paving asphalt during 1987. An additional four firms reported that they no longer are producers of paving asphalt.

This appendix summarizes the responses to the two-part refinery survey questionnaires. Part A requested general information from each refining firm on the overall operation their refineries and terminals, and their asphalt marketing situation. A separate Part B was requested from each firm for each of their refineries; it requested specific technical information on the asphalt production operations of each refinery

PART A. GENERAL INFORMATION

1. WHERE ARE YOUR COMPANY'S ASPHALT REFINERIES LOCATED (STREET ADDRESS)?

RESPONSE: Figure 1 indicates the number of responding refineries in each state and province.

2. WHAT IS THE CRUDE OIL THROUGHPUT OF EACH REFINERY IN BARRELS PER DAY?

RESPONSE: A completed response was received to this question for sixty-six of the seventy-two refineries. Total reported refinery throughput was 5,485,000 barrels per day (bpd), 4,937,000 bpd in the United States and 548,000 bpd in Canada. Mean throughput was 831060 bpd. Distribution of responses was as follows:

THROUGHPUT (bpd)	# OF REFINERIES
<50,000	37
50-100,000	13
100-150,000	6
150-200,000	1
200-250,000	4
250-300,000	1
300-350,000	2
350-400,000	1
400-450,000	1

3. WHERE ARE YOUR COMPANY'S TERMINALS LOCATED (CITY AND STATE)?

RESPONSE: Sixty-seven refineries responded to this question, providing the locations of eighty-seven refinery-owned terminals. Figure 2 indicates the number of responding terminals in each state and province.

4. WHICH REFINERIES SUPPLY EACH TERMINAL?

RESPONSE: Sixty-seven refineries responded to this question . The following table presents the distribution of terminals among the sixty-seven responding refineries:

# OF TERMINALS SUPPLIED	# OF REFINERIES
0	43
1	7
2	3
3	4
4	4
5	2
6	0
7	1
8	0
9	2
10	0
11	1

5. HOW MUCH ASPHALT IS PRODUCED AT EACH REFINERY AS A PERCENT OF YEARLY CRUDE OIL THROUGHPUT?

RESPONSE: A completed response was received for sixty-nine of the seventy-two refineries. Thirty-one (forty-five percent) reported asphalt production accounted for ten percent or less of crude oil throughput; nineteen (twenty-seven percent) reported eleven to twenty-five percent of throughput; ten (fifteen percent) reported twenty-six to fifty percent of throughput; eight (twelve percent) reported fifty-one to seventy-five percent of throughput; and one (one percent) reported that asphalt accounted for more than seventy-five percent of crude oil throughput.

6. HOW MANY MONTHS PER YEAR IS ASPHALT CEMENT PRODUCED AT EACH REFINERY?

RESPONSE: A completed response was received for sixty-four of the seventy-two refineries. Forty-six (seventy-two percent) reported asphalt production for ten to twelve months per year, fifteen (twenty-three percent) for seven to nine months per year and three (five percent) for four to six months per year.

7. IN WHICH STATES ARE ASPHALT CEMENTS MARKETED FROM EACH REFINERY?

RESPONSE: A completed response was received for all seventy-two refineries. The following table presents the number of refineries reported to supply each state and province:

STATE OR PROVINCE	# OF REFINERIES	STATE OR PROVINCE	# OF REFINERIES
Alaska	3	Alabama	7
Arkansas	3	Arizona	9
California	9	Colorado	8
Connecticut	4	Delaware	3
Florida	7	Georgia	7
Hawaii	2	Iowa	6
Idaho	6	Illinois	6
Indiana	1	Kansas	5
Kentucky	6	Louisiana	5
Massachusetts	4	Maryland	3
Maine	1	Michigan	6
Minnesota	5	Missouri	5
Mississippi	7	Montana	6
North Carolina	5	North Dakota	7
Nebraska	3	New Hampshire	3
New Jersey	5	New Mexico	4
Nevada	9	New York	7
Ohio	9	Oklahoma	6
Oregon	7	Pennsylvania	9
Rhode Island	2	South Carolina	5
South Dakota	6	Tennessee	5
Texas	9	Utah	6
Virginia	3	Vermont	2
Washington	6	Wisconsin	5
West Virginia	4	Wyoming	5
Alberta	7	British Columbia	7
Manitoba	5	Newfoundland	5
Nova Scotia	5	Ontario	6
Quebec	6	Saskatchewan	5
Yukon	5		

From another perspective, the following table indicates the distribution of refineries supplying the fifty states:

# OF REFINERIES	# OF STATES SUPPLIED
1	1
2	3
3	7
4	5
5	12
6	11
7	7
8	1
9	6
10	1

As may be noted, thirty-eight of the states are supplied with the output of five or more asphalt refineries.

8. IN WHICH STATES ARE ASPHALT CEMENTS MARKETED FROM EACH TERMINAL?

RESPONSE: A completed response was received for all seventy-two refineries. The following table presents the number of refinery-owned terminals reported to supply each state and province:

STATE	# OF TERMINALS	STATE	# OF TERMINALS
Alaska	3	Alabama	3
Arkansas	2	Arizona	8
California	6	Colorado	2
Connecticut	2	Delaware	5
Florida	1	Georgia	5
Hawaii	1	Iowa	3
Idaho	3	Illinois	8
Indiana	8	Kansas	5
Kentucky	8	Louisiana	1
Massachusetts	3	Maryland	6
Maine	0	Michigan	6

Minnesota	3	Missouri	4
Mississippi	2	Montana	2
North Carolina	8	North Dakota	3
Nebraska	2	New Hampshire	2
New Jersey	5	New Mexico	3
Nevada	7	New York	8
Ohio	10	Oklahoma	5
Oregon	3	Pennsylvania	11
Rhode Island	2	South Carolina	4
South Dakota	3	Tennessee	3
Texas	6	Utah	5
Virginia	8	Vermont	2
Washington	1	Wisconsin	3
West Virginia	4	Wyoming	1

From another perspective, the following table indicates the distribution of terminals supplying the fifty states:

# OF TERMINALS	# OF STATES SUPPLIED
0	1
1	5
2	9
3	12
4	3
5	6
6	4
7	1
8	7
9	0
10	1
11	1

9. ARE YOUR ASPHALT CEMENTS SOLD IN SIGNIFICANT AMOUNTS TO OTHER DISTRIBUTORS?

NEVER________ OCCASIONALLY_______ROUTINELY___________

RESPONSE: Thirty-seven of forty-one firms responded to this question. Of these, seven answered "NEVER", sixteen "OCCASIONALLY," and fourteen "ROUTINELY."

10. IF THE ANSWER TO QUESTION 9 IS "ROUTINELY," APPROXIMATELY HOW MANY TONS PER YEAR ARE SOLD? ________________

RESPONSE: The fourteen firms which responded "ROUTINELY" to Question 9 reported selling an average of 182,037 tons per year, or a total tonnage of 2,548,520.

11. WHICH DISTRIBUTORS ARE YOUR COMPANY'S PRINCIPAL CUSTOMERS FOR PAVING ASPHALT CEMENTS?

RESPONSE: The responses to this question are considered proprietary and were employed only to help develop a mailing list for the "Independent Asphalt Supplier Survey."

12. DOES YOUR COMPANY IMPORT SIGNIFICANT AMOUNTS OF ASPHALT CEMENT TO SUPPLEMENT ITS PRODUCTION?

________ YES ___________NO

RESPONSE: Thirty-eight of forty-one firms answered this question. Of these, only one responded "YES."

13. IF THE ANSWER TO QUESTION 12 IS YES, FROM WHERE AND IN WHAT QUANTITY IS THE ASPHALT CEMENT IMPORTED?

RESPONSE: The one firm that responded in the affirmative to Question 12 indicated that it imported 400,000 tons from Venezuela in 1987.

14. IN ORDER TO ASSURE THAT THIS SURVEY IS COMPLETE, WE WOULD LIKE TO CONTACT AS MANY FIRMS AS POSSIBLE WHICH IMPORT PAVING ASPHALT CEMENTS DIRECTLY INTO THE UNITED STATES. IF YOU KNOW OF ANY SUCH FIRMS IN YOUR MARKETING AREA, THEIR NAMES AND ADDRESSES WOULD BE HELPFUL.

RESPONSE: The responses to this question are considered confidential, and were employed only to help develop a mailing list for the "Independent Asphalt Supplier Survey."

15. DOES YOUR COMPANY EXCHANGE ASPHALT CEMENT PRODUCTS WITH OTHER PRODUCERS WITHIN YOUR MARKETING AREA WHEN THE NEED IS DICTATED BY LOCAL VARIATIONS IN DEMAND?

NEVER________ OCCASIONALLY_______ ROUTINELY__________

RESPONSE: Thirty-nine of forty-one firms answered this question. Of these, eleven replied "NEVER," twenty-three "OCCASIONALLY," and five "ROUTINELY."

16. IF THE ANSWER TO QUESTION 15 IS "ROUTINELY," APPROXIMATELY HOW MANY TONS OF YOUR ASPHALT CEMENT ARE EXCHANGED IN A TYPICAL YEAR? ________

RESPONSE: Four of five firms which answered Question 15 with the response "ROUTINELY" replied to this question, reporting an average exchange of 95,750 tons per year for a total of 383,000 tons.

PART B. REFINERY INFORMATION

I. Refinery Operations

1. WHERE IS THIS REFINERY LOCATED? (STREET ADDRESS)

RESPONSE: Figure 1 indicates the geographical locations of the responding refineries in each state and province.

2. WHAT IS THE DAILY ASPHALT CEMENT PRODUCTION CAPACITY OF THE REFINERY IN TONS?

____ >500; ____ 500-750; ____ 750-1,000;
____ 1,000-2,000; ____ 2,000-3,000; ____ 3,000-4,000;
____ 4,000-5,000; ____ 5,000-6,000; ____ >6,000.

RESPONSE: Sixty-eight of seventy-two refineries answered this question. The responses are presented in the following table:

PRODUCTION CAPACITY (tpd)	# OF REFINERIES
<500	9
500-750	12
750-1,000	12
1,000-2,000	13
2,000-3,000	8
3,000-4,000	3
4,000-,5000	1
5,000-6,000	4
>6,000	6

3. WHAT WAS THE ACTUAL ASPHALT CEMENT PRODUCTION OF THE REFINERY IN TONS?

a. DURING 1985?

____ LESS THAN 200,000; ____ 200,000-1,000,000;
____ 1,000,000-1,500,000; ____ MORE THAN 1,500,000.

b. DURING 1986?

____ LESS THAN 200,000; ____ 200,000-1,000,000;
____ 1,000,000-1,500,000; ____ MORE THAN 1,500,000.

c. DURING 1987?

____ LESS THAN 200,000; ____ 200,000-1,000,000;
____ 1,000,000-1,500,000; ____ MORE THAN 1,500,000.

RESPONSE: There were sixty-eight responses to all or part of this question. Answers are summarized in the following table:

TONS PER YEAR	# OF REFINERIES 1985	1986	1987
<200,000	31	33	29
200,000-1,000,000	31	30	34
1,000,000-1,500,000	3	3	3
>1,500,000	2	2	2

4. WHAT REFINERY OPERATIONS ARE EMPLOYED TO PRODUCE ASPHALT CEMENT? (CHECK AND RESPOND TO ALL APPLICABLE SECTIONS)

a. ____ ATMOSPHERIC DISTILLATION

RESPONSE: Sixty-eight refineries replied to this question, sixty responding "YES" and eight "NO."

IF ONLY ATMOSPHERIC DISTILLATION IS USED, WHAT IS THE MAXIMUM TRANSFER LINE TEMPERATURE? ____ °F?

RESPONSE: There were five responses; the mean maximum transfer line temperature reported was 695°F within a range of 590 to 740°F.

IF STEAM IS EMPLOYED, AT WHAT TEMPERATURE AND IN WHAT QUANTITY IS IT USED? ____ °F; ____ LB/BARREL OF ASPHALT CEMENT.

RESPONSE: There were thirteen responses. The mean steam temperature reported was 472°F within a range of 320 to 750°F. The mean steam quantity employed was 38 lbs per ton of asphalt within a range of 0.14 to 170 lbs per ton of asphalt.

b. ____ VACUUM DISTILLATION

RESPONSE: Sixty-nine refineries replied to this question, sixty-four responding "YES" and five "NO."

IF YOU EMPLOY VACUUM DISTILLATION, AT WHAT TEMPERATURE IS TOPPING CONDUCTED? _____ °F

RESPONSE: There were fifty-three responses; the mean crude topping temperature was 735°F within a range of 440 to 1000°F.

WHAT IS THE MAXIMUM TRANSFER LINE TEMPERATURE ____ °F AND VACUUM ____ mm OF Hg?

RESPONSE: There were fifty-five responses; the mean maximum transfer line temperature was 734°F within a range of 366 to 820°F. The mean reported vacuum was 54 mm Hg within a range of 5 to 300 mm Hg.

c. ____ <u>AIR BLOWING</u>

DOES YOUR PROCESS FOR PRODUCING ASPHALT CEMENT INCLUDE AIR BLOWING?

____ YES ____ NO

RESPONSE: Sixty-nine refineries responded to this question, nine answering "YES" and sixty "NO."

IF YES, DO YOU AIR BLOW

____ TO A SPECIFIC GRADE? OR

____ TO A HARD ASPHALT WHICH IS BLENDED BACK TO GRADE?

RESPONSE: Of the nine positive responses to the previous question, eight reported that they blow air to grade while only four also blow to a hard grade, which is blended back with a soft (low-viscosity) material.

WHAT PROPERTY IS EMPLOYED TO CONTROL BLENDING TO GRADE?

RESPONSE: Four refineries reported they employed viscosity, five employed penetration, two ductility, one ring and ball softening point, and one adhered strictly to blowing time and temperature.

WHAT MATERIAL IS EMPLOYED TO BLEND TO GRADE?

RESPONSE: One refinery blended back with vacuum distillation residua, two employed unblown paving grade asphalt, and one used an asphalt flux.

DO YOU USE A CATALYST IN THE AIR-BLOWING PROCESS?

____ YES ____ NO

IF YES, WHICH CATALYST IS USED?

RESPONSE: One refinery reported the use of ferric chloride as an air-blowing catalyst. The remaining eight refineries reported that they did not use any catalyst.

d. ____ SOLVENT REFINING

DO YOU EMPLOY SOLVENT REFINING TO PRODUCE PAVING ASPHALT CEMENT?

____ YES ____ NO

RESPONSE: Sixty-nine refineries answered this question. Thirteen employ solvent refining, fifty-six do not.

IF YES, WHAT IS YOUR CHARGE TO THE SOLVENT EXTRACTOR?

RESPONSE: Ten refineries answered this question. Eight reported they employed vacuum residua as the charge, one reported the use of asphalt flux, and one used waxy short residua.

DO YOU USE SUPERCRITICAL EXTRACTION SUCH AS ROSE TO PRODUCE PAVING ASPHALT CEMENTS?

____ YES ____ NO

RESPONSE: There were thirteen responses to this question, three "YES" and ten "NO."

WHAT IS THE VISCOSITY, PENETRATION OR SOFTENING POINT OF THE BOTTOMS OR OTHER FLUX WHICH ARE BLENDED WITH THE SOLVENT-REFINED HARD ASPHALT?

RESPONSE: There were nine responses to this question; none of the responses provided numerical data on the blended flux. Three refineries reported the use of a low-viscosity flux, while one uses a high penetration material. Another reported using a high viscosity material and one uses a vacuum gas oil. One co-reduces the solvent-refined asphalt with crude oil to grade, while two others actually reduce the asphalt to grade in the solvent-refining process.

WHAT ARE THE OPERATING PARAMETERS OF THE PROCESS USED?

RESPONSE: Ten refineries provided an answer to this question. The main operating parameters are the solvent to charge ratio, the solvent temperature, and the operating pressure within the solvent refining process unit. The temperature is generally below 200°F with the pressure in the range 450 to 500 psig. Propane is the usual solvent, but some refineries employ propane with a slight admixture of butane or another, lighter hydrocarbon.

5. ARE RESIDUA FROM OTHER REFINERY OPERATIONS, SUCH AS VIS-BREAKING, THERMAL TREATMENT OR CATALYTIC REFINING, USED IN THE ASPHALT CEMENT PRODUCTION STREAM?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Sixty-eight refineries replied to this question. Sixty-one indicated that residua from other processes were never used in the asphalt production stream, while six occasionally do this and one routinely does.

6. IF THE ANSWER TO QUESTION 5 IS "ROUTINELY" OR "OCCASIONALLY", PLEASE ESTIMATE WHAT PERCENT OF THE PRODUCTION STREAM THESE RESIDUA REPRESENT.

_____ VIS-BREAKING:

___ LESS THAN 2; ___ 3-5; ___ 6-10; ___ MORE THAN 10.

_____ THERMAL TREATMENT:

___ LESS THAN 2; ___ 3-5; ___ 6-10; ___ MORE THAN 10.

_____ CATALYTIC REFINING:

__ LESS THAN 2; __ 3-5; __ 6-10; __ MORE THAN 10.

RESPONSE: One refinery reported that it occasionally uses vis-breaking residua in the asphalt production stream refineries at a level of two percent or less. There were no reports of the use of thermal cracking or catalytic cracking residua.

_____ OTHER (PLEASE SPECIFY)______________________:

__ LESS THAN 2; __ 3-5; __ 6-10; __ MORE THAN 10.

RESPONSE: Six refineries answered this question in the affirmative. Four reported the use of residua from solvent deasphalting processes, while another indicated that it blends vacuum residua from a sweet crude oil. None reported the level at which these materials are blended into the asphalt production stream.

7. ARE RECYCLED LUBE OILS ADDED TO THE ASPHALT PRODUCTION STREAMS?

NEVER________ OCCASIONALLY______ ROUTINELY__________

RESPONSE: Sixty-eight refineries replied to this question. Sixty-five never employ recycled lube oils, three do so on an occasional basis, and one reported that this was a routine practice.

8. IF THE ANSWER TO QUESTION 7 IS "ROUTINELY," PLEASE ESTIMATE WHAT PERCENT OF THE PRODUCTION STREAMS THE RECYCLED LUBE OILS REPRESENT.

__ LESS THAN 0.1; __ 0.2-1.0; __ MORE THAN 1.0

RESPONSE: Two refineries reported that recycled lube oils were blended into the asphalt production stream at a level of less than 0.1 percent.

9. PLEASE PROVIDE A SIMPLIFIED FLOW CHART FOR THE PROCESS UNIT USED FOR ASPHALT CEMENT PRODUCTION; PLEASE INDICATE UNIT CAPACITIES AND OPERATING PARAMETERS.

RESPONSE: A representative flow chart is included at the end of Appendix I.

10. ARE RESIDUAL FUELS MARKETED FROM THIS REFINERY DURING PERIODS OF THE YEAR WHEN ASPHALT CEMENT DEMAND IS LOW?

CONTINUALLY _____ OR

NEVER______ OCCASIONALLY______ ROUTINELY_________

RESPONSE: Sixty-six refineries answered this question. Twenty-two reported continual marketing of residual fuels, eleven reported that residual fuels were never marketed, twenty-seven that such fuels were occasionally marketed, and six routinely market residual fuels.

11. ARE RESIDUA COKED AT THIS REFINERY?

NEVER_______ OCCASIONALLY______ ROUTINELY_________

RESPONSE: Sixty-seven refineries answered this question. Fifty-six responded that residua were never coked, three reported occasional coking, and eight indicated that residua were routinely coked.

12. WHAT WAS THE AMOUNT OF EACH GRADE OF PAVING ASPHALT CEMENT SHIPPED FROM THE REFINERY IN 1987?

RESPONSE: Detailed responses to this question were received from fifty-seven refineries. Totalled answers are tabulated below:

GRADE	AMOUNT (TONS)	GRADE	AMOUNT (TONS)
AC-2.5	343,875	AR-8000	420,484
AC-5	614,848	AR-16000	6,477
AC-10	1,937,104	40-50	9,000
AC-20	8,749,770	60-70	109,301
AC-30	1,724,548	85-100	1,476,133
AC-40	45,850	120-150	1,163,217
AR-1000	30,560	150-200	473,499
AR-2000	26,348	200-300	204,354
AR-4000	1,332,459	OTHER	677

Total paving asphalt reported shipped in 1987 was 18,668,504 tons.

13. PLEASE INDICATE THE GRADE AND AMOUNT IN TONS OF ANY SPECIAL TYPES OF ASPHALT CEMENT SHIPPED FROM THE REFINERY IN 1987 (FOR EXAMPLE, ASPHALT CEMENTS MEETING THE SPECIAL REQUIREMENTS OF A STATE HIGHWAY AGENCY, MUNICIPALITY, TOLL AUTHORITY, ETC.).

RESPONSE: Detailed responses to this question were received from twenty-two refineries. A total 1987 shipment of 1,684,095 tons of special grade asphalt was reported. The reported special grades are as follows: AC-3; AC-3.5; AC-7.5; AC-8; AC-15; AC-20; 65-80; 80-90; 110-160; 150; HMA-1; AR-2000W; AR-4000W; AR-6000; and polymer-modified asphalt.

14. ARE INTERMEDIATE GRADES OF ASPHALT CEMENT PRODUCED BY BLENDING A HARD AND A SOFT GRADE?

_______ YES _________NO

RESPONSE: Sixty-seven refineries answered this question: thirty-three responded "YES"and thirty-four responded "NO."

15. IF THE ANSWER TO QUESTION 14 IS YES, PLEASE DESCRIBE HOW THE BLENDING PROCESS IS CONDUCTED, HOW IT IS CONTROLLED, AND WHAT EQUIPMENT IS USED?

RESPONSE: Thirty-two refineries provided detailed answers to this question. In summary, twenty reported that blending was conducted by introducing precalculated amounts of the two grades into a blending tank, followed by recirculation through the tank and associated piping until a uniform product was obtained. The other twelve refineries employ an in-line blender at the transport loading facility to produce the desired grade to order as needed.

16. ARE SOFT GRADES OF ASPHALT CEMENT PRODUCED BY BLENDING A HARD GRADE WITH A MATERIAL WHICH DOES NOT MEET THE REQUIREMENTS FOR THE SOFTEST GRADE OF ASPHALT CEMENT?

_______ YES _________NO

RESPONSE: Sixty-eight refineries answered this question. Twenty-one responded "YES," forty-seven "NO."

17. IF THE ANSWER TO QUESTION 16 IS YES, PLEASE DESCRIBE HOW THE BLENDING PROCESS IS CONDUCTED, HOW IT IS CONTROLLED, AND WHAT EQUIPMENT IS USED?

RESPONSE: There were twenty detailed responses to this question. Thirteen refineries reported using tank blending to accomplish production, while seven employed in-line blending at the transport loading facility.

Typical materials blended with the hard grade of asphalt include very soft asphalt, e.g., a material with a viscosity of 170 poises or less at 140°F; asphalt flux; heavy vacuum gas oil; and oxidized asphalt flux.

Blending typically is controlled by measurement of the viscosity and penetration of the finished asphalt. In some instances, the material is also subjected to thin film oven loss and residue property measurements. Generally, all materials blended in tanks are subjected to a full round of testing to allow certification that the material meets specification.

18. ARE ANY OF THE FOLLOWING ADDITIVES BLENDED WITH ASPHALT CEMENT AT THE REFINERY?

ANTISTRIP AGENTS:

___ NEVER ____ OCCASIONALLY ____ ROUTINELY

SILICONE OILS:

___ NEVER ____ OCCASIONALLY ____ ROUTINELY

ELASTOMERS(RUBBERS):

___ NEVER ____ OCCASIONALLY ____ ROUTINELY

POLYMERS:

___ NEVER ____ OCCASIONALLY ____ ROUTINELYANTI-OXIDANTS:

___ NEVER ____ OCCASIONALLY ____ ROUTINELY

RESPONSE: Sixty-eight refineries responded to all or part of this question. Responses are summarized in the following table:

ADDITIVE	NEVER	# OF REFINERIES REPORTING OCCASIONALLY	ROUTINELY
ANTISTRIP AGENT	36	22	10
SILICONE OILS	53	3	6
ELASTOMERS	56	3	3
POLYMERS	54	8	2
ANTI-OXIDANTS	61	2	0

19. HOW MANY STORAGE TANKS ARE AVAILABLE FOR ASPHALT CEMENT AT THE REFINERY?

___ 1; ___ 2; ___ 3; ___ 4; ___ GREATER THAN 4.

RESPONSE: Sixty-nine refineries responded to this question. Fifty-six reported having more than four tanks available for asphalt storage. Two refineries had four tanks, eight employ three tanks, two employ two tanks, and one refinery had only one tank assigned to asphalt storage.

20. WHAT SIZE STORAGE TANK IS PRIMARILY USED FOR ASPHALT CEMENT?

___ LESS THAN 5,000 BARRELS; ___ 5,000-10,000 BARRELS; OR

___ GREATER THAN 10,000 BARRELS.

RESPONSE: There were sixty-nine responses to this question. Of those, fifty-nine refineries employ tanks larger than 10,000 barrels capacity, eight use tanks in the 5,000-10,000 barrel capacity range, and only two use tanks smaller than 5,000 barrel capacity.

21. DURING THE PAVING SEASON, WHAT IS THE ESTIMATED AVERAGE RESIDENCE TIME FOR ASPHALT CEMENT IN STORAGE AT THE REFINERY?

__ LESS THAN 3 DAYS; __ 3-10 DAYS;

__ 10-20 DAYS; __ MORE THAN 20 DAYS.

RESPONSE: There were sixty-eight responses to this question divided as follows: Three refineries stored asphalt cement for less than three days; twenty-five stored asphalt cement for three to ten days; twenty-six for ten to twenty days; and fourteen refineries stored asphalt cement for more than twenty days.

22. IN WHAT TEMPERATURE RANGE IS ASPHALT CEMENT STORED DURING THE PAVING SEASON? __________ °F

RESPONSE: Sixty-eight refineries provided an answer to this question. The mean storage temperature was 326°F with a range of 240 to 400°F.

23. IS INERT GAS BLANKETING USED IN THE ASPHALT CEMENT STORAGE TANKS?

________ YES __________ NO

RESPONSE: Sixty-eight refineries answered this question. Only six employ inert gas blanketing of the asphalt storage tanks.

24. IN A TYPICAL YEAR, APPROXIMATELY HOW MANY MONTHS' PRODUCTION OF ASPHALT CEMENT WILL BE STORED OVER THE WINTER SEASON?

__ LESS THAN 3; __ 3-6; __ MORE THAN 6.

RESPONSE: Sixty-six refineries answered this question. Thirty-seven store less than three months' production; twenty-four store three to six months' production; and five report that they typically store more than six months' production over the winter.

25. IN WHAT TEMPERATURE RANGE IS ASPHALT CEMENT STORED OVER THE WINTER SEASON? __________ °F

RESPONSE: Sixty-two refineries replied to this question. Of these, eighteen reported that asphalt was stored at the ambient winter temperature in their locality. Of those which maintained heated storage, the mean storage temperature was 293°F within a range of 100 to 400 °F.

26. HOW IS ASPHALT CEMENT TRANSPORTED FROM THE REFINERY?

TANKER-TRUCK:

____ NEVER ____ OCCASIONALLY ____ ROUTINELY

BARGE:

____ NEVER ____ OCCASIONALLY ____ ROUTINELY

RAILCAR:

____ NEVER ____ OCCASIONALLY ____ ROUTINELY

RESPONSE: Sixty-nine refineries responded to all or part of this question. Responses are summarized in the following table:

	# OF REFINERIES REPORTING		
TRANSPORT TYPE	NEVER	OCCASIONALLY	ROUTINELY
TANKER-TRUCK	3	0	66
BARGE	42	4	18
RAILCAR	22	17	29

27. IS ASPHALT CEMENT SHIPPED FROM THE REFINERY DIRECTLY TO HIGHWAY CONSTRUCTION CONTRACTORS WITH YOUR OWN TRANSPORT?

NEVER________ OCCASIONALLY_______ROUTINELY__________

RESPONSE: Sixty-nine refineries responded to this question. Fifty-three indicated that asphalt is never shipped in transports owned by the refinery, while seven occasionally do this, and nine do it routinely.

28. IS ASPHALT CEMENT PICKED UP FROM THE REFINERY BY INDEPENDENT TRANSPORT COMPANIES?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Sixty-nine refineries responded to this question. Sixty-six indicated that this is the routine mode for asphalt shipment. Only one refinery reported shipment was never made in this way, and two reported it was an occasional practice.

29. IS ASPHALT CEMENT PICKED UP FROM THE REFINERY BY TRANSPORT OWNED BY HIGHWAY CONSTRUCTION CONTRACTORS?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Of the sixty-eight refineries which replied to this question, fifty-three reported that this was done routinely, thirteen indicated it was done occasionally, and only two answered that it was never done.

30. DO YOU BELIEVE THAT YOUR PRODUCT IS BEING BLENDED WITH OTHER ASPHALT CEMENTS AT INDEPENDENT TERMINALS OR AT CONTRACTORS' FACILITIES?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Sixty-four refineries answered this question, divided as follows: thirteen "never," thirty-nine "occasionally," and twelve "routinely."

II. Crude Oil Supply

31. WHAT CRUDE OILS OR CRUDE OIL BLENDS ARE GENERALLY USED IN THE PRODUCTION OF ASPHALT CEMENT AT PRESENT? (THIS INFORMATION WILL BE EMPLOYED IN THE SELECTION OF A SUITE OF ASPHALT CEMENTS FOR USE THROUGHOUT THE ENTIRE SHRP

ASPHALT RESEARCH PROGRAM; ALL RESPONSES ARE CODED TO PROTECT THEIR PROPRIETARY NATURE.)

RESPONSE: Seventy-two refineries provided full or partial answers in response to this question. Detailed responses are summarized in the tables in Chapter 4 of the main report.

32. WHAT CHARACTERIZATION FACTOR DOES YOUR REFINERY EMPLOY TO CLASSIFY THE CRUDE OILS USED TO PRODUCE ASPHALT CEMENTS?

RESPONSE: Responses by forty refineries are presented in the following table:

CHARACTERIZATION FACTOR	# OF REFINERIES
UOP K FACTOR	16
CRUDE ASSAY	7
AGING INDEX	2
A.P.I. GRAVITY	3
CRUDE TYPE	4
PREVIOUS EXPERIENCE	2
ASPHALT PROPERTIES	2
NONE	4

33. PLEASE LIST THE CHARACTERIZATION FACTOR FOR EACH CRUDE OIL OR CRUDE OIL BLEND LISTED IN QUESTION 31.

RESPONSE: The mean value of the UOP K factors reported was 11.7 with a standard deviation of 2.0. The mean value of the A.P.I. gravity was 17.5 with a standard deviation of 6.4.

34. PLEASE INDICATE THE APPROXIMATE SULFUR CONTENT OF EACH CRUDE OIL OR CRUDE OIL BLEND LISTED IN QUESTION 31.

RESPONSE: Sixty-three refineries responded to this question. Responses are summarized in the figures in Chapter 4 of the main report.

35. PLEASE INDICATE THE APPROXIMATE VANADIUM CONTENT OF EACH CRUDE OIL OR CRUDE OIL BLEND LISTED IN QUESTION 31.

RESPONSE: Fifty refineries responded to this question. Responses are summarized in the figures in Chapter 4 of the main report.

36. PLEASE INDICATE THE APPROXIMATE NICKEL CONTENT OF EACH CRUDE OIL OR CRUDE OIL BLEND LISTED IN QUESTION 31.

RESPONSE: Fifty-nine refineries responded to this question. Responses are summarized in the figures in Chapter 4 of the main report.

37. PLEASE LIST ANY OTHER TRACE METALS WHICH ARE ROUTINELY ASSAYED IN CRUDE OILS OR CRUDE OIL BLENDS USED IN ASPHALT CEMENT PRODUCTION.

RESPONSE: There were twenty-one responses to this question. These are summarized in the following table:

TRACE ELEMENT ASSAYED	# OF REFINERIES
Fe	14
Cu	3
Na	4
Zn	2
Mg	2
Si	2
Ca	2
Pb	2
K	1

38. IS A CRUDE OIL ASSAY EMPLOYED TO DETERMINE THE AMOUNT OF ASPHALT OBTAINABLE FROM EACH CRUDE OIL?

_______ YES __________NO

RESPONSE: Sixty-seven refineries responded to this question. Forty-nine answered "YES," eighteen answered "NO."

39. IF THE ANSWER TO QUESTION 38 IS YES, WHAT PROPERTIES OF THE ASPHALT ARE DETERMINED DURING THE ASSAY?

RESPONSE: Forty-six responses were made to this question. Results are summarized in the following table:

ASPHALT PROPERTY	# OF REFINERIES
Viscosity at 275°F	33
Viscosity at 140°F	32
Penetration at 77°F	31
Penetration at 39.2°F	2
Thin film oven test	12
Rolling thin film oven test	3
Sulfur content	7
Ductility of TFO residue at 60°F	2
Flash point	11
Loss on heating	1
Specific gravity	9
Spot test	7
R&B Softening point	9
Solubility in trichloroethylene	3
Ductility at 77°F	7
Smoke point	1
Asphaltenes content	1

40. HOW OFTEN IS THE CRUDE OIL SLATE AT THE REFINERY ADJUSTED TO MAINTAIN OR MAXIMIZE ASPHALT CEMENT PRODUCTION?

RESPONSE: There were sixty-six responses, summarized as follows:

NEVER, 18; DAILY, 6; WEEKLY, 9; MONTHLY, 17; SEASONALLY, 16.

41. DOES THE REFINERY EMPLOY A DESALTING UNIT(S)?

_______ YES _________NO

RESPONSE: Sixty-eight refineries answered this question. Fifty-seven employ crude oil desalting, eleven do not.

42. IF THE ANSWER TO QUESTION 41 IS YES, PLEASE INDICATE WHAT DESALTING PROCESS IS USED (PLEASE SPECIFY EQUIPMENT TYPES, TRADE NAMES OR GENERIC CHEMICAL TYPES, ETC.).

RESPONSE: Thirty-eight refineries provided detailed answers to this question. Of these, twenty-nine employ electrostatic desalting units, while nine use electrostatic units combined with chemical demulsification.

43. ARE THE CRUDE OILS OR ASPHALT CEMENTS DEWAXED AT SOME POINT IN THE REFINING PROCESS?

_______ YES _________NO

RESPONSE: Of the sixty-six refineries that responded to this question, only four dewax their crude oils.

44. IN GENERAL, HAVE THE CRUDE OIL SLATES USED BY YOUR COMPANY FOR ASPHALT CEMENT PRODUCTION CHANGED IN THE PAST

6 MONTHS:

____ YES ____ NO

2 YEARS:

____ YES ____ NO

5 YEARS:

____ YES ____ NO

15 YEARS:

____ YES ____ NO

RESPONSE: Sixty one refineries responded to this question in full or in part. Responses are summarized in the figure in Chapter 4 of the main report.

PART C. TESTING AND QUALITY CONTROL

45. WHAT TEST PROCEDURES ARE EMPLOYED DURING THE REFINING PROCESS TO MONITOR THE PRODUCTION OF ASPHALT CEMENT?

RESPONSE: There were forty-five detailed answers to this question. Responses are summarized in the following table:

ASPHALT PROPERTY	# OF REFINERIES
Viscosity at 275°F	37
Viscosity at 210°F	1
Viscosity at 140°F	44
Penetration at 77°F	50
Thin film oven test	4
Rolling thin film oven test	2
Ductility of TFO residue at 60°F	1
Flash point	18
Loss on heating	1
Specific gravity	4
R&B Softening point	8
Ductility at 77°F	3

46. WHAT TESTS ARE ROUTINELY USED FOR THE QUALITY CONTROL OF FINISHED ASPHALT CEMENTS?

RESPONSE: There were responses by sixty-seven refineries to this question. Responses are summarized in the following table:

ASPHALT PROPERTY	# OF REFINERIES
Viscosity at 275°F	53
Viscosity at 140°F	62
Penetration at 77°F	66
Thin film oven test	47
Rolling thin film oven test	24
Flash point	60
Ductility at 77°F	54
Solubility in trichloroethylene	47
Spot test	27
A.P.I. gravity	1
Neutralization number	1
Loss on heating	2
Viscosity at 300°F	1
Viscosity at 210°F	1
Viscosity at 77°F	1
Ductility at 39.2°F	1
Ductility at 45°F	1
Ductility at 60°F	2
Specific gravity at 77°F	4
Density at 15°C	1
Ring and ball softening point	1
Salt content	1

47. AT WHAT FREQUENCY IS QUALITY CONTROL TESTING CONDUCTED?

______ BY LOT ____ BY VOLUME ____ BY TIME ____ RANDOMLY

RESPONSE: There were responses by sixty-seven refineries to this question. Forty-four test by lot, six by volume, fifteen by time period, and two at random intervals.

48. IS ACCEPTANCE (CERTIFICATION) TESTING PERFORMED BY STATE HIGHWAY AGENCY PERSONNEL ON ASPHALT CEMENTS SAMPLED AT THE REFINERY (AND/OR TERMINALS) TO DETERMINE COMPLIANCE WITH SPECIFICATIONS?

________ YES __________NO

RESPONSE: Sixty-five refineries answered this question. Forty-seven responded that state highway agency personnel sample for acceptance testing.

49. IF THE ANSWER TO QUESTION 48 IS YES, AT WHAT FREQUENCY IS THE SAMPLING CONDUCTED?

_____ BY LOT ____ BY VOLUME ____ BY TIME ____ RANDOMLY

RESPONSE: There were responses by forty-seven refineries to this question. Nineteen sample by lot, five by volume, five by time period, and eighteen at random intervals.

50. DURING THE LAST TWO YEARS, HAS YOUR COMPANY FAILED TO MEET AN ASPHALT CEMENT SPECIFICATION REQUIREMENT OF ANY AGENCY?

_______ YES _________NO

RESPONSE: Sixty-six refineries replied to this question. Of these, twenty-three (thirty-five percent) reported specification failure within the previous two years.

51. IF THE ANSWER TO QUESTION 50 IS YES, PLEASE INDICATE FREQUENCY OF FAILURE, WHICH REQUIREMENTS WERE FAILED, WHICH TEST METHODS WERE USED BY THE SPECIFYING AGENCY, AND WHAT REMEDIAL ACTIONS WERE TAKEN.

RESPONSE: Twenty-two refineries provided detailed responses to this question. In general, most reported no more than one or two problems per year or, in terms of failure rate, less than 0.5 percent.

Most failures involved noncompliance of the asphalt viscosity or penetration with the specification values. In three cases, the failure was attributed to contamination after the asphalt left the refinery or incorrect sampling technique.

When the asphalt was still within the control of the refinery, corrective action usually involved reblending of the stored material to specification or adjustment of the refinery operation to eliminate the problem.

52. ARE ASPHALT CEMENTS TESTED AFTER PROLONGED STORAGE, SUCH AS AFTER A WINTER PERIOD?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Sixty-five refineries replied to this question. Of these, thirteen never test after winter storage, five test occasionally, and forty-seven test on a routine basis.

53. IS THE WAX CONTENT OF CRUDE OILS OR ASPHALT CEMENTS DETERMINED?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Sixty-eight responses were received to this question. Fifty-five never measure wax content, ten measure it occasionally, and only three indicated that the wax content of the asphalt was measured routinely.

54. IF THE ANSWER TO QUESTION 53 IS "ROUTINELY" OR "OCCASIONALLY," WHAT TEST METHOD IS USED? (PLEASE DESCRIBE OR GIVE TEST METHOD DESIGNATION)

RESPONSE: The ten responses to this question are summarized below:

TEST METHOD	# OF REFINERIES
PERCENT SATURATES BY IATROSCAN	2
UOP METHOD	2
HOLDE (DIN) METHOD	1
ASTM D 2007 METHOD	2
SHELL HAZE METHOD FOR VGO	1
PARAFFIN CONTENT BY GC-MS	1
UNKNOWN	2

55. WHICH, IF ANY, SPECTROSCOPIC OR CHROMATOGRAPHIC ANALYSIS METHODS DO YOU USE TO EVALUATE CRUDE OILS OR ANY ASPECT OF ASPHALT CEMENT PRODUCTION?

RESPONSE: Forty-six refineries responded to this question. Answers are summarized in the following table:

TEST METHOD	# OF REFINERIES
Infrared (IR) spectroscopy	12
X-ray fluorescence	12
Thermal analysis	7
Atomic absorption spectroscopy	19
Nuclear magnetic resonance	8
High pressure liquid chromatography	8
Supercritical fluid chromatography	0
Thin-layer chromatography	1
Gas chromatography	6
ICP	1
GC-Mass Spectroscopy	1
Plasma emission	1
Mass spectroscopy	1
Dohrmann analysis	1
Ultraviolet spectroscopy	5
Electron microscopy	5

It should be noted that in most instances these techniques are not employed on a routine basis, but rather as needed due to changes in crude oil sources, etc.

PART D. CONCLUDING COMMENTS

56. PLEASE PROVIDE ANY COMMENTS OR ADDITIONAL INFORMATION CONCERNED WITH THE SUBJECTS OF QUESTIONS 1 THROUGH 55, OR ON TOPICS NOT COVERED OR INADEQUATELY COVERED BY THESE QUESTIONS.

RESPONSE: There were thirty-five responses to this question, most amplifying responses to other questions in the survey. These have been taken into consideration during the preparation of the main text.

Appendix II

Independent Asphalt Supplier Survey Results

Responses to the jobber survey questionnaire were received from thirteen firms in the United States which reported on a total of twenty independent terminals marketing paving asphalt during 1987.

This appendix summarizes the responses to the two-part jobber survey questionnaire. Part A requested general information from each firm on the overall operation of their terminals, and their asphalt marketing situation. A separate Part B was requested from each firm for each of their terminals; it requested specific technical information on the asphalt distribution operations of each terminal.

PART A. GENERAL INFORMATION

1. DOES YOUR COMPANY OPERATE TERMINALS SUPPLYING PAVING ASPHALT CEMENTS?

________ YES ________NO

RESPONSE: Thirteen firms responded to this question: eight answered "YES," five answered "NO."

2. WHICH COMPANIES ARE SOURCES OF THE ASPHALT CEMENTS WHICH YOU MARKET?

RESPONSE: The responses to this question are considered proprietary and confidential.

3. IS YOUR COMPANY WILLING TO ALLOW SAMPLING OF ASPHALT CEMENTS FROM ONE OR MORE OF ITS TERMINALS FOR USE IN A TESTING PROGRAM TO CHARACTERIZE OVERALL U.S. ASPHALT SUPPLY?

RESPONSE: Responses to this question were treated as confidential.

4. WILL YOUR COMPANY ALLOW VISITS TO ONE OR MORE OF ITS TERMINALS BY ASPHALT INSTITUTE PERSONNEL DURING ASPHALT CEMENT SAMPLING AND FOR FOLLOW-UP DISCUSSIONS WITH YOUR TECHNICAL PERSONNEL?

RESPONSE: Responses to this question were treated as confidential.

5. WHERE ARE YOUR COMPANY'S TERMINALS LOCATED (CITY AND STATE)?

RESPONSE: Seven of eight firms operating terminals which supply paving asphalt cements responded to this question. The distributions of twenty terminals are presented in Figure 13.

6. WHICH COMPANY IS THE PREDOMINANT SOURCE OF PAVING ASPHALT CEMENT FOR EACH TERMINAL?

RESPONSE: Seven of thirteen firms responded to this question. The following U.S. refining firms were identified: Cenex, Exxon USA, United Refining, Atlantic Refining, Seaview Petroleum, Valero Refining, Clark Refining, and Trifinery. In addition, Lagoven DIN (Spain) and an unnamed Venezuelan refiner were identified.

7. HOW MANY MONTHS PER YEAR IS ASPHALT CEMENT SHIPPED FROM EACH TERMINAL?

RESPONSE: Responses were given for sixteen of twenty terminals. Three market for four to six months a year, four for seven to nine months, and nine for ten to twelve months of the year.

8. IN WHICH STATES ARE ASPHALT CEMENTS MARKETED FROM EACH TERMINAL?

RESPONSE: The twenty terminals combined to supply asphalt in eighteen states as follows:

STATE	# OF TERMINALS SUPPLYING	STATE	# OF TERMINALS SUPPLYING
DE	1	ID	2
MA	1	MD	1
ME	2	MO	1
MT	1	NC	1
NH	1	NJ	3
NV	1	NY	3
OH	1	OR	2
PA	4	TX	4
VA	2	WA	2

9. ARE YOUR ASPHALT CEMENTS RESOLD TO OTHER DISTRIBUTORS?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Eight firms responded to this question: four answered "NEVER," four "OCCASIONALLY."

10. IF THE ANSWER TO QUESTION 9 IS "OCCASIONALLY" OR "ROUTINELY," PLEASE LIST YOUR PRINCIPAL CUSTOMERS AND THE APPROXIMATE NUMBER OF TONS RESOLD IN 1987.

RESPONSE: The responses to this question are considered confidential.

11. DOES YOUR COMPANY IMPORT ASPHALT CEMENT FOR SALE IN THE UNITED STATES?

_______ YES __________NO

RESPONSE: Twelve firms answered this question. Seven responded "YES" and five "NO."

12. IF THE ANSWER TO QUESTION 11 IS YES, FROM WHERE AND IN WHAT QUANTITY IS THE ASPHALT CEMENT IMPORTED? (IF BARRELS ARE YOUR USUAL UNIT OF MEASURE, PLEASE DIVIDE BY 5.56 TO CONVERT TO TONS).

RESPONSE: Five firms responded to this question. Of these, two imported a total of 8,200 tons from Canada; two imported a total of 20,000 tons from Mexico; three imported a total of 140,000 tons from Spain; and four imported a total of 375,000 tons from Venezuela. One firm reported imports from the Netherlands Antilles, but did not give a total amount.

13. IN ORDER TO ASSURE THAT THIS SURVEY IS COMPLETE, WE WOULD LIKE TO CONTACT AS MANY FIRMS AS POSSIBLE WHICH IMPORT PAVING ASPHALT CEMENTS DIRECTLY INTO THE UNITED STATES. IF YOU KNOW OF ANY SUCH FIRMS IN YOUR MARKETING AREA, THEIR NAMES AND ADDRESSES WOULD BE HELPFUL.

RESPONSE: The responses to this question were treated as confidential.

14. DOES YOUR COMPANY EXCHANGE ASPHALT CEMENT PRODUCTS WITH OTHER DISTRIBUTORS WITHIN YOUR MARKETING AREA WHEN THE NEED IS DICTATED BY LOCAL VARIATIONS IN DEMAND?

NEVER_______ OCCASIONALLY______ ROUTINELY_________

RESPONSE: Seven firms responded to this question. Of these, three answered "NEVER," three "OCCASIONALLY," and one "ROUTINELY."

15. IF THE ANSWER TO QUESTION 14 IS "OCCASIONALLY" OR "ROUTINELY," APPROXIMATELY HOW MANY TONS OF YOUR ASPHALT CEMENT ARE EXCHANGED IN A TYPICAL YEAR? ________

RESPONSE: There were three responses to this question. One firm reported exchanging 200,000 tons in a typical year, while the other two firms indicated only 1,000 tons each.

16. WHAT WERE THE TOTAL ASPHALT CEMENT SALES OF YOUR FIRM IN TONS

DURING 1985?______________

DURING 1986?______________

DURING 1987?______________

<u>RESPONSE</u>: Seven firms replied to this question. All reported that their sales totaled more than 15,000 tons in each of the specified years.

17. WHAT WAS THE AMOUNT OF EACH GRADE OF PAVING ASPHALT CEMENT SHIPPED BY YOUR FIRM IN 1987?

RESPONSE: There were responses to this question from three firms. These reported the following grades and total amounts for each:

AC-2.5	20,100	AC-5	66,100
AC-10	101,400	AC-20	783,500
AC-30	4,000	AC-40	1,000

None of the firms reported sales of AR-graded asphalts. Of the total of 976,000 tons of asphalt reported for 1987, eighty percent comprised AC-20 grade.

18. PLEASE INDICATE THE GRADE AND AMOUNT IN TONS OF ANY SPECIAL TYPES OF ASPHALT CEMENT SHIPPED IN 1987 (FOR EXAMPLE, ASPHALT

CEMENTS MEETING THE SPECIAL REQUIREMENTS OF A STATE HIGHWAY AGENCY, MUNICIPALITY, TOLL AUTHORITY, ETC.).

RESPONSE: Three firms reported sales of special grades of asphalt, namely, 100 tons of AC-20 with a penetration of 85 to 100; 400 tons of AC-20P, an AC-20 modified with polymer; and 20,000 tons of AC-LTX.

PART B. TERMINAL INFORMATION

I. TERMINAL OPERATIONS

1. WHERE IS THIS TERMINAL LOCATED? (STREET ADDRESS)

RESPONSE: Figure 13 indicates the number of responding terminals in each state.

2. DOES THE TERMINAL PRODUCE INTERMEDIATE GRADES OF ASPHALT CEMENT BY BLENDING A HARD AND A SOFT GRADE?

_______ YES _________NO

RESPONSE: Fifteen terminals responded to this question. Of these, nine replied "YES," and six replied "NO."

3. IF THE ANSWER TO QUESTION 2 IS YES, PLEASE DESCRIBE HOW THE BLENDING PROCESS IS CONDUCTED, HOW IT IS CONTROLLED, AND WHAT EQUIPMENT IS USED?

RESPONSE: There were answers to this question from nine terminals. Eight employ in-line blending of hard and soft grades drawn from separate tanks through a static mixer, presumably at the transport loading rack. One terminal reported that the hard and soft materials were blended together in a third storage tank.

4. ARE SOFT GRADES OF ASPHALT CEMENT PRODUCED BY BLENDING A HARD GRADE WITH A FLUX WHICH DOES NOT MEET THE

REQUIREMENTS FOR THE SOFTEST GRADE OF ASPHALT CEMENT, SUCH AS AN AC-2.5 OR AN AR-1000?

_______ YES _________NO

RESPONSE: There were replies from fifteen terminals to this question: nine responded "YES" and six "NO."

5. IF THE ANSWER TO QUESTION 4 IS YES, PLEASE DESCRIBE THE FLUX, HOW THE BLENDING PROCESS IS CONDUCTED, HOW IT IS CONTROLLED, AND WHAT EQUIPMENT IS USED?

RESPONSE: There were nine replies to this question. Eight terminals employ in-line blending of hard and soft grades drawn from separate tanks through a static mixer, presumably at the transport loading rack. One terminal reported that the hard and soft materials were blended together in a third storage tank.

Four flux types were identified: Hydroline 90; high flash vacuum gas oil; high flash vacuum residua; and a material with a viscosity equivalent to an AC-5.

6. ARE ASPHALT CEMENTS OF THE SAME GRADE, BUT FROM DIFFERENT REFINERS COMMINGLED IN STORAGE AT THE TERMINAL?

NEVER_______ OCCASIONALLY______ ROUTINELY_________

RESPONSE: Fifteen terminals responded to this question. Seven answered "NEVER," one "OCCASIONALLY," and seven "ROUTINELY."

7. ARE ANY OF THE FOLLOWING ADDITIVES BLENDED WITH ASPHALT CEMENT AT THE TERMINAL?

RESPONSE: There were replies to this question from fourteen terminals. They are distributed as follows:

	NEVER	OCCASIONALLY	ROUTINELY
ANTISTRIP AGENTS	6	3	5
SILICONE OILS	12	2	0
ELASTOMERS (RUBBERS)	10	4	0
POLYMERS	9	4	1
ANTI-OXIDANTS	14	0	0

8. HOW MANY STORAGE TANKS ARE AVAILABLE FOR ASPHALT CEMENT AT THE TERMINAL?

RESPONSE: There were responses from fifteen terminals to this question. Of these, ten had more than four storage tanks, one had four, three had three, and one had two.

9. WHAT SIZE STORAGE TANK IS PRIMARILY USED FOR ASPHALT CEMENT?

_______________ BARRELS

RESPONSE: Fifteen terminals responded to this question. The mean storage tank capacity was approximately 50,000 barrels; the maximum size reported was 150,000 barrels, while the minimum size was 18,000 barrels.

10. DURING THE PAVING SEASON, WHAT IS THE ESTIMATED AVERAGE RESIDENCE TIME FOR ASPHALT CEMENT IN STORAGE AT THE TERMINAL?

___ LESS THAN 3 DAYS; ___ 3-10 DAYS;
___ 10-20 DAYS; ___ MORE THAN 20 DAYS.

RESPONSE: There were replies from fifteen terminals to this question. Twelve indicated that their estimated average residence time was between ten and twenty days; the remaining three terminals reported a residence time between three and ten days.

11. IN WHAT TEMPERATURE RANGE IS ASPHALT CEMENT STORED DURING THE PAVING SEASON?

__________ °F

RESPONSE: Fifteen terminals responded to this question. The mean storage range was between 290 and 330°F. The maximum storage temperature reported was 350°F, while the minimum reported was 230°F.

12. IN A TYPICAL YEAR, APPROXIMATELY HOW MANY MONTHS' PRODUCTION OF ASPHALT CEMENT WILL BE STORED OVER THE WINTER SEASON?

__ LESS THAN 3; __ 3-6; __ MORE THAN 6.

RESPONSE: There were fifteen replies to this question. Of these, fourteen terminals reported storing three month's or less production over the winter season. The other terminal reported storing more than six month's production.

13. IN WHAT TEMPERATURE RANGE IS ASPHALT CEMENT STORED OVER THE WINTER SEASON?

________ °F

RESPONSE: Responses to this question were received from fifteen terminals. Three terminals indicated that winter storage took place in unheated tanks at ambient temperature. The remaining 12 maintain heated storage in the winter, with the average temperature range between 250 and 315°F. The maximum reported storage temperature was 340°F, while the minimum heated storage temperature was 100°F.

14. HOW IS ASPHALT CEMENT TRANSPORTED FROM THE TERMINAL?

RESPONSE: The responses to this question from fifteen terminals are tabulated below:

NUMBER OF TERMINALS REPLYING

	NEVER	OCCASIONALLY	ROUTINELY
TANKER-TRUCK:	0	6	10
BARGE:	0	9	1
RAILCAR:	15	0	4

15. IS ASPHALT CEMENT SHIPPED FROM THE TERMINAL DIRECTLY TO HIGHWAY CONSTRUCTION CONTRACTORS WITH YOUR OWN TRANSPORT?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Fifteen replies were received to this question. Of these, four answered "NEVER," seven "OCCASIONALLY," and four "ROUTINELY."

16. IS ASPHALT CEMENT PICKED UP FROM THE TERMINAL BY INDEPENDENT TRANSPORT COMPANIES?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Fifteen terminals responded: all indicated that this was "ROUTINELY" done.

17. IS ASPHALT CEMENT PICKED UP FROM THE TERMINAL BY TRANSPORT OWNED BY HIGHWAY CONSTRUCTION CONTRACTORS?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: Fifteen terminals responded: all indicated that this was "ROUTINELY" done.

18. DO YOU BELIEVE THAT YOUR PRODUCT IS BEING BLENDED WITH OTHER ASPHALT CEMENTS AT CONTRACTORS' FACILITIES?

NEVER________ OCCASIONALLY_______ ROUTINELY___________

RESPONSE: This question was answered by fifteen terminals. Of these, one replied "NEVER," nine "OCCASIONALLY," and five "ROUTINELY."

19. ARE RECYCLED LUBE OILS BLENDED WITH ASPHALT CEMENT AT THIS TERMINAL?

NEVER_______ OCCASIONALLY_______ ROUTINELY__________

RESPONSE: All fifteen terminals that replied to this question, answered "NEVER."

20. IF THE ANSWER TO QUESTION 19 IS "OCCASIONALLY" OR "ROUTINELY," PLEASE ESTIMATE WHAT PERCENT OF THE BLENDED MATERIALS THE RECYCLED LUBE OILS REPRESENT.

___ LESS THAN 0.1; ___ 0.2-1.0; ___ MORE THAN 1.0

RESPONSE: Based on Question 19, there were no replies to this question.

II. TESTING AND QUALITY CONTROL

21. WHAT TESTS ARE ROUTINELY USED FOR THE QUALITY CONTROL OF FINISHED ASPHALT CEMENTS?

RESPONSE: Fifteen responses were received to this question. These are presented in the following table:

	# OF TERMINALS REPLYING	
	YES	NO
VISCOSITY AT 140°F	15	0
VISCOSITY AT 275°F	14	1
PENETRATION AT 77°F	15	0
DUCTILITY AT 77°F)	12	3
FLASH POINT (COC)	13	2
SOLUBILITY IN TRICHLOROETHYLENE	9	6
THIN FILM OVEN TEST	12	3
ROLLING THIN FILM OVEN TEST	6	9
SPOT TEST	6	9
SMOKE POINT	3	-
LOSS ON HEATING	2	-
DUCTILITY AT 60°F	2	-
DUCTILITY AT 39.2°F	1	-

22. AT WHAT FREQUENCY IS QUALITY CONTROL TESTING CONDUCTED?

______ BY LOT ____ BY VOLUME ____ BY TIME ____ RANDOMLY

RESPONSE: Fifteen terminals gave answers to this question. Of these, thirteen conduct testing on a "BY LOT" basis, while one each conduct testing on a "BY TIME" and "RANDOM" basis, respectively.

23. IS ACCEPTANCE (CERTIFICATION) TESTING PERFORMED BY STATE HIGHWAY AGENCY PERSONNEL ON ASPHALT CEMENTS SAMPLED AT THE TERMINAL TO DETERMINE COMPLIANCE WITH SPECIFICATIONS?

_______ YES __________NO

RESPONSE: All fifteen responding terminals gave an affirmative answer to this question.

24. IF THE ANSWER TO QUESTION 23 IS YES, AT WHAT FREQUENCY IS THE SAMPLING CONDUCTED?

______ BY LOT ____ BY VOLUME ____ BY TIME ____ RANDOMLY

RESPONSE: Eight terminals test "BY LOT," four "BY TIME," and three "RANDOMLY."

25. DURING THE LAST TWO YEARS, HAS YOUR COMPANY FAILED TO MEET AN ASPHALT CEMENT SPECIFICATION REQUIREMENT OF ANY AGENCY?

_______ YES __________NO

RESPONSE: There were fifteen responses to this question. Of these, only one answered that their product had failed to meet a specification requirement within the last two years.

26. IF THE ANSWER TO QUESTION 25 IS YES, PLEASE INDICATE FREQUENCY OF FAILURE, WHICH REQUIREMENTS WERE FAILED, WHICH TEST METHODS WERE USED BY THE SPECIFYING AGENCY, AND WHAT REMEDIAL ACTIONS WERE TAKEN.

RESPONSE: One terminal reported two separate problems with meeting asphalt specifications.

In the first, the asphalt had too low a penetration. This was corrected through a switch to a supplier employing a different crude oil slate. In the second, the asphalt, as delivered, had too low a viscosity. No cause at the terminals could be discovered, and it was suspected that the asphalt may have been contaminated during transport to the customer.

27. ARE ASPHALT CEMENTS TESTED AFTER PROLONGED STORAGE, SUCH AS AFTER A WINTER PERIOD?

NEVER________ OCCASIONALLY______ ROUTINELY__________

RESPONSE: Fifteen terminals responded to this question: all answered "ROUTINELY."

PART C. CONCLUDING COMMENTS

28. PLEASE PROVIDE ANY COMMENTS OR ADDITIONAL INFORMATION CONCERNED WITH THE SUBJECTS OF QUESTIONS 1 THROUGH 28, OR ON TOPICS NOT COVERED OR INADEQUATELY COVERED BY THESE QUESTIONS.

RESPONSE: Six terminals gave replies to this question.

Two noted that they lease their terminals from another party, complete with quality control and laboratory testing personnel supplied by the lessor.

One terminal produces and markets latex and polymer-modified asphalts routinely.

Three terminals asked why the questionnaire had not requested information on blending to produce high-viscosity, hard grades such as AC-30 and AC-40.

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13. ABSTRACT *(Maximum 200 words)*

This report provides an abundance of information regarding the production, sources, distribution, and marketing of paving asphalt. It also assesses recent changes in paving asphalt manufacturing processes and crude oil supply. The report is based on 41 responses to a detailed technical questionnaire on refinery practices that was sent to 87 refining firms producing paving asphalt in the United States and Canada. It also includes information from 13 responses to a questionnaire that was sent to 30 firms operating as brokers or resellers of asphalt in the secondary distribution market. The information obtained from questionnaires was supplemented by on-site visits to 36 refineries, as well as by a review of current technical literature.

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