**UNITED STATES PATENT AND TRADEMARK OFFICE**

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**BEFORE THE PATENT TRIAL AND APPEAL BOARD**

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**Asphalt Products Unlimited, Inc.**
**Petitioner,**

**v.**

**Blacklidge Emulsions, Inc.**
**Patent Owner**

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**U.S. Patent No. 7,918,624**

**Case No. TBD**

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**EXHIBIT 1009**

**A BASIC ASPHALT EMULSION MANUAL**

# ASPHALT EMULSION

A Basic Asphalt Emulsion Manual

Manual Series No. 19

Third Edition

AEMA
ASPHALT EMULSION MANUFACTURERS ASSOCIATION

ASPHALT INSTITUTE

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The Asphalt Institute and the Asphalt Emulsion Manufacturers Association can accept no responsibility for the inappropriate use of this manual. Engineering judgment and experience must be used to properly utilize the principles and guidelines contained in this manual, taking into account available equipment, local materials and conditions.

All reasonable care has been taken in the preparation of this manual; however, the Asphalt Institute and the Asphalt Emulsion Manufacturers Association can accept no responsibility for the consequences of any inaccuracies it may contain.

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# FOREWORD

The primary purpose of this manual is to impart a basic understanding of asphalt emulsions to those who work with the product. Further, it is intended to be useful in choosing the emulsion that best fits a project's specific conditions. And it should be most helpful in evaluating pavement systems for construction and maintenance.

The manual is not written in such detail that one can use it to produce asphalt emulsions. Neither is it directed toward the specific features of one manufacturer's products. Rather, it explains the general characteristics of asphalt emulsions and their uses. In times past, lack of information of this type may to some extent have prevented realization of the full potential of emulsions.

A thorough study of the manual should enable one to recommend where, when and how emulsions should be used. It also should aid in the solving of problems that may arise on projects in which emulsions are used.

The Asphalt Institute and the Asphalt Emulsion Manufacturers Association have jointly published the third edition of "A Basic Asphalt Emulsion Manual." This publication was revised under the guidance of Mr. John E. Huffman, P.E., of Brown and Brown, Inc., Salina, Kansas, in his role as Publication Task Force leader for AEMA. This publication is available because of his hard work and dedication.


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# INTRODUCTION

Virtually all types of asphalt used in the United States are products of the refining of crude petroleum. Asphalt is produced in a variety of types and grades ranging from hard and brittle solids to thin liquids. The asphalt used for paving is normally in the middle of these two extremes. Although paving asphalt is a semi-solid or solid at ambient temperatures, it can be readily liquefied by heating, by adding a petroleum solvent, or by emulsifying it in water.

In the production of hot mix asphalt (HMA), heat is used liquefy the asphalt so it will coat the aggregate and remain workable during transport, laydown and compaction. As the asphalt cools, it hardens and regains the binding properties that make it an effective paving material. When a petroleum solvent such as naphtha or kerosene is added to the base asphalt to make it fluid, the product is called a cutback asphalt. In the field, the solvent evaporates as the cutback cures, restoring the asphalt's binding properties.

When asphalt is milled into microscopic particles and dispersed in water with a chemical emulsifier, it becomes an asphalt emulsion. The tiny droplets of asphalt remain uniformly suspended until the emulsion is used for its intended purpose. In the emulsion state, the emulsifier molecules orient themselves in and around droplets of asphalt. The chemistry of the emulsifier/asphalt/water system determines the dispersion and the stability of the suspension. When emulsions are used in the field, the water evaporates into the atmosphere, and the chemical emulsifier is retained with the asphalt.

## History of Asphalt Emulsion

Emulsions were first developed in the early 1900s. It was in the 1920s when emulsions came into general use in pavement applications. Their early use was in spray applications and as dust palliatives. The growth in the use of asphalt emulsions was relatively slow, limited by the type of emulsions available and a lack of knowledge as to how they should be used. Continuing development of new types and grades, coupled with improved construction equipment and practices, now gives a broad range of choices. Virtually any roadway requirement can be met with emulsions. Judicious selection and use can yield significant economic and environmental benefits.

A slow but steady increase in the amount of emulsions used came about between 1930 and the mid 1950s. Following World War II, traffic loads and volumes increased so much that roadway designers began to curtail the use of

**The Major Uses of Asphalt Emulsion**

| Surface Treatments | Asphalt Recycling | Other Applications | |
|---|---|---|---|
| • Fog sealing<br>• Sand sealing<br>• Slurry sealing<br>• Micro-surfacing<br>• Cape sealing | • Cold in-place<br>• Full depth<br>• Hot in-place<br>• Central plant | • Stabilization (soil and base)<br>• Maintenance patching<br>• Tack coats<br>• Dust palliatives | • Prime coats<br>• Crack filling<br>• Protective coatings |

asphalt emulsions. Instead, they specified hot mix asphalt requiring the use of asphalt cement. While the volume of asphalt cement used has increased greatly since 1953, the combined use of other asphalt products has remained almost constant. But there has been a steady rise in the volume of asphalt emulsions used.

Subsequently, several factors have contributed to interest in the use of asphalt emulsions:

- The energy crisis of the early 1970s. The middle east oil embargo prompted conservation measures by the U.S. Federal Energy Administration. Asphalt emulsion does not require a petroleum solvent to make it liquid. Asphalt emulsions can also be used in most cases without additional heat. Both of these factors contribute to energy savings.
- Concerns about reducing atmospheric pollution. There are little or no hydrocarbon emissions from asphalt emulsions.
- The ability of certain types of asphalt emulsions to coat damp aggregate surfaces. This reduces the fuel requirements for heating and drying aggregates.
- Availability of a variety of emulsion types. New formulations and improved laboratory procedures have been developed to satisfy design and construction requirements.
- The ability to use the cold materials at remote sites.
- The applicability of emulsions for use in the preventive maintenance to increase the service life of slightly distressed existing pavements.

Two major factors, energy conservation and atmospheric pollution, prompted the use of asphalt emulsion in applications that were typically supported by cutback asphalt. In one of the early actions, the Federal Highway Administration (FHWA) issued notices that directed attention to fuel savings that could be realized by using asphalt emulsions instead of cutback asphalts. While the substitution was not mandatory, it was strongly suggested that it be considered. Since that time, all states are substituting, allowing the substitution of, or even mandating the use of asphalt emulsions in place of cutback asphalts.

## Future of Asphalt Emulsion

The demand for a well maintained, efficient highway network continues. Asphalt is essential to meet these requirements. The Federal Highway Administration annual survey reported in "Highway Statistics" shows that the United States has about 6.3 million kilometers (3.9 million miles) in the roadway network. The survey also shows that about 93 percent of the paved roads have asphalt surfaces.

The 1993 survey showed 19.2% of the paved mileage on Interstate highways is in "fair" condition, 24.1% is in "mediocre" condition, and 8.4% in "poor" condition. Of the other major highways, 28.2% of the mileage is in "fair" condition, 22.9% in "mediocre", and 11.0% in "poor" condition. This means that 37,600 kilometers (23,400 miles) of Interstates and almost 380,000 kilometers (236,000 miles) of other major highways are either in need of repair, or soon will be. Not included in these figures are the 89.1% of other roads classified as collectors and locals.

The FHWA reports that the preservation of the nation's highways is currently a priority at all levels of government. The renewed interest has resulted in increased fiscal resources allocated to improving pavements. In the past, the major effort of FHWA has been new highway construction. There is now increasing emphasis on maintenance. Asphalt emulsions are an effective method of preventative and corrective maintenance of existing pavements.

In 1993, local, state and federal government spent $39.7 billion on capital improvements for our highways, and $23.4 billion was spent on maintenance and traffic services. Maintenance accounted for 31.2% of government highway spending in 1993, compared with 28.6% in 1973.

An example of the renewed interest is the proposed National Highway System (NHS) submitted to Congress in December of 1993. The goals of the NHS include a more effective linking of industry, recreation, medical services, tourism and disaster services with a national transportation system. It is expected to greatly improve urban traffic flow, improving air quality by reducing emissions up to 30%. The proposed incident management will also increase safety and decrease medical costs.

Current projections indicate the NHS will pay for itself within 15 years just in the decrease in costs related to fatalities. The improvements in additional economic development and job creation facilitated by improved transportation are expected to have a major impact on our economy. The NHS is projected to carry over 42% of the nation's travel. The NHS will encompass over 73,200 km (45,500 mi) of existing Interstate, 176,547 km (109,701 mi) of other existing highways, and 6,256 km (3,887 mi) of new construction. Approximately 60% of the existing mileage (152,640 km—94,850 mi) to be included in the NHS is currently listed as being in fair, mediocre or poor condition, and will need rehabilitation.

The Strategic Highway Research Program (SHRP) was a 5 year, $150 million research program to improve performance and durability of our nation's roads and to make those roads safer for both motorists and highway workers. One of the products of SHRP is the Superpave asphalt mix design system for hot mix asphalt. The Superpave system uses performance based criteria, taking into consideration specific project conditions such as climate, existing structure, traffic patterns and loads. Superpave includes new methods of characterizing asphalt binders used in hot mix asphalt. While the Superpave binder specifications did not specifically address asphalt emulsions at the time of this writing, the shift in the ways highway engineers are now looking at asphalt testing will undoubtedly have an effect on asphalt emulsions in the future.

The demands for a well-maintained roadway will continue to be high, and the demand for asphalt will persevere. There will be increased limitations in supply of quality raw materials. Because of these tremendous needs, every attempt should be made to utilize road materials in an efficient, conservative manner. This means increased use of recycling and high performance materials such as modified emulsions.

The asphalt paving industry is seeing many changes. In recent years asphalt emulsion technology has been innovative in meeting the challenges of increased traffic, shrinking budgets and environmental concerns. A clear understanding of the "why and how" of using asphalt emulsions offers a promise of efficient use. The proper use of asphalt emulsions can result in high performance pavements and thrifty but versatile maintenance systems. This manual is directed toward those ends.

To aid in understanding unfamiliar technical terms, a glossary is provided in Appendix A.

Many types of emulsion products are used in our daily lives. Mayonnaise, latex paint, and ice cream are some of the more common emulsions. In each case, certain mechanical and chemical processes are involved to combine two or more materials that will not mix under normal conditions. An entire scientific field is devoted to the study of emulsification. Just as an understanding of how an engine works isn't necessary to operate an automobile, neither do you have to understand complex emulsion chemistry to build a good pavement with an asphalt emulsion. The key is to select the right emulsion for the aggregate and construction system involved. Throughout this text when the term "emulsion" is used it is intended to mean "asphalt emulsion."

## Composition of Asphalt Emulsions

An asphalt emulsion consists of three basic ingredients: asphalt, water, and an emulsifying agent. On some occasions, the emulsion may contain other additives, such as stabilizers, coating improvers, antistrips, or break control agents.

It is well known that water and asphalt will not mix, except under carefully controlled conditions using highly specialized equipment and chemical additives. The blending of asphalt and water is the same as an auto mechanic trying to wash grease from his hands with only water. Only with a detergent or soapy agent can grease be successfully removed. The soap particles surround the globules of grease, break the surface tension that holds them, and allow them to be washed away.

Some of the same physical and chemical principles apply in the formulation, production, and use of asphalt emulsions. The object is to make a stable dispersion of the asphalt cement in water — stable enough for pumping, prolonged storage, and mixing. Furthermore, the emulsion should "break" quickly after contact with aggregate in a mixer or after spraying on the roadbed — "breaking" is the separation of the water from the asphalt. Upon curing, the residual asphalt retains all of the adhesion, durability, and water-resistance of the asphalt cement from which it was produced.

## Asphalt Emulsion Classification

Asphalt emulsions are classified into three categories: anionic, cationic, and nonionic. In practice, the first two types are more widely used in roadway construction and maintenance. Nonionics may become more important as emulsion technology advances. The anionic and cationic classes refer to the electrical charges surrounding the asphalt particles. This identification system stems from a basic law of electricity—like charges repel one another and unlike charges attract.

When two poles (an anode and a cathode) are immersed in a liquid and an electric current is passed through, the anode becomes positively charged and the cathode becomes negatively charged. If a current is passed through an emulsion containing negatively charged particles of asphalt, they will migrate to the anode. Hence, the emulsion is referred to as anionic. Conversely, positively charged asphalt particles will move to the cathode and the emulsion is known as cationic. With nonionic emulsions, the asphalt particles are neutral and do not migrate to either pole.

Emulsions are further classified on the basis of how quickly the asphalt droplets will coalesce; i.e., revert to asphalt cement. The terms RS, MS, SS and QS have been adopted to simplify and standardize this classification. They are relative terms only and mean rapid-setting, medium-setting, slow-setting and quick-setting. The tendency to coalesce is closely related to the speed with which an emulsion will become unstable and break after contacting the surface of an aggregate. An RS emulsion has little or no ability to mix with an aggregate, an MS emulsion is expected to mix with coarse but not fine aggregate, and SS and QS emulsions are designed to mix with fine aggregate, with the QS expected to break more quickly than the SS.

Emulsions are further identified by a series of numbers and letters related to viscosity of the emulsions and hardness of the base asphalt cements. The letter "C" in front of the emulsion type denotes cationic. The absence of the "C" denotes anionic in American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) specifications. For example, RS-1 is anionic and CRS-1 is cationic.

The numbers in the classification indicate the relative viscosity of the emulsion. For example, an MS-2 is more viscous than an MS-1. The "h" that follows certain grades simply means that harder base asphalt is used. An "s" means that softer base asphalt is used.

The "HF" preceding some of the anionic grades indicates high-float, as measured by the float test. High-float emulsions have a gel quality, imparted by the addition of certain chemicals, that permits a thicker asphalt film on the aggregate particles and prevents drain off of asphalt from the aggregate. These grades are used primarily for cold and hot plant mixes, seal coats and road mixes.

ASTM and AASHTO have developed standard specifications for these grades of emulsion:

| **Asphalt Emulsion** (ASTM D977, AASHTO M140) | **Cationic Asphalt Emulsion** (ASTM D2397, AASHTO M208) |
|---|---|
| RS-1 | CRS-1 |
| RS-2 | CRS-2 |
| HFRS-2 | — |
| MS-1 | — |
| MS-2 | CMS-2 |
| MS-2h | CMS-2h |
| HFMS-1 | — |
| HFMS-2 | — |
| HFMS-2h | — |
| HFMS-2s | — |
| SS-1 | CSS-1 |
| SS-1h | CSS-1h |

Most producers may not stock all grades of emulsion. As well, many states have their own specifications that do not follow ASTM or AASHTO guidelines for naming emulsions. Communication and planning between user and producer helps facilitate service and supply of a given grade.

Quick setting emulsions have been developed for slurry seals. Cationic quick set (CQS) emulsions are widely used for their versatility with a wide range of aggregates and rapid setting characteristics. Several states use CQS and QS emulsion specifications for slurry seal applications. These specifications are similar to ASTM and AASHTO CSS-1h and SS-1h requirements except that the cement mixing requirement is waived.

Micro-surfacing uses an emulsion often referred to as CSS-1h-p. As with quick set emulsions, micro-surfacing emulsions are required to meet ASTM and AASHTO CSS-1h requirements with the exception of the cement mixing test. In addition, a minimum polymer content normally is specified as 3% of solids based on the weight of the asphalt in the emulsion. This addition enhances the high temperature performance of the asphalt and permits application of micro-surfacing in wheel ruts and other areas where multiple stone depths are required.

The expanding use of polymer modified asphalts has contributed a whole new family of emulsion grades. Adding one letter (usually P, S or L) to the end of the grade (e.g. HFRS-2P) normally designates modified emulsions.

Cationic emulsion specifications (ASTM D 2397, AASHTO M 208) permit solvent in some grades but restrict the amount. Some user agencies specify an additional cationic sand-mixing grade designated CMS-2s that contains more solvent than other cationic grades.

The general uses of asphalt emulsion are given in Table 5.1 and are discussed in detail later in this publication.

## Variables Affecting Quality and Performance

There are many factors that affect the production, storage, use, and performance of an asphalt emulsion. It would be hard to single out any one as being the most significant. Variables having a significant effect include:

- Chemical properties of the base asphalt cement
- Hardness and quantity of the base asphalt cement
- Asphalt particle size in the emulsion
- Type and concentration of the emulsifying agent
- Manufacturing conditions such as temperature, pressure, and shear
- Ionic charge on the emulsion particles
- Order of addition of the ingredients
- Type of equipment used in manufacturing the emulsion
- Properties of the emulsifying agent
- Addition of chemical modifiers or polymers
- Water quality (hardness)

These factors can be varied to suit the available aggregates or construction conditions. It is always advisable to consult the emulsion supplier with respect to a particular asphalt-aggregate combination, as there are few rules that apply under all conditions.

## Emulsion Ingredients

An examination of the three main constituents—asphalt, water, and emulsifier—is essential to an understanding of why asphalt emulsions work as they do.

### ➤➤ Asphalt

Asphalt cement is the basic ingredient of asphalt emulsion and, in most cases it makes up from 50 to 75 percent of the emulsion. Asphalt chemistry is a complex subject, and there is no need to examine all the properties of asphalt cement. Some properties of the asphalt cement do significantly affect the finished emulsion. There is not an exact correlation, however, between the properties and the ease with which the asphalt can be emulsified. Although hardness of base asphalt cements may vary, most emulsions are made with asphalts in the 60-250 penetration range. On occasion, climatic conditions may require a harder or softer base asphalt. In any case, chemical compatibility of the emulsifying agent with the asphalt cement is essential for production of a stable emulsion.

The principal source of asphalt is the refining of crude petroleum. Asphalt is primarily composed of large hydrocarbon molecules, and its chemical composition is diverse. The colloidal makeup of the asphalt depends on the chemical nature and percentage of the hydrocarbon molecules and their relationship to each other. The varying chemical and physical characteristics of asphalt, therefore, are primarily due to inherent variations in crude oil sources and refining practices. Of course, the properties of the asphalt cement will have an effect on the performance of the residual asphalt on the road.

The complex interaction of the different molecules makes it almost impossible to predict accurately the behavior of an asphalt to be emulsified. For this reason, constant quality control is maintained on emulsion production. Each emulsion manufacturer has its own formulations and production techniques. They have been developed to achieve optimum results with the asphalt cement and emulsifying chemicals that are used.

### ➤➤ Water

The second ingredient in an asphalt emulsion is water. Its contribution to the desired properties of the finished product cannot be minimized. Water may contain minerals or other matter that affect the production of stable asphalt emulsions. Accordingly, water considered suitable for drinking might not be suitable for asphalt emulsions.

Water found in nature may be unsuitable because of impurities, either in solution or colloidal suspension. Of particular concern is the presence of calcium and magnesium ions. These ions benefit the formation of a stable cationic emulsion. In fact calcium chloride is often added to cationic emulsions to enhance storage stability. These same ions, however, can be harmful in anionic emulsions. That is because water-insoluble calcium and magnesium salts (often referred to as "soap scum") are formed in the reaction with water soluble sodium and potassium salts normally used as emulsifiers. In a like manner, carbonate and bicarbonate anions can help stabilize an anionic emulsion because of their buffering effect, but they can destabilize cationic emulsions by reacting with water soluble amine hydrochloride emulsifiers.

Water containing particulate matter should not be used in emulsion production. It can be especially harmful in cationic emulsions. The usually negatively charged particles quickly absorb the cationic emulsifying agents, destabilizing the emulsion. The use of impure water may result in an imbalance of the emulsion components that can adversely affect performance or cause premature breaking.

## ➤➤ *Emulsifying Agents*

Asphalt emulsion properties greatly depend on the chemical used as the emulsifier. The emulsifier is a surface-active agent, or a surfactant. The emulsifier keeps the asphalt droplets in stable suspension and controls the breaking time. It is also the determining factor in the classification of the emulsion as anionic, cationic, or nonionic.

In the early days of asphalt emulsion production, materials such as ox-blood, clays, and soaps were used as emulsifying agents. As emulsion demand increased, more efficient emulsifying agents were found. Many chemical emulsifiers are now commercially available.

The most common anionic emulsifiers are fatty acids, which are wood-product derivatives such as tall oils, rosins, and lignins. Anionic emulsifiers are saponified (turned into soap) by reacting with sodium hydroxide or potassium hydroxide.

Most cationic emulsifiers are fatty amines (e.g. diamines, imidazolines, and amidoamines). The amines are converted into soap by reacting with acid, usually hydrochloric. Another type of emulsifying agent, fatty quartenary ammonium salts, is used to produce cationic emulsions. They are water soluble salts and do not require the addition of acid. They are stable, effective cationic emulsifiers.

By broad definition, surface active chemicals are water soluble substances whose presence in solution markedly changes the properties of the solvent and the surfaces they contact. They are categorized by the way they dissociate or ionize in water. Structurally they possess a molecular balance of a long lipophilic (oil-loving), hydrocarbon tail and a polar, hydrophilic (water-loving) head. Surfactants are adsorbed at the interface between liquids and gases or liquid and solid phases. They tend to concentrate at the interface such that the hydrophilic groups orient themselves towards the more polar phase, and the lipophilic groups towards the less polar phase. The surfactant molecule or ion acts as a bridge between two phases.

Basically, there are three types of surfactants that are classified according to their dissociation characteristics in water:

(1) **Anionic Surfactants** – Where the electrovalent and polar hydrocarbon group is part of the negatively charged ion, when the compound ionizes:

**ANIONIC**
$CH_3(CH_2)_n\ COO^-Na^+$

(2) **Nonionic Surfactants** – Where the hydrophilic group is covalent and polar, and which dissolves without ionization:

**NONIONIC**
$CH_3(CH_2)_n\ COO\ (CH_2CH_20)_X\ H$

(3) **Cationic Surfactants** – Where the electrovalent and polar hydrocarbon group is part of the positively charged ion when the compound ionizes:

**CATIONIC**
$CH_3(CH_2)_n\ NH_3^+Cl^-$

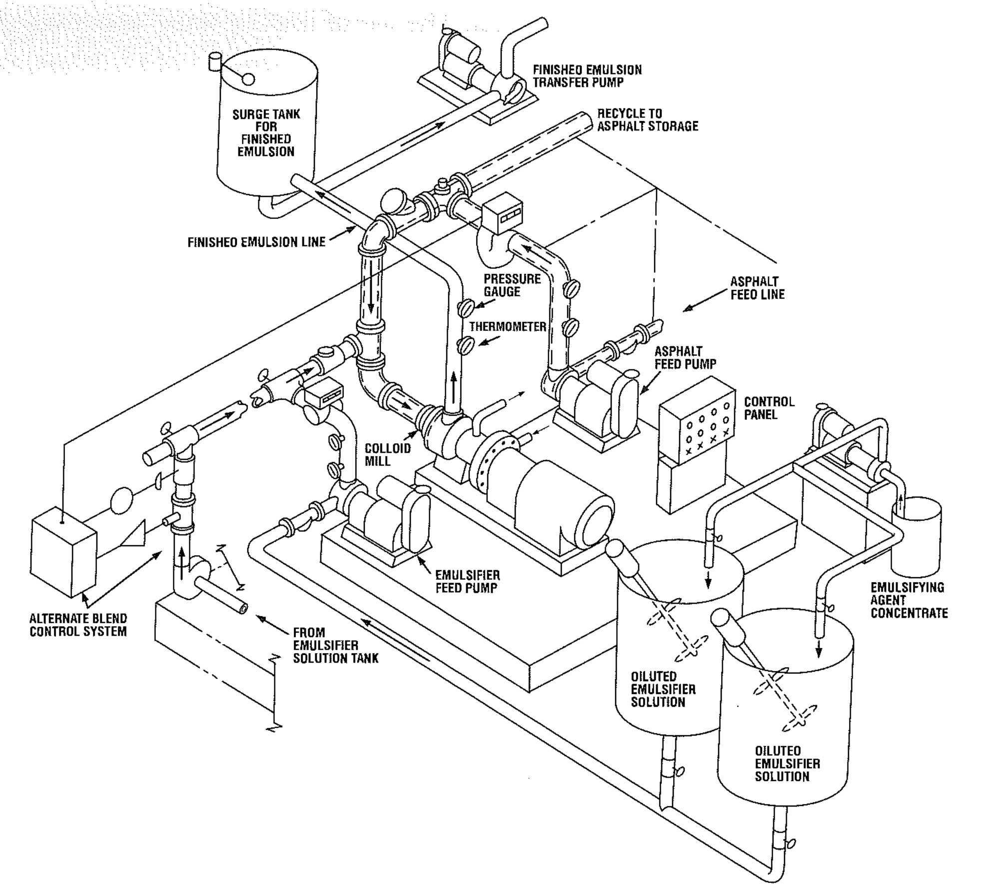


Figure 2.1 Diagram of an Asphalt Emulsion Manufacturing Plant

The emulsifier is the single most important component in any asphalt emulsion formulation. To be an effective emulsifier for asphalt, a surfactant must be water soluble and possess a proper balance between the hydrophilic and lipophilic properties. The emulsifier, used in combination with an acceptable asphalt, good quality water and adequate mechanical input, is the major factor in emulsification, emulsion stability and ultimate field application performance.

Each manufacturer has its own procedure for using surfactants in asphalt emulsion production. In most cases, the surfactant is combined with the water before introduction into the colloid mill. However, it may be combined with the asphalt cement just before it goes into the colloid mill.

## Producing the Emulsion

### ➤➤ Emulsifying Equipment

The basic equipment to prepare an emulsion includes a high-speed, high-shear mechanical device (usually a colloid mill) to divide the asphalt into tiny droplets. A schematic diagram of a typical asphalt emulsion manufacturing plant is shown in Figure 2.1. Also needed are an emulsifier solution tank, heated asphalt tank, pumps, and flow-metering gauges.

The colloid mill has a high-speed rotor that revolves at 17-100 Hz (1,000-6,000 rpm) with mill clearance settings in the range of about 0.25 to 0.50 mm (0.01 to 0.02 in.). Typically asphalt emulsions have droplet sizes smaller than the diameter of a human hair, or about 0.001 to 0.010 mm (0.00004 to 0.0004 in.). Particle size analyzers are commonly used to characterize emulsion quality. Asphalt droplet sizes depend upon the mechanical energy density imparted by the mill.

Separate pumps are used to meter asphalt and the emulsifier solution into the colloid mill. Because the emulsifier solution can be highly corrosive, it may be necessary to use equipment made of corrosion resistant materials.

## ➤➤ *The Emulsifying Process*

In the emulsification process, heated asphalt is fed into the colloid mill where it is divided into tiny droplets. At the same time, water containing the emulsifying agent is fed into the colloid mill. The asphalt entering the colloid mill is heated to a low viscosity, and the water temperature is also adjusted to optimize emulsification. These temperatures vary and depend upon the emulsification traits of the asphalt cement and the compatibility between the asphalt and the emulsifying agent. Extremely high asphalt temperatures are not used because the temperature of the emulsion leaving the mill must be below the boiling point of water, unless a heat exchanger is used to cool the emulsion. The emulsion is then usually pumped into bulk storage tanks. These tanks may be equipped with mechanical agitation to keep the emulsion uniformly blended.

The method of adding the emulsifier to the water varies according to the manufacturer's procedure. Some emulsifiers, such as amines, must be mixed and reacted with an acid to be water soluble. Others, such as fatty acids, must be mixed and reacted with an alkali to be water soluble. Emulsifier mixing is typically done in a batch mixing tank. The emulsifier is introduced into warm water containing acid or alkali and agitated until completely dissolved.

Asphalt and emulsifier solution must be proportioned accurately. This is normally done with flow meters, but monitoring the temperature of each phase and the mill discharge can also control the proportioning. If temperature regulation is used, the desired outlet temperature of the finished emulsion is calculated from the various emulsion ingredients and then used to control the asphalt content percentage.

Asphalt particle size is a vital factor in making a stable emulsion. A microscopic photograph of a typical emulsion (Figure 2.2) reveals these average particle sizes:

| | |
|---|---|
| Smaller than 0.001 mm (1 μm) | 28 percent |
| 0.001-0.005 mm (1-5 μm) | 57 percent |
| 0.005-0.010 mm (5-10 μm) | 15 percent |

These microscopic-sized asphalt droplets are dispersed in water in the presence of the chemical surface active emulsifier (surfactant). The surfactant causes a change in the surface tension at the contact area between the asphalt droplets and the surrounding water, and this allows the asphalt to remain in a suspended state. The asphalt particles, all having a similar electrical charge, repel each other, which aids in keeping them suspended.

## Breaking and Curing

### ➤➤ Breaking

If the asphalt emulsion is to perform its ultimate function as a binder, the water must separate from the asphalt phase and evaporate. This separation is called "breaking." For surface treatments and seals, emulsions are formulated to break chemically upon contact with a foreign substance such as aggregate or a pavement surface. When using anionic and cationic rapid-setting and medium-setting emulsions, the initial placement of the asphalt emulsion droplets on the aggregate develops through electrochemical phenomena.

For slow-setting emulsions, the mechanism is water evaporation. For dense mixtures, more time is needed to allow for mixing and placement. Therefore, emulsions used for mixtures are formulated for delayed breaking. A rapid-set emulsion will have a short breaking time (within one to five minutes after being applied), whereas a medium- or slow-set material may take considerably longer.

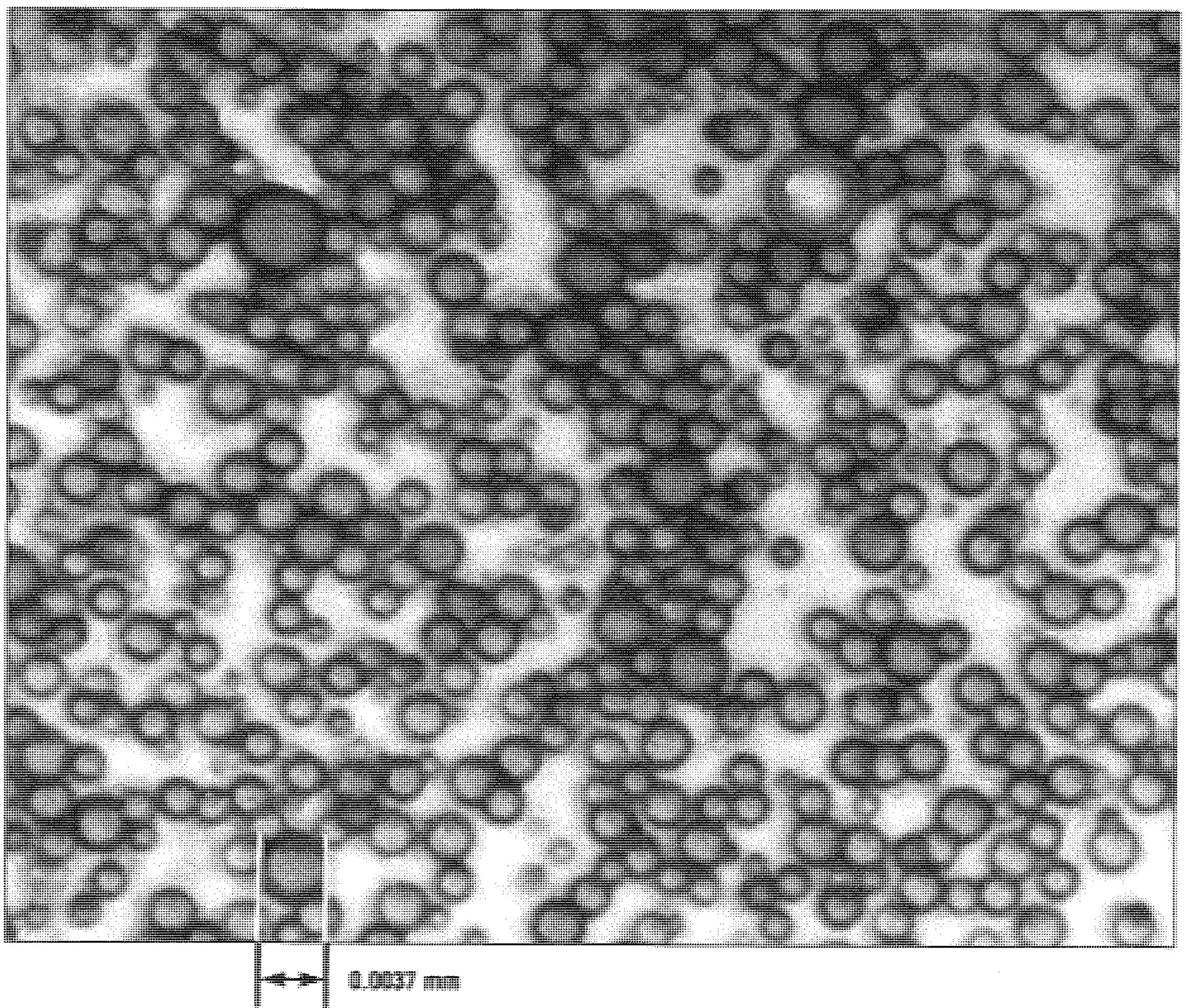


Figure 2.2 Relative Sizes and Distribution of Asphalt Particles in an Emulsion

The specific type and concentration of emulsifying agent primarily control the rate of breaking. However other factors, listed below, also play an important role in breaking the emulsion. In order to achieve optimum results, it is necessary to control all of these factors to meet the specific requirements of the field use of the asphalt emulsion. The supplier should have more information regarding the optimum use of its emulsions.

## ➤➤ *Curing*

Curing involves the development of the mechanical properties of the asphalt cement. The end result is a continuous cohesive film that holds the aggregate in place with a strong adhesive bond. For this to happen, the water must completely evaporate, and the asphalt emulsion particles have to coalesce and bond to the aggregate. The water is removed by evaporation, by pressure (rolling), and by absorption into the aggregate. Water evaporation can be fairly rapid under favorable weather conditions, but high humidity, low temperatures, or rainfall soon after application can deter proper curing. When medium setting and slow setting grades are used for paving mixes, the use of slightly damp aggregates facilitates the mixing and coating process. The development of strength in the SS types depends mainly on evaporation and absorption.

Mixing grade emulsions usually contain some petroleum solvent to aid in the mixing and coating process. During curing, some of this solvent evaporates. There has been recent emphasis on the development of solventless mixing grade emulsions. For example, the cure of micro-surfacing is rapid enough to allow traffic within one hour.

## ➤➤ *Factors Affecting Breaking and Curing*

Some of the factors affecting breaking and curing rates of asphalt emulsions include:

- Water Absorption – A rough-textured, porous aggregate speeds the setting time by absorbing water from the emulsion.
- Aggregate Moisture Content – While wet aggregate may facilitate coating, it tends to slow the curing process by increasing the amount of time needed for evaporation.
- Weather Conditions – Temperature, humidity, and wind velocity all have a bearing on water evaporation rate, emulsifier migration and water release characteristics. While breaking usually occurs more quickly at warmer temperatures, that is not always the case. Hot weather can cause skin formation on chip seals, trapping water and delaying curing. Some chemical formulations have also recently been developed to break rapidly at cool temperatures.
- Mechanical Forces – Roller pressure and, to a limited extent slow moving traffic, forces the water from the mix and helps attain mix cohesion, cure and stability.
- Surface Area – Greater aggregate surface area, particularly excessive fines or dirty aggregate, accelerates the breaking of the emulsion.
- Surface Chemistry – Intensity of the aggregate surface charge, in combination with the intensity of emulsifier charge, can impact setting rate, particularly for cationic emulsions. Calcium and magnesium ions on the aggregate surface can react with and destabilize certain anionic emulsifiers, accelerating setting.

- Emulsion and Aggregate Temperature – Breaking is retarded when emulsion and aggregate temperatures are low. This is particularly evident in micro-surfacing.
- Type and Amount of Emulsifier – The surfactant used in the manufacture of the emulsion determines the breaking characteristics of seal coat and mixing grade emulsions.

These factors must be considered in determining working time after the emulsion has been sprayed or mixed with the aggregate in the field. The emulsion supplier is the best source of information.

Through a long history of successful field use of asphalt emulsions, these handling, storing and sampling procedures have been established. These general guidelines should be followed. Any questions about the handling, storage or sampling of asphalt emulsions should be referred to your emulsion supplier.

## Storing Asphalt Emulsions

Asphalt emulsion, a dispersion of fine droplets of asphalt cement in water, has both the advantages and disadvantages of the carrier medium, water. When storing emulsified asphalts:

**DO** store as you would fluid water – between 10°C (50°F) and 85°C (185°F), depending on the intended use and specific product.

**DO** store at the temperature specified for the particular grade and application. Table 3.1 shows the normal storage temperature ranges.

**DO NOT** permit the asphalt emulsion to be heated above 85°C (185°F). Elevated temperatures evaporate the water, changing the characteristics of the asphalt emulsion.

**DO NOT** let the emulsion freeze. This breaks the emulsion, separating the asphalt from the water. The result will be two layers in the tank, neither of which will be suited for the intended use, and the tank will be difficult to empty.

**DO NOT** allow the temperature of the heating surface to exceed 100°C (212°F). This will cause premature breakdown of the emulsion on the heating surface.

**DO NOT** use forced air to agitate the emulsion. It may cause the emulsion to break.

Storage tanks should be insulated for protection from freezing and most efficient use of heat. A skin of asphalt can form on the surface of emulsions when exposed to air. Therefore, it is best to use tall, vertical tanks that expose the least amount of surface area to the air. Most fixed storage tanks are vertical but horizontal tanks are often used for short-term field storage. Skinning can be reduced by keeping horizontal tanks full to minimize the area exposed to air.

Side-entering propellers located about one meter (three feet) up from the tank bottom may be used to prevent surface skin formation. Large diameter, slow-turning propellers are best and should be used to roll over the material. Over-mixing should be avoided. Tanks may also be circulated top to bottom with a pump. Over-pumping is to be avoided.

| Table 3.1 Storage Temperatures for Asphalt Emulsions | | |
|---|---|---|
| | Temperature, °C (°F) | |
| Grade | Minimum | Maximum |
| RS-1 | 20° (70°) | 60° (140°) |
| RS-2, CRS-1, CRS-2, HFRS-2 | 50° (125°) | 85° (185°) |
| SS-1, SS-1h, CSS-1, CSS-1h, MS-1, HFMS-1 | 10° (50°) | 60° (140°) |
| CMS-2, CMS-2h, MS-2, MS-2h, HFMS-2, HFMS-2h, HFMS-2s | 50° (125°) | 85° (185°) |

## Handling Emulsified Asphalts

**DO** when heating asphalt emulsion, agitate it gently to eliminate or reduce skin formation.

**DO** protect pumps, valves, and lines from freezing in winter. Drain pumps and service according to the manufacturer's recommendations.

**DO** blow out lines and leave drain plugs open when they are not in service.

**DO** use pumps with proper clearances for handling emulsified asphalt. Tightly fitting pumps can bind and seize.

**DO** warm the pump to about 65°C (150°F) to facilitate start-up.

**DO** when diluting asphalt emulsion, check the compatibility of the water with the emulsion by testing a small quantity.

**DO** if possible, use warm water for diluting, and always add the water slowly to the emulsion (not the emulsion to the water).

**DO** avoid repeated pumping and recirculating, as the viscosity may drop and air may become entrained, causing the emulsion to be unstable.

**DO** place inlet pipes and return lines at the bottom of tanks to prevent foaming.

**DO** pump from the bottom of the tank to minimize contamination from skinning that may have formed.

**DO** remember that emulsions with the same grade designation can be very different chemically and in performance.

**DO** haul emulsion in truck transports with baffle plates to prevent sloshing.

**DO** agitate emulsions that have been in prolonged storage. This may be done by recirculation.

**DO NOT** mix different classes, types, and grades of emulsified asphalt in storage tanks, transports, and distributors. See Table 3.2 for recommendations.

**DO NOT** apply severe heat to pump packing glands or pump casings. The pump may be damaged.

**DO NOT** dilute rapid-setting grades of asphalt emulsion with water. Medium and slow setting grades may be diluted, but always add water slowly to the asphalt emulsion. Never add the asphalt emulsion to a tank of water when diluting.

**DO NOT** load asphalt emulsion into storage tanks, tank cars, tank transports, or distributors containing remains of incompatible materials. See Tables 3.2, 3.3a and 3.3b.

**DO NOT** subject emulsified asphalt or air above it to an open flame, heat, or strong oxidants. Adequate ventilation is required.

**DO** avoid breathing fumes, vapors, and mist.

**DO** obtain a copy of the supplier's material safety data sheet (MSDS). Read the MSDS carefully and follow it.

**Table 3.2 Guide for Condition of Emptied Tanks Before Loading Asphalt Emulsions**

| PRODUCT TO BE LOADED | LAST PRODUCT IN TANK: Asphalt Cement (includes industrial asphalt) | Cutback Asphalt and residual fuel oils | Cationic Emulsion | Anionic Emulsion | Crude Petroleum | Any Product Not Listed |
|---|---|---|---|---|---|---|
| **Cationic Emulsion** | Empty * | Empty to no measurable quantity | OK to load | Empty to no measurable quantity | Empty to no measurable quantity | Tank must be cleaned |
| **Anionic Emulsion** | Empty * | Empty to no measurable quantity | Empty to no measurable quantity | OK to load | Empty to no measurable quantity | Tank must be cleaned |

* Any material remaining will produce dangerous conditions

## Table 3.3 Possible Causes of Contamination of Asphalt Material or Samples and Suggested Precautions

**Table 3.3a Haulers and Hauling Vehicles**

Field observations and studies of test results have indicated that contamination of materials during transportation often occurs.

| Possible Causes | Precautions |
|---|---|
| (a) Previous load not compatible with emulsion being loaded. | Examine the log of loads hauled or check with the supplier to determine if previous material hauled is detrimental. If it is, make sure vehicle tanks, unloading lines, and pump are properly cleaned and drained before being presented for loading. Provide a ramp at the unloading point at the plant to ensure complete drainage of vehicle tank while material is still fluid. |
| (b) Remains of diesel oil or solvents used for cleaning and flushing of tanks, lines, and pump. | When this is necessary, make sure all solvents are completely drained. |
| (c) Flushing of solvents into receiving storage tank or equipment tanks. | Do not allow even small amounts to flush into storage tank; entire contents may be contaminated. |

## Table 3.3b Mixing Plant Storage Tank and Equipment

Many investigations and test results point to mix plant storage tanks and associated equipment as the source of contamination.

| Possible Causes | Precautions |
|---|---|
| (a) Previous material left over in tank when changing to emulsion. | Any material allowed to remain must be compatible with the emulsion, and the amount remaining in the tank must be insufficient to cause emulsion to become out of specification. If in doubt, check with your supplier.<br>To be on the safe side, tank should be drained or cleaned prior to using tank for each different type or grade of asphalt. Be sure discharge line connects at low point of storage tank to ensure complete emptying when changing type or grades of asphalt or cleaning tank. |
| (b) Solvents used to flush hauling vehicle tank discharged into storage tank. | Observe unloading operations, caution driver about flushing cleaning materials into storage tank. If possible, provide place for hauler to discharge cleaning materials. |
| (c) Flushing of lines and pump between storage tank and mixing plant with solvents and then allowing this material to return to tank. | If necessary to flush lines and pump, suggest providing bypass valves and lines to prevent solvents from returning to tank. A better solution is to provide insulated, heated lines and pump, thereby eliminating the necessity of flushing. |
| (d) Cleaning of distributor tank, pump, spray bar, and nozzles with solvents. | Be sure all possible cleaning material is drained off or removed prior to loading. |
| (e) Dilutions from hot oil heating systems. | Check reservoir on hot oil heating system. If oil level is low, or oil has been added, check system for leakage into the asphalt supply. |

## Table 3.3c Non-Representative or Contaminated Sample

Test results are greatly dependent upon proper sampling techniques. Extra care is required by the sampler to obtain samples that are truly representative of the material being sampled and will do much to eliminate the possibility of erroneous test results by reason of improper sampling. Make sure samples are taken only by those authorized persons who are trained in sampling procedures.

| Possible Causes | Precautions |
|---|---|
| (a) Contaminated sampling device (commonly called a "sample thief"). | If sampling device (described in ASTM D 140 or AASHTO T 40) is cleaned with diesel oil or solvent, make sure that it is thoroughly drained and then rinsed out several times with emulsion being sampled prior to taking sample. |
| (b) Samples taken with sampling device from top of tank where, under certain conditions, contaminants can collect on the surface. | In taking a sample from the top of a tank, lower the sampling device below the extreme top before opening. Note: This sample may come from the top one-third of the tank. |
| (c) Contaminated sample container. | Use only new clean containers. Never wash or rinse a sample container with solvent. Wide-mouthed plastic jars or bottles or plastic-lined cans should be used. |

| Table 3.3c (continued) | |
|---|---|
| **Possible Causes** | **Precautions** |
| (d) Sample contaminated after taking. | **DO NOT** submerge container in solvent or wipe the outside of the container with a solvent-saturated rag. If necessary to clean spilled emulsion from outside of container, use a clean dry rag. Make sure container lid is tightly sealed prior to storage or shipment. Ship to testing laboratory promptly. |
| (e) Samples taken from spigot in lines between storage tank and mixing plant. | If the sampling spigot is in a suction line between the tank and pump, this requires stopping the pump prior to taking a sample. Samples thus taken are by gravity and only representative of emulsion localized in the pipe area of the spigot. Instead, the spigot should be between the pump and spigot.<br>**DO NOT** take a sample while the hauling vehicle is pumping into storage tank.<br>**DO NOT** take a sample without allowing enough time for circulation and thorough mixing of emulsion.<br>**DO** drain off sufficient material through spigot prior to taking a sample to ensure removal of any material lodged in spigot.<br>**DO** take a sample slowly during circulation to be more representative of the emulsion being used. |
| (f) Samples taken from unloading line of hauling vehicle. | Drain off sufficient emulsion through spigot prior to taking a sample to ensure removal of any material lodged there. Sample should be taken after one-third and not more than two-thirds of the load has been removed. Take the sample slowly to be sure it is representative of the emulsion being used. |

## Sampling Asphalt Emulsions

The purpose of any sampling method is to obtain samples that will show the true nature and condition of the material. The general procedure is described below. The standard procedure is further detailed in "Standard Methods of Sampling Bituminous Materials," ASTM D 140 or AASHTO T 40.

Containers for sampling asphalt emulsion shall be wide-mouth jars or bottles made of plastic, or wide-mouth plastic-lined cans with lined screw caps, or plastic-lined triple-seal friction-top cans. The size of samples shall correspond to the required sample containers, which is generally 4 liters (1 gallon).

Whenever practical, the asphalt emulsion shall be sampled at the point of manufacture or storage. If that is not practical, samples shall be taken from the shipment immediately upon delivery. Three samples of the asphalt emulsion shall be taken. The samples shall be sent as soon as possible to the laboratory for testing.

## ➤➤ *Sampling Precautions*

- Sample containers shall be new. They shall not be washed or rinsed. If they contain evidence of solder flux, or if they are not clean and dry, they shall be discarded. Top and container shall fit together tightly.
- Care shall be taken to prevent the samples from becoming contaminated. (See Table 3.3c.) The sample container shall not be submerged in solvent, nor shall it be wiped with a solvent saturated cloth. Any residual material on the outside of the container shall be wiped with a clean, dry cloth immediately after the container is sealed and removed from the sampling device.
- The sample shall not be transferred to another container.
- The filled sample container shall be tightly and positively sealed immediately after the sample is taken.

## ➤➤ *Safety Precautions*

Safety precautions are mandatory at all times when handling asphalt materials. These safety precautions include, but are not limited to:

- Gloves shall be worn and sleeves shall be rolled down and fastened over the gloves at the wrist while sampling and while sealing containers.
- Face shields should be worn while sampling.
- There shall be no smoking while sampling asphalts.
- Avoid prolonged breathing of fumes, vapors and mists.
- During sealing and wiping, the container shall be placed on a firm level surface to prevent splashing, dropping or spilling the material.

## ➤➤ *Protection and Preservation of Samples*

- Immediately after filling, sealing, and cleaning, the sample containers shall be properly marked for identification with a permanent marker on the container itself, not on the lid.
- Samples of emulsions shall be packaged, labeled, and protected from freezing during shipment.
- All samples should be packaged and shipped to the laboratory the same day they are taken. The containers should be tightly sealed and packed in protective material to reduce the probability of damage during shipment.
- Each sample should be identified with this information:
  - Shipper's name and bill of lading or loading slip number
  - Date sampled
  - Sampler's name
  - Product grade
  - Project identification
  - Other important information as necessary.

# TESTING

Proper interpretation of laboratory test results can greatly aid in determining the traits of an asphalt emulsion. As advances have been made in asphalt emulsion technology, corresponding advances in emulsion testing have evolved. Some of these tests are designed to measure performance qualities. Others deal with composition, consistency, and stability of the material. Laboratory tests are normally performed for these purposes:

- To provide data for specification requirements
- To control the quality and uniformity of the product during manufacturing and use
- To predict and control the handling, storage, and field performance properties of the material

A review of emulsion specifications used across the United States reveals a wide variety of requirements. Many are directly related to the emulsions produced by specific manufacturers. Because it is impractical to discuss the multitude of requirements and test methods, this chapter deals primarily with the methods in ASTM D 244 and AASHTO T 59. However, a few non-ASTM tests that are often used, especially with emulsions that have been modified with polymers, have also been included. ASTM is considering the adoption of some of these tests.

There are a number of new tests, mostly for asphalt cements, that are in the developmental stage. For instance, SHRP came up with new test procedures, testing apparatus, and specifications that are part of the Superpave binder specification. Many of these tests are currently available and could probably be applied to asphalt emulsion residues. The tests are designed to better measure the various properties of asphalt cements, emulsions, emulsion residues, and modified systems. They will be included in this manual as they become incorporated in asphalt emulsion specifications.

This chapter will first consider the tests that apply to asphalt emulsions. It then describes the tests run on the asphalt emulsion residue after the water has been removed by distillation or evaporation.

## Asphalt Emulsion Tests

Proper sample handling is important to achieve valid test results. Asphalt emulsions are made hot, some are stored hot, and some are transported and applied hot. Hot samples collected in the field are often delivered to the laboratory at ambient temperatures. Asphalt emulsion samples with viscosity requirements at 50°C (122°F) should be heated to 50 ± 3°C (122 ± 5°F) in a 70°C (160°F) water bath or oven. Samples should be stirred, not shaken, to insure homogeneity.

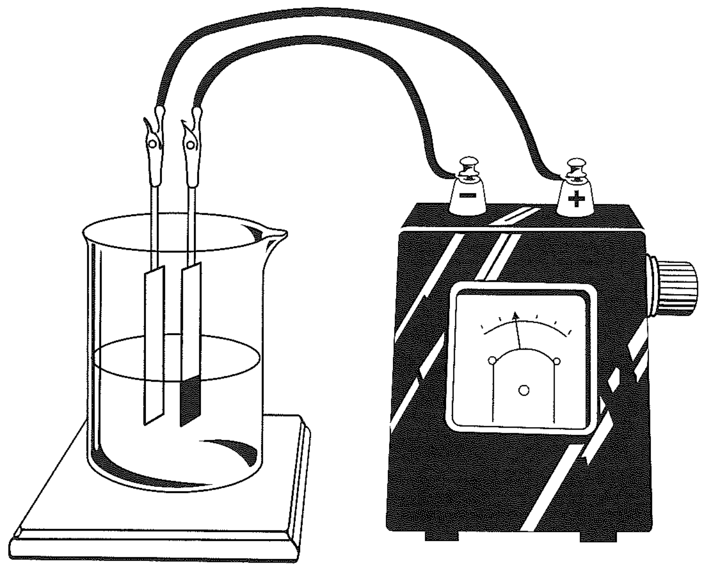


Figure 4.1 Particle Charge Test

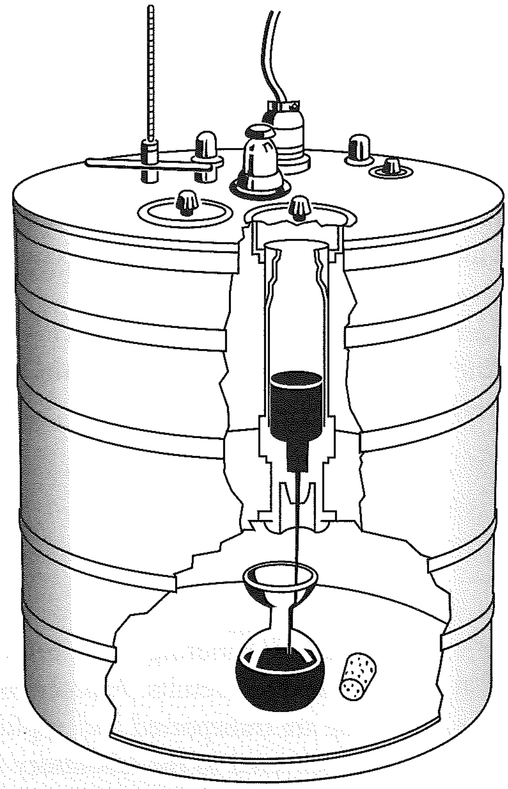

Figure 4.2 Saybolt Furol Viscosity Test

## ➤➤ *Particle Charge Test*

The particle charge test is used to identify cationic emulsions. It is performed by immersing a positive electrode (anode) and a negative electrode (cathode) into an emulsion sample and connecting them to a controlled direct-current electrical source (Figure 4.1). At the end of the test period, the electrodes are observed to determine if the cathode has an appreciable layer of asphalt deposited on it. If so, the emulsion is cationic.

## ➤➤ *Emulsion Viscosity*

Viscosity is defined as a fluid's resistance to flow. For asphalt emulsions, the Saybolt Furol viscosity test (Figure 4.2) is used as a measure of viscosity. Results are reported in Saybolt Furol seconds. Depending on the type of emulsion, one of two testing temperatures are used, 25°C and 50°C (77°F and 122°F).

## ➤➤ *Demulsibility*

The demulsibility test indicates the relative rate at which the colloidal asphalt globules in the rapid-setting asphalt emulsion will break when spread in thin films on soil or aggregate. Calcium chloride causes the minute asphalt globules present in the anionic asphalt emulsion to coalesce. A solution of calcium chloride and water is thoroughly mixed with the RS emulsion and the mixture is poured over a sieve to determine how much the asphalt globules coalesce. Specifications prescribe the concentration of the solution and the minimum amount of asphalt to be retained on the sieve (typically 60 percent). Rapid setting emulsions are expected to break almost immediately upon contact with aggregate, such as when chip sealing.

A similar test is run on cationic rapid-setting emulsions. However, rather than calcium chloride solution, a solution of dioctyl sodium sulfosuccinate is used.

## ➤➤ *Identification Test for Cationic Rapid Setting Emulsion*

This is a recent ASTM D244 test that has taken the place of the classification test. Like the classification test, it involves the coating of silica sand. In this new test, the sand is first washed with hydrochloric acid and isopropyl alcohol, but unlike the classification test, no portland cement is used. The emulsion is mixed with the sand for two minutes. At the end of the mixing period, an excess of uncoated area compared to the coated area is considered positive identification of a cationic rapid setting emulsion.

## ➤➤ *Identification of Cationic Slow-Set Emulsions*

This is also a relatively new ASTM D244 test that is used if the result of the particle charge test is inconclusive. A weighed amount of washed and dried silica sand is mixed with a weighed amount of CSS asphalt emulsion and mixed until the aggregate is completely coated. The amount of emulsion in the mix should be 5% by total weight of sand. The mix is cured for 24 hours and then placed in a beaker of boiling distilled water. After 10 minutes, the sample is placed on a level surface and the coating is observed. If the coating is in excess of 50% of the total mix, it is considered a positive test for a cationic slow setting emulsion.

## ➤➤ *Settlement and Storage Stability Tests*

These tests indicate the emulsion's stability in storage. They detect the tendency of asphalt globules to settle over a period of time. A prescribed volume of emulsion is allowed to stand in a graduated cylinder for a specified time (five days for the settlement test and 24 hours for the storage stability test). Samples are then taken from the top and bottom of the cylinder. Each sample is placed in a beaker and weighed and heated to evaporate the water. The residue is then weighed. The weights obtained are used to find the difference, if any, between the asphalt residue content in the upper and lower portions of the cylinder. This provides a measure of settlement. Many agencies will accept the 24-hour test, while others require the five-day test.

## ➤➤ *Cement Mixing*

The cement mixing test does the same for slow setting asphalt emulsions as the demulsibility test does for rapid setting grades. In the field, the SS grades are often mixed with fine materials and dusty aggregates. In the cement mixing test, a sample of asphalt emulsion is mixed with finely ground portland cement and the mixture is washed over a 1.40 mm (No. 14) sieve. Specifications limit the amount of material that can be retained on the sieve. The result of this test indicates the ability of a slow-setting emulsified asphalt to mix with a high surface area material without breaking.

## ➤➤ *Sieve Test*

The sieve test is another measurement of quality and stability of the emulsion. The retention of an excessive amount of asphalt particles on a sieve indicates that problems may occur in the handling and application of the material. In the sieve test, a representative sample of asphalt emulsion is poured through an 850 µm (No. 20) sieve. For anionic emulsions, the sieve and retained asphalt are rinsed with a mild sodium oleate solution and then with distilled water. For cationic emulsions, distilled water only is used for rinsing. After rinsing, the sieve and asphalt are dried in an oven and the amount of retained asphalt determined by weighing.

## ➤➤ *Coating Ability and Water Resistance*

This test has three purposes. It determines the ability of an asphalt emulsion to: (1) coat the aggregate thoroughly, (2) withstand mixing action while remaining as a film on the aggregates and (3) resist the washing action of water after the completion of mixing. The test is primarily used to identify medium-setting asphalt emulsions suitable for mixing with coarse-graded calcareous aggregates. This test is not adaptable to rapid-setting or slow-setting asphalt emulsions.

The reference aggregate is coated with calcium carbonate dust and then mixed with the asphalt emulsion. About one-half of the mixture is then placed on absorbent paper for a visual inspection of the surface area of aggregate coated by the asphalt emulsion. The remainder of the mixture is sprayed with water and rinsed until the rinse water runs clear. This material is then placed on absorbent paper and inspected for coating. The test is then repeated and for this second run, the aggregate is coated with water before the emulsion is added, mixed and then visually inspected for good, fair or poor coating ability.

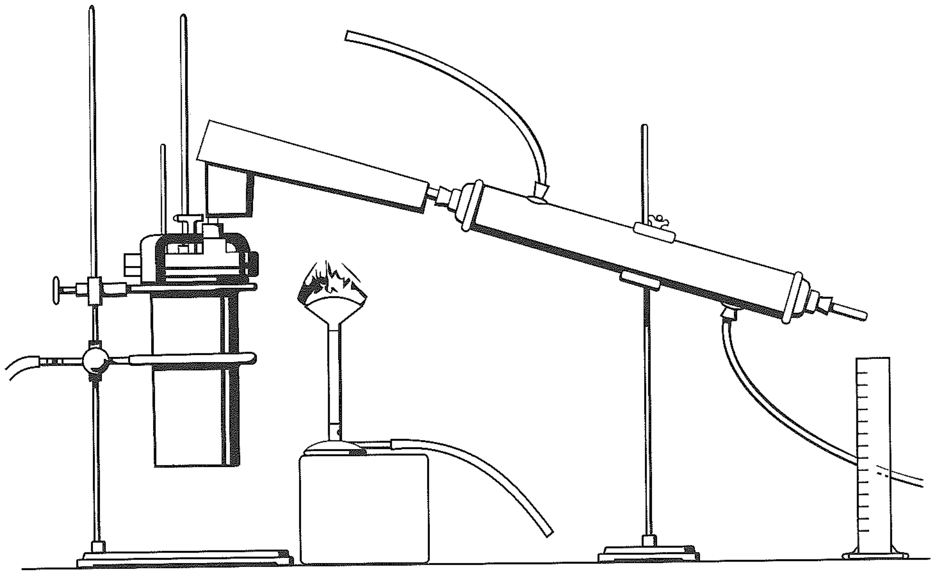

Figure 4.3 Distillation Test for Asphalt Emulsion

## ➤➤ Field Coating Test

Field coating tests are used at the project site to determine:

- The ability of an asphalt emulsion to coat the job aggregate
- The ability of the emulsion to withstand mixing
- The water resistance of the emulsion-coated aggregate

Measured amounts of the job aggregate and job emulsion are hand mixed. The ability of the aggregate to remain coated during a five-minute cycle is observed. The resistance of the coating to wash-off is determined by filling a container of the coated aggregate with water and emptying it five times. The coating of the aggregate is visually rated as good, fair, or poor. A rating of good means that the aggregate is fully coated (except for pinholes and sharp edges). A rating of fair indicates an excess of coated over uncoated aggregate area. A rating of poor indicates an excess of uncoated over coated aggregate area.

## ➤➤ Unit Weight of Asphalt Emulsion

The unit weight (kg/liter or lb/gallon) is computed by finding the weight of an asphalt emulsion in a standard measure of known volume. Results are reported to the nearest 0.01 kg/liter at 25°C (lb/gal at 77°F).

## ➤➤ Residue and Oil Distillate by Distillation

Distillation is used to separate the water from the asphalt. If the material contains oil, it will be separated along with the water. The relative proportions of asphalt cement, water, and oil in the emulsion can be measured after the distillation has finished. Additional tests may be run on the asphalt cement residue to determine the physical properties of the end-use asphalt.

The distillation test procedure for asphalt emulsion uses an aluminum alloy still and ring burners (Figure 4.3). Normally, the distillation is run at a temperature of 260°C (500°F) for fifteen minutes. Since the emulsion seldom approaches this temperature in the field, it should be noted that some residue properties could be altered, such as elastic properties given by polymer modification. Some agencies have changed the temperature and time at which the distillation test is run for these special products.

## ➤➤ Residue by Evaporation

The oven evaporation test is carried out in an oven at a temperature of 163°C (325°F) for three hours. This test may be used in lieu of the distillation test, but the procedure usually yields lower penetration and ductility results than the distillation test. The evaporation test may not be used if a float test is to be run on the residue.

## Examination of Residue

The same desirable characteristics in the base asphalt cement should show up in the residual asphalt after emulsification and coalescence. In some cases, the properties are actually improved. The most common tests run on the residue include specific gravity, solubility in trichloroethylene, penetration, ductility and the float test. These tests are described in detail in ASTM D70, D2042, D5, D113 and D139 (AASTHO T228, T44, T49, T51 and T50) respectively.

Specific gravity of the residue is usually not specified by user agencies. However, the information is often useful for making volume corrections at various temperatures.

The solubility test is a measure of the bituminous portion of the asphalt residue. The portion that is soluble in trichloroethylene represents the actual asphalt binder and the insoluble portion represents inorganic contaminants. Solubility is determined by dissolving the asphalt cement in the solvent and separating the soluble and insoluble portions by filtering.

The penetration test is a measure of the hardness of the asphalt residue at the specified test temperature. This test measures the depth of penetration of a standard needle under a load of 100g for five (5) seconds at a temperature of 25°C (77°F). However, other temperatures and loads are sometimes used when additional information is desired.

The ductility of asphalt is its ability to be extended or pulled into a narrow thread. This test is run by molding a briquette of asphalt cement under standard conditions and dimensions. The asphalt briquette is then brought to a specified test temperature in a water bath. It is pulled at a specified rate of speed until the thread connecting the two ends breaks. The elongation at which the thread of material breaks is designated as ductility.

The float test is performed on the residue from distillation of high float asphalt emulsions. The test is a measure of the resistance to flow at an elevated temperature. In the test, a test plug is formed by cooling the asphalt residue in a brass collar (Figure 4.4). The collar is then screwed into the bottom of an aluminum float and placed into a testing bath of water heated to 60°C (140°F). The time required for the hot water to break through the plug is measured in seconds.

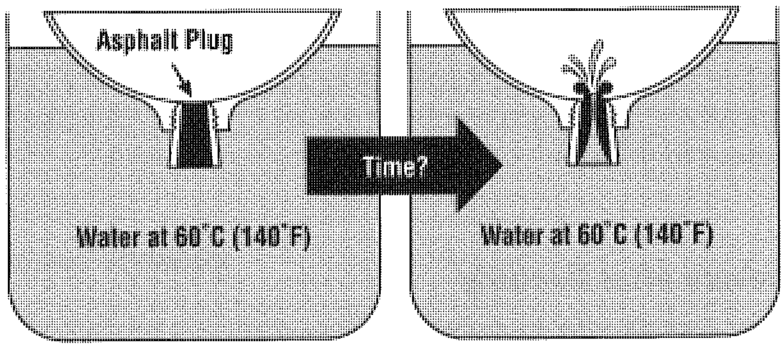


Figure 4.4 Float Test

## Additional Emulsion and Residue Tests

In recent years, other tests that are not included in the ASTM or AASHTO standards have been developed to measure unique properties of asphalt emulsions and their residues. Many of these methods were designed to test materials that have been modified by polymers or other modifiers. Some of these tests are discussed below and ASTM and/or AASHTO are considering a few for adoption. The first three tests given are run on the emulsion and the others are run on the emulsion residue.

### ➤➤ Breaking Index

The breaking index test is designed to measure the quickness of break of very rapid setting asphalt emulsions used for chip seal. Specified silica sand is added with stirring to 100 grams of the emulsion under controlled conditions of rate and temperature. The weight of the sand in grams needed to cause the system to break (turn black and sticky) is considered the breaking index.

### ➤➤ Vialit Test

The Vialit procedure has been found quite useful in the design of surface treatments (chip seals) using an RS or CRS asphalt emulsion. The asphalt emulsion is poured at its design application rate onto a metal plate and allowed to flow to a uniform film thickness. Aggregate is applied to the binder-covered plate and embedded by rolling. After it is cured, treated with water and dried again, the plate is turned upside down. A 500 gram steel ball is dropped from a specified height three times on the reverse side of the plate and the weight loss of the aggregate is measured. There are various ways of reporting the results. This test is particularly helpful using the actual job aggregate under the field humidity and temperature conditions.

## ➤➤ Zeta Potential

The zeta potential is a measurement of the intensity of the positive or negative charge of asphalt emulsion and/or aggregate particles. A Zeta Meter measures the speed of movement (electrophoretic mobility) of individual asphalt emulsion droplets or aggregate particles when placed in an aqueous medium. The intensity of charge each droplet or particle inherently possesses, either positive or negative, can be expressed in millivolts (1/1000 volt) as the Zeta Potential.

## ➤➤ Elastic Recovery after Ductility

The elastic recovery after ductility measures the ability of the test specimen to recover to its original length after being elongated in a ductilometer (see ductility test earlier). The sample is pulled to a specified length at a specified temperature. The thread is then cut in the middle. After a specified time, the thread is measured again to see how closely it returns to its original position. The percentage of recovery is reported.

## ➤➤ Force Ductility

The force ductility is also run in a ductilometer (see ductility test earlier). Unlike the regular ductility test, the actual force that is necessary to cause this elongation is measured. A special force ductility adapter is necessary for this method and a strip chart recorder or computer data acquisition set-up is also required. The measured results may be reported in several ways. One of the most common is the ratio obtained from the first and second peaks yielded by the graph.

## ➤➤ Ring and Ball Softening Point

The ring and ball softening point test (ASTM D36/AASHTO T53) was developed not by the road paving industry but rather by the roofing and waterproofing industry. It is another method of measuring a rheological property of an asphalt or residue at elevated temperatures and is used for specification purposes by some agencies. Two disks of the sample in brass rings are heated at a controlled rate in a liquid bath. Each disc supports a steel ball. The softening point is the temperature at which the discs of asphalt soften enough to allow the balls to drop.

## ➤➤ Tensile Strength (Stress)

Similar to the force ductility test, the tensile strength is a measure of the force required to stretch the sample. Rather than the horizontal ductilometer, however, this test uses an upright tensile pull machine. A strip chart recorder or computer plots the stress (force) against the strain (elongation). The result is usually reported as the stress in $kg/cm^2$ at a specified elongation (strain).

## ➤➤ *Torsional Recovery*

Torsional recovery is also used to measure the elastic properties of a modified asphalt residue. This test measures the recovery of a sample, and is conducted in a three-ounce tin or penetration cup. A shaft and arm assembly is immersed in the molten sample and upon cooling is twisted to a 180-degree arc from the starting point. After a specified time the recovery mark is read and data reported as a percent recovery. There are a number of variations of this test.

## ➤➤ *Toughness and Tenacity*

The toughness and tenacity test uses a tensile pull machine similar to that used in the tensile strength test. The force necessary to pull the sample is measured. However, the method of reporting the results differs for this test. The area under the stress/strain curve generated by this test is measured in two different ways and is reported as toughness and tenacity. Great care must be taken with the interpretation of the data generated by this test. Major variations in test results between two or more laboratories are common because of the difficulty of reading the area under the curve.

# SELECTING THE RIGHT TYPE AND GRADE

Successful performance of asphalt emulsions requires selecting the proper type and grade for the intended use. Guidelines presented in this chapter should help select the specific grade and type of emulsion to be used.

The first consideration in picking the right type and grade of emulsion is how the emulsion will be used. Is it for a seal coat, a plant mix (central or mixed-in-place), a recycled mix or a prime coat application? Is it for some type of surface application, such as a chip seal, fog seal, slurry seal or micro-surfacing? Is it for a maintenance mix? Once this decision is made, other project variables must then be considered. Some other factors that affect the selection are:

- Climatic conditions anticipated during construction. The choice of emulsion grade, the design of mix or treatment and the selection of construction equipment should be dictated by the conditions at the time of construction.
- Aggregate type, gradation and availability.
- Construction equipment availability.
- Geographical location. The hauling distance and, in some cases, water availability are important considerations.
- Traffic control. Can traffic be detoured or only controlled through the work area?
- Environmental considerations.

While general guidelines can be given for selecting emulsions, laboratory testing is strongly recommended. There is no good substitute for a laboratory evaluation of the emulsion and the aggregate to be used. Different types and quantities of emulsion should be tried with the aggregate to find the best combination for the intended use. An experienced technician can determine the type and amount of emulsion to be used.

## General Emulsion Uses

Each grade of asphalt emulsion is designed for specific uses. They are described in general terms here. Table 5.1 shows the general uses of standard asphalt emulsion types and grades.

### ➤➤ Rapid-Setting Emulsions

The rapid-setting grades are designed to react quickly with aggregate and revert from the emulsion to the asphalt. They are used primarily for spray applications, such as aggregate (chip) seals, sand seals, and surface treatments. The RS-2, HFRS-2 and CRS-2 grades have high viscosity to prevent runoff. Polymer modified versions of these emulsions are routinely used where rapid adhesion is necessary, such as in high traffic areas, when there is minimal traffic control, or where there is heavy truck traffic.

## Table 5.1 General Uses of Asphalt Emulsion

| Type of Construction | ASTM D977 AASHTO M208 | | | | | | | | | ASTM D2397 AASHTO M 140 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RS-1 | RS-2 | HFRS-2 | MS-1, HFMS-1 | MS-2, HFMS-2 | MS-2h, HFMS-2h | HFMS-2s | SS-1 | SS-1h | CRS-1 | CRS-2 | CMS-2 | CMS-2h | CSS-1 | CSS-1h |
| **Asphalt-Aggregate Mixtures:** | | | | | | | | | | | | | | | |
| Plant Mix (Hot or Warm) | | | | | | X[A] | | | | | | | | | |
| Plant Mix (Cold) | | | | | | | | | | | | | | | |
| Open-Graded Aggregate | | | | | X | X | | | | | | X | X | | |
| Dense-Graded Aggregate | | | | | | | X | X | X | | | | | X | X |
| Sand | | | | | | | X | X | X | | | | | X | X |
| Mixed-in-Place | | | | | | | | | | | | | | | |
| Open-Graded Aggregate | | | | | X | X | | | | | | X | X | | |
| Well-Graded Aggregate | | | | | | | X | X | X | | | | | X | X |
| Sand | | | | | | | X | X | X | | | | | X | X |
| Sandy Soil | | | | | | | X | X | X | | | | | X | X |
| **Asphalt-Aggregate Applications:** | | | | | | | | | | | | | | | |
| Single and Multiple Surface Treatments | X | X | X | | | | | | | X | X | | | | |
| Sand Seal | X | X | X | X | | | | | | X | X | | | | |
| Slurry Seal | | | | | | | X | X | X | | | | | X | X |
| Micro-surfacing | | | | | | | | | | | | | | | X[E] |
| Sandwich Seal | | X | X | | | | | | | | X | | | | |
| Cape Seal | | X | | | | | | | | | X | | | | |
| **Asphalt Applications:** | | | | | | | | | | | | | | | |
| Fog Seal | | | | X[B] | | | | X[C] | X[C] | | | | | X[C] | X[C] |
| Prime Coat | | | | | X[D] | | | X[D] | X[D] | | | | | X[D] | X[D] |
| Tack Coat | | | | X[B] | | | | X[C] | X[C] | | | | | X[C] | X[C] |
| Dust Palliative | | | | | | | | X[C] | X[C] | | | | | X[C] | X[C] |
| Mulch Treatment | | | | | | | | X[C] | X[C] | | | | | X[C] | X[C] |
| Crack Filler | | | | | | | | X | X | | | | | X | X |
| **Maintenance Mix:** | | | | | | | | | | | | | | | |
| Immediate Use | | | | | | | X | | | | | X | X | | |
| Stockpile | | | | | | | X | | | | | | | | |

[A] Grades other than HFMS-2h may be used where experience has shown that they give satisfactory performance.
[B] Diluted with water by the manufacturer.
[C] Diluted with water.
[D] Mixed-in prime only.
[E] Polymer must be added during or prior to emulsification.

## ➤➤ *Medium-Setting Emulsions*

Medium-setting grades are designed for mixing with graded aggregate. Because these grades are formulated not to break immediately upon contact with aggregate, they can coat a wide variety of graded aggregates. Mixes using medium setting emulsions can remain workable from a few minutes to several months depending upon the formulation. Mixes are produced in pugmills and travel plants or can be road mixed. In recent years, they have been used in cold recycling applications.

Examples of medium-setting emulsions are MS-2, CMS-2 and HFMS-2. Nomenclature for medium-setting emulsions varies from state to state. Consultation with your local emulsion manufacturer is suggested for recommendations.

High float is a special class of anionic MS emulsion. The major difference between these emulsions and the conventional medium-setting is the existence of a gel structure in the asphalt residue that is measured by the float test. The float characteristic increases film thickness. While regular asphalt may have a tendency to flow or migrate, the high float residues are designed to stay in place up to 70°C (160°F). Therefore, high float residues are less susceptible to changes in temperature and very resistant to flow at high temperatures during the summer.

Polymer modified versions of medium-setting emulsions may be used where additional stability or improved durability is needed or where improved water resistance is important.

## ➤➤ *Slow-Setting Emulsions*

The slow-setting grades are designed for mixing stability. They are used with high fines content, dense-graded aggregates. The slow-setting grades have long workability times to ensure good mixing with dense-graded aggregates. These mixes are not designed for stockpile storage. All slow-setting grades have low viscosity that can be further reduced by adding water. When diluted, these grades can also be used for tack coats and fog seals and as dust palliatives. The slow-setting grade of emulsion depends mostly upon evaporation of the water for coalescence of the asphalt particles. The slow-setting emulsions in mixing applications are generally used for dense-graded aggregate-emulsion bases, soil-asphalt stabilization, asphalt surface courses and for some recycling and slurry sealing.

Polymer modified slow-setting emulsions may be used where additional mixture stability is needed or a better bond is necessary, the latter in the case of a tack coat or fog seal.

## ➤➤ *Quick-Setting and Micro-Surfacing Emulsions*

Quick-setting and micro-surfacing emulsions are not currently specified by ASTM or AASHTO. They are, however, widely used across the country.

The quick-setting grades are designed specifically for slurry seal applications when a quick curing time is necessary. This allows a quicker opening to traffic than the slow-setting slurry seal emulsions. Quick-setting slurry seals are designed to be placed at the thickness of the largest aggregate in the gradation. Micro-surfacing emulsions are polymer modified and allow mixes to be placed at greater thickness than slurry seals. The newly micro-surfaced pavement can normally be opened to traffic in less than an hour after placement. Laboratory evaluation is more important for quick-setting and micro-surfacing emulsions to determine compatibility with job aggregates. The emulsion supplier should be contacted for recommended acceptable aggregate sources.

## Guidelines for Successful Performance

The success with any type and grade of asphalt emulsion system is best ensured by strictly adhering to these steps:

1. Conduct complete laboratory testing using the actual aggregate and emulsion that are to be used on the project.
2. Select grades in conformance with Table 5.1 and the previous information.
3. Adhere to the specifications and guides for usage.
4. Carefully handle the emulsion to prevent contamination, settlement of the asphalt droplets or premature coalescence.
5. Contact the emulsion manufacturer's representative when special or unusual problems occur.

# SURFACE TREATMENTS

Asphalt surface treatment is a broad term embracing several types of asphalt and asphalt-aggregate applications, usually less than 25 millimeters (1 in.) thick and applied to any kind of road surface. The road surface may be a primed granular base, or an existing asphalt or portland cement concrete (pcc) pavement. Surface treatments applied to an existing pavement surface are often called seal coats.

A single surface treatment, commonly called a chip seal, involves spraying asphalt emulsion and immediately spreading and rolling a thin aggregate cover. For multiple surface treatments, the process is repeated a second or even a third time with the aggregate size becoming smaller with each application.

A sandwich seal is a relatively new technique in which a large aggregate is placed first, asphalt emulsion (normally polymer modified) is sprayed onto the aggregate, and immediately followed by an application of smaller aggregate on top that locks in the seal. A Cape seal is a single surface treatment followed by a slurry seal or micro-surfacing to fill in the voids between large aggregates.

A slurry seal is a mixture of dense graded aggregate, emulsified asphalt, fillers, additives and water. The slurry seal is applied as a thin surface treatment using a specially designed slurry seal machine. Micro-surfacing is much like slurry seal, but through the addition of polymers and the use of specialized design techniques, micro-surfacing provides greater durability and can be placed thicker.

When properly constructed, asphalt surface treatments are economical, easy to place and long lasting. They all seal and add life to road surfaces but each type has one or more special purposes. A surface treatment is not a pavement in itself. It is primarily a cost-effective maintenance technique for prolonging the service life of a pavement. It resists traffic abrasion and provides waterproofing for the underlying structure. A surface treatment adds very little structural strength and, therefore, normally is not considered when determining the load carrying capability of a pavement.

While a surface treatment can provide an excellent skid resistant surface when used correctly, it is not a cure-all for all pavement problems. A clear understanding of the advantages and limitations of asphalt emulsion surface treatments is essential for best results. Traffic count, existing pavement condition, existing pavement structure, climatic conditions and available materials should all be taken into consideration when selecting and designing a surface treatment.

## Uses of Surface Treatments

Surface treatments are primarily used to:

- Provide an economical, all-weather surface for light to medium traffic. When polymer modified emulsions and high quality aggregates are used, surface treatments can be used for higher volume traffic applications.
- Provide a waterproof barrier that prevents the intrusion of moisture into underlying materials.
- Provide a skid-resistant surface. Pavements that have become slippery because of bleeding or wear and polishing of surface aggregates may be treated with sharp, hard aggregate to restore skid resistance. Sandwich seals are ideal for this purpose.
- Give new life to a dry, weathered surface. A weathered, raveled pavement can be restored to useful service by application of a single or multiple surface treatment.
- Provide temporary cover for a new base course. The surface treatment is appropriate cover for a new base course to be used through a winter or for planned stage construction. The surface treatment, especially a double seal coat, makes an excellent temporary surface until the final asphalt courses are placed.
- Salvage old pavements that have deteriorated because of aging and shrinkage or stress cracking. Although having little or no structural strength, a surface treatment can preserve the existing structural value by waterproofing and serve as an adequate stop-gap measure until a more permanent upgrading can be completed.
- Delineate shoulders from traffic lanes.

The need for a strong base or sound pavement under asphalt surface treatments cannot be overemphasized. The surface treatment is not designed to correct a pavement that is structurally deficient. Common base defects may include unstable materials, inadequate compaction, poor aggregates, lack of drainage and insufficient strength for the traffic.

## Surface Treatment Materials

To produce high quality, durable, surface treatments, both the asphalt emulsion and the aggregate must meet established quality standards. Although other types of asphalt materials may be used for surface treatments, this manual only addresses the use of asphalt emulsions.

### ➤➤ Asphalt Emulsion

Emulsions offer several advantages over other types of asphalt materials:

- They can be used with damp aggregate, which are actually preferred.
- They do not need highly elevated temperatures for proper application.
- They eliminate the fire hazard associated with cutback asphalts.
- They avoid the air quality problems associated with cutback asphalts.
- They provide quicker chip retention than cutback asphalts.
- They can be custom formulated for the existing conditions and available aggregates in most situations.

One of the keys to good performance lies in the selection of the correct type, grade, and application rate of emulsion. When the proper grade is selected, the asphalt emulsion for surface treatment will:

- Be fluid enough during application to spray properly and cover the surface uniformly
- Retain the proper consistency after application to wet the surface being treated and the applied aggregate
- Cure and develop adhesion to the aggregate and the surface quickly
- Hold the aggregate tightly to the road surface after rolling and curing, preventing loss of aggregate
- Not bleed or strip with changing weather conditions when applied at the proper rate

Table 6.1 shows the types of emulsified asphalt recommended for surface treatments and seals. Rapid setting asphalt emulsions are normally used for surface treatments, to react quickly with the aggregate and cure rapidly. High volume traffic roads may require a polymer modified rapid-setting emulsion.

Table 6.2 gives typical application temperature ranges for the various types and grades, including those not used for surface treatments but still which can require spray application. The use of these materials with relatively low temperatures is a significant energy-saving feature.

## ➤➤ Aggregate

Any aggregate used on the surface is subjected to the abrasive action of traffic. If it is not hard enough to resist rapid wear, the pavement may become a skid hazard when wet. Most hard aggregates can be used successfully for surface treatments. Aggregates can be tested for abrasion resistance using the Los Angeles Abrasion Test, ASTM C 131 (AASHTO T 96). For surface treatment use, the abrasion wear should be not more than 45 percent. Crushed particles with rough surface texture and relatively low absorption will produce the best results. The aggregate selected must also meet the job requirements for size, shape, and cleanliness.

***Size.*** The aggregate should be as close to one size as is economically practical, preferably in the range of 6 to 16 mm (1/4 to 5/8 in.) for single surface treatments. Larger sizes may be used in multiple treatments. If it is much larger than 16 mm (5/8 in.), it can cause objectionable tire noise. If much finer than 6 mm (1/4 in.), it is difficult to spread evenly. Also, finer aggregate lowers the allowable range for asphalt application rate.

Generally, the largest particle should be no more than twice the diameter of the smallest one. An allowance should be made for a slight amount of oversized and undersized particles. For single treatments, the top size is limited by the amount of emulsified asphalt that can be applied in one pass of the distributor without flowing off the surface.

***Shape.*** The ideal shape for surface treatment aggregate is cubical. Flat or elongated particles are undesirable as they tend to become aligned on their flat sides and may be completely covered with asphalt when enough is used to hold the cubical particles in place (Figure 6.1). If all particles

## Table 6.1 Asphalt Emulsion Surface Treatments and Seal Coats

| Construction Type | Description and Uses | Typical Asphalt Emulsions | Construction Hints |
|---|---|---|---|
| Single Surface Treatment (Chip Seal) | Single most important low cost maintenance method. Produces an all-weather surface, renews weathered pavements, improves skid resistance, lane demarcation, and seals pavement. | CRS-2, RS-2 | Spray-applied. Many types of textures available. Keys to success: Coordinate construction, use hard, clean aggregate and proper calibrate spray equipment. |
| Double Surface Treatment | Two applications of binder and aggregate. The second chip application uses a smaller sized stone than the first. Durable, provides some leveling, available in a number of textures. | CRS-2, RS-2, HFRS-2 | See Chip Seal. |
| Triple Surface Treatment | Three applications of binder and 3 sizes of chips are applied. Provides up to a 20 mm (3/4") thick, flexible pavement. Level as well as providing a seal, tough wearing surface. | CRS-2, RS-2, HFRS-2 | Spray-applied in three lifts. |
| Cape Seal | Combines a single chip seal with a slurry seal. Provides the rough, knobby surface of a chip seal to reduce hydroplaning yet has a tough sand matrix for durability. Test track data indicate better studded tire damage resistance than a chip seal. Friction values can be higher than conventional hot mix asphalt. | CQS-1h, CSS-1h, QS-1h, SS-1h, RS-2, CRS-2 | Apply a single aggregate chip seal. After curing, broom loose material and apply the slurry seal. Have the strike-off ride on the rock surface to form the matrix. Avoid excess slurry that can cover the desired knobby stone texture of the chips. |
| Sandwich Seal | Improves skid resistance, seals pavement. | RS-2, CRS-2, HFRS-2 (usually polymer modified) | Spread large aggregate, spray apply emulsion, and then cover with smaller aggregate to lock in larger aggregate. Clean aggregate required. |
| Sand Seal | Restores uniform cover. In city street work, improves street sweeping, traffic line visibility. Enriches dry, weathered pavement; reducing raveling. | CRS-1, CRS-2<br>RS-1, RS-2<br>MS-1, HFMS-1<br>HFRS-2 | Spray-applied with sand cover. Roll with pneumatic roller. Avoid excess binder. |
| Slurry Seal | Used in airport and city street maintenance where loose aggregate cannot be tolerated. Seals, fills minor depressions, provides an easy-to-sweep surface. The liquid slurry is machine-applied with a sled-type box containing a rubber-edged strike-off blade. | CQS-1h, CSS-1h, QS-1h, SS-1h | Pretest the aggregate and emulsion mix to achieve desired workability, setting rate, and durability. Calibrate equipment prior to starting the project. |
| Micro-surfacing | High performance resurfacing used in highway, city street and airport maintenance where a durable, friction resistant resurfacing is required. Rapid roadway surface correction. Special rut filling application boxes and stringent design criteria permit filling wheel ruts up to 1.5 inches in depth in one pass. | CSS-1h (polymer modified) | A mix design should be required. Calibrate equipment prior to starting the project. Experienced personnel required for proper application. |
| Seal Coat | Applied to existing asphalt surfaces. Improves aesthetics, provides some crack sealing, and enriches weathered surfaces. | SS-1, SS-1h, CSS-1, CSS-1h | Spray or squeegee applied, with angular sand added. Allow complete cure before trafficking. |
| Fog Seal | A light spray application of binder applied to the surface of a chip seal, an open-graded mix, or a weathered hot mix surface. Provides some crack sealing, reduces raveling and enriches weathered surfaces. | SS-1, SS-1h, CSS-1, CSS-1h | Spray-applied with or without sand cover. Dilute the emulsion with water to help achieve coverage without adding excess binder. |

**Note1: The quick-set grades of emulsion (QS-1h, CQS-1h) have been developed for slurry seals. While not yet standardized, their use is rapidly increasing, as the unique quick-setting property solves one of the concerns associated with the use of slurry seals.**
**Note 2 : The micro-surfacing grades of emulsion have been developed for high traffic and rut fill applications. While not yet standardized, their use is widespread.**

**Table 6.2 Suggested Distributor Spraying Temperatures for Various Grades of Asphalt Emulsion**

| Type and Grade of Asphalt Asphalt Emulsion* | Spraying Temperatures (°C) | (°F) | Type and Grade of Asphalt Asphalt Emulsion* | Spraying Temperatures (°C) | (°F) |
|---|---|---|---|---|---|
| RS-1 | 20-60 | 70-140 | HFMS-2s | 20-70 | 70-160 |
| RS-2 | 50-85 | 125-185 | SS-1 | 20-70 | 70-160 |
| HFRS-2 | 50-85 | 125-185 | SS-1h | 20-70 | 70-160 |
| MS-1 | 20-70 | 70-160 | CRS-1 | 50-85 | 125-185 |
| MS-2 | 20-70 | 70-160 | CRS-2 | 50-85 | 125-185 |
| MS-2h | 20-70 | 70-160 | CMS-2 | 20-70 | 70-160 |
| HFMS-1 | 20-70 | 70-160 | CMS-2h | 20-70 | 70-160 |
| HFMS-2 | 20-70 | 70-160 | CSS-1 | 20-70 | 70-160 |
| HFMS-2h | 20-70 | 70-160 | CSS-1h | 20-70 | 70-160 |

*** Temperatures also apply to polymer-modified versions of these emulsions.**

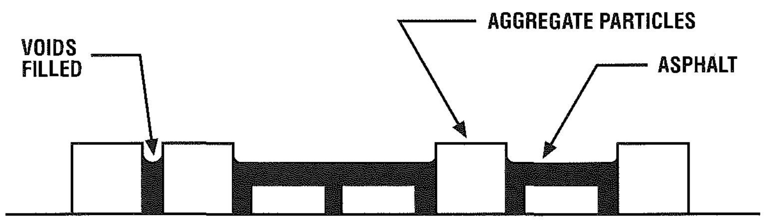


Figure 6.1 Flat Particles Are Covered When Enough Asphalt Is Used to Hold Cubical Particles

are flat, it takes so little asphalt to hold them that control becomes difficult. Rounded aggregate, such as uncrushed river gravel or pea gravel, will tend to roll over with traffic and dislodge, posing a difficult design solution.

***Cleanliness.*** Clean aggregate is very important. If the particles are dusty or coated with clay or silt, the emulsion may not stick. The dust produces a film that prevents the asphalt from adhering to the aggregate surface. Care should be taken not to contaminate the aggregate stockpile.

## Types of Treatments and Seals

### ➤➤ Single Surface Treatment

A single surface treatment, often called a "chip seal," may be used for one of several reasons:

- As an interim measure pending application of an asphalt mixture
- To correct surface raveling and oxidation of old pavements
- To provide a waterproof, skid resistant surface over an existing pavement structure

A single treatment is especially suited for light to medium duty traffic and as a preventive or interim maintenance procedure. For higher traffic roads, a polymer modified emulsion used with high quality aggregate should be considered. Single treatments may also be used following crack sealing. The surface treatment is applied to resist the abrasive forces of the traffic.

***Design of Single Surface Treatments.*** When a decision has been made to use a surface treatment, the next step is to find the proper rates of application for asphalt emulsion and aggregate. The objective is to produce a pavement surface one stone thick with enough asphalt to hold the aggregate in place, but not so much asphalt that it will bleed.

When a one-sized cover aggregate is dropped by a spreader on an asphalt film, the particles will be randomly oriented. After compaction under traffic, the particles will realign with about 20 percent voids between the particles. A desirable design is based upon 60-75 percent of the voids being filled with asphalt emulsion.

There are several theoretical procedures for determining the quantity of cover aggregate. These usually involve determining the average least dimension, the voids and loose unit weight of the cover aggregate. Mathematical calculations, coupled with laboratory testing, are usually employed in determining the required quantities of asphalt and aggregate. Rather than presenting a complex means of making these determinations, Table 6.3 is given as a general guideline. This table gives a range of asphalt and aggregate applications with respect to the specific size of aggregate being used. The suggested quantities of asphalt cover the average range of conditions that include primed granular bases and old pavement surfaces. The quantities and types of materials may be varied according to local conditions and experience. Traffic count and conditions should also be considered in surface treatment design.

For a specific design, consult your local department of transportation or asphalt emulsion manufacturer for assistance.

### ➤➤ Multiple Surface Treatments

A multiple treatment can produce a surface thickness of about 12 to 20 mm (1/2 to 3/4 in). If properly designed and constructed, double surface treatments give about three times the service life of a single surface treatment for about 1 1/2 times the construction cost. Because the cover aggregate for the second layer is smaller, loss of particles from the surface treatment is greatly minimized.

In a double or triple surface treatment, the largest size of stone in the first course determines the surface layer thickness. The subsequent courses serve to fill the voids in the mat of the first

**Table 6.3 Quantities of Asphalt and Aggregate for Single Surface Treatments[1,2,3,4]**

| Nominal Size of Aggregate | Size No. | Quantity of Aggregate kg/m² (lb/yd²) | Quantity of Asphalt l/m² (gal/yd²) | Type and Grade of Asphalt* |
|---|---|---|---|---|
| 19.0 to 9.5 mm (3/4 to 3/8 in.) | 6 | 22-27 (40-50) | 1.8-2.3 (0.40-0.50) | RS-2, CRS-2 |
| 12.5 to 4.75 mm (1/2 in. to No. 4) | 7 | 14-16 (25-30) | 1.4-2.0 (0.30-0.45) | RS-1, RS-2, CRS-1, CRS-2 |
| 9.5 to 2.36 mm (3/8 in. to No. 8) | 8 | 11-14 (20-25) | 0.9-1.6 (0.20-0.35) | RS-1, RS-2, CRS-1, CRS-2 |
| 4.75 to 1.18 mm (No. 4 to No. 16) | 9 | 8-11 (15-20) | 0.7-0.9 (0.15-0.20) | RS-1, MS-1, CRS-1, HFRS-2 |
| Sand | AASHTO M-6 | 5-8 (10-15) | 0.5-0.7 (0.10-0.15) | RS-1, MS-1, CRS-1, HFRS-2 |

*** Including polymer modified versions of these emulsions**

[1] These quantities of asphalt cover the average range of conditions that include primed granular bases and old pavement surfaces. The quantities and types of materials may be varied according to local conditions and experience.

[2] The lower application rates of asphalt shown in the above table should be used for aggregate having gradations on the fine side of the specified limits. The higher application rates should be used for aggregate having gradations on the coarse side of the specified limits.

[3] It is important to adjust the asphalt quantity for the surface condition of the road, increasing it if the road is absorbent, badly cracked, or coarse, and decreasing it if the road is flushed with asphalt. (See table below.)

[4] It is important to adjust the asphalt quantity for traffic count and conditions. An increase in traffic will mean a decrease in asphalt content.

**Correction for Surface Condition**

| Pavement Texture | Correction** L/m² | Correction** (gal/yd²) |
|---|---|---|
| Black, flushed asphalt | -0.04 to -0.27 | (-0.01 to -0.06) |
| Smooth, non-porous | 0.00 | (0.00) |
| Absorbent – slightly porous, oxidized | 0.14 | (0.03) |
| – slightly pocked, porous, oxidized | 0.27 | (0.06) |
| – badly pocked, porous, oxidized | 0.40 | (0.09) |

****This correction must be made from observations at the job site.**

cover aggregate. The extent to which these voids are filled determines the texture and riding quality of the multiple surface treatment.

A good, long-lasting pavement can be produced by increasing the thickness with additional surface treatments, either single or multiple, as traffic conditions demand.

***Design of Multiple Surface Treatments.*** There are several arbitrary design methods for multiple surface treatments. In the method described here, each course is designed as though it is a single surface treatment. For each succeeding course, the nominal top size of cover stone should be approximately one-half the size of the previously placed aggregate. No allowance is made for wastage. After the first course, no correction is made for underlying surface texture.

As a general guideline, asphalt quantities for each course are added together. In a double seal, 40 percent of the total is applied for the first application and 60 percent for the second application. In a triple surface treatment, 30 percent of the total may be applied for the first application, 40 percent for the second and 30 percent for the third. (See Tables 6.4 and 6.5.)

## Table 6.4 Quantities of Asphalt and Aggregate for Double Surface Treatment

| | Nominal Size of Aggregate | Size No. | Quantity of Aggregate kg/m² (lb/yd²) | Quantity of Asphalt l/m² (gal/yd²) |
|---|---|---|---|---|
| 12.5mm (1/2") Thick | | | | |
| 1st Application* | 9.5 to 2.36 mm (3/8 in. to No. 8) | 8 | 14-19 (25-35) | 0.9-1.4 (0.20-0.30) |
| 2nd Application | 4.75 to 1.18 mm (No. 4 to No. 16) | 9 | 5-8 (10-15) | 1.4-1.8 (0.30-0.40) |
| 15.9mm (5/8") Thick | | | | |
| 1st Application* | 12.5 to 4.75 mm (1/2 in. to No. 4) | 7 | 16-22 (30-40) | 1.4-1.8 (0.30-0.40) |
| 2nd Application | 4.75 to 1.18 mm (No. 4 to No. 16) | 9 | 8-11 (15-20) | 1.8-2.3 (0.40-0.50) |
| 19.0mm (3/4") Thick | | | | |
| 1st application* | 19.0 to 9.5 mm (3/4 to 3/8 in.) | 6 | 22-27 (40-45) | 1.6-2.3 (0.35-0.50) |
| 2nd Application | 9.5 to 2.36 mm (3/8 in. to No. 8) | 8 | 11-14 (20-25) | 2.3-2.7 (0.50-0.60) |

***If applied on untreated granular (stone) base, a penetrating prime is used in lieu of emulsion (See Chapter 8).**

## Table 6.5 Quantities of Asphalt and Aggregate for Triple Surface Treatment

| | Nominal Size of Aggregate | Size No. | Quantity of Aggregate kg/m² (lb/yd²) | Quantity of Asphalt l/m² (gal/yd²) |
|---|---|---|---|---|
| 12.5mm (1/2") Thick | | | | |
| 1st Application* | 9.5 to 2.36 mm (3/8 in. to No. 8) | 8 | 14-19 (25-35) | 0.9-1.4 (0.20-0.30) |
| 2nd Application | 4.75 to 1.18 mm (No. 4 to No. 16) | 9 | 5-8 (10-15) | 1.1-1.6 (0.25-0.35) |
| 3rd Application | 4.75mm to 150 µm (No. 4 to No. 100) | 10 | 5-8 (10-15) | 0.9-1.4 (0.20-0.30) |
| 15.9mm (5/8") Thick | | | | |
| 1st Application* | 12.5 to 4.75 mm (1/2 in. to No. 4) | 7 | 16-22 (30-40) | 0.9-1.4 (0.20-0.30) |
| 2nd Application | 9.5 to 2.36 mm (3/8 in. to No. 8) | 8 | 8-11 (15-20) | 1.4-1.8 (0.30-0.40) |
| 3rd Application | 4.75 to 1.18 mm (No. 4 to No. 16) | 9 | 5-8 (10-15) | 0.9-1.4 (0.20-0.30) |
| 19.0mm (3/4") Thick | | | | |
| 1st application* | 19.0 to 9.5 mm (3/4 to 3/8 in.) | 6 | 19-25 (35-45) | 1.1-1.6 (0.25-0.35) |
| 2nd Application | 9.5 to 2.36 mm (3/8 in. to No. 8) | 8 | 11-14 (20-30) | 1.4-1.8 (0.30-0.40) |
| 3rd Application | 4.75 to 1.18 mm (No. 4 to No. 16) | 9 | 5-8 (10-15) | 1.1-1.6 (0.25-0.35) |

***If applied on untreated granular (stone) base, a penetrating prime is used in lieu of emulsion (See Chapter 8).**

In multiple surface treatments, the first course of cover aggregate generally determines the thickness. Subsequent courses partially fill the upper voids in the previously placed courses.

## ➤➤ *Cape Seal*

A Cape seal involves application of a slurry seal or micro-surfacing to a newly-constructed single surface treatment. The slurry or micro-surfacing application helps fill the voids between the chips. Cape seals provide a highly durable surface treatment. The slurry bonds the chips to prevent loss and the chips prevent undue traffic abrasion and erosion of the slurry. Cape seals are often used because of the color of the finished surface treatment.

***Design of Cape Seal.*** For a successful Cape seal, it is important that the single surface treatment have a lower asphalt content than a conventional chip seal. The project should follow standard surface treatment design criteria and slurry seal or micro-surfacing specifications and methods (Table 6.6). The most critical element to avoid in a Cape seal is an excess of slurry that eliminates the desired knobby surface texture. A cure time of four to ten days should be allowed between placement of the surface treatment and subsequent slurry seal application. The surface treatment should be broomed before application of the slurry seal or micro-surfacing to remove loose cover material or other foreign material that would prevent adherence.

**Table 6.6 Quantities of Asphalt and Aggregate for Cape Seal**

| | Nominal Size of Aggregate | Size No. | Quantity of Aggregate kg/m$^2$ (lb/yd$^2$) | Quantity of Asphalt l/m$^2$ (gal/yd$^2$) | Slurry Mixture (Type I) kg/m$^2$ (lbs/yd$^2$) |
|---|---|---|---|---|---|
| 12.5mm (1/2") Thick | 9.5 to 2.36 mm (3/8 in. to No. 8) | 7 | 14-16 (25-30) | 1.4-2.0 (0.30-0.45) | 2.7`-4.5 (6-10) |
| 19.0mm (3/4") Thick | 19.0 to 9.5 mm (3/4 to 3/8 in.) | 6 | 22-27 (40-50) | 1.8-2.3 (0.40-0.50) | 3.5-5.5 (8-12) |

## ➤➤ *Sandwich Seal*

A sandwich seal is constructed by spreading a large aggregate [15-20 mm (5/8-3/4 in)], followed by the spraying of emulsion, and then an application of a smaller aggregate [5-13 mm (1/4-1/2 in]. The emulsion is normally a polymer modified version of RS-2, CRS-2, or HFRS-2, and typically is applied at a rate greater than for a single surface treatment but less than for a double. The smaller aggregate locks down the larger aggregate. The application of the large aggregate helps overcome existing problems of a bleeding surface. The aggregates must be clean and free of dust.

## ➤➤ *Sand Seal*

A sand seal is a spray application of asphalt emulsion followed with a light covering of fine aggregate, such as clean sand or screenings. Although this is a rather simple operation, it can be useful in correcting a number of pavement flaws. Usually, RS-1, CRS-1, MS-1 or HFMS-1 emulsions are applied at a rate of about 0.70 to 1.25 liter/m$^2$ (0.15 to 0.28 gal/yd$^2$). This is followed by about 5.5 to 12 kg/m$^2$ (10 to 22 lb/yd$^2$) of sand or screenings cover. In some locations, sand seals are used when good sources of aggregates for chip seals are not available.

The sand seal is used primarily to:

- Enrich a dry, weathered or oxidized surface. The sand seal will help prevent loss of material from the old surface by traffic abrasion.
- Prevent the intrusion of moisture and air. When an existing pavement surface begins to crack, moisture and air may pass into the underlying pavement structure thereby reducing its load carrying ability. A sand seal can provide a barrier to prevent this intrusion.
- Develop a skid-resistant surface texture. By selecting a sharp, angular fine aggregate, a highly skid-resistant surface can be provided. Examples of angular aggregates are slag sand, or other manufactured sands. The sand may also be used to "soak up" spots of asphalt that have appeared because of an overly rich surface.

## ➤➤ *Slurry Seal*

A slurry seal is a mixture of dense graded aggregate, emulsified asphalt, fillers, additives and water. The mixture is applied as a surface treatment. Slurry seal can be both a preventive and a corrective maintenance technique. The treatment does not increase the structural strength of a pavement section. Any pavement that is structurally weak in localized areas should be repaired before applying the slurry seal. Ruts, humps, low pavement edges, crown deficiencies, or other surface irregularities that diminish riding quality should be corrected before placing the slurry seal.

Slurry seal is a very effective maintenance technique for the surfaces of older pavements. It will fill the surface cracks, stop raveling and loss of matrix, improve skid resistance and generally protect the pavement and reduce water and oxidation deterioration and thus extend overall pavement service life.

Slurry seal has a number of advantages:

- Rapid application and quick return of traffic to the pavement
- No loose cover aggregate
- Excellent surface texture and friction resistance
- Ability to correct minor surface irregularities
- Minimum loss of curb height
- No need for manhole and other structure adjustment
- Excellent low cost treatment for urban streets

Slurry seal is applied in a thickness of 3 to 9 mm (1/8 to 3/8 in.). The machine used for mixing and application is a self-contained, continuous-flow mixing unit (Figure 6.2). It accurately delivers to the mixing chamber predetermined amounts of aggregate, mineral filler, additives, water, and asphalt emulsion.

Figure 6.2 Slurry Seal Equipment

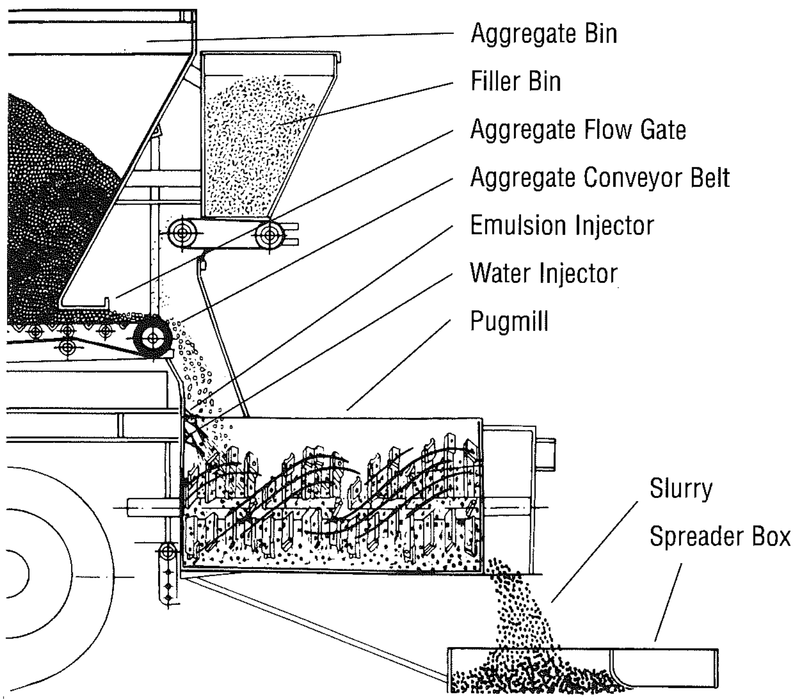


Figure 6.3 Flow Diagram of a Typical Slurry Seal Mixer

**Table 6.7 Slurry Seal Aggregate Gradings***

| **Gradation Type** | I | II | III |
|---|---|---|---|
| **General Usage** | Crack filling & fine seal | General seal, medium textured surfaces | Produces highly textured surfaces |
| **Sieve Size** | **Percent Passing** | **Percent Passing** | **Percent Passing** |
| 9.5 mm (3/8in.) | 100 | 100 | 100 |
| 4.75 mm (No. 4) | 100 | 90-100 | 70-90 |
| 2.36 mm (No. 8) | 90-100 | 65-90 | 45-70 |
| 1.18 mm (No. 16) | 65-90 | 45-70 | 28-50 |
| 600 μm (No. 30) | 40-65 | 30-50 | 19-34 |
| 300 μm (No. 50) | 25-42 | 18-30 | 12-25 |
| 150 μm (No. 100) | 15-30 | 10-21 | 7-18 |
| 75 μm (No. 200) | 10-20 | 5-15 | 5-15 |
| Residual Asphalt Content, % weight of dry aggregate | 10-16 | 7.5-13.5 | 6.5-12 |
| Application Rate, $kg/m^2$ ($lb/yd^2$), based on weight of dry aggregate | 3.6-5.4 (8-12) | 5.4-9.1 (12-20) | 8.2-13.6 (18-30) |

*** Recommended by the International Slurry Surfacing Association.**

The slurry machine has a continuous flow mixing unit with either a single or double shafted pugmill. Mixed slurry seal is discharged from the pugmill into a spreader box. The spreader box is equipped with flexible squeegees and has an adjustable width. Spreader boxes may be equipped with hydraulically power augers to uniformly distribute material across the spreader box width. Augured boxes are especially beneficial when quick-set (QS) emulsion is used or when the pavement contains grades greater than 8%. One type of slurry mixer unit is shown in Figure 6.3.

Slurry seal aggregate must be clean, angular, durable, well graded, and uniform. A 100% crushed material should be used when it is available. An individual aggregate or a blend of aggregates to be used in a slurry mix should meet these limits:

- Sand equivalent value, ASTM D 2419 (AASHTO T 176) = 45 minimum.
- Soundness, ASTM C88 (AASHTO T104) = 15% maximum using $Na_2SO_4$ or 25% maximum using $MgSO_4$.
- Los Angeles abrasion loss, ASTM C 131 (AASHTO T 96) Grading C or D = 35% maximum.

Three aggregate gradations are used for slurry seals (Table 6.7). Type I gradation is a thin sealing course that provides maximum crack penetration and good sealing properties. Type I slurry seal also makes an excellent pretreatment for a hot mix asphalt overlay or chip seal. It performs well in low traffic density areas where the primary objective is sealing, such as parking lots, light aircraft airfields, or shoulders.

Type II is the most widely used slurry seal gradation. Type II slurry seal protects the underlying pavement from oxidation and water damage and it improves surface friction. In addition, Type II slurry seals can correct severe raveling. It is used for moderate traffic density pavements.

The Type III gradation is used to attain heavy application rates and high surface friction values. Type III slurry seal is used for heavy traffic density roadways.

Asphalt emulsion used in the slurry seal may be SS-1, CSS-1, SS-1h, QS-1h, CSS-1h or CQS-1h. The cement mixing test is waived for CQS-1h and QS-1h emulsions. The correct emulsion for any given slurry seal aggregate can be verified by a mix design.

Relatively small amounts of liquid or powdered additives can be added to the slurry seal mixture. The materials may be used to improve mix characteristics, setting characteristics or other post cure properties. These additives include portland cement, lime and aluminum sulfate in addition to some organic chemicals. The performance of any given additive must be demonstrated in the mix design. Water used in the slurry must be potable and compatible with the mix.

Performing a mix design in the laboratory prior to the application is important for selecting the proper materials and a compatible mixture. The International Slurry Surfacing Association's Design Technical Bulletins contain further information on mix design. Correct blending should produce slurry with a creamy homogeneous texture that will flow smoothly in a rolling wave ahead of the strike-off squeegee. There should be no emulsion runoff.

It is essential to calibrate each slurry seal machine with the exact materials to be used on the slurry project. The calibration should reflect the materials proportions designated by the mix design. Reports of previous calibrations on these same materials may be accepted if they were performed within the current calendar year. Trial applications should be used as a final check of slurry consistency and workability.

It is important to repair all areas of base failure before applying the slurry seal. Seal cracks in the pavement surface with an acceptable crack sealant. Finally, the surface must be cleaned of all loose materials, oil spots, vegetation and other foreign matter. Any standard cleaning method will be acceptable. If water is used, cracks must be dry before applying the slurry seal.

A tack coat is not generally required prior to slurry seal application unless the surface is extremely dry and raveled or is concrete or brick. If required, the tack coat should consist of one part of emulsified asphalt and three parts of water. The distributor shall be capable of applying the dilution evenly at a rate of 0.25 to 0.45 l/m$^2$ (0.05 to 0.10 gals/yd$^2$). The tack coat must cure before applying the slurry seal.

When required by local conditions, the surface shall be lightly dampened by fogging with water ahead of the spreader box. The rate of application of the fog spray can be adjusted during the day to suit current conditions. Spray bars are located on the slurry seal machine for water fogging. Excessive fogging that creates puddles in front of the spreader box should be avoided.

During application of the slurry seal, there should be no lumping, balling, or unmixed aggregate visible in the spreader box. Enough material should be carried in all parts of the spreader box so that complete coverage is attained. Overloading of the spreader must be avoided. Streaks, such as those caused by oversized aggregate, should be repaired at once with a hand squeegee.

Care must be taken to prevent excessive buildup of slurry seal at longitudinal and transverse joint lines. A maximum of 150 mm (6 in) of overlap is permitted on longitudinal joints. Transverse joints must be smooth enough to permit quiet transition of vehicles.

Hand squeegees and hand drags are used to improve joints, correct minor imperfections and place the slurry in areas inaccessible to the machine. The area to be handworked should first be lightly dampened with water. The slurry seal can then be deposited and immediately worked onto the surface with hand squeegees. Care should be exercised not to leave an unsightly appearance in handworked areas. Hand application of slurry seal should be limited and should only be conducted in areas impossible to reach by machine.

Rolling is seldom required for a slurry seal. Use of a pneumatic tired roller can assist in airport and parking lot projects where existing traffic does not sufficiently compact the slurry after application. A common 9 to 11 tonne (10 to 12 ton) nine-wheel pneumatic tired roller with 350-425 kPa (50-60 psi) tire pressure is adequate, and two passes of the roller are generally sufficient. It is important to roll when the slurry seal is set enough to support the roller without having material pick up on the tires. Steel wheeled rollers are not appropriate for slurry seal. These rollers tend to bridge on the high spots of the pavement and fail to compact in the low areas. They will also mark the surface and could crush the larger aggregate.

Slurry should not be placed when the temperature of the pavement or air is below 10°C (50°F) and falling, but may be applied when both pavement and air temperature are above 7°C (45°F) and rising. Slurry seal should not be applied when there is the possibility that the finished product will freeze within 24 hours after application. Slurry should not be applied during excessively foggy conditions or in periods of rain.

Additional information on slurry seal can be obtained from:

International Slurry Surfacing Association
1200 19th Street NW
Suite 300
Washington, D.C. 20036

## ➤➤ *Micro-Surfacing*

Like slurry seal, micro-surfacing is a mixture of well graded aggregate, asphalt emulsion, fillers, additive and water, but through the addition of polymers and the use of specialized design techniques, micro-surfacing can achieve multiple stone depths.

As a surface treatment, micro-surfacing imparts protection to the underlying pavement and provides renewed surface friction values. Special emulsifiers in micro-surfacing emulsions contribute quick setting characteristics. Formulations are required under average conditions to allow the return of straight running traffic to the surface in one hour. Minor reprofiling can be achieved with multiple application. Special equipment permits the filling of wheel ruts up to 40 mm (1 1/2 in.) deep in one pass.

Micro-surfacing features and benefits include:

- Quick set, quick traffic feature.
- Chemical break permits night time application.
- Suitable for use on high traffic volume, limited access highways.
- Single pass application rates of 11 to 16 kg/m$^2$ (20-30 lbs/yd$^2$), yielding micro-surfacing depths from 9 to 16 mm (3/8 to 5/8 in.) in depth.
- Scratch course followed by a finishing course provides minor reprofiling and a new riding surface.
- Rut filling followed by a finishing course provides proper water drainage and reduces the possibility of vehicle hydroplaning.

Figure 6.4 Continuous Laydown Micro-Surfacing Unit

Micro-surfacing is mixed and placed by specialized, compartmented, self-powered trucks. Highly accurate proportioning assures proper ratios of the continuous feed for each component. The mixing chamber is a double shafted, multi-bladed pugmill that quickly combines and thoroughly mixes the materials. The semi-fluid micro-surfacing mixture falls into an augured screed box and is deposited on the pavement across a full lane width as the truck moves forward on the roadway.

Continuous laydown micro-surfacing trucks (Figure 6.4) are supplied with aggregate and asphalt emulsion by nurse trucks and produce resurfacing with a minimum of transverse joints. This type of equipment is capable of producing up to 450 tonnes (500 tons) of micro-surfacing per day. Truck mounted units can also be used for micro-surfacing if proper feed accuracy and rapid pug mill mixing can be achieved. These units return to the stockpile for refilling after depositing a full load of aggregate.

Micro-surfacing rut boxes are designed to deposit material directly into pavement wheel ruts. Multiple rut filling passes can correct depressions in excess of 50 mm (2 in.) in depth. This technique permits the correction of hydroplaning hazards without milling the existing surface.

Aggregates used for micro-surfacing are manufactured, 100% crushed stone such as granite, slag, limestone, chat, or other high quality aggregate. An individual aggregate or blend of aggregates must meet these standards for use in micro-surfacing:

- Sand equivalent value, ASTM D 2419 (AASHTO T 176) = 60 minimum.
- Soundness, ASTM C88 (AASHTO T104) = 15% maximum using $Na_2SO_4$ or 25% maximum using $MgSO_4$.
- Los Angeles abrasion loss, ASTM C 131 (AASHTO T 96) Grading C or D = 30% maximum.

The two generally accepted aggregate gradations for micro-surfacing are listed in Table 6.8. Type II aggregate is used for general resurfacing of streets and medium volume roadways. Type III aggregate is used for heavy traffic resurfacing, minor reprofiling, rut filling and areas where high friction values are desirable.

CSS-1h-p emulsions are the most widely used for micro-surfacing system. These materials are used to trigger the proper breaking characteristic in the mix. Organic surfactants are often used as mixing aid additives. As with slurry seal, the water used in micro-surfacing must be potable and compatible with the mix.

A micro-surfacing mix design must be performed in the laboratory prior to application. Correct blending of materials should produce a semi-fluid mixture of thoroughly coated material. There should be no emulsion runoff. Setting of the material and the appearance of clear water should take place within 30 minutes.

**Table 6.8 Micro-Surfacing Aggregate Gradings***

| **Gradation Type** | II | III |
|---|---|---|
| **General Usage** | General resurfacing, sealing and renewal of surface friction | High volume roadway resurfacing, rut filling. Produces high-friction surfaces |
| **Sieve Size** | **Percent Passing** | **Percent Passing** |
| 9.5 mm (3/8 in.) | 100 | 100 |
| 4.75 mm (No. 4) | 90-100 | 70-90 |
| 2.36 mm (No. 8) | 65-90 | 45-70 |
| 1.18 mm (No. 16) | 45-70 | 28-50 |
| 600 µm (No. 30) | 30-50 | 19-34 |
| 300 µm (No. 50) | 18-30 | 12-25 |
| 150 µm (No. 100) | 10-21 | 7-18 |
| 75 µm (No. 200) | 5-15 | 5-15 |
| Residual Asphalt Content, % weight of dry aggregate | 5.5-9.5 | 5.5-9.5 |
| Application Rate, kg/m$^2$ (lb/yd$^2$), based on weight of dry aggregate | 5.4-9.1(12-20) | 8.2-13.6 (18-30) |

*** Recommended by the International Slurry Surfacing Association.**

It is important to calibrate the micro-surfacing machine with the exact materials to be used on the project. The calibration should reflect the materials proportions designated by the mix design. Reports of previous calibrations on these same materials may be accepted given that they were performed within the current calendar year. Trial applications may be used as a final check of slurry consistency and workability. Night application of micro-surfacing requires special formulations. It is advisable to demonstrate the formulation's ability to cure in night conditions with trial passes before the project is to begin.

It is important to repair all areas of base failure before application of micro-surfacing. Seal cracks in the pavement surface with an acceptable crack sealant. Finally, the surface must be cleaned of all loose material, oil spots, vegetation, and other foreign matter. Any standard cleaning method will be acceptable. If water is used, cracks must be dry before applying the micro-surfacing.

Micro-surfacing is self-tacking. A tack coat is not required unless the surface to be treated is extremely dry and raveled or is concrete or brick. If required, the tack coat should consist of one part of emulsified asphalt and three parts of water. The distributor shall be capable of applying the dilution evenly at a rate of 0.23 to 0.45 $l/m^2$ (0.05 to 0.10 $gal/yd^2$). The tack coat must cure before the micro-surfacing application.

When required by local conditions, lightly dampened the surface by fogging with water ahead of the spreader box. The rate of application of the fog spray can be adjusted during the day based on the current conditions. Spray bars are located on the micro-surfacing machine for water fogging. Enough material should be carried in all parts of the spreader box at all times to attain complete coverage. Overloading of the spreader must be avoided. Streaks, such as those caused by oversized aggregate, should be repaired at once with a hand squeegee.

Care must be taken to prevent excessive buildup of micro-surfacing at longitudinal and transverse joint lines. Longitudinal joints should be minimized and placed on the center lane lines, when possible. A maximum of 150 mm (6 in) of overlap is permitted on longitudinal joints. Transverse joints must be smooth enough to permit quiet transition of vehicles.

Hand squeegees and hand drags are used to improve joints, correct minor imperfections and place the micro-surfacing areas inaccessible to the machine. The areas to be handworked should first be lightly dampened with water. The micro-surfacing can then be deposited and immediately worked onto the surface with hand squeegees. Care should be exercised not to leave an unsightly appearance to the handworked areas. Hand application of micro-surfacing should be limited.

Rolling is rarely required for micro-surfacing as vehicular traffic normally provides adequate compaction. When rolling is required by special conditions, a 9 to 11 tonne (10 to 12 ton) nine-wheel pneumatic tired roller with 350-425 kPa (50-60 psi) tire pressure is adequate for use and two passes of the roller is generally sufficient. It is important to roll when the micro-surfacing is set enough to support the roller without having material pick up on the tires. Steel wheeled rolling is not recommended. These rollers tend to bridge on the high spots of the pavement and fail to compact in the low areas. They also can mark the surface and could crush larger aggregate.

In general, micro-surfacing should cure for 24 hours between multiple passes. This curing permits water to evaporate and strength to build in the underlying passes. Also, traffic consolidation in filled ruts and other thick areas will build maximum compacted strength.

Micro-surfacing normally should not be placed when the temperature of the pavement or air is below 10°C (50°F) and falling, but may be applied when both pavement and air temperatures are above 7°C (45°F) and rising. Application should not be attempted when there is a possibility that the finished product will freeze within 24 hours after application. Micro-surfacing should not be applied during rain.

Additional information on micro-surfacing can be obtained from:

International Slurry Surfacing Association
1200 19th Street NW
Suite 300
Washington, D.C. 20036

## ➤➤ *Seal Coat*

A seal coat is an application of asphalt emulsion to an existing paved asphalt surface. The asphalt emulsion may be sprayed or squeegeed on the existing pavement surface. This type of maintenance treatment is primarily employed to improve the aesthetics of an existing pavement by providing a uniform black color to the surface and to obscure differences in the pavement surface texture. In addition, the sealer will provide an impervious membrane that will slow the rate of weathering of the asphalt in the underlying pavement.

The types of emulsion used for seal coats are SS-1, SS-1h, CSS-1, and CSS-1h. Coarse, angular sand is generally added to the emulsion for increased skid resistance. It is added at a rate of 0.5-0.8 kg per liter (4-7 lb. per gallon) of emulsion. About 0.5 $l/m^2$ (0.1 $gal/yd^2$) should be applied in a single application. If an additional application is desired, it should be applied at a right angle to the first on. The seal coat must be allowed to completely cure before traffic is applied to prevent pickup by vehicle tires.

## ➤➤ *Fog Seal*

A fog seal is a light application of diluted slow-setting emulsion sprayed on an existing asphalt surface. The emulsion can be diluted up to one part emulsion to five parts water (1:5) but in most cases, a one to one dilution is used. The asphalt emulsions normally used are SS-1, SS-1h, CSS-1 and CSS-1h.

A fog seal can be a valuable maintenance aid. However, it is not a substitute for asphalt surface treatments such as sand or chip seals. It is used to renew old asphalt surfaces that have become dry and brittle with age and to seal very small cracks and surface voids. It also coats aggregate particles at the surface. This corrective action can prolong pavement life and possibly delay the need for major maintenance or rehabilitation, particularly if applied in a timely manner.

The total quantity of fog seal is normally from 0.45 to 0.70 $l/m^2$ (0.10 to 0.15 $gal/yd^2$) of diluted material. The surface condition or texture, dryness and degree of cracking of the pavement determine the quantity required. The seal coat should be allowed to completely cure before traffic is applied to prevent pickup by vehicle tires.

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Over-application of the fog seal must be avoided as this will result in asphalt pickup by vehicles and possibly a slippery surface. When excess emulsion is applied, a light application of fine sand on the affected area may correct the problem.

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## Surface Treatment Construction

The equipment used for surface treatment construction has a major impact on the quality of the finished product. It should be kept in proper adjustment and good operating condition using routine maintenance and frequent inspections for excessive wear, breakdown and calibration.

### ➤➤ The Asphalt Distributor

The asphalt distributor is the most important piece of equipment used in surface treatment construction (Figure 6.5). It is used to uniformly apply the asphalt emulsion over the surface at the specified rate.

The distributor consists of either a truck-mounted or trailer-mounted insulated tank with controls to set the asphalt application rate. At the rear of the tank is a spray bar equipped with nozzles through which the asphalt is forced under pressure onto the pavement surface. Spray bars can cover widths of 3 to 9 m (10 to 30 ft.) in a single pass, depending on the pump capacity. A hand spray is included to apply the emulsion to areas that cannot be reached with the spray bar.

The distributor tank typically has a capacity of 3,000 to 20,800 liters (800 to 5,500 gal.). The

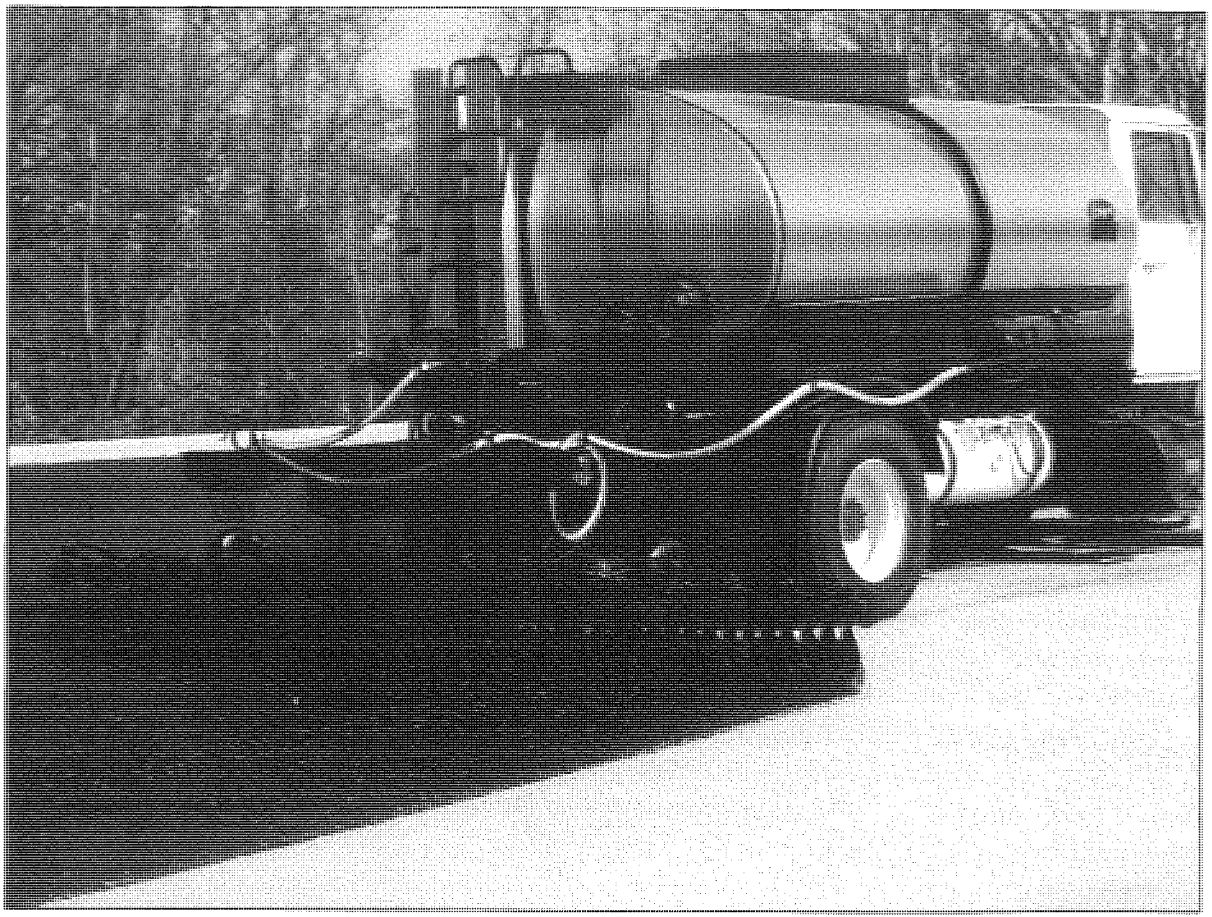

Figure 6.5 Asphalt Distributor

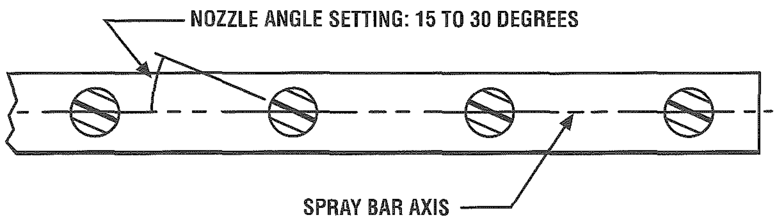


Figure 6.6 Proper Nozzle Angle Setting

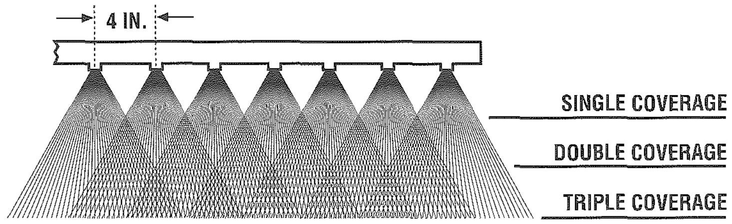


Figure 6.7 Spray Bar Height Must Be Set Exactly for Proper Coverage

tank has a circulating system that includes the spray bar. Pressure generated when a noncirculating or not bypassed spray bar is shut off can cause the emulsion to break and plug the unit with asphalt. The tank is also equipped with one or more heaters used to bring the emulsified asphalt to the proper spraying temperature. Extreme care is required when using these heaters. Premature breaking of the emulsion may occur if heating temperatures are too high. If the heaters are to be used, the emulsion should be circulating in the tank while heat is applied and excessive temperatures must not be allowed.

Two extremely important adjustments are the spray nozzle angle setting and spray bar height. The angle of the nozzle openings must be adjusted so that the spray fans will not interfere with each other. The recommended angle, measured from the spray bar axis, is from 15 to 30 degrees (Figure 6.6). To ensure a uniform spread, the spray bar must be set and maintained at the proper height above the pavement surface. If it is set too high, wind distortion of the spray fans may occur. The best results usually are achieved with an exact double coverage, but triple coverage can sometimes be used with spray bars with 100 mm (4 in) nozzle spacing. Figure 6.7 illustrates the heights of the spray bar necessary to achieve these coverages.

Three controls are standard equipment on most distributors. One is a valve system that governs the flow of asphalt material. Another is a pump tachometer or pressure gauge that registers pump output. The third is a bitumeter with an odometer that indicates the number of meters (feet) per minute and the total distance traveled.

Despite the precise controls on a distributor, it is always advisable to check the rate of application in the field. This can be done with a shallow metal tray exactly one square meter (one sq. yd.) in area. If a tray is not available, a sheet of heavy paper or cardboard can also be used. The tray is weighed and placed on the surface to be sprayed. Immediately after the distributor has passed, the tray is removed and weighed again. The difference between the two is the mass (weight) of the asphalt emulsion. The asphalt emulsion application rate can then be determined by this equation:

$$R = w/D$$

where

$R$ = asphalt emulsion application rate, liters/m$^2$ (gal/yd$^2$)

$w$ = mass (weight) of asphalt emulsion on tray, kg/m$^2$ (lb/yd$^2$)

$D$ = density of asphalt emulsion at 15.6°C (60°F), kg/liter (lbs/gal)

*Note: The rate at the spraying temperature can be determined by dividing R by the M temperature-volume correction factor (see Table B-1, Appendix B).*

## ➤➤ Aggregate Spreader

The aggregate spreader is second only to the asphalt distributor in the order of importance of surface treatment equipment. It applies a uniform aggregate cover at the specified rate. Spreaders range from the simple vane type attached to a truck tail gate to the highly efficient self-propelled type.

Tail gate spreaders are usually one of two types. One is a steel plate to which is attached a series of vanes to provide coverage across the lane (Figure 6.8). Another is a truck-mounted hopper with a feed roller activated by small wheels driven by the truck wheels (Figure 6.9). In each case, the truck backs up to spread the stone. This prevents the freshly applied asphalt from being picked up by the truck tires.

Mechanical aggregate spreaders contain hoppers and a built-in distribution system to ensure a uniform spread of the cover aggregate across the entire lane width. Mechanical spreaders are either truck-attached (Figure 6.10) or self-propelled (Figure 6.11). In both types, the aggregate is dumped from a truck into a receiving hopper for spreading. The truck-attached spreader typically contains an auger and a roughened spread roll in the hopper that ensures a positive, uniform feed of material. The self-propelled unit has a similar feed mechanism.

One difference is that the self-propelled spreader contains a scalping screen over the aggregate

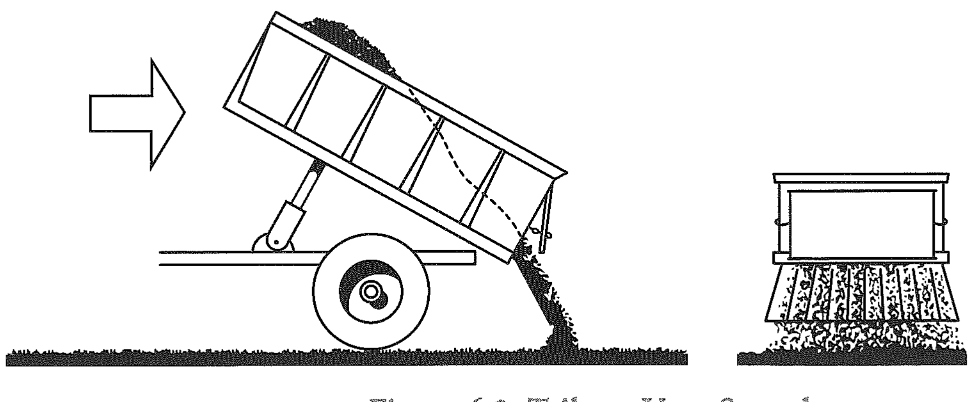

Figure 6.8 Tailgate Vane Spreader

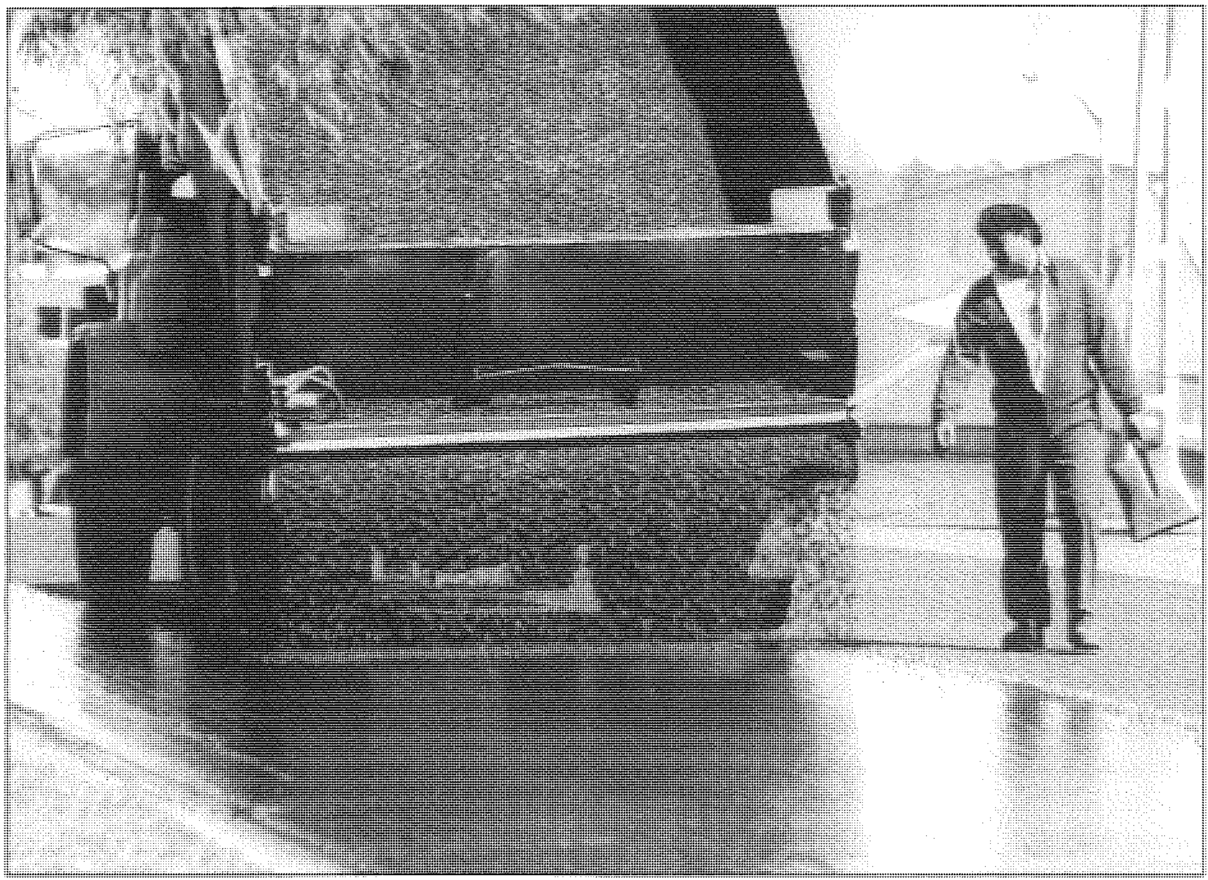

Figure 6.9 Hopper-Type Tailgate Spreader

receiving hopper. Another is that there can be a sloped screen that allows the larger particles to drop into the asphalt film first with the finer particles falling afterwards through the screen. This system ensures that the larger particles are sufficiently embedded in the asphalt to hold them in place. The self-propelled unit has the advantage of being able to closely follow behind the asphalt distributor, with minimum stopping to change aggregate trucks.

Mechanical self-propelled aggregate spreaders should be calibrated to apply the design quantity of cover stone for any given project. The required equipment can be very simple and may consist only of several sheets of canvas, each exactly one square meter (square yard), and a scale. By making several runs at different speeds and gate openings over the sheets of canvas and carefully weighing the aggregate deposited on them, the gate opening and spreader speed required to apply the cover stone at the specified rate per square meter (square yard) can be quickly determined.

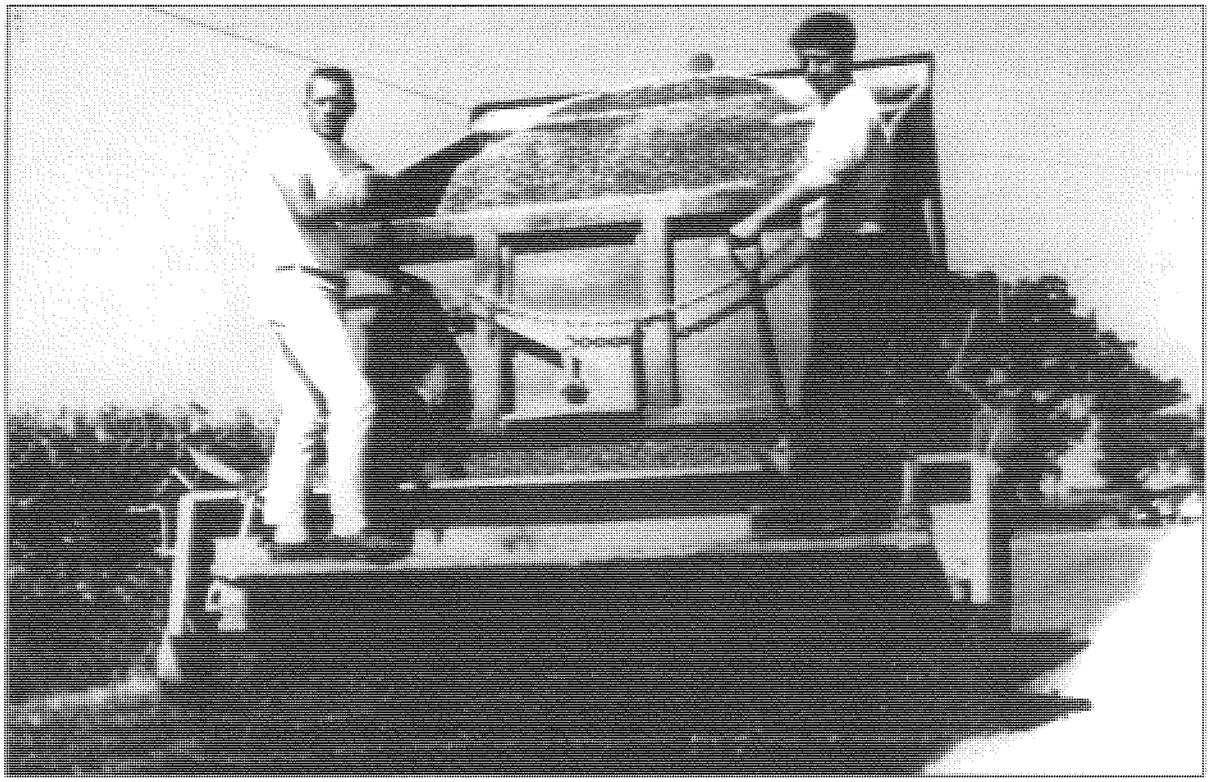

Figure 6.10 Truck-Attached Mechanical Spreader

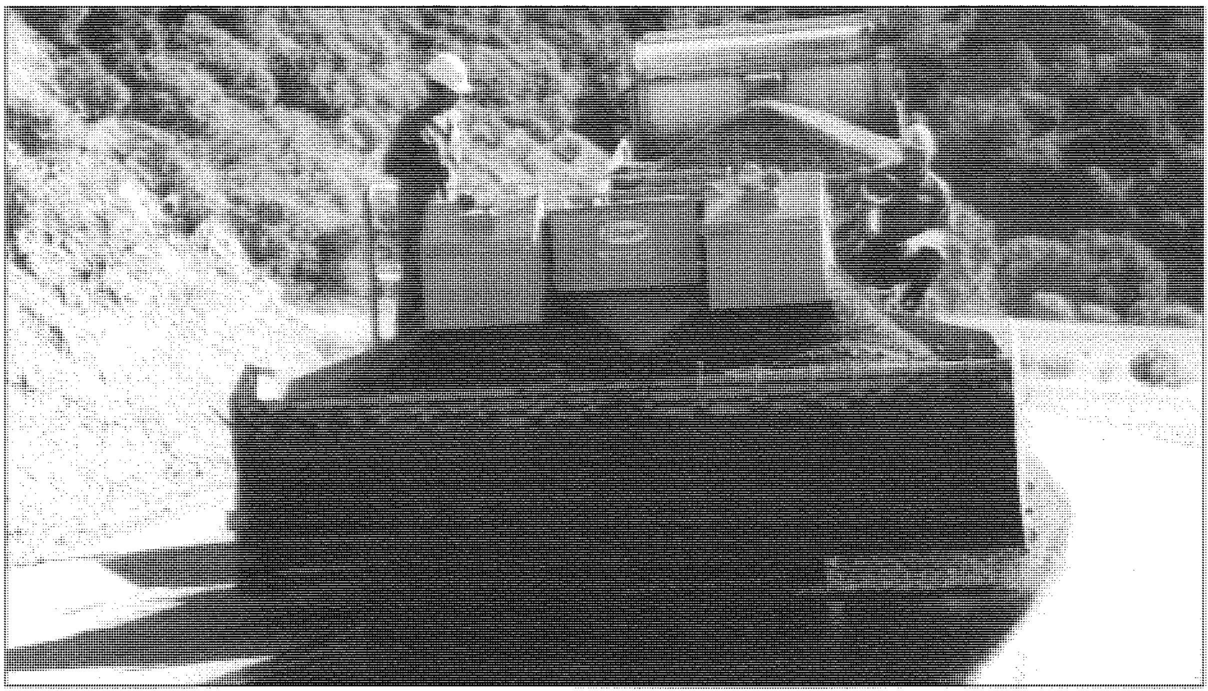

Figure 6.11 Self-Propelled Mechanical Spreader

Figure 6.12 Pneumatic-Tired Roller

## ➤➤ Rollers

Rolling presses the aggregate down into the asphalt binder, promoting better adhesion. Unless the cover aggregate is properly embedded in the asphalt film, there is a good possibility that some may be lost through traffic abrasion. For single surface treatments, pneumatic-tired rollers produce best results (Figure 6.12). They force the aggregate firmly into the asphalt binder without crushing the particles. The tires press into small depressions to better seat the particles. Steel-wheeled rollers tend to bridge over such depressions and may fracture the aggregate. If the roller speed is too high, the roller may dislodge the aggregate.

Figure 6.13 Power Sweeper

## ➤➤ *Power Broom*

Unless the surface to be covered is completely clean, the asphalt may not adhere to the pavement. Therefore, it is necessary to clean the whole surface before spraying the asphalt emulsion (Figure 6.13). Power sweepers or brooms are also used to remove loose particles after the treatment is completed. On a new surface treatment, it is advisable to lightly broom during cooler periods of the day to prevent chip roll over.

## ➤➤ *Trucks*

Enough trucks must be available to ensure that the surface treatment operation can proceed without interruption. Frequent stops and starts may cause variations in asphalt spray distribution, rate of aggregate cover, or both, and result in a non-uniform surface. By staggering backing patterns, trucks can also be used to roll the finished surface treatment to help embed the aggregate before the regular rolling is begun. Truck speed and turning should be carefully controlled to prevent dislodging chips.

Figure 6.14 Surface Treatment Operation

## ➤➤ Sequence of Operations

The sequence of operations is basically the same for all types of surface treatment construction:

1. Patch potholes and repair damaged areas in the existing pavement. Allow enough time for curing of the patch mix. If a coarse patch mix is used, fog sealing may be advisable.
2. Clean the surface with a power sweeper or rotary broom or by another approved method.
3. Spray the asphalt emulsion binder at the specified rate and proper temperature.
4. Spread the cover aggregate at the specified rate immediately behind the asphalt spray application (emulsion still brown in color) to achieve maximum possible chip wetting.
5. Roll the cover aggregate adequately to properly seat particles in asphalt film.

Figure 6.14 shows a proper surface treatment operation. If a double or triple surface treatment is required, steps 3 through 5 will be repeated once or twice.

All equipment must be in proper working order before construction begins. An adequate supply of aggregate should be available on the job site, or scheduled for delivery at proper intervals with adequate haul trucks to permit continuous spreading operations. The required quantity of asphalt emulsion should also be stored or scheduled to arrive promptly at the job site to prevent delays in construction. An adequate traffic control plan should be developed.

## ➤➤ Precautions

Most problems with surface treatments are caused by failure to adhere to common-sense construction practices. Even when the highest quality aggregates and asphalt emulsions are used, inferior surface treatments may result unless strict guidelines are followed. An attempt at short cuts or construction during poor weather will probably result in poor performance and increased maintenance.

Surface treatment operations should not be carried out during periods of cold or wet weather. Conventional guidelines recommend air temperatures of at least 10°C (50°F) in the shade and rising. Generally, the temperature of the road surface should be above 27°C (80°F) before an asphalt spray application can be applied. The asphalt emulsion may not break or cure properly at lower temperatures and therefore, the asphalt will not satisfactorily retain the cover aggregate.

Surface treatments should not be constructed in the rain, when rain is threatening, or on wet pavement. The water may cause a loss of the partly cured emulsion from the cover aggregate. New technology has produced emulsions, usually polymer modified, which can be used at cooler temperatures or at night. Your local asphalt emulsion supplier should be contacted for specific recommendations.

A simple rule of thumb can be cited when rapid-setting emulsions are used for surface treatments. The emulsion selected should break just after the first roller pass has been made. This assumes that the roller is following closely behind the aggregate spreader and that the spreader, in turn, is trailing immediately behind the asphalt distributor. This sequence should result in good wetting of the cover aggregate by the asphalt emulsion and the development of satisfactory adhesion between the emulsion and cover aggregate. Also, good cover aggregate retention should occur when the surface treatment is opened to traffic.

## ➤➤ Checking Application Rate

Checks on the rate of application of asphalt emulsion should be made after each run with the distributor. This can be simply done using this formula:

| **S.I. Metric** | **U.S. Customary** |
|---|---|
| R = TM / WL | R = 9TM / WL |

where:

- R = Rate of application, liter/$m^2$ (gal/$yd^2$)
- T = Total liters (gallons) spread from the distributor at the spraying temperature, that is, gauge stick reading before spread minus gauge stick reading after spread
- W = Width of spread, m (ft)
- L = Length of spread, m (ft)
- M = Multiplier for correcting asphalt volume to basis of 15.6°C (60°F) (from Table B-1 in Appendix B).

## Surface Treatment Safeguards

A few simple safeguards will greatly increase the chance of success when a surface treatment is used. These "common-sense" items apply to most other types of construction as well.

- The design is done properly and all materials used meet the job specifications to assure the job will give the desired performance.
- The existing pavement structure is strong enough to support expected traffic loads before the surface treatment is applied.
- All construction equipment is inspected to insure proper operation. Calibration of gauges, meters and aggregate spreader and inspection of spray nozzles are completed.
- The asphalt emulsion and aggregate are compatible. The proper emulsion (cationic or anionic) is chosen and the aggregate is free from dust and slightly moist for the best results.
- The emulsion application rate and amount of cover aggregate is carefully designed.
- The proper type and weight of rollers are selected.
- Proper construction techniques are followed.
- There is proper traffic control.
- The work is performed only in weather conditions suitable for the type of emulsion selected. Improvements in technology have led to new emulsions that can be formulated specifically for cooler weather.

Adhering to the simple safeguards will help prevent problems. Three of the most common problems and their causes are:

### ➤➤ *Streaking*

This is the non-uniform application of the asphalt emulsion on the road surface (Figure 6.15). Longitudinal streaking shows up as alternating lean and heavy narrow bands of asphalt running parallel to the centerline of the pavement. Streaking not only leaves an unsightly appearance, it can also greatly reduce service life through the loss of cover aggregate. A single centerline streak may be caused by too little or too much emulsified asphalt at the joint between two applications.

Causes of longitudinal streaking include:

- An improper spray bar height causing incorrect overlap of the spray fans.
- Spray bar changing height as the distributor load decreases with asphalt discharge.
- Nozzles on spray bar are not set at correct angle, not all set at same angle, the wrong size, different in size, plugged or restricted, or have imperfections.
- Incorrect asphalt emulsion pump speed or pressure
- Asphalt emulsion too cold.
- Asphalt emulsion viscosity too high for existing conditions and equipment.

### ➤➤ *Bleeding (Flushing)*

This is a surface that is too rich in asphalt (Figure 6.16). Bleeding can cause a slick, hazardous condition, especially during wet weather. The most common causes of bleeding of a surface treatment are an improper application rate of asphalt emulsion, improper aggregate application, or

Figure 6.15 Longitudinal Streaking

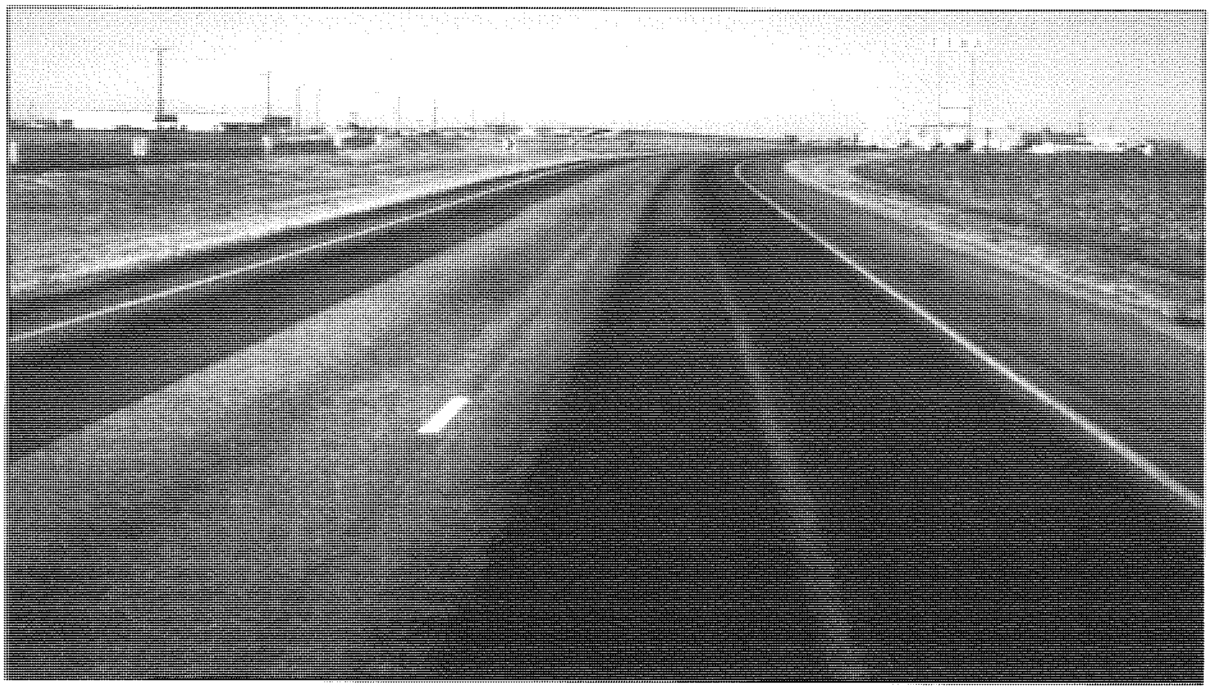

Figure 6.16 Bleeding Asphalt

Figure 6.17 Loss of Cover Aggregate

water vapor pressure from the base or subgrade causing stripping that results in the asphalt coming to the surface. Bleeding may also be a result of pre-existing bleeding of the old surface. This may be addressed using a sandwich seal.

### ➤➤ *Loss of Cover Aggregate*

This is the whipping-off of aggregate under traffic from a surface treated pavement that leaves the asphalt uncovered (Figure 6.17). This condition can be dangerous because loose aggregate thrown by the tires of a moving vehicle can cause windshield damage. Also, the aggregate-free asphalt, now resembling bleeding, can become a skid hazard.

Several things can cause the loss of cover aggregate:

- The aggregate may not adhere to the applied emulsion if not spread at the proper time.
- Dry, dusty aggregate may cause premature breaking of the asphalt emulsion that leaves insufficient asphalt to hold the aggregate under traffic.
- If not rolled immediately after placing, the aggregate may not become seated firmly enough to hold under traffic.
- Other causes include: not enough asphalt emulsion; too little aggregate embedment; weather too cool before, during and after application; high humidity; the surface being treated too wet or dusty; fast traffic too soon on the new surface treatment; a surface that absorbs part of the asphalt leaving too little to hold the aggregate; and rain washing away the emulsion.

The Transportation Research Board (TRB) defines stabilization as "the modification of soils or aggregates by incorporating materials that will increase load carrying capacity, firmness and resistance to weathering displacement." Soil stabilization with asphalt emulsion is very adaptable to stage construction where additional courses or lifts are added with increased traffic loading. Asphalt emulsion can be excellent for stabilization through its cementing and waterproofing properties.

Advances in asphalt emulsion technology make it possible for emulsion mixes to be used in a wide variety of pavement construction, rehabilitation and maintenance applications. Table 7.1 lists the major uses of asphalt emulsion mixes.

**Table 7.1 Major Uses of Asphalt Emulsion Mixtures**

| Mixture Use | Purpose of Emulsion Treatment |
|---|---|
| As a construction aid | To facilitate the construction of the pavement and in some cases provide a working platform. |
| Upgrading of marginal aggregates | To improve an aggregate to the quality of a good untreated granular base. |
| As a temporary wearing surface | To provide a surface that may be used until a permanent surface of hot mix asphalt or high type emulsion mix is placed. |
| To reduce the total pavement thickness | To increase the strength of the pavement materials and reduce the required pavement structure thickness from that required using untreated materials |
| Open-graded base and surface mixes | To produce a high quality mix for heavy traffic load applications. These mixes have good flexibility and resistance to permanent deformation. |
| Dense-graded wearing surface | To produce a mix for stable surfaces course that will not develop rutting and shoving. |
| Pavement subbase | Allow for the use of lessor quality aggregates to produce an acceptable subbase layer. For this application, sands, silty sands and poorer graded sand-gravels can be used. |
| Immediate use and stockpile maintenance mixtures | Provide workable patching mixtures that can be designed for immediate use or for long term storage. |

## Asphalt Emulsion Mixtures

There are three types of asphalt emulsion-aggregate mixtures: dense-graded, sand and open-graded. Dense-graded mixtures have aggregates that are graded from the maximum size down to and including material passing the 75 µm (No. 200) sieve. They include a wide variety of aggregate types and gradations and can be used for all types of pavement applications.

Sand emulsion mixtures are produced by treating bank-run sands, poorly graded sand-gravels and "dune" or "sugar" sands with asphalt emulsions. Sand mixes are generally restricted to fine granular sands and silty sands low in clay content. Sand mixes have provided good performance as subbase and base layers when produced with the proper emulsion grades. For these mixes, the emulsions typically used are slow setting and high float medium setting, with harder or "h" grades preferred.

Open-graded mixtures provide high air voids to drain water through the mix. These mixtures have been used very successfully for both base and surface courses. Because of the relatively simple plant equipment required and high mix production rates possible, these mixes are economically attractive when a high quality mix is required for heavy traffic loading. In some cases, the long-term performance of open-graded mixes has been comparable to hot mix asphalt. These mixes have shown good resistance to fatigue, reflection cracking, rutting and shoving.

## Mixture Design

A mix design is required for asphalt emulsion-aggregate mixes. It is essential that trial mixes be prepared in the laboratory to determine the grade and percent of emulsion and mixture properties of workability, stability and strength. The emulsion mixture's susceptibility to water damage should be determined. Asphalt emulsion-aggregate mixture design is described in Chapter 10.

Although general guidelines are presented in Chapter 5 for asphalt emulsion selection, some personal judgment may be required. The decision on selecting a type and grade of emulsion must not only consider the characteristics of the aggregate but also of the asphalt residue—-hard or soft base, containing solvent, polymer modified—-and the curing rate of the emulsion (medium or slow setting).

## Aggregates

The characteristics of the aggregate in any emulsion mix are very important in obtaining good mixture properties and performance. Aggregate makes up 90 to 95 percent by weight of an emulsion mixture.

A wide variety of aggregate types and gradations may be used successfully for emulsion mixes. Tables 7.2, 7.3 and 7.4 show some of the typical gradations and other aggregate properties for dense-graded, open-graded, and sand emulsion mixes, respectively. Certain standards must be maintained for the quality of the aggregates, including the amount of material finer that 75 µm (No. 200) sieve, the plastic fines content and durability. The mineral aggregates should be tested by the methods listed in Table 7.5.

Compatibility of the aggregate with the asphalt emulsion is important and should be determined. The mineral composition of the aggregate can have a significant influence on the performance of the mix. Therefore, as previously noted, it is necessary to prepare trial mixtures in the laboratory. A laboratory evaluation is completed to determine if the blending of an imported aggregate is necessary.

## Table 7.2 Aggregates for Dense-Graded Emulsion Mixtures

| Sieve Size | Semi-Processed Crusher, Pit or Bank Run | Processed Dense-Graded Asphalt Mixtures, Percent Passing by Weight | | | | |
|---|---|---|---|---|---|---|
| 50 mm (2 in.) | – | 100 | – | – | – | – |
| 37.5 mm (1-1/2 in.) | 100 | 90-100 | 100 | – | – | – |
| 25.0 mm (1 in.) | 80-90 | – | 90-100 | 100 | – | – |
| 19.0 mm (3/4 in) | – | 60-80 | – | 90-100 | 100 | – |
| 12.5 mm (1/2 in.) | – | – | 60-80 | – | 90-100 | 100 |
| 9.5 mm (3/8 in.) | – | – | – | 60-80 | – | 90-100 |
| 4.75 mm (No. 4) | 25-85 | 20-55 | 25-60 | 35-65 | 45-70 | 60-80 |
| 2.36 mm (No. 8) | – | 10-40 | 15-45 | 20-50 | 25-55 | 35-65 |
| 1.18 mm (No. 16) | – | – | – | – | – | – |
| 600 μm (No. 30) | – | – | – | – | – | – |
| 300 μm (No. 50) | – | 2-16 | 3-18 | 3-20 | 5-20 | 6-25 |
| 150 μm (No. 100) | – | – | – | – | – | – |
| 75 μm (No. 200) | 3-15 | 0-5 | 1-7 | 2-8 | 2-9 | 2-10 |
| Sand Equivalent, Percent | 30 min. | 35 min. | 35 min. | 35 min. | 35 min. | 35 min. |
| Los Angeles Abrasion @ 500 Revolutions | – | 40 max. | 40 max. | 40 max. | 40 max. | 40 max. |
| Percent Crushed Faces | – | 65 min. | 65 min. | 65 min. | 65 min. | 65 min. |

## Table 7.3 Aggregates for Open-Graded Emulsion Mixtures

| Sieve Size | Base | | | Open-Graded Surface Course |
|---|---|---|---|---|
| | Coarse | Medium | Fine | |
| 37.5 mm (1-1/2 in.) | 100 | – | – | – |
| 25.0 mm (1 in.) | 95-100 | 100 | – | – |
| 19.0 mm (3/4 in) | – | 90-100 | – | – |
| 12.5 mm (1/2 in.) | 25-60 | – | 100 | – |
| 9.5 mm (3/8 in.) | – | 20-55 | 85-100 | 100 |
| 4.75 mm (No. 4) | 0-10 | 0-10 | – | 30-50 |
| 2.36 mm (No. 8) | 0-5 | 0-5 | 0-10 | 5-15 |
| 1.18 mm (No. 16) | – | – | 0-5 | – |
| 75 μm (No. 200) | 0-2 | 0-2 | 0-2 | 0-2 |
| Los Angeles Abrasion @ 500 Revolutions | 40 max. | 40 max. | 40 max. | 40 max. |
| Percent Crushed Faces | 65 min. | 65 min. | 65 min. | 65 min. |

**Additives** Two additives used in emulsion mixes are portland cement and hydrated lime. These additives can be very effective in obtaining higher early strength and reducing the water susceptibility of emulsion mixes, particularly those produced with sand and sand-gravel aggregates. The amount of cement and lime used typically has been from 1 to 2 percent by weight of dry aggregate. Although initially added dry, these materials are now being added in a slurry form or as cement-water or lime-water mixtures. Laboratory testing is required to determine if the additives are of sufficient benefit to justify the increased cost.

## Table 7.4 Aggregates for Sand Emulsion Mixtures

| Sieve Size | Total Percent Passing | | |
|---|---|---|---|
| | Poorly-Graded | Well-Graded | Silty Sands |
| 12.5 mm (1/2 in.) | 100 | 100 | 100 |
| 4.75 mm (No. 4) | 75-100 | 75-100 | 75-100 |
| 300 µm (No. 50) | – | 15-30 | – |
| 150 µm (No. 100) | – | – | 15-65 |
| 75 µm (No. 200) | 0-12 | 5-12 | 12-20 |
| Sand Equivalent, percent | 40 max. | 40 max. | 40 max. |
| Plasticity Index | 65 min. | 65 min. | 65 min. |

## Table 7.5 Aggregates Evaluation Procedures

| Characteristics | Method of Test | |
|---|---|---|
| | ASTM | AASHTO |
| Amount of material finer than 75 µm (No. 200) Sieve in aggregate | C 117 | T 11 |
| Unit weight of aggregate | C 29 | T 19 |
| Sieve analysis, fine and coarse aggregates | C 136 | T 27 |
| Sieve analysis of mineral filler | D 546 | T 37 |
| Abrasion of coarse aggregates Los Angeles Machine | C 131 | T 96 |
| Plastic fines in graded aggregates and soils by use of the Sand Equivalent Test | D 2419 | T 176 |

### Production of Emulsion Aggregate Mixtures

Various methods can be used to produce emulsion-aggregate mixtures. One method is termed "mixed-in-place," in that the mixture is produced in place, on the roadway. Mixed-in-place production can use one of a variety of mixing procedures, such as a motor grader, rotary mixer, or road-reclaiming machine. This method is often used to strengthen the in-place soils. Mixing may also be completed by more sophisticated equipment, such as by central and travel mixing plants.

There are a number of factors to be considered when selecting the type of emulsion mixture production method. The factors to be considered in determining the most appropriate mixing method should include: (1) project location, (2) project size, (3) traffic conditions to maintain, or if the road can be closed, (4) whether imported aggregate is necessary to improve the mixture properties, (5) pavement type and thickness, and (6) climatic conditions.

## Mixed-in-Place Production

Mixed-in-place production will stabilize the existing aggregates directly on the roadbed. A laboratory evaluation will determine if the addition of an imported aggregate will be necessary to improve the mixture properties. If one is used, the imported aggregate is placed on the surface of the material to be stabilized. The aggregate usually is placed in a windrow and the size or volume calculated and controlled to obtain the proper emulsion content.

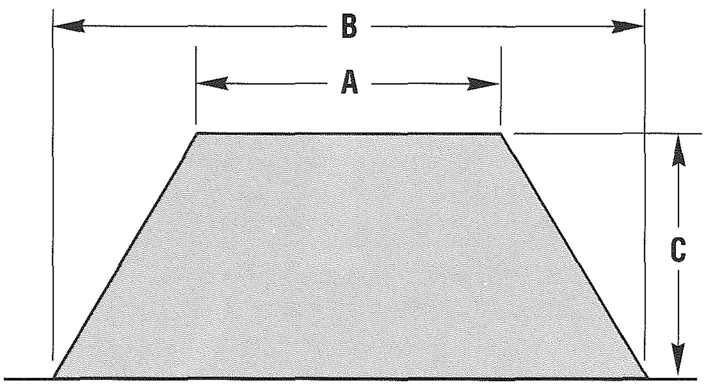


Figure 7.1 Dimensions for Windrow Volume

## ➤➤ Application Rates

If the road material and any imported aggregate are being windrowed, the dimensions of the windrow need to be measured as shown in Figure 7.1 and the volume and quantity of aggregate determined.

$$V_W = \frac{(A + B)\,C}{2}$$

where

$V_W$ = volume of the windrow, $m^3$ per linear meter ($ft^3$ per linear foot)
A, B, and C = dimensions of the windrow, meters (feet) (Figure 7.1)

$$W_a = W_1\,V_W$$

where

$W_a$ = quantity of aggregate, kg per linear meter (lb per linear foot) of windrow
$W_1$ = loose quantity of dry aggregate, $kg/m^3$ ($lb/ft^3$)

The rate of application for asphalt emulsion along the windrow is determined by:

$$A = \frac{(W_a \times P)}{(100 \times M)}$$

where

$A$ = application rate of asphalt emulsion, liter per linear meter (gal per linear foot)
$W_a$ = quantity of aggregate, kg per linear meter (lb per linear foot)
$P$ = emulsion content, percent by weight of dry aggregate
$M$ = mass (density) of asphalt, kg/l (lb/gal) [obtained from emulsion supplier]

The required forward speed of the asphalt distributor (or of mixing unit, if emulsion being added by it) is determined by the formula:

$$S = D_p / A$$

where

$S$ = forward speed of mixing unit or distributor, m/min (ft/min)
$D_p$ = pump discharge rate, l/min (gal/min)
$A$ = application rate of asphalt emulsion, liter per linear meter (gal per linear foot)

*Example:* Windrow dimensions of A = 1.5 m (4.9 ft), B = 2.0 m (6.6 ft) and C = 0.15 m (0.5 ft)
Emulsion content = 5.9 percent and density = 1.00 kg/l (8.33 lb/gal)
Loose quantity of aggregate, $W_1$ = 1440 kg/m$^3$ (90 lb/ft$^3$)

Volume of aggregate in windrow:

$$V_W = \frac{(A + B)\ C}{2} = \frac{(1.5 + 2.0) \times 0.15}{2} = 0.26\ m^3/m\ (2.8\ ft^3/ft)$$

Quantity of aggregate in windrow:

$$W_a = W_1\ V_W = 1440 \times 0.26 = 374.\ 4\ kg/m\ (252\ lb/ft)$$

Asphalt emulsion application rate:

$$A = \frac{(W_a \times P)}{(100 \times M)} = \frac{(374.4 \times 5.9)}{(100 \times 1.00)} = 22.1\ l/m\ (1.86\ gal/ft)$$

Forward speed of distributor or mixer, assuming a constant asphalt pump discharge of 200 l/min (53 gal/min):

$$S = \frac{D_p}{A} = \frac{200}{22.1} = 9\ m/min\ (29.5\ ft/min)$$

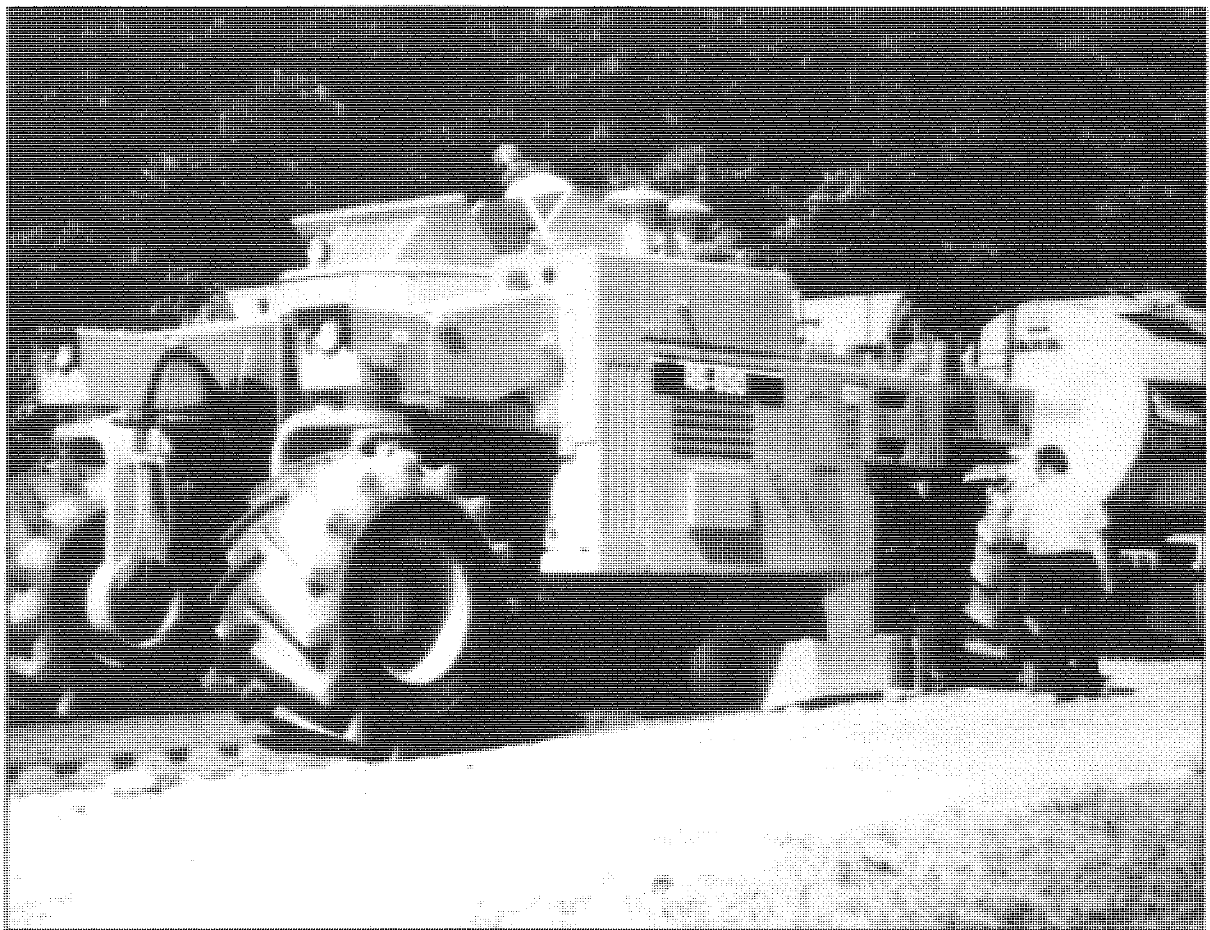

Figure 7.2 Road Reclaiming Machine

## ➤➤ Rotary/Reclaimer Mixing

Rotary cross-shaft type mixers have been used for many years for the in-place mixing of asphalt emulsions. These mixers consist of a mobile mixing chamber mounted on a self-propelled machine. The chamber is open on the bottom and inside it is normally a transverse rotating shaft equipped with tines or cutting blades. The depth of cutting and mixing can be varied and is controlled by a depth indicator. The asphalt emulsion may be added either through a spray bar inside the mixing chamber or by an asphalt distributor spraying the emulsion on the surface being processed. Rotary mixers typically have been used for the in-place mixing of aggregates and sandy soils.

With the increase in asphalt pavement recycling and greater thickness of asphalt material, more powerful and heavier machines have been developed called "road reclaimers" (Figure 7.2). These machines normally have a reclamation rotor equipped with carbide-tipped tools for more effective pulverization of existing asphalt and other road materials. Liquid additive systems are available for both emulsion and water. This equipment is increasingly being used instead of rotary mixers for the in-place mixing of emulsions. Reclamation and recycling using asphalt emulsion are discussed in Chapter 9.

Figure 7.3 Travel Plant, Hopper Type

## ➤➤ *Travel Plants*

Travel plants are self-propelled pugmill mixing plants that proportion and mix asphalt emulsion and aggregates in-place as they move along the road. The type of travel plant typically used receives aggregate into a hopper from a haul truck, adds and mixes the asphalt emulsion in a pugmill and spreads the mix at the rear by a strike-off screed as it moves forward on the surface being paved (Figure 7.3). This travel plant has a tank for the storage of asphalt emulsion.

The purpose of the travel plant is to produce a uniform, properly coated asphalt emulsion-aggregate mixture. The asphalt content on travel plants is set by adjusting the gate opening and controlling the volume of aggregate supplied from the feed hopper. However, travel plants now are available with an aggregate weigh belt system that is interlocked with the asphalt pump to control the addition of emulsion.

## ➤➤ *Blade Mixing*

Blade mixing is the least efficient and precise of the mixed-in-place methods and is primarily applicable when short lengths or small areas are being stabilized. The success of blade mixing is very dependent on the capability of the motor grader operator and, therefore, experienced personnel are required.

For blade mixing, the asphalt emulsion is applied by an asphalt distributor on a flattened windrow of in-place or imported material immediately ahead of the motor grader. The blade of the

Figure 7.4 Blade Mixing Operation

motor grader mixes the materials through a series of tumbling and rolling actions (Figure 7.4). If pre-wetting water is required, the water is applied to the material prior to the addition of emulsion and in an amount slightly higher than needed and thoroughly mixed with the aggregate. To assure a more uniform windrow, place the windrow material with a spreader box or windrow sizer. The emulsion required by the material in the windrow must be determined and the emulsion needed per linear meter (foot) of windrow is calculated.

There is a possibility of variation in the gradation of the windrow material in the windrow, requiring a fluctuation in the emulsion demand. Therefore, very close attention must be given to the appearance of the mix as mixing progresses. It is important that as much uniformity as possible be obtained in the material gradation and emulsion and moisture contents. The mixing operation should consist of as many manipulations with the motor grader as required to thoroughly disperse the emulsion and achieve adequate coating of the aggregate. However, excessive mixing passes should be avoided. The result could be stripping of the asphalt coating from the aggregate with certain combinations of aggregate and emulsion.

When blade mixing, the mold board of the motor grader should give a rolling action to the material. Care must be used to prevent extra material from being taken from the mixing table and incorporating it into the mixture being processed. Also, none of the material should be lost over the edge of the mixing table. After the mixing has been completed, the material should be moved to one side of the roadbed in preparation for spreading.

## ➤➤ Spreading and Compacting

The mixture should always be spread to a uniform thickness, whether in a single pass or in several thinner layers, so that no thin areas exist in the final mat. No layer should be thinner than about two times the maximum dimension of the largest aggregate, nor thicker than 150 mm (3 in.). Also, experience has shown sand mixes should be placed in compacted thicknesses of no greater than 50 mm (2 in.). Mixtures that do not require aeration may be spread to the required thickness immediately after mixing.

Breakdown or initial rolling of emulsion mixes should begin just before or as the emulsion begins to break. Breaking is indicated by a noticeable color change from brown to black. When this occurs, there is enough water in the mixture to act as a lubricant for the aggregate particles but not enough to fill void spaces. By this time, the mixture should also be able to support the roller without excessive displacement. If the mixture ruts or shoves during compacting, rolling should be discontinued until there is a reduction in the moisture content to permit proper compaction.

After one course is thoroughly compacted, other courses can be placed on it. The spreading operation should be repeated as many times as required to bring the mat to the proper grade and cross slope. For a smooth top or surface course, the motor grader should be used to trim and level as the rollers complete compaction of the upper layer. When the mat has been shaped to its final required cross-section, finish roll with a steel-wheeled roller until all roller and other marks are eliminated.

The rollers most frequently used for the compaction of emulsion mixes are pneumatic-tired, vibratory smooth steel-wheeled, single or two drum, and static steel-wheeled rollers. With thicker lifts of dense-graded mix, vibratory padfoot rollers sometimes are used for breakdown rolling. The rolling equipment and how to be used will depend upon the type, properties and layer thickness of the emulsion mix.

## Emulsion Plant Mix (Cold)

The central or stationary plant mixing of emulsions allows for the production of very high quality mixes due to more precise control of materials. This method of mixing provides some advantages over hot mix asphalt:

- Economy - High production rates are combined with mobility and low capital cost in equipment. This mixing method is ideally suited for projects in remote locations.
- Low Pollution - Although some possible dust from stockpiles and hauling, the emissions are very low from central plant cold mix production, hauling, spreading and compaction.
- Safety - In high fire hazard areas, such as in forests and grasslands, the possibility of fires is greatly reduced because there is no dryer burner and flame.

## ➤➤ Mixing Plants

The production of high quality cold mixes requires a well-controlled operation. The setup for a central cold mix plant may vary depending on the quality required and the type of mix. However, as a minimum, it is recommended the plant have (1) a twin shaft pugmill [mixer], (2) a trailer or tank for emulsion storage, (3) metered pumps for emulsion and water and the piping, valves and

Figure 7.5 Cold-Mix Continuous Plant

spray bars for them, (4) one or more aggregate feeder bins, (5) belt conveyors for moving aggregate and mix, and (6) a power source. The pugmill should allow for variation in the mixing time to ensure proper coating of the aggregate with emulsion. Also, the use of a surge bin or storage silo is desirable for more continuous mixing and improved mix uniformity. Batch type pugmills can be used but the production of these mixes is ideally suited for continuous type mixers (Figure 7.5).

## ➤➤ *Laydown and Compaction*

For plant produced emulsion mixes, the paving procedures are similar to those used for hot mix asphalt. Base courses may be laid with self-propelled base spreaders or even with a blade. However, self-propelled pavers are recommended for heavy traffic surface courses. Cold mixes generally are stiffer or not as workable as hot mix asphalt, with open-graded mixtures being the most difficult to place. Proper paver operation is very critical to obtaining a uniform and smooth mat. This includes keeping the paver speed as constant as possible and the level of mix on the augers at a nearly constant depth. If mix sticks to the paver screed or tearing of the mat occurs, a change in the mixing time or the water content can eliminate the problem. The screed should not be heated.

Plant produced emulsion mixes are placed in lifts of 100 mm (4 in.) or more but compaction and curing proceeds quicker with lifts of 50 to 75 mm (2 to 3 in.). For open-graded mixes, the breaking of the asphalt emulsion usually occurs fairly quickly. With open-graded mixes, rolling normally may begin immediately behind the paver. However, the emulsion in dense-graded mixes typically does not break for some time. Because of the higher moisture contents for mixing, a delay in the compaction of dense-graded mixes is usually required. The amount of delay is dependent on the lift thickness and the curing conditions of air temperature, humidity and wind. The rate of water loss controls when compaction may begin.

Because of the extreme tackiness of open-graded mixes and an initial low stability until obtaining some aggregate interlock, the breakdown rolling is best accomplished with a static steel-wheeled roller. Vibratory rolling of open-graded mixes is not recommended because fracture of aggregate and asphalt bonding can occur. A light "choke" or "blotter" of a coarse sand or fine crusher screenings may be applied after steel-wheeled rolling. The choke or blotter permits rolling with a pneumatic-tired roller and prevents pick-up and damage by traffic. The sand or screenings is applied with a conventional self-propelled chip spreader or sand spinner at the rate of 3.3 to 6.6 kg/m$^2$ (6 to 12 lb/yd$^2$).

## ➤➤ *Precautions*

There are precautions that should be taken with cold asphalt emulsion-aggregate mixes to assure good performance:

- Dense-graded mixes normally have good resistance to water damage during construction. However, if rain occurs before the mixture is cured, traffic should be kept off, if possible, or limited until cured and the necessary compaction accomplished.
- The water content should be no more than is required to adequately disperse the emulsion and achieve good mix workability.
- Mixtures should mixed only enough to properly disperse the emulsion. Overmixing may cause the emulsion to break prematurely or strip from the aggregate.
- For faster curing, place the mix in several thin layers rather than in a single thick lift.
- These mixtures should not be sealed too soon. Entrapped water and petroleum distillates can create problems.
- If raveling occurs under traffic, the loose material should be broomed off as soon as possible to prevent further damage to the surface. If the raveling continues, the surface should be fog sealed with a light application of a slow-setting emulsion (SS or CSS) diluted with water. The rate of application and amount of water for dilution can be varied as required to prevent further raveling and a tacky surface and pickup by traffic.

## ➤➤ *Seal Coat*

Dense-graded and sand mixes normally require a seal coat for waterproofing and to provide a wearing surface. Chip seals are frequently used for dense-graded mixes but a fog or sand seal may be adequate in some situations. For open-graded mixes, a seal coat is not necessary except when required to prevent water from entering the pavement and going into the underlying base course or subgrade. As with any emulsion surface treatment, seal coats for asphalt emulsion-aggregate mixes need to be properly designed and applied. Do not apply the seal coat until the mixture has completely cured.

## Emulsion Plant Mix (Warm and Hot)

The production of warm and hot plant-mix using asphalt emulsion as the binder is somewhat comparable to the production of hot mix asphalt using asphalt cement. However, the mixing time is less and the plant operating temperatures are lower. An advantage of mixing at lower temperatures is the ability to coat large-size and open-graded aggregates with thick films of asphalt. Another benefit is the thorough mixing achieved because initial distribution of the asphalt occurs while the asphalt is emulsified and in a highly dispersed state. Also, this method of mixing significantly reduces the asphalt hardening when compared to conventional hot mix asphalt because of the water vapor produced.

### ➤➤ Materials

The aggregates should meet the quality requirements of ASTM, AASHTO, state or federal agency and other acceptable specifications. Other aggregates may be specified provided that local experience shows they have produced acceptable warm or hot asphalt emulsion paving mixtures. The production and blending of aggregates for these mixes requires the same degree of quality control as hot mix asphalt.

The asphalt emulsions normally used for warm and hot emulsion mixes are HFMS-2, HFMS-2h or polymer modified grades of these emulsions.

### ➤➤ Mixing Plants

The mixing plant may be either a batch or drum mix plant. On batch plants, the pugmill mixing chamber should be vented to allow for steam to escape. The discharge end of the asphalt emulsion circulating pipe should be kept below the surface of the emulsion in the storage tank to prevent foaming. Also, the asphalt transfer system must allow turning off or reducing the heat on all lines, pumps and jacketed asphalt weigh buckets. The temperature of the emulsion should never reach the boiling point of water [100°C (212°F)], and is usually kept below 85°C (185°F).

### ➤➤ Mixing and Temperatures

The minimum mixing time needs to be established and is based on the amount of coating of aggregate particles as determined by ASTM D2489, "Test for Degree of Particle Coating of Bituminous-Aggregate Mixtures." The minimum acceptable percentage of coated particles will vary with aggregate gradation, particle shape, surface texture, asphalt content and use of the warm or hot mixed material.

Warm asphalt emulsion mixes typically are produced at a temperature of 66 to 104°C (150 to 220°F). For hot emulsion mixes, the production temperature is 104 to 127°C (220 to 260°F).

### ➤➤ Construction Methods

Warm or hot emulsion mixes typically are spread with a self-propelled paving machine. In general, the same construction procedures are used for these mixtures as for hot mix asphalt. For hot emulsion mixtures, a minimum delay should occur between discharge from the mixing plant and placement to prevent the mix from becoming stiff and difficult to spread. However, some warm emulsion mixtures, produced with emulsions having very soft asphalt residues and a small quantity of solvent, may be stockpiled and placed cold.

For warm and hot emulsion mixes, compaction should begin when the mix will support the roller without shoving. For warm mixes, the breakdown rolling can be completed with a self-propelled pneumatic or double drum (tandem) vibratory roller followed by finish rolling with a steel-wheeled roller. For hot mixes, rolling should be accomplished with steel-wheeled static and/or vibratory rollers.

## Maintenance Mixtures

One of the most time-consuming maintenance activities is the patching of potholes and other weak or failed areas in the pavement. It is generally agreed that the use of high quality, hot mix asphalt (HMA) is preferred for the best results, even though it generally costs more initially. However, HMA is not available year-round in many locations. Therefore, maintenance patching often must be completed using stockpiled cold mixes.

No matter how good the characteristics of the mix, there is no substitute for good construction procedures when patching. Proper preparation of the pothole or other areas to be repaired is essential. The Asphalt Institute publication *Asphalt in Pavement Maintenance*, Manual Series No. 16 (MS-16), provides procedures for making repairs that, if properly followed, will ensure successful results.

Maintenance mixes consist of two types—-one for immediate use and the other for up to six months storage or stockpiling.

### ➤➤ Immediate Use Maintenance Mixes

Asphalt emulsions can be used very effectively in the preparation of maintenance mixtures for immediate use. The emulsion-aggregate mixture can be mixed in a pugmill and transported to the area where to be used. Although plant mixes are preferred, acceptable mixes can be produced with an asphalt distributor and mixing by cross-shaft mixer or blade at a mixing site. The heating of the aggregate is normally not necessary with emulsions as good coating and adhesion can be obtained without it.

The asphalt emulsions recommended for this purpose are CMS-2, CMS-2h, and HFMS-2s. Other types of emulsions may be acceptable if experience has proven them satisfactory. Aggregates should meet the quality requirements outlined previously for asphalt-aggregate mixtures. The aggregate gradations recommended are given in Table 7.2.

Asphalt emulsions containing small amounts of solvents generally produce the best cold patching mixes. The mixture does not gain full strength, however, until the solvent evaporates. Also, patching mixes should not be placed with an excess amount of mixing water due to the curing time required before the patch can opened to traffic.

Figure 7.6 Stockpiled Asphalt Emulsion-RAP Maintenance Mix

## ➤➤ *Stockpile Maintenance Mixes*

During the cold weather months, most maintenance mixes used are those stored in stockpiles. These mixes can be produced in late summer or early fall and transported and stored in quantity in remote locations for later use. Mixes are usable for periods up to six months and are workable without the use of heat. A thin crust normally is formed on the surface of the stockpile, but beneath the crust, the mix still has the characteristics of a freshly made mix.

The production of stockpile maintenance mixes is a relatively simple operation. The basic equipment required for mixing large quantities of mix includes a pugmill mixer and a system for obtaining both the correct amount of aggregate and asphalt emulsion. The control of materials is preferably done by weight. Recommended aggregate gradations for stockpile mixes are given in Table 7.2.

The completed mixture should be stored in a clean area to prevent contamination and not stored in a low area or depression where water could get into the mix. If available, mix storage in a covered area provides the best protection and helps retain mixture workability.

Stockpile life depends considerably on the formulation of the asphalt emulsion. Mix workability comes from using an emulsion that contains some solvent. Stockpile life and workability at low temperatures are in direct proportion to the amount of solvent in the emulsion. The use of solvents in asphalt materials is increasingly being limited by air quality requirements. However, asphalt emulsions normally have less solvent content than the cutback asphalts required for stockpiled mixes. For prolonged stockpiling and to be usable at lower temperatures, a high float medium setting HFMS-2s emulsion is recommended. Other nonstandard grades have also been used with success for stockpiling maintenance mixtures.

## ➤➤ Maintenance Mixes Using RAP

Many asphalt pavement overlay projects include cold planing/milling and can produce large quantities of reclaimed asphalt pavement (RAP). There are a number of uses for RAP in pavement applications, and an increasing one is the use of RAP to produce maintenance mixes.

It is recommended that, when possible, cold milling be used for pavement removal. Cold milling can produce RAP material in small enough pieces that would not require further crushing. Stockpile management is very important with RAP. Choose a location to stockpile the RAP where it can be processed and stored for maintenance uses. Separate RAP from sources and quality to create more uniform stockpiles.

Asphalt emulsion is usually added to the RAP by plant mixing. Special emulsion formulations have been developed for RAP maintenance mixes, since softening of the aged RAP asphalt binder is desired. Emulsion contents of 1 to 2.5 percent by dry weight of RAP are typical for these mixes. A mix design is recommended for determining the emulsion content. RAP maintenance mixes are stored in stockpiles (Figure 7.6) and their handling is very similar to other emulsion maintenance mixes.

These mixes are used successfully for both thin and deep patching, the latter including pothole repair. In areas where coarse, crushed aggregates are not available, the use of RAP usually results in superior maintenance mixes to those produced from local aggregates.

# MISCELLANEOUS APPLICATIONS

The previous chapters in this manual have described the use of asphalt emulsions for mixes and various types of surface treatments or seal coats. Asphalt emulsions can also be used for a number of other applications connected with both the construction and maintenance of paved surfaces. This chapter does not cover every possible use, but it offers guidelines for the more common ones.

## Tack Coat

A tack coat is a very light spray application of diluted asphalt emulsion (Figure 8.1). It is used to create a bond between an asphalt overlay being placed and the existing surface. A tack coat is recommended for all overlays. The only possible exception might be when an additional course is placed within two to three days on a freshly-laid asphalt surface.

Asphalt emulsions commonly used for tack coats are diluted SS-1, SS-1h, CSS-1 and CSS-1h. The emulsion is diluted by adding an equal amount of water. A test dilution is recommended to be certain that the water to be used is compatible with the emulsion. To prevent premature breaking, the water always is added to the emulsion and not the emulsion to the water. If practical, warm water is preferred for dilution. The diluted material typically is applied at a rate

Figure 8.1 Applying Tack Coat

of 0.25 to 0.70 l/m$^2$ (0.05 to 0.15 gal/yd$^2$). Tack coat should be applied only to an area that can be covered by the same day's paving.

The best results are obtained when the tack coat is applied while the pavement surface is dry and the surface temperature is above 25°C (80°F). The surface to be tack coated must be clean and free of loose material so it will adhere. A good tack coat results in a very thin but uniform coating of residual asphalt on the surface when the emulsion has broken.

Too much tack coat can create a slippage plane between two pavement courses as the asphalt acts as a lubricant instead of an adhesive. Fat spots or bleeding could occur on the surface of the new pavement that are not only unsightly but can produce slick pavement conditions. Pneumatic-tired rolling of spotty or non-uniform tack coats will help spread the asphalt and lessen the probability of fat spots.

After spraying the tack coat, time must be allowed before the overlay is placed for the complete breaking of the diluted emulsion (brown to black color). Traffic should be kept off of the tacked area. Freshly tacked pavement is generally too slick for safe driving, particularly before the emulsion has broken.

A tack coat also is essential in a good patching operation. The area to be patched must be thoroughly cleaned and all loose material removed. A fairly heavy tack coat of asphalt emulsion is then sprayed or painted over the entire area to be patched, including vertical sides. The tack coat helps hold the patch and provides a watertight seal between the patch and surrounding pavement.

## Mulch Treatment

Soil erosion presents a serious problem in the construction of embankments and areas adjacent to pavements. The most common method of preventing the erosion is the use of vegetation to stabilize these areas. However, during the time between the seeding and germination, seeds are susceptible to being washed and blown away.

Several procedures have been developed to protect the seeds until germination. An effective method is the use of asphalt emulsion as a spray mulch or a mulch tie-down. In these applications, asphalt emulsion leaves a thin membrane over the seeded area or holds a hay or straw mulch in-place. Both approaches have been successful and are designed to achieve the same result. Because they differ in procedure, each are discussed separately.

### ➤➤ Asphalt Emulsion Spray Mulch

In this system, the asphalt emulsion is sprayed directly onto the seeded area and forms a thin membrane cover. The thin film of asphalt has three beneficial effects:

- The asphalt cover holds the seeds in-place and prevents their loss by erosion.
- Because of its dark color, the asphalt absorbs and holds solar heat during the germination period.
- The asphalt membrane holds moisture in the soil and promotes faster germination and growth.

As the young seedlings emerge from the soil, they can break through the thin asphalt cover. The membrane eventually disintegrates as the seedlings mature and cover the entire ground area.

Asphalt emulsion grades typical for this application are SS-1, SS-1h, CSS-1 and CSS-1h. The application rate is normally 0.70 to 1.35 $l/m^2$ (0.15 to 0.30 $gal/yd^2$). Special care is required to apply the optimum amount of asphalt emulsion. The nature of the soil and the slope of the area being treated determine the exact amount. Too little emulsion may not hold the soil against erosion and too much may leave a thick membrane and delay growth.

The area to be mulched must be reasonably smooth so that uniform coating is possible. Depressions in the surface may collect pools of asphalt and ridges may be coated only on one side or with no asphalt on the other side. The asphalt emulsion can be applied with a hand-held spray nozzle or with an offset spray bar attached to an asphalt distributor.

## ➤➤ *Asphalt Emulsion Mulch Tie-Down*

Asphalt emulsion can be used for anchoring straw or hay to a seeded area. There are two procedures that can be used.

In one procedure, the straw or hay mulch is distributed over the prepared area at a rate of 3.4 to 4.5 tonnes/ha (1.5 to 2 tons/acre). The seed is then mixed with water and liquid fertilizer and applied with a hydraulic seeder. A spray application of about 0.45 $l/m^2$ (0.10 $gal/yd^2$) of asphalt emulsion follows (Figure 8.2). The emulsion can be applied in a solid pattern or a saw-tooth checkerboard or perpendicular pattern. The solid pattern is the most effective, especially when the wind velocity is high. If the amount of mulch is increased, the quantity of emulsion must be increased proportionally.

Figure 8.2 Using Asphalt Emulsion to Tie Down Mulch

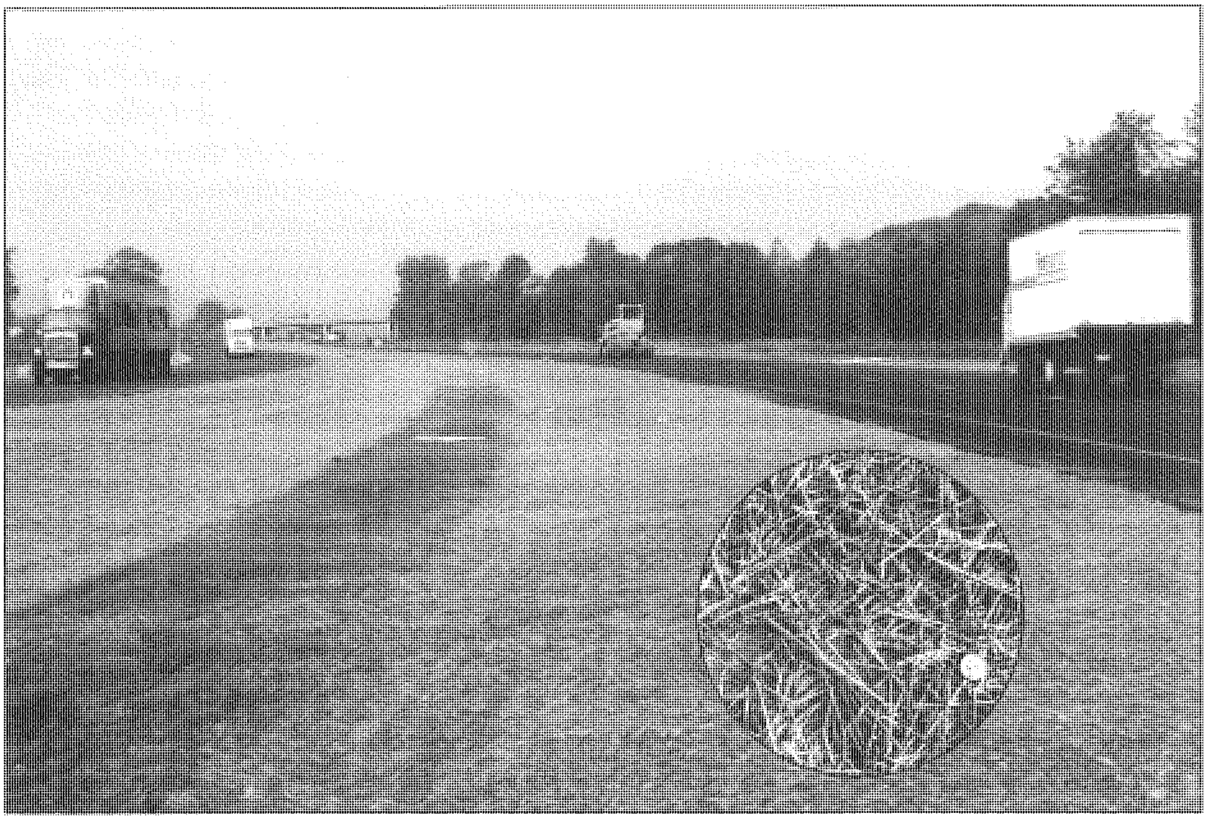

Figure 8.3 Completed Section of Interstate Highway With Asphalt Emulsion Mulch on Median and Close-Up

The second method begins with the hydraulic application of seed and fertilizer directly to the prepared soil. The mulch and emulsion are discharged together through a special blower equipped with twin jets and the two materials are mixed in flight (Figure 8.3). This procedure has at least two advantages:

- Mulch and asphalt emulsion are applied in a single application reducing both cost and time required
- It results in better bonding between the emulsion and the hay/straw mulch

The asphalt emulsions used with mulch tie-down are SS-1, SS-1h, CSS-1, and CSS-1h.

## Crack Sealing

A maintenance department can devote a large amount of time and money sealing cracks in pavement surfaces. Depending upon the location and size of the cracks, this maintenance may be considered either corrective or preventive. In either case, the technique for sealing cracks is the same.

Cracking occurs in many forms, from small hairline cracks to major cracks having a width of 25 mm (1 in) or more. Larger cracks or more severely cracked areas may not always be correctable crack sealing. It is often necessary to completely remove the cracked material and repair the area with a full-depth or deep asphalt patch.

Knowledge about the more common types of cracking helps determine the proper maintenance procedure. Cracks generally fall into one of these following categories:

- Alligator cracks: Interconnected cracks forming a series of small blocks resembling an alligator's skin or chicken wire.
- Edge cracking: Cracking that occurs along the outer edge of the pavement, usually within 300 to 600 mm (1 to 2 ft) of the edge and when paved shoulders do not exist.
- Reflective cracks: Cracks in asphalt overlays and surface treatments that reflect the crack pattern in the pavement structure below.
- Shrinkage or block cracks: Interconnected cracks forming a series of large blocks, usually with sharp corners or angles.
- Slippage cracks: Crescent shaped cracks that point in the direction of the thrust of the wheels on the pavement surface.
- Linear cracks: A crack that may be parallel or transverse to the centerline, or randomly located in the pavement surface.

If cracking results from a defect beneath the pavement surface, it is doubtful that sealing the cracks will provide a long-term solution. In many instances, correction of the defect in the underlying pavement is necessary to solve the cracking problem. This section only addresses the type of cracking that can be addressed with asphalt emulsion as a sealant, i.e., longitudinal, reflective, shrinkage and linear cracks. For more information on pavement repair procedures, refer to *Asphalt in Pavement Maintenance*, Manual Series No. 16 (MS-16), Asphalt Institute.

The best time for sealing is as soon as possible after a crack develops. A crack can continue to widen, so crack sealing must be continued to be effective. The failure to seal cracks properly can lead to further and more severe pavement damage from water intrusion and freeze-thaw. Sealing cracks with asphalt emulsion is relatively simple and inexpensive and can delay or postpone major maintenance if properly used.

Before cracks are to be filled, loose material in the crack should be blown out using compressed air. Foreign material not removal by blowing should be removed by steel wire brush or router.

Crack sealing may begin when the cracks have been properly prepared. Small cracks, less than 6 mm (1/4 in.) width, are difficult to seal effectively. For large cracks, an asphalt emulsion slurry, or emulsion mixed with sand, should be forced into the crack until it is about 3 to 6 mm (1/8 to 1/4 in.) from the surface. After curing has occurred, finish sealing by filling the remaining depth of the crack with asphalt emulsion (Figure 8.4). The surface of the sealed crack should be covered with a light application of dry sand to prevent pickup by traffic.

The asphalt emulsion grades used for crack sealing are SS-1, SS-1h, CSS-1 and CSS-1h.

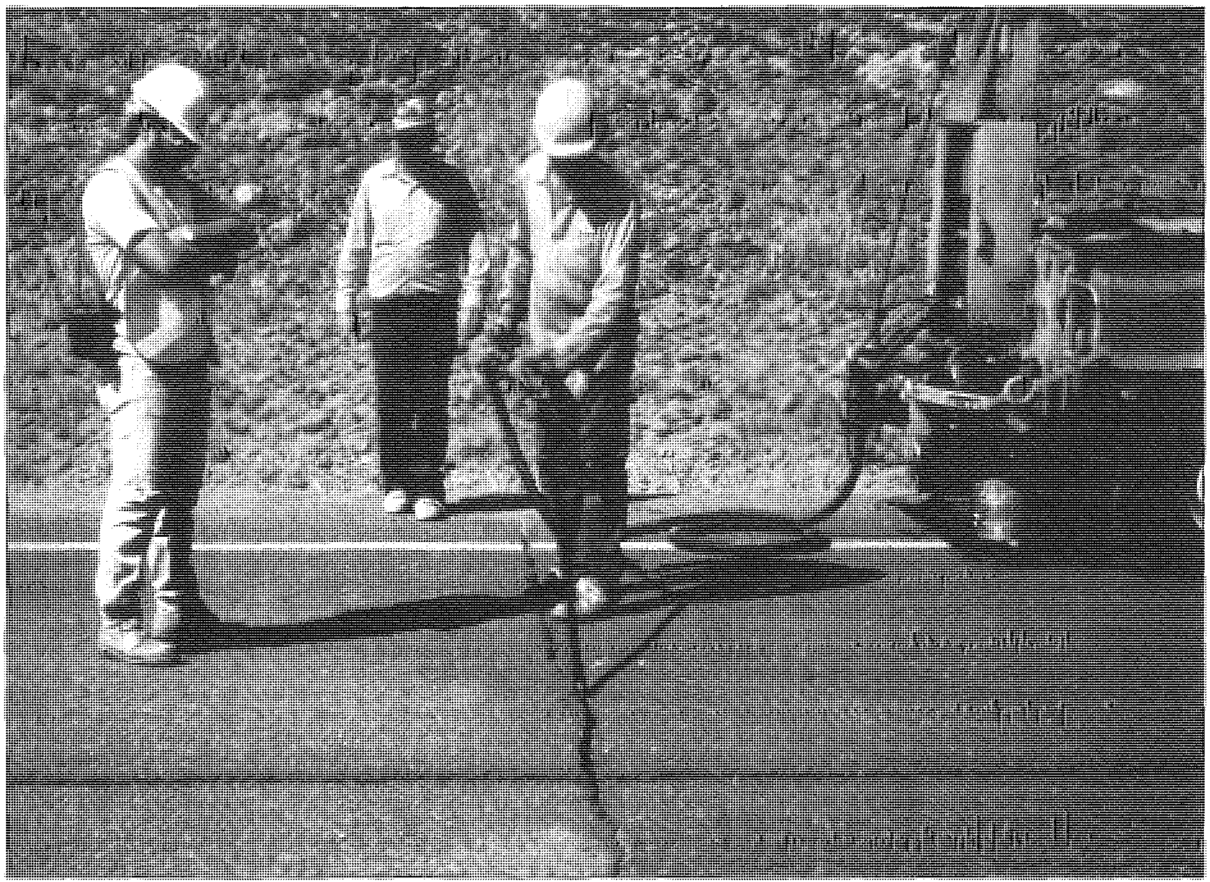

Figure 8.4 Filling a Crack With Asphalt Emulsion

**Prime Coat** Prime coats typically have been spray applications of low viscosity asphalt on granular base in preparation for placing an asphalt mixture. A prime coat performs several important functions:

- Coats and bonds loose mineral particles on the surface of the base
- Hardens or toughens the surface of the base
- Waterproofs the surface of the base by plugging capillary or interconnected voids
- Provides adhesion or bond between the base and the asphalt mixture

In order for the prime coat to satisfy these functions, some asphalt must penetrate into the base.

Prime coats generally are being used less frequently, particularly when the total asphalt thickness is 100 mm (4 in.) or greater. With increased asphalt thickness, there is less possibility of surface water penetration into and pavement slippage on the base. A prime coat should be considered, however, when a granular base is to be carried through an extended period, such as the winter months, or when to be exposed to abrasion damage by traffic. Even though some engineers question the benefits of priming, it should be considered when any doubts exist about the results if it were eliminated.

In the past, the asphalt for prime coating was usually a low viscosity, medium or rapid curing (MC or RC) cutback asphalt. The use of asphalt emulsions is increasing and new emulsion grades have been developed for priming. SS-1, SS-1h, CSS-1 and CSS-1h can be used if they are mix-in-place with the top 50-75 mm (2-3 in.) of the aggregate base "Penetrating emulsion prime" (PEP) and "asphalt emulsion prime" (AEP) grades are also now available.

The emulsion grade and/or technique selected to replace cutback asphalt for a penetrating prime will depend upon a number of factors. The amount and size of voids in the base material will influence emulsion penetration and determine the emulsion grade, application rate, dilution, and if multiple applications and mixing are required.

When the base surface consists of fine grained materials, those passing the 75 µm (No. 200) sieve, the surface will act as a filter and not let the emulsion asphalt particles penetrate. Dampening the surface and/or the adding surfactants cannot overcome the filtering action. Being a mechanical problem, it requires a mechanical solution. Therefore, the surface may need to be loosened by scarifying and the emulsion mixed to a specific depth for an acceptable prime.

Emulsions for priming almost always require dilution with water. The dilution rates normally have ranged from 1:1 to 10:1 (water to emulsion) dependent upon the base material characteristics and method of treatment. The application rates can vary for a 1:1 diluted emulsion from as low as 2.3 $l/m^2$ (0.5 $gal/yd^2$) for high fines and tight bases and up to 6.8 $l/m^2$ (1.5 $gal/yd^2$) for loose sands and very porous surfaces. In very dense material, it may be necessary to use a higher dilution and make multiple applications at lower rates. This is done to improve penetration and prevent runoff and puddling of the emulsion.

## Dust Palliative

On a road without an asphalt surface, one vehicle per day can create a large quantity of dust. Also, accident rates are much higher on unsurfaced roads. A lack of funding and very low traffic volume may not allow for placing an asphalt mixture or surface treatment, so another method is required for dust control.

Asphalt emulsion can be a practical and low cost solution to controlling dust problems. A diluted emulsion is sprayed directly on the unsurfaced road as a dust control agent or palliative. SS-1, SS-1h, CSS-1 and CSS-1h diluted with five or more parts of water by volume are used. The diluted material is sprayed with an asphalt distributor in repeated light applications as required. The application rates normally are from 0.45 to 2.3 $l/m^2$ (0.1 to 0.5 $gal/yd^2$). The total quantity applied depends on the condition of the existing surface.

Some penetration of the emulsion is expected and with higher voids, more emulsion can be applied. As with other spray treatments without cover material, small test sections are recommended to determine the best application rate for the existing road conditions.

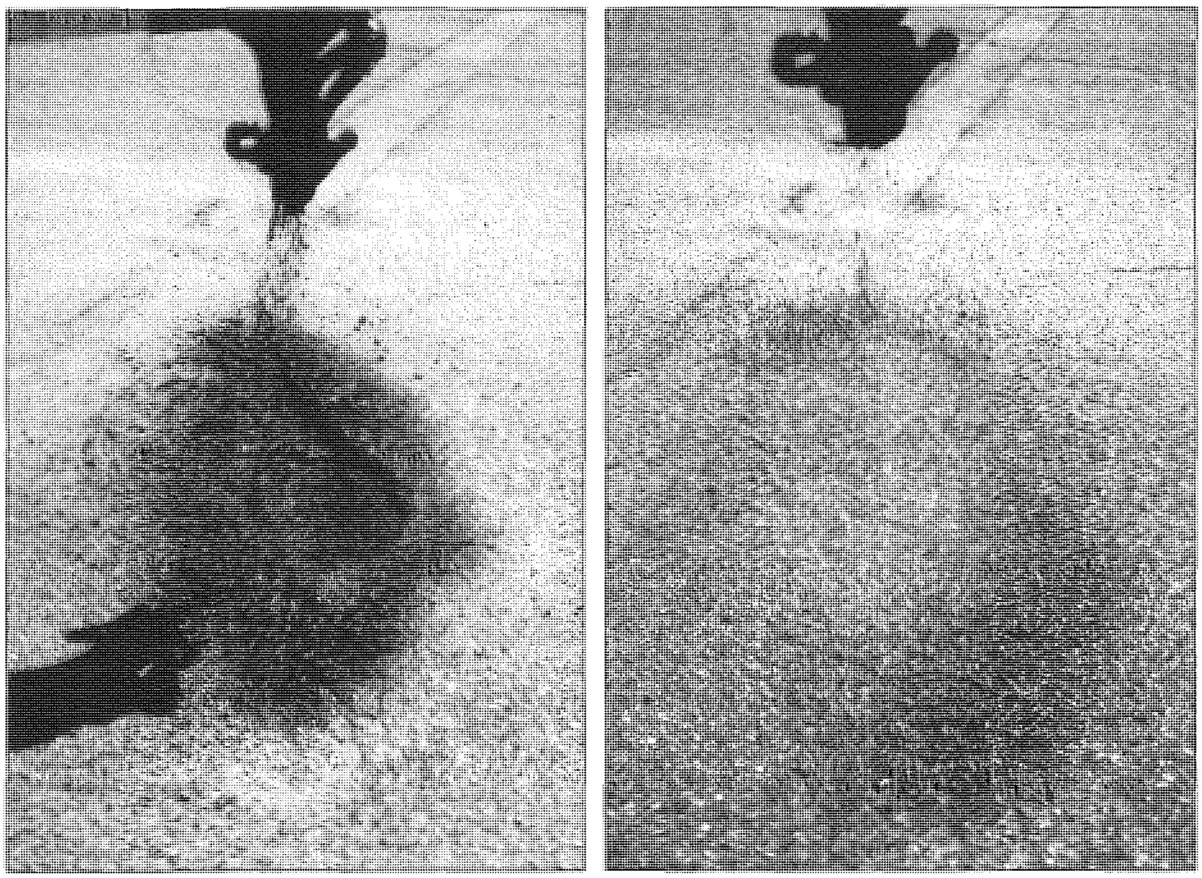

Figure 8.5 Spray-Injection Process – Tack Coat (L), Completed Patch (R)

**Repair of Potholes**

The methods typically used for the repair of potholes using asphalt emulsions are throw-and-roll, semi-permanent and full-depth removal and replacement. All of these methods involve placing cold mix in the pothole with a shovel and compacting with a truck tire, vibratory plate compactor or steel-wheeled roller. Maintenance mixes for these repair methods and other patching are covered in Chapter 9 of this Manual. For information on pavement repair procedures, refer to *Asphalt in Pavement Maintenance*, Manual Series No. 16 (MS-16), Asphalt Institute.

Another method for repairing potholes is by spray-injection. A special piece of equipment, either trailer or truck-mounted, combines together and blows asphalt emulsion and coarse crushed aggregate into the pothole (see Figure 8.5). The spray-injection procedure consists of these steps:

- Blowing of water and debris from the pothole.
- Spraying a tack coat of asphalt emulsion on the sides and bottom of the pothole.
- Blowing of emulsion and aggregate into the pothole.
- Covering the repaired area with a thin layer of aggregate.
- Opening the repair to traffic as soon as workers and equipment are clear. (This method of repair requires no compacting after the cover aggregate has been placed.)

Experience has shown that the asphalt emulsion to use for spray injection varies between summer and winter application. Summer application, for temperatures above 10°C (50°F), works best with CRS-2, RS-2 or HFRS-2 grades. Limiting the penetration of the residue to a maximum of 135 within the range allowed in the emulsion specification has also shown beneficial in the performance of spray-injected patches placed in warm weather.

Winter applications [colder than 10°C (50°F)] call for a CMS-2, MS-2 or HFMS-2 emulsion. Requiring the penetration of the residue to be a minimum of 135 within the range allowed in the emulsion specification has also shown beneficial in the performance of spray-injected patches placed in cool weather.

For good aggregate coating under either temperature condition, experience has shown the emulsion temperature should be about 65°C (150°F), and the emulsion's Saybolt Furol viscosity at 50°C (122°F) should be limited to 250 seconds.

Aggregate sizes that work best for spray injection are AASHTO or ASTM size No. 9 [4.75 to 1.18 mm (No. 4 to No. 16)] with no more than 3 percent passing the 75 μm (No. 200) sieve. Crushed aggregate material is recommended for spray injection. Using the emulsions described above, an asphalt emulsion content of approximately seven percent by weight of aggregate works best for warm weather conditions, while spray injection patched placed in winter conditions perform well at an asphalt emulsion content of about five percent by weight of aggregate.

Recycling is defined as "the reuse, usually after some processing, of a material that already has served its first-intended purpose". Relative to asphalt pavement recycling, there are several methods available. Therefore, each project being considered for recycling must be carefully evaluated to determine the method most appropriate. The factors should include: (1) existing pavement condition, (2) existing pavement material types and thickness, (3) recycled pavement structural requirements and (4) availability of recycling additives.

## Types of Recycling

The Asphalt Recycling and Reclaiming Association (ARRA) recognizes five types of asphalt pavement recycling:

- Cold Planing – The asphalt pavement is removed to a specified depth and the surface is restored to a desired grade and cross slope and free of humps, ruts and other surface imperfections. The pavement removal or "milling" is completed with a self-propelled rotary drum cold planing machine. The reclaimed asphalt pavement (RAP) is transferred to trucks for removal and stockpiled for hot or cold recycling.
- Hot Recycling – RAP is combined with new aggregate and asphalt cement and/or recycling agent to produce hot mix asphalt (HMA). Although batch type hot mix plants are used, drum plants typically are used to produce the recycled mix. Most of the RAP is produced by cold planing but also can be produced from pavement removal and crushing. The mix placement and compacting equipment and procedures are those typical of HMA construction.
- Hot In-Place Recycling – The recycling is performed on-site, in-place and the pavement typically is processed to a depth of from 20 to 40 mm (3/4 to 1-1/2 in.). The asphalt pavement is heated, softened and scarified to the depth specified. An asphalt emulsion or other recycling agent is added, and with one of the processes, new HMA is incorporated as required. The three hot in-place recycling methods are heater-scarification, repaving and remixing.
- Cold Recycling – Although cold recycling is performed using the central or stationary plant process, the method most commonly used is cold in-place recycling (CIR). For CIR, the existing asphalt pavement typically is processed to a depth of from 50 to 100 mm (2 to 4 in.). The pavement is pulverized and the reclaimed material is mixed with an asphalt emulsion or emulsified recycling agent, spread and compacted to produce a base course. Cold recycled bases require a new asphalt surface. Lower traffic pavements may use an asphalt emulsion surface treatment. Higher traffic pavements may use a modified emulsion surface treatment or an HMA surface.
- Full-Depth Reclamation – With FDR, all of the pavement section, and in some cases a predetermined amount of underlying material, are mixed

with asphalt emulsion to produce a stabilized base course. Base problems can be corrected with this construction. Full depth reclamation consists of six basic steps: pulverization, additive and/or emulsion incorporation, spreading, compacting, shaping, and placement of new asphalt surface.

This chapter will describe those methods where asphalt emulsions are most frequently used — cold recycling and full depth reclamation.

## Candidates for Recycling

A candidate for recycling is usually an old asphalt pavement, from hot mix asphalt to an aggregate base with surface treatment. Candidate pavements will have severe cracking and disintegration, such as pot holes (Figure 9.1). Frequently the poor condition is due to the pavement being too thin or weak for the traffic and so it is being over-stressed. Poor drainage can also accelerate the rate and amount of pavement deterioration. All types of asphalt pavements can be recycled: low, medium and high traffic volume highways, county roads, city streets, airport taxiways, runways and aprons, and parking lots. Many asphalt pavements have aggregate bases and some sandy soils for the subgrade, allowing both upgrading and strengthening by stabilization with asphalt emulsion.

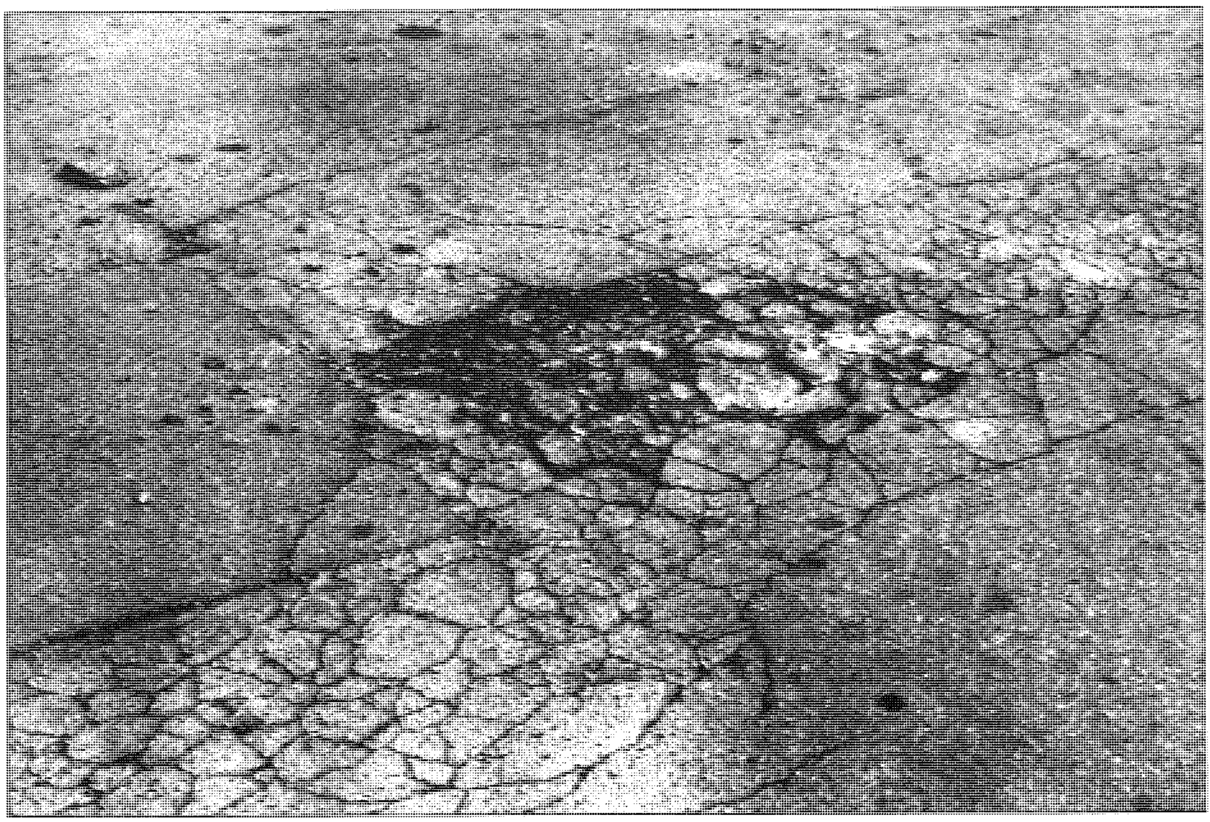

Figure 9.1 Deteriorated Asphalt Pavement and Candidate for Recycling

**Table 9.1 Materials Evaluation Procedures – Cold Recycling and Full-Depth Reclamation**

| Characteristics | Method of Test | |
|---|---|---|
| | ASTM | AASHTO |
| Bitumen content of bituminous paving mixture | D 2172 | T 164 |
| Recovered asphalt from a bituminous paving mixture | D 1856 | T 170 |
| Sieve analysis of fine and coarse aggregates | C 136 | T 27 |
| Amount of materials finer than 75 µm (No. 200) sieve in mineral aggregate by washing | C 117 | T 11 |
| Liquid limit, plastic limit and plasticity index of soil | D 4318 | T 89/90 |
| Sand equivalent value of soil or aggregate | D 2419 | T 176 |
| Penetration of bituminous materials | D 5 | T 49 |
| Viscosity of asphalt by vacuum capillary viscometer | D 2171 | T 202 |

An essential part of selecting any asphalt pavement rehabilitation method is determining the existing pavement condition. The type and amount of pavement defects need to be evaluated. The strength of the current pavement structure and its materials needs to be determined. The current and future traffic needs must be investigated.

Very important to the success of pavement recycling is proper materials sampling and testing. Pavement cores and/or test holes are used to determine the type, thickness and condition of the various pavement layers and to obtain representative samples for laboratory testing. For asphalt materials, testing typically includes conventional asphalt extraction for both asphalt content and aggregate sieve analysis. For cold recycling, a solvent or "Abson" recovery also may be included to determine the asphalt properties, including penetration at 25°C (77°F) and absolute viscosity at 60°C (140°F). For aggregate bases and subgrade soils, a washed sieve analysis and sand equivalent or plasticity index are normally completed. The typical tests performed are in Table 9.1. A mixture design is required to determine the type and amount of asphalt emulsion or emulsified recycling agent, premixing water content (if new aggregate is required), and the stability and strength (modulus) properties of the recycled mixture.

## Advantages

Cold recycling and full depth reclamation of asphalt pavements provide many environmental and other advantages:

- Natural resources are conserved through the reuse/salvaging of aggregate and asphalt in existing pavements.
- Pavement materials disposal is greatly reduced or eliminated.
- Energy is conserved as the construction is completed in-place/on-grade and no fuel is required for heating.

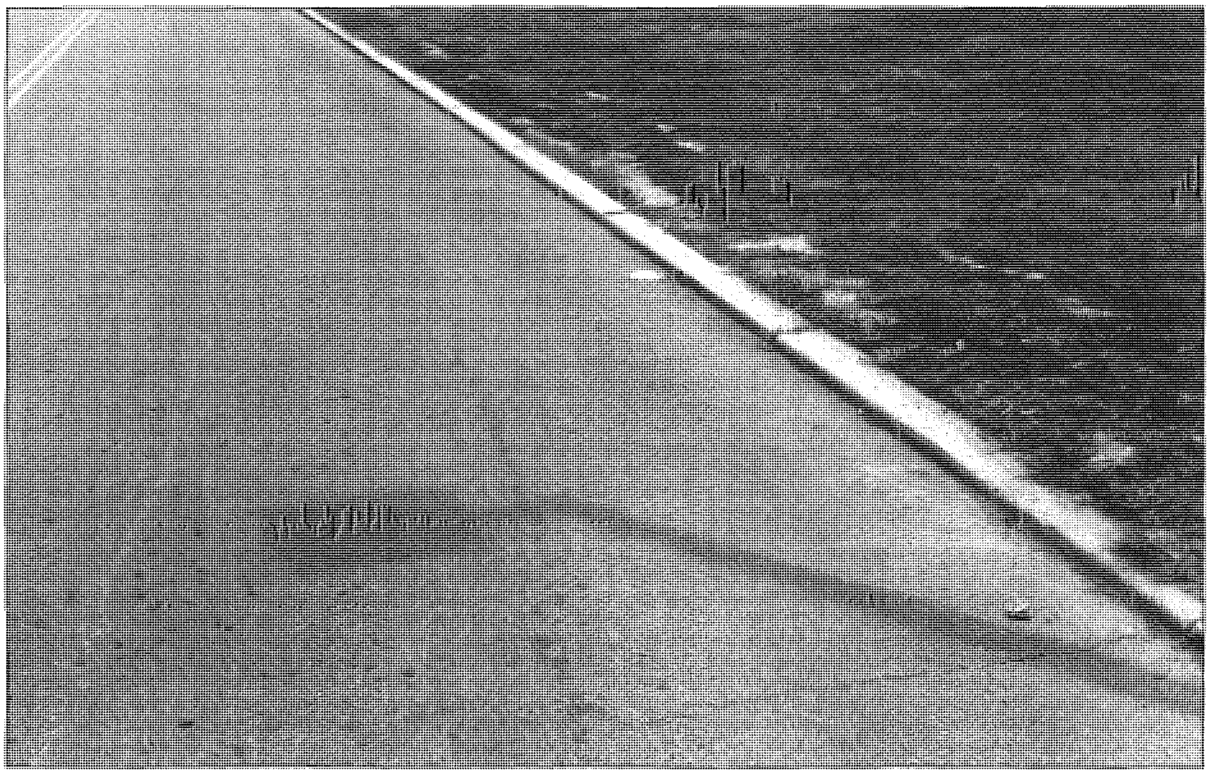

Figure 9.2 Loss of Curb Height/Reveal and Drainage Capacity

- Reflective cracking can be controlled since it is normally reduced or delayed with CIR and eliminated by FDR.
- Pavement crown and cross slope can be improved or restored.
- Loss of curb reveal can be reduced or eliminated (Figure 9.2).
- Pavement maintenance costs can be reduced.

## Cold Recycling

The emulsions typically used are the medium-setting grades of regular MS and CMS, high float HFMS and polymer modified versions of these grades. For some cold recycling, cationic slow-setting grades of CSS-1 and CSS-1h have been used. New aggregate can be added to improve mixture gradation or to reduce the asphalt content if necessary. Also, to increase recycled mixture early strength and resistance to water damage, small amounts of cement or lime can be added (1 to 1.5% by weight of RAP). Cement and lime were initially added dry but now are being added as a slurry (cement or lime and water). Cold recycling can be either by central/ stationary plant mixing or mixing in-place/on-grade.

### ➤➤ Plant Mixed

When plant mix cold recycling, the reclaimed asphalt pavement is usually obtained by cold planing or milling (Figure 9.3) and the RAP hauled to the plant site and stockpiled. Cold mixing plants normally consist of (1) a feed hopper or hoppers, (2) conveyor belts, (3) twin-shaft pugmill

Figure 9.3 Cold Planing/Milling Machine Removing Asphalt Pavement

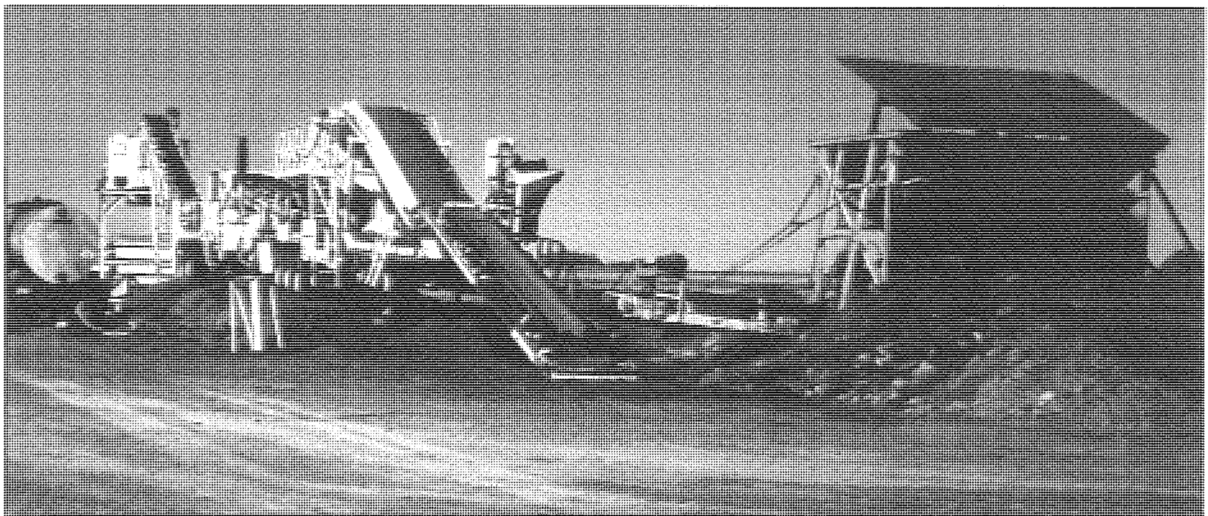

Figure 9.4 Central/Stationary Plan With RAP Sizing Unit

mixer, (4) emulsion and water meters, valves, piping and spray bars, (5) emulsion and water tanks or tankers, (6) mix storage bin or silo, and (7) a power supply (Figure 9.4). Some mixing plants also may have a screening and crushing unit to reduce any agglomerated, oversized RAP. The cold plant recycled mix is hauled to the paving site in either end or bottom dump trucks. Spreading is with a conventional self-propelled asphalt paver or motor grader and compacting by pneumatic-tired or steel-wheeled rollers (see Chapter 7). An emulsion surface treatment or HMA surface is required for waterproofing and to provide a wearing course.

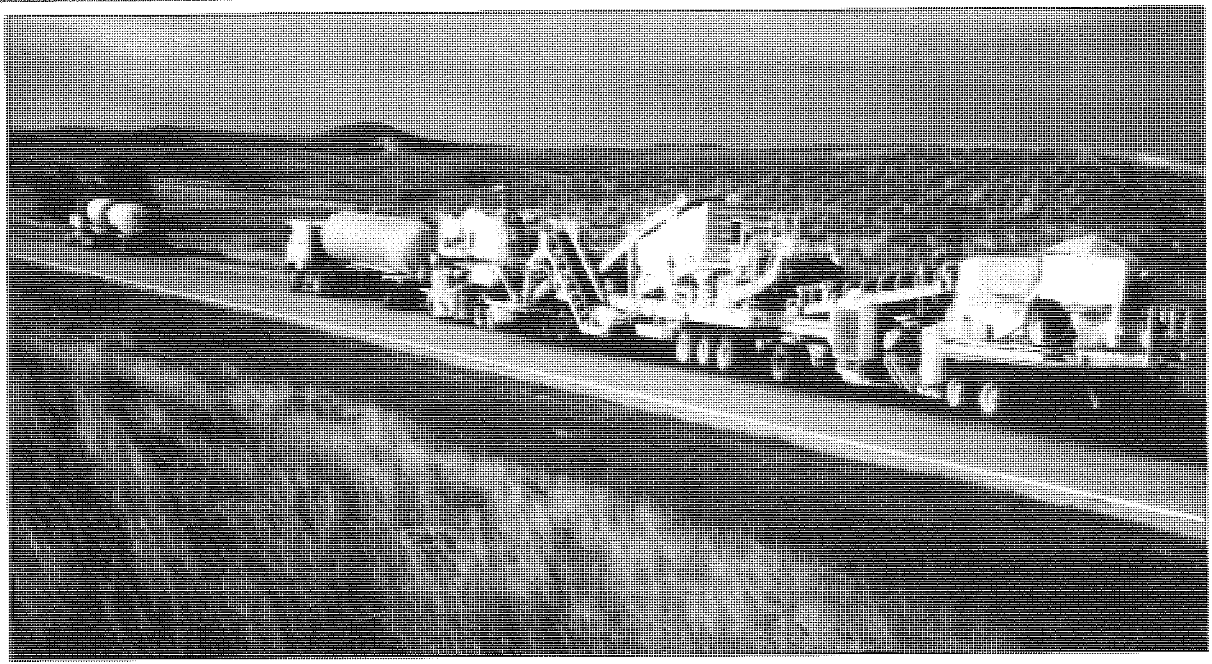

Figure 9.5 Multiple Unit or "Train" for Cold In-Place Recycling

## ➤➤ *Mixed In-Place*

This method of cold recycling has gained widespread acceptance and is the most cost effective because of being completed in-place and on-grade. The existing asphalt pavement is typically recycled by either single unit or multiple unit (train) processing (Figure 9.5). With either of these processes, the total gradation of the pulverized pavement is controlled by the maximum particle size.

The first step in CIR is pulverization of the asphalt pavement, usually with a cold planing or milling machine. Water is sprayed on the milling machine cutting head to cool the carbide tipped cutting teeth. The water application rate must also be controlled because it acts as the pre-wetting water in the emulsion mix. The addition and mixing of asphalt emulsion may be by a milling machine with single unit processing or with a travel plant/paver or trailer mounted pugmill for multiple unit processing (Figure 9.5). Although spreading can accomplished with a motor grader, most CIR mix is placed with a conventional self-propelled asphalt paver equipped with automatic screed control to provide the desired depth, cross slope and smoothness.

Proper compaction procedures are required for cold recycled mixes, whether produced by central plant or in-place mixing methods. With an uncompacted lift thickness up to 150 mm (6 in.), a delay in beginning the initial or breakdown rolling usually is required. The time of delay in rolling is dependent upon how rapidly the asphalt emulsion breaks (begins to turn from a brown to black color). Besides the breaking characteristics of the emulsion, the depth of mix and climatic conditions (temperature, humidity and wind) influence when rolling can begin. With thicker lifts, a large pneumatic-tired roller is usually specified. The roller is required to have a mass of 23 to 27 tonnes (25 to 30 tons) and tire pressures of 620 kPa (90 psi). A tandem vibratory steel-wheeled roller normally is used for both intermediate and finish rolling, the former with vibration and the latter operated statically.

If the surface of the CIR ravels when opened to traffic, a fog seal of diluted slow setting emulsion should be applied. If raveling occurs, the amount of emulsion in the cold recycled mix may need to be increased. Adequate curing of the cold recycled mixes is required prior to placement of any new asphalt surface course. Inadequate curing can produce high retained moisture contents that increase the possibility of asphalt stripping and slow rates of strength development after the surface is placed.

## Full-Depth Reclamation

When an asphalt pavement has insufficient structural strength, full depth reclamation with asphalt emulsion may be the solution. The depth of FDR depends upon the existing pavement thickness, subgrade soil conditions and future traffic. The depth typically ranges from 150 to 250 mm (6 to 10 in.). The existing asphalt mix, granular base and sometimes subgrade soil are processed on-grade and in-place, and treated with an asphalt emulsion to produce a new pavement with improved load carrying capability. The process uses 100 percent of the materials and the recycles the complete pavement.

The pulverization of the asphalt pavement and mixing of the asphalt emulsion normally are accomplished with road reclaiming machines (Figure 9.6). During pulverization, new aggregate or RAP may be added. Asphalt emulsion may be added with an asphalt distributor but will require multiple emulsion applications and mixings. The emulsion typically is added through a metered

Figure 9.6 Asphalt Pavement Reclaiming Machine Adding Asphalt Emulsion

liquid system on the reclaiming machine, producing better control of the asphalt content and increased productivity.

Compaction procedures for full depth reclaimed materials are very similar to those for conventional asphalt emulsion mixes as pneumatic-tired and steel-wheeled rollers are used. Generally the depth of compaction should be limited to 100 mm (4 in.) per lift. However, lifts of 125 to 150 mm (5 to 6 in) and more in depth have been placed when initial rolling has been with vibratory padfoot rollers that compact from the bottom up.

When a rolling procedure results in cracking or severe displacement of the mix, it should be discontinued until the problem is identified and eliminated. In some instances, the problem may be an underlying wet, weak subgrade. This condition must be corrected by drying or stabilization with cement, fly ash or lime before FDR can proceed.

An important step in the FDR process is the final grading of the surface. This work typically is completed with a motor grader. The final grading is particularly important if the final surface is to be an asphalt emulsion surface treatment. For some highway and airport projects, the finished surface may be established by trimming with a cold planing/milling machine having automatic grade and cross slope control and using a fixed reference or stringline.

As with other types of asphalt emulsion paving, FDR bases require waterproofing and a wearing course. Although HMA is generally used, single or double chip seals, slurry seals or other asphalt surface treatments may be all that is required for low traffic volumes. Also, high quality cold emulsion mixes, such as open-graded asphalt emulsion mix, are being placed as the surface course.

# MIX DESIGN METHODS

There is no universally accepted asphalt emulsion-aggregate mix design method for either dense or open-graded cold mixtures. However, nearly all of the dense-graded methods are modifications of the Hveem (ASTM D 1560 and 1561 or AASHTO T 246 and 247) or Marshall (ASTM D 1559 or AASHTO T245) test methods.

The attempt in this chapter is to standardize two design methods for use with asphalt emulsion cold mixtures. One method is for the design of mixes having dense-graded aggregate and the second for mixes having open-graded aggregate. The method for open-graded mixes is based on a procedure developed by the Pennsylvania Department of Transportation. In trying to achieve somewhat standardized design procedures, consideration is given to currently used designs, availability of equipment and different emulsion and aggregate types. These procedures should be viewed as provisional as new procedures and equipment, such as those resulting from the Strategic Highway Research Program (SHRP), will be applied to future asphalt emulsion-aggregate mix design procedures.

## Dense-Graded Aggregate Mix Design

This design method is for asphalt emulsion cold mixtures containing dense-graded mineral aggregates with a maximum size of 25 mm (1 in.) or less and either medium or slow setting types of emulsions. This design method is applicable to mixtures produced by either road or plant mixing at ambient temperatures and whether placed immediately or stockpiled for later placement.

### ➤➤ Aggregates

Dense-graded aggregates meeting the requirements of Table 7.2 are among those suitable for asphalt emulsion mixtures. For the gradations containing appreciable fines, aeration or drying prior to compaction may be required.

### ➤➤ Asphalt Emulsions

Two types of asphalt emulsions are used for producing dense-graded emulsion cold mixtures — slow setting (SS) and medium setting (MS) types. Medium setting emulsions are normally used with aggregates that do not have excessive amounts of material passing the 75 µm (No. 200) sieve and/or if stockpiling of the mixture is desired. Conversely, slow setting emulsions normally are used with more dense aggregates [higher amounts of material passing 75 µm (No. 200) sieve] and stockpiling is not desired.

## ➤➤ Determination of Trial Emulsion Content

There are several procedures available to determine a design starting point for the trial emulsion or residual asphalt content of a mixture. For this design procedure, two simple formulas are used within the procedure — one for base mixtures and another one for surface mixtures. The formulas are based on the percentage of aggregate passing the 4.75 mm (No. 4) sieve and in most cases will give a satisfactory starting point.

1. Determine the Residue Content of the Asphalt Emulsion to be used using ASTM D 244, "Residue and Oil Distillate by Distillation".
2. Estimate an Initial Emulsion Content based on the Dry Weight of Aggregate using the appropriate formula for the mix being designed:

Base Mixtures
$$\%\ Emulsion = \frac{[(0.06 \times B) + (0.01 \times C)] \times 100}{A}$$

Surface Mixtures
$$\%\ Emulsion = \frac{[(0.07 \times B) + (0.03 \times C)] \times 100}{A}$$

where:

% Emulsion = Estimated initial percent asphalt emulsion by dry weight of aggregate
A = Percent residue of emulsion by distillation (Step 1)
B = Percent of dry aggregate passing 4.75 mm (No. 4) sieve
C = 100 - B = Dry aggregate retained on 4.75mm (No. 4) sieve

## ➤➤ Coating and Adhesion Testing

The preliminary evaluation of each asphalt emulsion selected for mixture design is accomplished through a coating test and an adhesion test. The trial emulsion content determined above is combined with the damp job aggregate, corrected to a dry weight. The coating is visually estimated as satisfactory or unsatisfactory for the intended use of the mix. Surface mixtures normally require a much greater degree of coating than do base mixtures.

Some asphalt emulsions may require pre-mixing water. If balling of the asphalt with fines is observed, coating at additional water contents should be evaluated. If the degree of coating is considered satisfactory, then the adhesion test is completed. If the coating is considered unacceptable, the emulsion used should be modified or another emulsion selected and the mix design started over.

**A. Coating Testing Procedure**

(1) Determine the moisture content of a representative sample of the aggregate. Care must be taken to maintain the moisture in the field sample. If the aggregate is received dry or dried for blending, the estimated stockpile moisture must be added to the aggregate or individual combined aggregate samples 24 hours prior to performing any test.

(2) Weight the equivalent of 500 grams of dry aggregate (500 grams + moisture) into a suitable mixing bowl.

(3) If required, weigh in the premixing water and mix by hand for 10 seconds or until visually uniformly dispersed.

(4) Weigh in the trial emulsion content to the moist aggregate at the anticipated use temperature and mix vigorously by hand for 60 seconds or until sufficient dispersion has occurred throughout the mixture.

(5) Place the mixture on a flat surface and visually estimate the degree of coating. If desired, a portion of the fresh mix can be evaluated for water resistance by totally submersing the mix in water (about twice the volume of water to mix) and then pouring off the water, placing the mixture on a flat surface and visually estimating the degree of retained coating. If satisfactory, check the asphalt adhesion. If the adhesion is not acceptable, then the emulsion used should modified or another grade selected.

**B. Adhesion Testing Procedure**

(1) Cure a 100 gram portion of the above produced mix (not submersed in water) in a shallow container for 24 hours in a forced draft oven at 60°C (140°F).

(2) Put the oven-cured mix in a 600-ml beaker containing 400 ml of boiling distilled water.

(3) Bring the water back to boiling and maintain boiling and stir the water at one revolution per second for three minutes.

(4) Pour off the water and place the mix on a piece of white absorbent paper.

(5) After the mix has dried, visually evaluate the amount (percent) of retained asphalt coating. If satisfactory, continue the mix design or if not acceptable, then the emulsion used should be modified or another grade selected.

## ➤➤ *Preparation of Test Specimens*

Prepare three or more specimens each at a minimum of three different emulsion contents, with one below and one above the trial emulsion content. If the mixture in the coating test appears to be dry, start with the trial emulsion content and increase the content for each of the other two content levels. Conversely, if the mixture in the coating test appears rich, reduce the content for the other levels. A normal difference between the emulsion contents is one percent, or a residual asphalt content difference of 0.65% for an emulsion with a 65% residual content.

**A. Mixing Procedure**

(1) Weigh into suitable mixing bowls the appropriate amount of wet job aggregate, corrected to a dry aggregate weight, to obtain a compacted specimen height of 63.5 ± 6 mm (2.5 ± 0.25 in.) for each individual batch. The amount normally required is about 1200 grams of dry aggregate. Care must be taken so that the aggregate for each batch is representative of the project aggregate. If necessary, the aggregate can be dried, separated into sizes, and then reblended into individual batch sizes. If this is done, water equivalent to the stockpile or desired moisture content must be added to each batch and the batch covered to prevent loss of moisture for about 24 hours prior to mixing with emulsion.

(2) If pre-mix water is required, weigh onto the aggregate the predetermined amount as determined in the coating test and hand mix for 10 seconds or until the moisture is uniformly dispersed. This must be completed immediately prior to the addition and mixing of the emulsion.

(3) Weigh the predetermined amount of emulsion onto the ambient damp aggregate and stir vigorously for 60 seconds or until sufficient emulsion dispersion has occurred in the mixture.

**B. Compaction Procedure**

(1) Aeration or drying of a dense-graded mixture is often required prior to specimen compaction. Any time the total liquid volume (emulsion + water in aggregate) exceeds the voids mineral aggregate (VMA) plus any absorbed liquid volume, proper compaction cannot be achieved. This condition can be identified if the Marshall hammer bounces and/or liquid exudes from the specimen. When this condition exists, place the mixture in a shallow container and use a fan and occasional stirring to reduce the moisture content so that proper compaction can be achieved. Always use a new batch and not the one that could not be compacted satisfactorily.

(2) Thoroughly clean the specimen mold assembly and the face of the compaction hammer. Place a paper disc in the bottom of the mold before the mixture is introduced. Transfer the entire batch into the mold and spade the mixture vigorously with a spatula 15 times around the perimeter and 10 times over the interior of the mold. With the spatula, smooth the surface of the mix into a slightly rounded shape.

(3) Place the mold assembly on the compaction pedestal in the mold holder and apply 50 blows with the compaction hammer with a free fall of 457.2 mm (18.0 in.). Remove the base plate and collar and reverse the molded specimen and reassemble. Apply 50 blows of compaction to the face of the reversed specimen.

(4) Remove the base plate, collar and paper discs, and place the mold containing the compacted specimen on a perforated shelf in a 60°C (140°F) forced draft oven for 48 hours. For some mixtures, it may be necessary to push the specimen down level with the bottom of the mold so that the oven shelf supports it during curing.

(5) Remove the mold containing the compacted specimen from the oven and while still at 60°C (140°F), apply a static load of 178 kN (40,000 lbs.) by the double plunger method where a free-fitting plunger is placed at both the bottom and top of the specimen in the mold. Apply the load at a rate to give about 1.3 mm/min. (0.05 in./min.) of compression and maintain the full load for one minute and then release.

(6) Allow the compacted specimen to cool in the mold for a minimum of one hour prior to extracting the specimen for testing.

## ➤➤ *Testing of Compacted Specimens*

Approximate volumetrics and stability values can be determined from the compacted specimens if desired. The volumetrics often are not evaluated because they are normally calculated only as approximations because of the possibility of some moisture in the cured compacted specimens and the larger number of specimens required for more exact values. If more exact values are desired, the moisture must be accounted for in the compacted specimens and the theoretical maximum density must be determined using moisture free, loose mixture.

**A. Volumetrics**

(1) The easiest and most often used method to determine bulk density is to divide the weight of the specimen in air by its measured and calculated volume. If for no other reason, the bulk density should be determined so that the compaction and/or composition of like specimens are validated.

$$D_b = \frac{W_a}{H \times A}$$

where:

$D_b$ = Measured bulk density of a compacted mixture specimen
$W_a$ = Compacted specimen weight in air
H = Height of compacted specimen
A = Cross sectional area of a compacted specimen ($\pi r^2$)

(2) Other volumetrics, such as voids, voids filled and voids in mineral aggregate, etcetera can be determined by properly accounting for moisture and following the appropriate ASTM testing procedures, including D 70, D 1188, D 2041, D 2726 and D 3203.

**B. Stability Testing**

(1) Marshall stability and flow are determined following the procedures of ASTM D 1559 beginning at paragraph 5 (Procedure), except that the compacted specimens shall be placed in an air bath for a minimum of two (2) hours at the test temperature of 25 ± 1°C (77 ± 1.8°F). A stability value of 2224 N (500 lbs.) or greater has been found to be satisfactory for most pavements with low to moderate traffic volumes. Local experience may justify a different minimum stability value.

(2) Hveem stability is determined following the "Resistance to Deformation" procedures of ASTM D 1560 (paragraphs 4 through 9), except that the compacted specimens shall be placed in an air bath for a minimum of two (2) hours at the test temperature of 25 ± 1°C (77 ± 1.8°F). A stability value of 30 or greater has been found to be satisfactory for most pavements with low to moderate traffic volumes. Local experience may justify a different minimum stability value.

## Open-Graded Aggregate Mix Design

This mix design method covers procedures for preparing trial mixtures of open-graded emulsion mixtures using aggregates having gradations as indicated in Table 7.3 of this manual. Job aggregate and a compatible asphalt emulsion are used to establish an optimum emulsion content based on an evaluation of asphalt runoff. Medium setting asphalt emulsions are used for open graded mixtures.

To summarize this method, mixtures are made with varying emulsion contents in one percent increments and subjected to a runoff method to determine the asphalt residue runoff. The asphalt emulsion content that gives an asphalt residue runoff of 10 grams is recommended as the optimum emulsion content.

### ➤➤ Preparation of Mixtures

These procedures are used for the preparation of open-graded aggregate-asphalt emulsion mixtures for testing and determination of the optimum emulsion content.

a. Obtain a representative sample of job aggregate and dry to a constant weight in a forced draft oven at 60°C (140°F). After oven drying, cool the sample at ambient temperature for a minimum of two hours.
b. Preweigh a sufficient number of 2000-gram batch samples of the dried aggregate using the average stockpile gradation.
d. Using stainless steel bowls, mix the aggregate with 40 grams of water (2%) until all of the aggregate is damp. Cover the bowl with a clean cloth and leave covered for 15 minutes.
e. Add the appropriate amount of asphalt emulsion preheated to 60°C (140°F) to the dampened aggregate and prepare the mix by hand mixing for 2 minutes using a log-handled spoon. Observe and record the workability of the mix, such as stiff, satisfactory or sloppy, and the percent of coating. Emulsion contents in 1.0% increments by weight of dry aggregate are recommended. A beginning emulsion content of 4.0% is recommended for very coarse maximum size aggregates and 6.0% for the finest maximum size aggregates.

### ➤➤ Testing Procedures

a. Immediately after preparation of the mixture, transfer the whole batch onto a 2.36 mm (No. 8) sieve that is placed above the tared standard pan. Prior to transferring the mix, lightly dampen the 2.36 mm (No. 8) sieve with water.
b. Allow the mix to drain into the standard pan at ambient temperature for 30 minutes.
c. Lift off the 2.36 mm (No. 8) sieve containing the drained mix and determine and record the mass of the standard pan containing the drained emulsion/runoff ($W_1$). Subtract the tared weight of the pan to determine the Asphalt Runoff in grams.
d. Remove the drained mix from the 2.36 mm (No. 8) sieve and spread the mix onto a paper-lined tray. Surface dry the mix with a fan and evaluate the percent of asphalt coating.
e. Place the standard pan containing runoff in a forced draft oven at 110 ± 5°C (230 ± 9°F) and dry to a constant mass. Determine and record the final mass ($W_2$). Subtract the tared weight of the pan to determine the Asphalt Residue Runoff in grams.

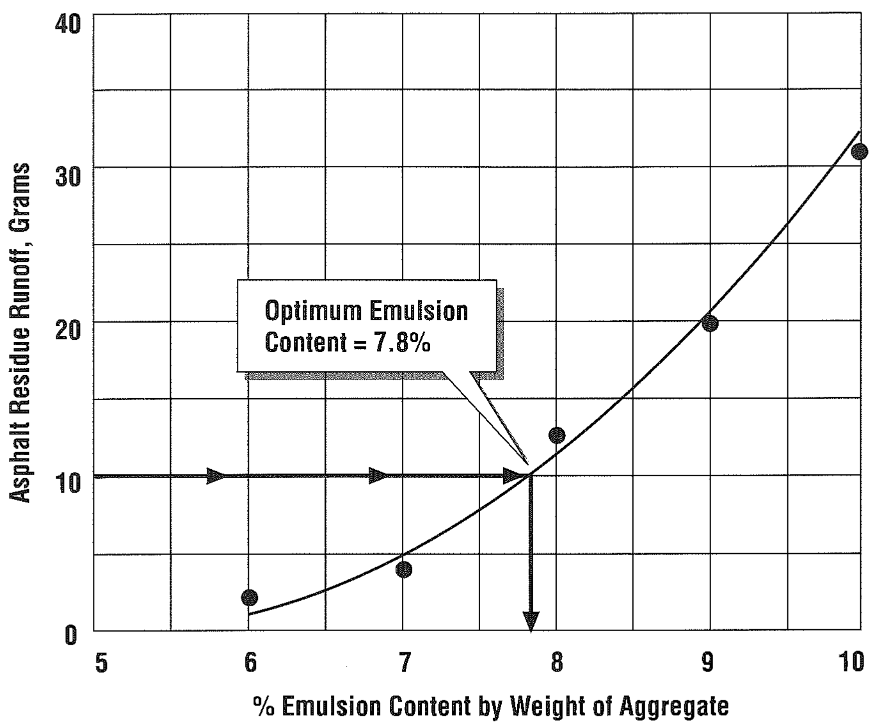


Figure 10.1 Selection of Optimum Emulsion Content Open-Graded Aggregate-Asphalt Emulsion Mixture

## ➤➤ *Optimum Emulsion Content Determination*

a. Plot the % Emulsion Content by Weight of Aggregate versus the Asphalt Residue Runoff in grams on a graph and draw a smooth curve (Figure 10.1).
b. Draw a horizontal line at 10 grams of Asphalt Residue Runoff on the Y-axis to intersect with the curve. Read the corresponding % emulsion content on the X-axis to the nearest 0.1 percent. This is the optimum emulsion content.

## ➤➤ *Final Results*

a. Report these results:
   (1) Optimum Emulsion Content, percent
   (2) Mix Workability (stiff, satisfactory or sloppy)
   (3) Mix Coating, percent

At the optimum asphalt emulsion content, the mixture must have satisfactory workability. It is preferred that coating be as close as possible to 100%. Mixes shall be considered suitable, however, if they have a minimum of 85% coating if used as a surface course and 60% coating if used as a base course.

APPENDIX A GLOSSARY

## ➤➤ *Aggregate*

**Aggregate:** A hard inert mineral material, such as gravel, crushed rock, slang, or sand.

**Coarse Aggregate:** Aggregate retained on the 2.36mm (No. 8) sieve.

**Fine Aggregate:** Aggregate passing the 2.36mm (No. 8) sieve.

**Sand:** Fine aggregate resulting from natural disintegration and abrasion of rock or processing of completely friable sandstone.

**Dense-Graded Aggregate:** Aggregate that is graded from the maximum size down through filler with the object of obtaining an asphalt mix with a controlled void content and high stability.

**Open-Graded Aggregate:** Aggregate containing little or no mineral filler or in which the void spaces in the compacted aggregate are relatively large and interconnected.

**Sandy Soil:** A material consisting essentially of fine aggregate particles smaller than 2.36 mm (No. 8) sieve and usually containing material passing a 75 μm (No. 200) sieve. This material usually exhibits some plasticity characteristics.

**Reclaimed Asphalt Pavement (RAP):** Existing asphalt mixture that has been pulverized, usually by milling, and is used like an aggregate in the recycling of asphalt pavements.

## ➤➤ *Asphalt*

**Asphalt:** "A dark brown to black cementitious material in which the predominating constituents are bituminous which occur in nature or are obtained in petroleum processing" (ASTM D8). Asphalt is a constituent in varying proportions of most crude petroleum.

**Asphalt Cement:** Asphalt that is refined to meet specifications for paving, roofing, industrial, and special purposes. Heat is required to make it fluid.

**Asphalt Prime Coat:** An application of asphalt primer to an absorbent surface. It is used to prepare an untreated base for an asphalt surface. The prime penetrates or is mixed into the surface of the base and plugs the voids, hardens the top and helps bind it to the overlying asphalt course.

**Asphalt Primer:** A fluid asphalt of low viscosity (highly liquid) that penetrates into a non-bituminous surface upon application.

**Asphalt Tack Coat:** A very light application of asphalt emulsion diluted with water. It is used to ensure a good bond between the surface being paved and the overlying new course.

**Cutback Asphalt:** Asphalt cement that has been liquefied by blending with petroleum solvents.

**Asphalt Emulsion:** An emulsion of asphalt cement and water that contains a small amount of an emulsifying agent. Emulsified asphalt droplets may be of either the anionic (negative charge) or cationic (positive charge).

## ➤➤ *Asphalt Emulsion*

**Emulsifying Agent or Emulsifier:** The chemical added to the water and asphalt that keeps the asphalt in stable suspension in the water. The emulsifier determines the charge of the emulsion and controls the breaking rate.

**Breaking:** The phenomenon when the asphalt and water in the emulsion separate, beginning the curing process. The rate of breaking is controlled primarily by the emulsifying agent.

**Curing:** The development of the mechanical properties of the asphalt binder. This occurs after the emulsion has broken and the emulsion particles coalesce and bond to the aggregate.

**Residue:** The asphalt binder that remains after the emulsion has broken and cured.

## ➤➤ *Equipment*

**Aggregate Spreaders:** Machines used for spreading aggregate evenly at a uniform rate on a surface.

> **Mechanical Spreaders:** Spreader boxes that are mounted on wheels. The spreaders are attached to and pushed by dump trucks.
>
> **Self-Propelled Spreaders:** Spreaders having their own power units and two hoppers. The spreader pulls the truck as it dumps its load into the receiving hopper. Conveyor belts move the aggregate forward to the spreading hopper.
>
> **Tail Gate Spreaders:** Boxes with adjustable openings that are attached to and suspended from the tailgates of dump trucks.
>
> **Whirl Spreaders:** Spreaders that are attached to or are built onto dump trucks. Aggregate is fed onto the spreader disc through an adjustable opening and the speed of the disc controls the width of spread.

**Aggregate Trucks:** Trucks equipped with hydraulic lifts to dump the aggregate into the spreader.

**Asphalt Distributor:** A truck or a trailer having an insulated tank and a heating system. The distributor applies asphalt to a surface evenly and at a uniform rate.

**Cold In-place Recycling Train:** A unit consisting of a large milling machine towing a screening/crushing plant and pugmill mixer for the addition of asphalt emulsion and production of cold mix base.

**Milling Machine:** A self-propelled unit having a cutting head equipped with carbide tipped tools for the pulverization and removal of layers of asphalt materials from pavements.

**Reclaiming Machine:** A self-propelled unit having a transverse cutting and mixing head inside of a closed chamber for the pulverization and mixing of existing pavement materials with asphalt emulsion. Asphalt emulsion (and mixing water) may be added directly through the machine by a liquid additive system and spray bar.

**Power Sweeper:** A power operated rotary broom used to clean loose material from the pavement surface.

**Pneumatic-Tired Rollers:** Rollers with a number of tires spaced so their tracks overlap while giving kneading compaction.

**Steel-Wheel Static Rollers:** Tandem or three-wheel rollers with cylindrical steel rolls that apply their weight directly to the pavement.

**Steel-Wheel Vibratory Rollers:** A roller having single or double cylindrical steel rolls that apply compactive effort with weight and vibration. The amount of compactive force is adjusted by changing the frequency and amplitude of vibration.

**Stationary Plants:** Mixing plants located at a mixing site that mix asphalt emulsion and aggregates hot, warm, or cold. The simplest plants are for cold mixing and consist of aggregate feeder bin(s), asphalt and water metering systems, and a pugmill for mixing.

**Travel Plants:** Self-propelled pugmill plants that proportion and mix aggregates and asphalt as they move along the road. There are three general types of travel plants:

1. One that moves through a prepared aggregate windrow on the roadbed, adds and mixes the asphalt as it goes, and rear discharges a mixed windrow ready for aeration and spreading.
2. One that receives aggregate into its hopper from haul trucks, adds and mixes asphalt, and spreads the mix to the rear as it moves along the roadbed.
3. Batch mixing units, such as slurry machines, that haul materials to the site and then mix and apply the materials.

## ➤➤ *Types of Asphalt Surface Treatments and Mixes*

**Asphalt Emulsion Mix (Hot):** A mixture of asphalt emulsion and mineral aggregate usually prepared in a conventional hot mix asphalt plant at a temperature less than 125°C (260°F). It is spread and compacted at a temperature above 95°C (200°F).

**Pavement Base and Surface:** The lower or underlying pavement course atop the subbase or subgrade and under the top or wearing course.

**Plant Mix (Cold):** A mixture of asphalt emulsion and mineral aggregate prepared in a central mixing plant and spread and compacted while the mixture is at or near ambient temperature.

**Maintenance Mix:** A mixture of asphalt emulsion and mineral aggregate for use in relatively small areas to patch holes, depressions, and distressed areas in existing pavements. Appropriate hand or mechanical methods are used in placing and compacting the mix.

**Recycled Asphalt Mix:** A mixture produced after processing existing asphalt pavement materials. The recycled mix may be produced by hot or cold mixing at a plant, or by processing the materials cold and in-place.

**Asphalt Application:** The application of sprayed asphalt coatings not involving the use of aggregates.

**Asphalt-Aggregate Applications:** Applications of asphalt material to a prepared aggregate base or pavement surface followed by the application of aggregate.

**Single Surface Treatment:** A single application of asphalt to a road surface followed immediately by a single layer of aggregate. The thickness of the treatment is about the same as the nominal maximum size aggregate particles.

**Multiple Surface Treatment:** Two or more surface treatments placed one on the other. The aggregate maximum size of each successive treatment is usually one-half the previous one, and the total thickness is about the same as the nominal maximum size of the first course. A multiple surface treatment may be a series of single treatments that produces a pavement course up to 25mm (1 in.) or more in thickness. A multiple surface treatment is a denser wearing and waterproofing course than a single surface treatment, and it adds some strength.

**Seal Coat:** A thin surface treatment used to improve the surface texture and protect an asphalt surface. The main types of seal coats are surface treatments, fog seals, and sand seals. slurry seals, and micro-surfacing, cape seals, and sandwich seals.

**Fog Seal:** A light application of diluted asphalt emulsion. It is used to renew old asphalt surfaces, seal small cracks and surface voids, and inhibit raveling.

**Slurry Seal:** A mixture of emulsified asphalt, well-graded fine aggregate, mineral filler or other additives, and water. It is applied from 3 to 10 mm (1/8 to 3/8 in.) thick and used to renew pavement surfaces and retard moisture and air intrusion into underlying pavement. Slurry seal will fill minor cracks, restore a uniform surface texture, and restore friction values.

**Micro-Surfacing:** A mixture of polymer modified asphalt emulsion, crushed dense graded aggregate, mineral filler, additives, and water. Micro-surfacing provides thin resurfacing of 10 to 20 mm (3/8 to 3/4 inch) to the pavement and returns traffic use in one hour under average conditions. Materials selection and mixture design make it possible for micro-surfacing to be applied in multiple applications and provide minor reprofiling. The product can fill wheel ruts up to 40 mm (1.5 in.) in depth in one pass and produces high surface friction values. Micro-surfacing is suitable for use on limited access, high-speed highways as well as residential streets, arterials and roadways.

**Cape Seal:** A surface treatment where a chip seal is followed by the application of either slurry seal or micro-surfacing.

**Sandwich Seal:** A surface treatment consisting of the application of a large aggregate, then a spray applied asphalt emulsion (normally polymer modified), and covered with a smaller aggregate.

## Table B-1 Temperature-Volume Corrections for Asphalt Emulsion

| °C^t | °F | M* | °C^t | °F | M* | °C^t | °F | M* |
|---|---|---|---|---|---|---|---|---|
| 10.0 | 50 | 1.00250 | 35.0 | 95 | 0.99125 | 60.0 | 140 | 0.98000 |
| 10.6 | 51 | 1.00225 | 35.6 | 96 | 0.99100 | 60.6 | 141 | 0.97975 |
| 11.1 | 52 | 1.00200 | 36.1 | 97 | 0.99075 | 61.1 | 142 | 0.97950 |
| 11.7 | 53 | 1.00175 | 36.7 | 98 | 0.99050 | 61.7 | 143 | 0.97925 |
| 12.2 | 54 | 1.00150 | 37.2 | 99 | 0.99025 | 62.2 | 144 | 0.97900 |
| 12.8 | 55 | 1.00125 | 37.8 | 100 | 0.99000 | 62.8 | 145 | 0.97875 |
| 13.3 | 56 | 1.00100 | 38.3 | 101 | 0.98975 | 63.3 | 146 | 0.97850 |
| 13.9 | 57 | 1.00075 | 38.9 | 102 | 0.98950 | 63.9 | 147 | 0.97825 |
| 14.4 | 58 | 1.00050 | 39.4 | 103 | 0.98925 | 64.4 | 148 | 0.97800 |
| 15.0 | 59 | 1.00025 | 40.0 | 104 | 0.98900 | 65.0 | 149 | 0.97775 |
| 15.6 | 60 | 1.00000 | 40.6 | 105 | 0.98875 | 65.6 | 150 | 0.97750 |
| 16.1 | 61 | 0.99975 | 41.1 | 106 | 0.98850 | 66.1 | 151 | 0.97725 |
| 16.7 | 62 | 0.99950 | 41.7 | 107 | 0.98825 | 66.7 | 152 | 0.97700 |
| 17.2 | 63 | 0.99925 | 42.2 | 108 | 0.98800 | 67.2 | 153 | 0.97675 |
| 17.8 | 64 | 0.99900 | 42.8 | 109 | 0.98775 | 67.8 | 154 | 0.97650 |
| 18.3 | 65 | 0.99875 | 43.3 | 110 | 0.98750 | 68.3 | 155 | 0.97625 |
| 18.9 | 66 | 0.99850 | 43.9 | 111 | 0.98725 | 68.9 | 156 | 0.97600 |
| 19.4 | 67 | 0.99825 | 44.4 | 112 | 0.98700 | 69.4 | 157 | 0.97575 |
| 20.0 | 68 | 0.99800 | 45.0 | 113 | 0.98675 | 70.0 | 158 | 0.97550 |
| 20.6 | 69 | 0.99775 | 45.6 | 114 | 0.98650 | 70.6 | 159 | 0.97525 |
| 21.1 | 70 | 0.99750 | 46.1 | 115 | 0.98625 | 71.1 | 160 | 0.97500 |
| 21.7 | 71 | 0.99725 | 46.7 | 116 | 0.98600 | 71.7 | 161 | 0.97475 |
| 22.2 | 72 | 0.99700 | 47.2 | 117 | 0.98575 | 72.2 | 162 | 0.97450 |
| 22.8 | 73 | 0.99675 | 47.8 | 118 | 0.98550 | 72.8 | 163 | 0.97425 |
| 23.3 | 74 | 0.99650 | 48.3 | 119 | 0.98525 | 73.3 | 164 | 0.97400 |
| 23.9 | 75 | 0.99625 | 48.9 | 120 | 0.98500 | 73.9 | 165 | 0.97375 |
| 24.4 | 76 | 0.99600 | 49.4 | 121 | 0.98475 | 74.4 | 166 | 0.97350 |
| 25.0 | 77 | 0.99575 | 50.0 | 122 | 0.98450 | 75.0 | 167 | 0.97325 |
| 25.6 | 78 | 0.99550 | 50.6 | 123 | 0.98425 | 75.6 | 168 | 0.97300 |
| 26.1 | 79 | 0.99525 | 51.1 | 124 | 0.98400 | 76.1 | 169 | 0.97275 |
| 26.7 | 80 | 0.99500 | 51.7 | 125 | 0.98375 | 76.7 | 170 | 0.97250 |
| 27.2 | 81 | 0.99475 | 52.2 | 126 | 0.98350 | 77.2 | 171 | 0.97225 |
| 27.8 | 82 | 0.99450 | 52.8 | 127 | 0.98325 | 77.8 | 172 | 0.97200 |
| 28.3 | 83 | 0.99425 | 53.3 | 128 | 0.98300 | 78.3 | 173 | 0.97175 |
| 28.9 | 84 | 0.99400 | 53.9 | 129 | 0.98275 | 78.9 | 174 | 0.97150 |
| 29.4 | 85 | 0.99375 | 54.4 | 130 | 0.98250 | 79.4 | 175 | 0.97125 |
| 30.0 | 86 | 0.99350 | 55.0 | 131 | 0.98225 | 80.0 | 176 | 0.97100 |
| 30.6 | 87 | 0.99325 | 55.6 | 132 | 0.98200 | 80.6 | 177 | 0.97075 |
| 31.1 | 88 | 0.99300 | 56.1 | 133 | 0.98175 | 81.1 | 178 | 0.97050 |
| 31.7 | 89 | 0.99275 | 56.7 | 134 | 0.98150 | 81.7 | 179 | 0.97025 |
| 32.2 | 90 | 0.99250 | 57.2 | 135 | 0.98125 | 82.2 | 180 | 0.97000 |
| 32.8 | 91 | 0.99225 | 57.8 | 136 | 0.98100 | 82.8 | 181 | 0.96975 |
| 33.3 | 92 | 0.99200 | 58.3 | 137 | 0.98075 | 83.3 | 182 | 0.96950 |
| 33.9 | 93 | 0.99175 | 58.9 | 138 | 0.98050 | 83.9 | 186 | 0.96925 |
| 34.4 | 94 | 0.99150 | 59.4 | 139 | 0.98025 | 84.4 | 184 | 0.96900 |
| | | | | | | 85.0 | 185 | 0.96875 |

Legend: t = observed temperature in degrees Celsius (Fahrenheit)
M = multiplier for correcting volumes to the basis of 15.6°C (60°F)

* Multiplier (M) for °C is a close approximation

## Table B-2 Quantities at Depths in Cylindrical Tanks in a Horizontal Position

| Percent Depth Filled | Percent of Capacity | Percent Depth Filled | Percent of Capacity | Percent Depth Filled | Percent of Capacity | Percent Depth Filled | Percent of Capacity |
|---|---|---|---|---|---|---|---|
| 1 | 0.20 | 26 | 20.73 | 51 | 51.27 | 76 | 81.50 |
| 2 | 0.50 | 27 | 21.86 | 52 | 52.55 | 77 | 82.60 |
| 3 | 0.90 | 28 | 23.00 | 53 | 53.81 | 78 | 83.68 |
| 4 | 1.34 | 29 | 24.07 | 54 | 55.08 | 79 | 84.74 |
| 5 | 1.87 | 30 | 25.31 | 55 | 56.34 | 80 | 85.77 |
| 6 | 2.45 | 31 | 26.48 | 56 | 57.60 | 81 | 86.77 |
| 7 | 3.07 | 32 | 27.66 | 57 | 58.86 | 82 | 87.76 |
| 8 | 3.74 | 33 | 28.84 | 58 | 60.11 | 83 | 88.73 |
| 9 | 4.45 | 34 | 30.03 | 59 | 61.36 | 84 | 89.68 |
| 10 | 5.20 | 35 | 31.19 | 60 | 62.61 | 85 | 90.60 |
| 11 | 5.98 | 36 | 32.44 | 61 | 63.86 | 86 | 91.50 |
| 12 | 6.80 | 37 | 33.66 | 62 | 65.10 | 87 | 92.36 |
| 13 | 7.64 | 38 | 34.90 | 63 | 66.34 | 88 | 93.20 |
| 14 | 8.50 | 39 | 36.14 | 64 | 67.56 | 89 | 94.02 |
| 15 | 9.40 | 40 | 37.39 | 65 | 68.81 | 90 | 94.80 |
| 16 | 10.32 | 41 | 38.64 | 66 | 69.97 | 91 | 95.55 |
| 17 | 11.27 | 42 | 39.89 | 67 | 71.16 | 92 | 96.26 |
| 18 | 12.24 | 43 | 41.14 | 68 | 72.34 | 93 | 96.93 |
| 19 | 13.23 | 44 | 42.40 | 69 | 73.52 | 94 | 97.55 |
| 20 | 14.23 | 45 | 43.66 | 70 | 74.69 | 95 | 98.13 |
| 21 | 15.26 | 46 | 44.92 | 71 | 75.93 | 96 | 98.66 |
| 22 | 16.32 | 47 | 46.19 | 72 | 77.00 | 97 | 99.10 |
| 23 | 17.40 | 48 | 47.45 | 73 | 78.14 | 98 | 99.50 |
| 24 | 18.50 | 49 | 48.73 | 74 | 79.27 | 99 | 99.80 |
| 25 | 19.61 | 50 | 50.00 | 75 | 80.39 | | |

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