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CHAPTER 6 FOG AND REJUVENATING SEALS

6.1 OVERVIEW

Fog and rejuvenating seals are two of many pavement preservation strategies used to defer surface degradation and extend pavement surface life. The primary purpose of using a fog seal is to seal the road surface and defer surface degradation. The primary purpose of using rejuvenating seal is to soften the stiffness of the oxidized Hot Mix Asphalt (HMA) pavement surface and to extend the life of the pavement surface. Some rejuvenators contain asphalt which also seals the surface in addition to adjusting the properties of the asphalt emulsion mixture. Fog and rejuvenating seals can be added to an agency's toolbox as a cost-effective preservation treatment.

6.1.1 Fog Seal

Fog seals are usually asphalt emulsion diluted with water then applied to the asphalt surface of a road, street or highway. The Asphalt Emulsion Manufacturers Association (AEMA) defines a fog seal as "a light spray application of dilute asphalt emulsion used primarily to seal an existing asphalt surface to reduce raveling and enrich dry and weathered surfaces" (Asphalt Institute, 2008). Others refer to fog seals as enrichment treatments or rejuvenators since they may add fresh asphalt, other additives or combination of asphalt and additives to an aged surface and lengthen the pavement surface life. Asphalt emulsion fog seals are also useful in chip seal applications to hold chips in place in fresh seal coats. These are referred to as flush coats in California. This can help prevent vehicle damage arising from flying chips. The Asphalt Institute also adds that fog seals can seal small cracks (Asphalt Institute, 2008).

Fog seals are a method of adding asphalt to an existing pavement surface to improve sealing or waterproofing, prevent further stone loss by holding aggregate in place, or simply improve the surface appearance. For the seals to be effective, they must penetrate into the existing HMA surface. However, too heavy of application can result in slick pavements and tracking of excess material.

6.1.2 Rejuvenating Seal

Rejuvenating seals are a combination of various chemicals, or a mixture of asphalt emulsion and recycling agents applied to the asphalt pavement surface. Rejuvenating emulsions restore the maltenes or light components that have oxidized and soften the existing binder, thus reducing the viscosity and improving the flexibility of the binder. It is also used to seal the pavement and reduce future oxidation. There are a variety of rejuvenating seals used in California. Rejuvenating emulsions include polymer modified rejuvenating emulsions.

Rejuvenating emulsions also include products that have additives (Maltene Replacement Technology, MRT) that soften the existing binder and reduce viscosity. These also improve the flexibility of the binder, which reduces the likelihood of cohesive failure. This may be beneficial in situations where the surface has an open texture, and the existing binder is brittle due to aging. As with conventional emulsions, if these emulsion types do not penetrate the surface, they may create a slippery surface after they break. Therefore, for the rejuvenating seals to be effective, they must penetrate the existing HMA surface.

Recently, bio-based rejuvenators have been increasingly utilized. Over the last 5 years, several organizations, including AASHTO, and the Technical Services Program Emulsion Task Force have sponsored a study to improve the science in emulsion technology to create consistent performance-based standards regarding specifications, test methods, and design practices. Auburn University, Auburn, Alabama, has been performing this study. A short and very informative article was published by NCAT entitled, “Evaluation of Rejuvenating Fog Seals”, This article describes the different components that make up the rejuvenating emulsions.

The chemical composition of asphalt binder is commonly characterized by its SARA fractions - saturates (S), aromatics (A), resins (R), and asphaltenes (A) - which exhibit progressively increasing molecular polarity, from the least polar saturates to the highly polar asphaltenes. Asphalt is frequently described as a colloidal system in which asphaltenes are dispersed within an oily matrix composed of saturates, aromatics, and resins. In crude oils, asphaltenes are stabilized by naturally occurring resins that act as surfactant-like agents.

Another good source of informative articles on fog seals is published by the Pavement Preservation Journal. One bio-friendly fog seal uses flax oil, and this type of rejuvenator may have a shorter absorption and drying time. The bio-friendly fog seals may not have a foul smell that other fog seals may have. These products are produced under various trade names, and some may require heavier or lighter application rates than traditional fog seals.

At this time (2025), Caltrans hasn’t included bio-based rejuvenators in either Section 37 or Section 94 of their 2025 Standard Specifications.

6.2 PROJECT SELECTION

6.2.1 Fog Seal

General Considerations

The original use of the fog seal was from the Asphalt Institute around 30 years ago. A diluted SS-1 asphalt emulsion was applied daily to new HMA paving on Pacific Coast highways. This was because, as fog rolled in each evening, the paving contractor would experience raveling of the newly placed asphalt on curves.

Fog seals are used as a method of enriching the pavement surface and holding aggregate in place. Thus, they are suitable to treat raveled and/or aged pavements. There is, currently, no simple way of quantifying the degree of aging in a pavement other than by visual inspection. HMA pavements will age at different rates due to mixture's properties, traffic, and climate zone. Some modified asphalts such as asphalt rubber and polymer modified asphalts will age at a slower rate than conventional or neat binders. Fog seals will not correct distresses such as cracking, base failures, excessive raveling, or other severe pavement defects.

On the traveled way, fog seals should only be used where surface penetration of the emulsion can be confirmed; that is, aged and raveled hot mix surfaces, chip-sealed surfaces, and open graded asphalt surfaces. On shoulders, gores, or dikes, penetration is desirable, but it is not essential. Fog seals darken the pavement surface and enable better pavement delineation.

In general, traffic level is not a determining factor except in job set up. For situations requiring that the sealed pavement be opened to traffic shortly after the application of the seal, a blotter coat of sand may be used to prevent pick-up. Fog seal used on the traveled way should generally be limited to only those locations having an open surface texture. This includes chip seals, heavily aged dense graded and open graded. However, the seal may fill voids and reduce or eliminate the drainage function of Open-Graded Friction Coarse (OGFC). OGFC should be cleaned prior to application of a fog seal to maintain its drainage function. Figure 6-1 shows a typical fog seal application, while Figures 6-2 through 6-5 shows a range of suitable and unsuitable surfaces for fog seal project selection. The results of good fog seal applications are shown in Figures 6-4 and 6-5. Always check the application rate and ensure that the emulsion has been diluted correctly.

Figure 6-1 Fog Seal Application

Figure 6-2 Suitable Surface, Heavily Aged Dense Graded HMA with Loss of Fines

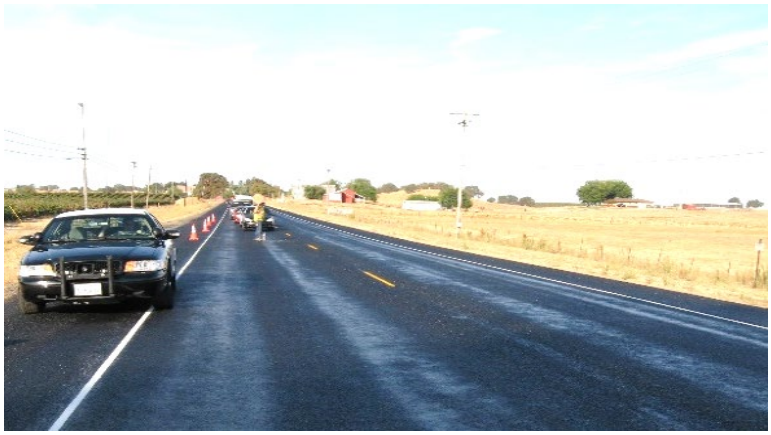

Figure 6-3 Dense Graded HMA with Closed Surface with Bleeding, Not Suitable for Fog Seal or Rejuvenator Seal

Figure 6-4 Three-year-old Suitable Surface, Open Graded HMA for Fog Seal or Rejuvenator Seal

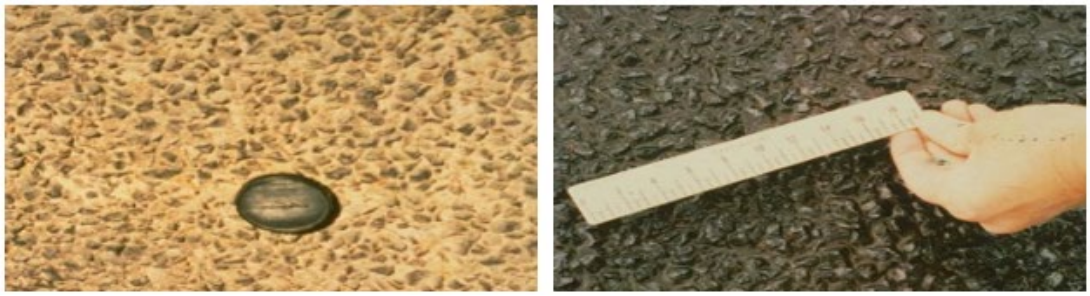

Figure 6-5 Chip Seal Before (Lt.) and After Fog Seal or Flush Coat (Rt.)

Fog seals (with sand blotter coats) may be used as a pavement maintenance treatment on both shoulders and mainline of highways. This protects the HMA or chip seal surface. The sand will generally be removed by the traffic, or may be swept, leaving a good surface texture.

Flush coats (fog seals with light sanding) are used as a construction seal coat for new chip seals to lock the chips in place. This reduces vehicle/windshield damage due to flying chips when traffic is allowed on the new seal. Fog seals with sand blotter coats may also be used as a pavement maintenance treatment on lower speed roads or low traffic volume roads. This protects the HMA or chip seal surface from oxidizing and losing fines.

Fog seals are also suitable for sealing new shoulders, gores, or dikes where surface texture isn't critical. During construction on milled or ground HMA surfaces, fog seals may be used to keep dust down and prevent rock loss before the next surface treatment is placed or paved.

Fog seals may be used to protect an HMA surface that is not aged significantly (i.e., within 1-2 years of placement after a major rehabilitation or maintenance treatment). This creates a layer of asphalt that seals surface voids and prevents air and water ingress. Fog seals may also be applied to a pavement that is showing severe raveling resulting from a dry mix (too little binder).

More recently, bio-based fog seals, such as those derived from soy oil, have been developed as a sustainable alternative to traditional petroleum-based fog seals. The manufacturers of these products claim that it protects asphalt from oxidation, potholing, and edge cracking, and that it extends the life of the surfacing when applied every 3-5 years. Transportation Research Board (TRB) published this study for bio-based fog seal for the 12th International Conference on Low Volume Roads in 2019, at Kalispell, Montana (Bo Yang, et. al. 2019).

Benefits and Limitations

Fog seals are an inexpensive way of arresting raveling and adding binder back into aged surfaces. They can also hold chips in place in fresh chip seals, (or older chip seals beginning to lose aggregate) reducing the potential for vehicle damage.

Fog seals are not useful as seal coats on tight surfaces without the addition of aggregates as they will reduce surface texture and may create a slippery surface. If the skid number of the existing pavement is already low, the project is not appropriate for fog seal. Fog seals should not be used on Rubberized Asphalt Concrete (RHMA) or polymer modified mixes unless the pavements are over five years old as these binders age slower than traditional binders.

The application of fog seals is also limited by weather. Rain is a factor affecting cure; therefore, fog seals should not be used when rain is in the weather forecast. The emulsion should be fully cured before freezing conditions are encountered. In addition, seal coats applied in the winter have less time to penetrate the pavement and are more prone to cause slick surface conditions.

Summary

In summary, the following guidelines should be considered when selecting a fog seal project:

- Pavement Surface Condition – Dry mixes, high air voids, and surfaces showing minor and/or moderate raveling or cracking. Fog seals can also be used on chip seals to prevent aggregate loss.
- Pavement Age – relatively newer pavement (not more than 2 years in service).
- Pavement Surface Mix – can be used on dense, gap, and open-graded mixes; however, the seal must penetrate.
- Recommendations of District Maintenance Engineer and District Materials Engineer.
- Seals micro-cracking.
- Improves appearance of pavement, giving it a new uniform black color.
- Used as a flush coat on a fresh chip seal, to lessen rock loss.

6.2.2 Rejuvenating Seal

General Considerations

All asphalts harden as they age, primarily due to oxidation, volatile compounds loss, and other aging mechanisms. The hardening of an asphalt film takes place at different rates depending on the access of air and temperature conditions of the pavement. Permeable pavements or pavements with high void contents can therefore age faster. Water ingress can also carry dissolved oxygen and trace of elements that may promote aging. This means that pavements with open surfaces tend to age faster than those with closed surfaces. However, if modified binders are used in chip seal applications (e.g., asphalt rubber, polymer modified asphalt), the thicker films and superior durability created by the higher binder content reduce the rate of aging.

Aging results in a binder that is more brittle. These binders eventually experience cohesive binder failures and aggregate loss or raveling under traffic loads. In some cases, the asphalt produces oxidized compounds that are acidic and bond well to the aggregate; however, these compounds may also react with water causing adhesive failure or stripping.

Benefits and Limitations

Rejuvenating seal is one way to soften the hardness of oxidized asphalt concrete surface, making it less brittle and less prone to cracking. The major benefit of the rejuvenating seals is to improve the flexibility of the asphalt binder and slow down the rate of aging and oxidization. “Rejuvenating emulsions can be applied as a fog seal when the level of surface distresses is greater than what would normally be used as a criterion for typical chip or fog seals.”, per Road Resources (2024).

Rejuvenating seals may not be appropriate for using on rubberized asphalt concrete or polymer modified mixes. Rejuvenating seals may lower the skid resistance of the existing pavement surface immediately after the application of the seals. If the skid numbers of the existing pavement are already low, the project is not appropriate for applying a rejuvenating seal coat. The use of rejuvenating seals may also be limited by the weather conditions. The application of a rejuvenating seal coat should follow the manufacturer’s recommendations.

Summary

In summary, the following guidelines should be considered when selecting a rejuvenating seal project:

- Pavement Surface Condition – Old and oxidized surface or surface starting to oxidize or show raveling. In addition to oxidation, a pavement surface may begin to show evidence of distress cracking. If the existing HMA surface is cracking, a rejuvenating scrub seal should also be considered. A rejuvenating scrub seal is the application of a rejuvenating emulsion followed by the application of aggregate, similar to a chip seal.

- Pavement Age – Generally used on pavement over 2 years old or more.
- Pavement Surface Mix – Can be used on dense-, gap- and open-graded mixes; however, the seal must penetrate the existing HMA surface.

6.3 MATERIALS

6.3.1 General Terminology

Essential emulsion terminologies used for fog and rejuvenating seals are defined below:

- **Original Emulsion** – A mixture of asphalt cement and water that contains an emulsifying agent. Original slow-setting grade emulsions may contain up to 43% water and original rapid setting grades may contain an addition of chemicals to reduce cure time.
- **Diluted Emulsion** – An original emulsion that has been diluted by adding an amount of water equal to or more than the total volume of original emulsions which contain 30-50% additional water. (See Chapter 2, Figure 2-09).
- **Residual Asphalt Content** – The amount of asphalt remaining on the pavement surface after the emulsion has broken and cured (after all water has evaporated).

6.3.2 Materials and Specifications

The materials used in fog seals are usually asphalt emulsion and water. These products are covered by Caltrans Standard Specifications, 2025, “37-4 Fog Seals and Flush Coats”. Rejuvenators may be used to soften and revitalize the aged binder in the pavement. Rejuvenation treatments require special attention in design and must comply with 94-1.02H, “Rapid-Setting Polymer-Modified Rejuvenating Asphalt Emulsion”, of the Caltrans Standard Specifications, 2025.

The emulsion types recommended for fog seals may be cationic (i.e., a positive surface charge on the asphalt particles), or anionic (i.e., a negative surface charge on the asphalt particles). The primary types used are:

- CSS-1h – Cationic Slow Set
- SS-1h – Anionic Slow Set
- CQS-1h – Cationic Quick Set
- LMCQS-1h – Latex Modified Cationic Quick Set

Asphalt emulsions typically contain up to 50 percent water. However, any dilution referred to is additional water added to the emulsion. Residual asphalt is the binder left on the HMA surface after all water (i.e., any added water and the original emulsion water) has evaporated. Section 37-4.02B, “Materials”, of the Standard Specifications, 2025, states, “You determine the grade of slow-setting or quick setting asphaltic emulsion to be used.” Please note that “Rapid Setting” is not used for fog seals.

Rejuvenating emulsions should be used on pavement showing age related distress associated with stiffening of existing binder. Generally. This will take place after three years of service. They may be emulsions of exclusive rejuvenating additives and may include asphalt, polymer latex, and other additives. The Caltrans Standard Specifications, 2025, Please note that Section 94-1.02H has a specification for rejuvenating emulsions RSPM-Rapid Setting Polymer-Modified (Rejuvenator), and its rejuvenating agent requirements which are for chip seals and not fog seals or flush coats. Refer to Section 37-2.03A for acceptable chip seal emulsions, and Section 37-4.02 for acceptable fog seal emulsions.

6.3.3 Design Tools

Fog seals are chosen based on the existing pavement surface condition. The objective is to determine the application rate and dilution rate. The actual application rates may vary during the construction depending on the surface condition of the HMA. There are several tests which can help to determine the appropriate application rate of a rejuvenating fog seal in the project's design phase. A pilot project employing fog rejuvenating seals was constructed in 2012. The project was monitored by the California Pavement Preservation Center (C2PC) and a complete project report entitled "Fog Rejuvenating Seals in the Northern Districts" was prepared (Urbanek et. al. 2013). The following tests were performed by the Center during these projects at various locations with different climates, and pavement types.

- The Circular Track Meter (CTM) as shown in Figure 6-6 is a test that measures the macro texture of the pavement surface. It emits a laser beam that rotates in a circular pattern that coincides with the direction of traffic.

Figure 6-6 Circular Track Meter (CTM) for ASTM E2157-01

- The Dynamic Friction Tester (DFT) shown in Figure 6-7 is an instrument used for measuring the surface friction as a function of speed under wet conditions and the test method is described in ASTM E1911-09ae1. The DFT includes both a measuring unit and a control unit. The measuring unit, shown in Figure 6-7, has a horizontal spinning disc with three rubber boots which are the actual contact points. As the disc increases its velocity, the apparatus begins to flood the surface of the pavement with water to simulate wetted conditions.

Figure 6-7 Dynamic Friction Tester with Control Unit

- The completed ring test shown in Figure 6-8 is used to determine the correct emulsion application rate for a road about to receive a fog seal. The ring test kit consists of a 6 in diameter template, a crayon, an applicator brush, a pipette, and a sample of the emulsion to be applied. The test is performed by using the template to draw a circle on the pavement surface, preferably in the wheel path (WP), and applying the emulsion within the drawn circle. The optimal application rate should provide uniform, full coverage of the pavement within the circle, with no emulsified asphalt draining outside.

Figure 6-8 Completed Ring Tests

- Figure 6-9 shows a kit used to determine emulsion application rate by spraying the 1-yd^2 of material with a spray as shown below. The material is weighed both before and after application of emulsion to determine the rate by dividing the amount of emulsions over the area of the circle.

Figure 6-9 Emulsion Application Test Kit

- Figure 6-10 shows the sand patch test kit which measures the Mean Texture Depth (MTD) of the pavement and is described by ASTM E965-96(2006). The test requires the use of sand and a rubber puck. The sand is specially manufactured and consists entirely of glass beads that have been graded to a specific size. For this test, the gradation of the sand (glass beads) was passing the #60 sieve.

Figure 6-10 Sand Patch Test Being Performed ASTM E965 - 96 (2006)

- The British pendulum test (BPT) shown in Figure 6-11 measures the low-speed frictional resistance between the pavement surface and a rubber slider mounted on the end of a pendulum arm and the surface to be tested and the test method is described by ASTM E 303-93 (1998). The low-speed friction is primarily determined by the micro-texture of the pavement's surface; and therefore, the BPT indirectly measures the available micro-texture of the pavement.

Figure 6-11 British Pendulum Tester (ASTM E303 1998)

- The Caltrans skid trailer shown in Figure 6-12 is designed to determine the skid resistance of paved surfaces with a full-sized automotive tire. The test method is ASTM E274-06. The skid trailer utilizes a measurement that is representative of the steady-state frictional force on a locked test wheel as it is dragged over a wetted pavement surface under constant load and at a constant speed. During testing the major frictional plane is parallel to the direction of travel and perpendicular to the pavement.

Figure 6-12 ASTM Skid Trailer (Ontario MTO 2010)

6.4 CONSTRUCTION

This section is focused on the application of fog seal coats including rejuvenating seal coats. Construction of rejuvenating seals should follow the manufacture's guidelines and recommendations, and must meet the current Caltrans Standard Specifications, 2025.

6.4.1 General Description

A fog seal is designed to coat, protect, and/or rejuvenate the existing asphalt binder on an HMA pavement. The addition of asphalt will also improve the waterproofing of the surface and reduce its aging susceptibility by lowering permeability to water and air. To achieve this, the fog seal material (emulsion) must partially fill the voids in the surface of the pavement. Therefore, during its application it must have sufficiently low viscosity to not break before it penetrates the surface voids of the pavement. This can be accomplished by using either a slow setting or a quick setting emulsion that is diluted with water. Emulsions that are not adequately diluted with water may not properly penetrate the surface voids resulting in excess asphalt on the surface of the pavement after the emulsion breaks. This may result in a pavement with low skid resistance or a slippery surface. Figure 6-13 conceptually shows a fog seal application.

During application, the emulsion wets the pavement surface. Cationic (positively charged) emulsions can displace water from the surface of an aggregate or aged asphalt film. The emulsion then breaks by loss of water and chemical action, forming a film of new binder on the aggregate and existing binder film. The rate at which the emulsion breaks is dependent on several factors with weather conditions (e.g., wind, rain, temperature, etc.) being dominant factors. For anionic (negatively charged) emulsions, there is no surface specific interaction with most aggregates. The emulsion breaks due to water loss by evaporation and absorption of water by the aggregates and surface voids of the pavement.

Figure 6-13 shows single, double, and triple overlap of emulsion application dependent on the height of the spray bar. An inspector should frequently check the application rate and visually observe that there is no streaking, and that the fog seal has a uniform appearance. The application rate may need adjusting if the HMA surface condition changes. Nozzles should be set to a 15 to 30 degrees longitudinally with the spray bar.

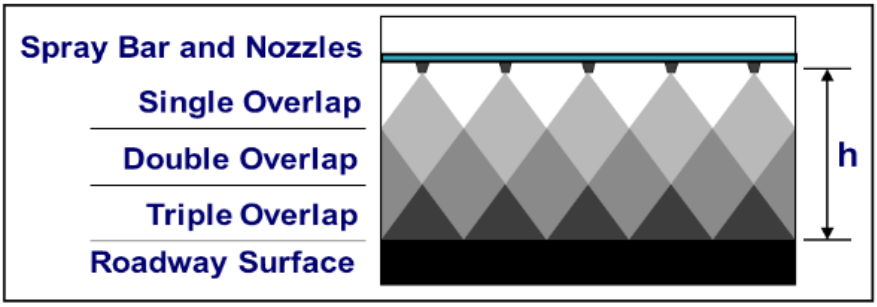

Figure 6-13 Spray Bar Height Arrangement (CP2 Center Manual, October 2019)

6.4.2 Site Conditions

To be effective, fog seals need to break quickly (process of evaporation of water begins; the emulsion turns black from brown) and cure completely (lose water to form a cohesive and non-tacky film). This should be at a rate that allows traffic to be accommodated without the binder being picked up by vehicle tires. The binder must be adequately cured or else it

must be sanded. Most asphalt films do not form well at low temperatures in the absence of low viscosity diluents. Weather forecasts should show warm conditions and no rain to ensure successful applications. Unless otherwise specified, fog seals should not be applied when the ambient temperature is below 60°F (16°C), and pavement temperature below 59°F (15°C). However, there are some rejuvenators that can be placed at an ambient temperature down to 40ºF. Furthermore, Caltrans specifications and the manufactures recommendations must be followed. Emulsion must not be applied if rain or freezing temperatures are forecasted within 24 hours of placing the fog seal per the Standard Specifications, 2025.

If unexpected rain occurs, prior to the emulsion breaking, the emulsion may wash out of the pores of the pavement and break on the pavement surface creating a slippery condition. Rain can also cause the emulsion to run off and pollute nearby waterways.

6.4.3 Surface Preparation

Immediately before applying a fog seal, the pavement surface must be cleaned with a road sweeper, power broom, and/or flushed with a water truck to remove dust, dirt, and debris. The pavement surface must be clean and dry before applying the fog seal. Complete flushing with water 24 hours prior to the application of the fog seal to allow for adequate drying.

6.4.4 Materials Preparation

Asphalt emulsions (original emulsions) must be diluted further before use. This additional dilution reduces viscosity and allows the application of small amounts of residual binder to be adequately controlled. Generally, the supplier will dilute the original emulsion, in the field or at the plant. A dilution rate of 50% (1:1) (equal parts water to equal parts emulsion) is typical. Dilution water must be potable and free from detectable solids or incompatible soluble salts (hard water). When diluted, the viscosity drops from 120 cp to about 40 cp for a 40-60% dilution.

This is the "normal" rate of dilution, but not always the best. During cooler conditions, on steep grades, tight asphalt surfaces, high humidity, high wind conditions, it will be difficult to hold a 0.10 gal/yd^2 application of diluted seal coat on the surface to get the (normally desired optimum) 0.03-0.035 residual asphalt on these conditions, it sometimes takes a 0.08 gal/yd^2 application of 60/40 or 0.07 gal/yd^2 at 70/30 ratio. Using these guidelines, a less experienced user may cut the application rate without changing the dilution rate, sacrificing the performance of the seal by reducing the residual asphalt. The dilution rate should be set by the Resident Engineer.

Water can be checked for compatibility with the emulsion by mixing a small amount of the emulsion in a can (approximately 0.26 gal [1 liter]). The materials are mixed for 2-3 minutes with a stirrer and the resulting mixture is poured through a pre-wetted No.100 (150 μm) sieve. If more than 1% by weight of material is retained on the sieve, the water is not compatible and spray jets may clog. This test is illustrated in Figure 6-14.

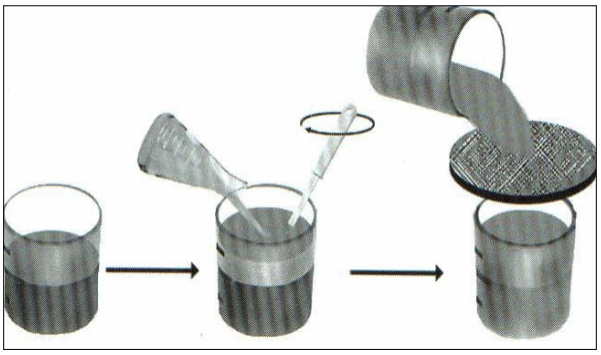

Figure 6-14 Simple Water Compatibility Test Method (Asphalt Institute, 2008)

Incompatible water may be treated with 0.5-1.0% of a compatible emulsifier solution (the emulsion manufacturer can provide advice regarding compatible solutions). The emulsifier solution should be added to the water tank and circulated for 10-15 minutes via pump before adding to the emulsion. If a water treatment is used, the compatibility test should be repeated using the treated water to ensure compatibility.

It is common practice for emulsion to be diluted not more than 24 hours before its intended use. This is to avoid settlement of the diluted emulsion. Both the original or diluted emulsion may be circulated using a centrifugal or other suitable pump to maintain its uniformity (AEMA, 2017). With the different types of emulsions that have been developed, check with the manufacturer or supplier for their recommendations on maximum storage time after the emulsion has been diluted before it is applied.

6.4.5 Application Rates and Spraying

Properly calibrated distributor trucks shall be used to apply the emulsion. Spray nozzles with 1/8-inch to 3/16-inch (4 to 5 mm) openings are recommended (AEMA, 2017). The emulsion may be heated to 122°F (50°C) maximum, although generally the emulsion is sprayed at ambient temperature (AEMA, 2017). The emulsion is sprayed at a rate that is dependent on the surface conditions (see Table 6-1). A test section, representative of the entire surface, should be chosen to approximate application rates). Typical application rates for diluted emulsion (1:1) range from 0.03-0.22 gal/yd^2 (0.15 to 1.0 l/m^2) depending on the surface conditions (Hicks, 2002). A 1:1 diluted emulsion is an original emulsion that has been subsequently diluted with equal parts water. Table 6-1 outlines the typical application rates for varying surface types and degree of dilution. Several sections of the Caltrans Standard Specifications, 2025, require test strips of 1,500 feet be placed prior to beginning construction. The test strip will verify to the Resident Engineer (RE) and contractor that the selected fog seal application rate is appropriate.

Table 6-1 Initial Target Fog Seal Application Rate

Surface Type	Residual Rate, gal/yd^2	Undiluted, gal/yd^2	Diluted 1:1, gal/yd^2
Dense-Graded HMA	0.015-0.021	0.025-0.035	0.05-0.07
Open-Graded HMA	0.021-0.027	0.035-0.045	0.07-0.09
Chip Seal (<1/2-inch aggregate)	0.027-0.033	0.045-0.055	0.09-0.11
Chip Seal (≥ ½ inch aggregate)	0.029-0.039	0.055-0.065	0.11-0.13

AASHTO Section 410 Construction Guide Specification for Emulsified Asphalt Fog Seal, 2020

6.4.6 Estimating Application Rates

To estimate the application rate, the RE shall take a one liter can of diluted emulsion (usually 1:1 dilution rate) and pour evenly over an area of 1.2 yd^2 (1 m^2). This represents a diluted application rate of 1.2 yd^2 (1 m^2). If the emulsion is not absorbed into the surface after 2-3 minutes, decrease the application rate of the emulsion and apply to a new 1.2 yd^2 (1 m^2) area and repeat until the approximate application rate is determined. If, after the first test, the surface looks like it can absorb more emulsion, increase the application rate of the emulsion and spread it over a new 1.2 yd^2 (1 m^2) area. Repeat until the approximate application rate is determined. This same procedure can be followed using gallons and square yards to determine application rate, which is the preferred unit of measure for the contractors and Caltrans. A guide entitled “4 Fog Seal Application”, that states, “The series is provided through the joint efforts of the Pavement Preservation Program of the Federal Highway Administration (FHWA), and the Foundation for Pavement Preservation (FP2).” These guides are available on the FHWA website and offer a good source of information to both Resident Engineers and Inspectors.

The Caltrans Standard Specifications, 2025, uses ASTM D2995-14 for measuring spread rates of emulsions for fog seals. The pavement surface should be sampled and tested at least on the first day of production. Either slow setting or quick setting asphalt emulsion may be used for fog seal. The ring test may also be a suitable test for measuring an approximate spread rate for emulsion.

6.4.7 Traffic Control

Traffic control must be in place before workforces and equipment enter into the work zone. Traffic control is required both for the safety of the traveling public and the personnel performing the work. Traffic control includes construction signs, construction cones and/or barricades, flag personnel, and pilot cars to direct traffic clear of the construction operation. For detailed traffic control requirements, refer to the Caltrans project specifications and the Caltrans Code of Safe Operating Practices.

Traffic control is also required to protect the integrity of the application. The curing time for the fog seal material will vary depending on the pavement surface conditions and the weather conditions at the time of application. Under ideal conditions, including increasing air and surface temperatures, traffic should be kept off the fog seal material for at least two hours, and acceptable skid test (CT 342) values are achieved. If the results of CT 342 show low skid numbers, sand can be applied as a remedy. Caltrans Standard Plans, 2025, has several plans for traffic control for various highway configurations. See Temporary Traffic Control Systems, T-9 through T-22 of the Standard Plans.

6.4.8 Safety (Personal Protection Equipment)

All employees are advised to wear and use the safety gear required for a fog seal operation. This includes hard hats, approved Caltrans shirts, safety vests, earplugs, gloves, safety glasses, and others. See Chapter 2 of the Caltrans Construction Manual, dated June 2023, for construction requirements and personnel duties.

6.4.9 Quality Control

Quality control and workmanship are critical to the performance and life of a fog seal treatment. There must be a cooperative effort between Caltrans and the contractor to conduct inspections of all project equipment before and during the project. The primary pieces of equipment for a fog seal operation are the distributor truck/equipment and distributor bar. It is critical that each is functioning as required by the project specifications. The spray bar must be set to the appropriate height (distance) from the pavement surface and the nozzles must be set at the proper angle to assure a uniform application of material (Asphalt Institute, 2008). The material temperatures should also be measured for quality control purposes.

The emulsion must be sampled and tested and must conform to specifications according to the established sampling and testing procedures if not from an approved source. Also, a certificate of compliance must accompany each load of emulsion delivered to the project. Project inspections should be conducted so that any deficiencies in workmanship or materials are addressed and corrected. This process will also assist the department in identifying the performance of various fog seal materials; how they are performing on various surface conditions and how they are performing in various climatic zones.

6.4.10 Post Treatment

Sand blotters may be used, at approximately 0.20 lb./ft^2 (1 kg/m^2), to allow early opening to traffic or to increase skid resistance. Sweeping may be required. The Resident Engineer should assess road conditions after sand application and before opening to traffic. Even with sand cover, traffic control may be required to keep traffic slower.

Skid resistance (coefficient of friction) can be measured using CT 342 or a Caltrans approved test. This should be done after the application has cured to ensure the proper value is measured. The final surface shall yield a coefficient of friction not less than 0.3 per

Caltrans CT 342. To ensure success, it is recommended that the coefficient of friction also be measured prior to any fog seal application. An estimate of 10% drop in the coefficient of friction can be expected after treatment. The coefficient of friction increases after a few days of traffic.

A treated pavement shall not be opened to traffic until an acceptable value of 0.3 is recorded in accordance with Caltrans CT 342. If a treated pavement does not produce an acceptable coefficient of friction, see Table 6-2 for corrective action. Permeability may be monitored by CT 341 to ensure that an effective seal has been achieved. This should be done at the discretion of the Resident Engineer.

6.5 TROUBLESHOOTING AND FILED CONSIDERATIONS

6.5.1 Troubleshooting Guide

This section provides information to assist maintenance personnel in troubleshooting problems with fog seals, along with “dos and don’ts” that address common problems that may be encountered during construction.

The troubleshooting guide presented in Table 6-2 associates common problems to their potential causes. For example, a slick surface may be caused by wet pavement, a high application rate, or rain. Cold weather could also contribute to slick pavements as the emulsion break may be delayed. The emulsion will be tacky and pickup if the existing road surface is dry or dusty, or the wrong emulsion is used, and it is not penetrating the HMA surface.

In addition to the troubleshooting guide, Table 6-3 lists some application problems and their recommended solutions.

Table 6-2 Trouble Shooting Fog Seal Problems

Cause	Slick Surface	Not Breaking	Washes Off	Tacky Picks Up on Tires	Will Not Dilute	Breaks Too Fast	Dilution Wrong
Acidic Water					Anionic		
Alkaline Water					Cationic		
Application Too High	□	□	□	□			□
Application Too Low						□	□
Cold Weather	□	□					
Hard Water					Anionic		
Hot Weather				□		□	
Rain	□	□	□				
Road Dusty				□		□	
Road Too Dry				□		□	
Road Wet	□	□	□				
Wrong Emulsion		□	□	□	□	□	

Table 6-3 Common Problems and Related Solutions

Problem	Solution
Spattering of the Emulsion	Reduce The Rate of Dilution. Check The Spray Bar Height. The Spray Pressure May Be Set Too High.
Streaking of the Emulsion	Check That the Emulsion Temperature Is Not Too Cold. Ensure The Emulsion Viscosity Is Not Too High. Check That the Nozzles Are at the Same Angle. Check That the Spray Bar Height. Is Not Too High or Too Low. Check That the Spray Bar Pressure Is Not Too High. Check All Nozzles to Ensure That They Are Not Clogged.
Bleeding Or Flushing of the Emulsion	Reduce The Emulsion Application Rate, As It May Be Too High. Check Application and Dilution Rate and Recalibrate Sprayer, If Necessary.
Surface Coefficient of Friction Is Too Low Per CT 342	Apply Coating of Clean Dry Sand. Sweep Sand with Rotary Broom to Distribute Sand, and to Increase Coefficient of Friction. Perform CT 342. Minimum Allowable Coefficient of Friction Needs to Be Stated in the Project's Special Provisions as a Criteria for Opening to Traffic.*

**Do not open treated surface until coefficient of friction is at least 0.3 as determined by CT 342.*

6.5.2 Dos and Don'ts

The following list provides a quick reference to avoid making common mistakes with fog seals. Also review Section 4-9402, Caltrans Construction Manual, dated July 2019, "Before Work Begins".

Table 6-4 Reference to Avoid Common Mistakes with Fog Seals

Reference
Do check water compatibility before dilution.
Do check dilution - has it been done, by whom, and when? [(b)]
Do ensure that there is no contamination of the base emulsion by water, oils, or other liquids.
Do obtain a certificate of compliance if emulsion is to be used prior to completion of sampling and testing. [(1)]

Table 6-4 Reference to Avoid Common Mistakes with Fog Seals (Continued)

Reference
Do sample asphaltic emulsion in accordance with Table 6-1.12 "Materials Acceptance Sampling and Testing", note if any additional water was added on the Form TL-0101, Sample identification card, and the ratio of added water to the total mixture, and Type/Grade of emulsion, and supplier.(3)
Do record on Form CEM-3701, "Test Result Summary" to record sampling and shipping date, within 2-days of sampling. (Ship to specified laboratory or METS 2-1quart samples) (3)
Do prevent contamination by other emulsions. (See Chapter 2 of this manual)
Do protect emulsions from freezing or localized boiling due to the application of direct heat.
Do heat emulsion slowly and ensure heating coils are under the liquid level (max 122°F (50°C)).
Do load from the bottom of tankers or sprayers to avoid foaming.
Do check equipment (distributor trucks, storage tanks, and nozzles on spray bar, and sand spreader) (1).
Do check application rates.
Do exercise proper traffic control.
Do ensure that personnel on the job are properly trained.
Do add water to emulsion, not emulsion to water. (b)
Do not store diluted emulsion longer than 96 hours per Caltrans recent recommendations[3].
Do not over circulate emulsion. Tanks should be circulated from top to bottom. (2)
Do not apply emulsion if air temperature is < 50°F (10°C) (3)
Do not apply emulsion if rain or cool temperatures are forecast within 24 hours. (3)
Do not continue application if adequate breaking period is not available.
Do not open treated surface to traffic until coefficient of friction is at least 0.3 as determined by CT 342.

1. *Section 4-9402, Caltrans Construction Manual, dated July, 2019*
    a. *Rapid setting emulsions and polymer modified emulsion must not be diluted.*
    b. *Dilution should be done by the producer/manufacturer, not the contractor, prior to deliver to job site.*
2. *AEMA recommendations.*
3. *Manufacturer or Producer may have other recommendations regarding storage times for diluted emulsions.*

6.5.3 Section 37-4, "Fog Seals and Flush Coats", Caltrans Standard Specifications, dated 2025. Filed Considerations

The following field considerations are a guide through the important aspects of performing a fog seal project. The various tables contain items that should be considered to promote a successful job outcome. Thorough answers to these questions should be determined, as required, before, during, and after application of fog seal. The appropriate staff to do this will vary by job type and size. Some topics may need attention from several staff members. The field personnel should be acquainted with its contents. The intent of the tables is not

to form a report but to bring attention to important aspects and components of the project process. Some information is product specific and contained in the relevant standard specifications, standard special provisions, or special provisions.

If personnel lack experience, the Resident Engineer may write a Contract Change Order (CCO) to include joint training for both Caltrans and contractors' staff. This Just-in-Time Training (JITT) would be furnished by the contractor by a trainer approved by the Resident Engineer. Some projects may include JITT as a contract bid item. The objective of this training is to provide current standards, and to improve the product quality.

Table 6-5 Field Considerations

Design Decisions	
Project Review	• Is the project a good candidate for a fog seal? • What is the existing surface type? • Has surface absorption been tested? • How much raveling has occurred? • How much bleeding or flushing exists? • Do not apply to smooth, non-porous, and asphalt-rich surfaces. • Review project for bid/plan quantities. • What is the relative cost?
Document Review	• Bid Specifications • Special Provisions • Emulsion Specifications • Traffic Control Plan (TCP)
Pre-construction Review	
Materials Checks	• What is the type and dilution rate of the emulsion selected? • Is the emulsion from an approved source? • Has the emulsion been sampled and submitted for testing (if required)? • Is water to be used compatible with emulsion? • Is sand required? Is the sand cover within specifications? • Is the emulsion temperature within specified application temperature? • Has a check been done on the absorption ability of surface, i.e., sand patch test?
Pre-fog Seal Inspection	
Surface Preparation	• Is the surface clean and dry? • Have all necessary pavement distresses been repaired? • Has the existing surface been inspected for drainage problems?

Table 6-5 Field Considerations (Continued)

	Equipment Inspection
Broom	• Are the bristles the proper length? • Can the broom be adjusted vertically to avoid excess pressure on the surface?
Spray Distributor	• Does the distributor truck have a current calibration sticker? • Is the spray bar at the proper height for good emulsion coverage? • Are all nozzles uniformly angled at 15 to 30 degrees from the spray bar axis? • Are all nozzles free of clogs? • Is the spray pattern uniform and does it properly overlap (double or triple)? • Is the application pressure correct? • Is there a working and calibrated thermometer on site? • Has water been added to emulsion in correct proportion and circulated? • Is the application rate being monitored throughout the project?
Sand Spreader	• Do the spreader gates function properly and are their settings correct? • Is the sand spread uniformly across the entire lane? • Is the sand free flowing? • Are the truck hook-up hitches in good condition?
Trucks	• Is the truck box clean and free of debris and other materials? • Is the truck hook-up hitch in working order? • Is a truck box apron or extension required for loading the sand spreader?
All Equipment	• Is all equipment free of leaks? • Is all equipment calibrated and clean?

Table 6-5 Field Considerations (Continued)

Onsite Responsibilities	
Traffic Control	• Do the signs and devices used match the traffic control plan? • Does the work zone comply with Caltrans traffic control policies as laid out in the current Caltrans Safety Manual and the Caltrans Standard Plans, 2023? • Do flaggers hold traffic for not more than the specified periods of time? • Does the pilot car lead traffic slowly - 25 mph (40 kph) or less -over fresh sand blotted fog seals? If not sanded, allow at least 2 hours before opening to traffic. • Are unsafe conditions promptly reported to the Resident Engineer? • Are signs removed or covered when construction is complete?
Weather Requirements	• Are minimum surface and air temperatures adhered to? • Are air and surface temperatures checked at the coolest location on the project? • Do air and surface temperatures meet agency requirements? • Are high winds expected during application of the fog seal? High winds can cause emulsion drift onto vehicles, and the diluted emulsion application may not uniformly coat the pavement surface. • Will the expected weather conditions delay the breaking of the emulsion? High temperatures, humidity, and wind will affect how long the emulsion takes to break. • Is the application of the fog seal discontinued if rain is likely?
Binder	
Binder Application	• Are the agency guidelines and specifications being followed? • Is the surface oxidized and porous? More oil can be applied to dried-out and porous surfaces. • Is there a high traffic volume on the road? Less oil must be applied on roads with high traffic volumes. • Does the emulsion soak into the surface? If not, application rate is too high. • Is the surface texture coarse? Apply fog seal at a lower speed to increase application. • Are manhole covers and drainage inlets protected to keep emulsion from coating utility covers, and from entering water bodies?

Table 6-5 Field Considerations (Continued)

Binder	
Checking Application Rates	**Binder - Method A (Recommended for Calibration)** • The weight of a 1 yd^2 (0.84 m^2) carpet, pan or, non-woven geotextile material, or cardboard is recorded and placed on the road surface. • The distributor applies emulsion over the material. • The weight of the coated material is recorded. • The weight of the material without emulsion is subtracted from the weight of the emulsion coated material. • The difference of the weights (i.e., lb./yd^2 or kg/m^2) must be converted to gal/yd^2 or l/m^2, using the specific gravity of the emulsion. If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate.
Binder Application Calculations	
Checking Application Rates	**Example – Checking Fog Seal Application Rate (Method A)** • Given: Applying a Fog Seal with a 1:1 diluted emulsion. Tight surface texture. Recommended application rate of 0.03 – 0.11 gal/yd^2 (see Table 6-1). Specific gravity of Emulsion (G_E) = 1.010. Unit Weight of Water (γ_W) = 62.4 lb./ft^3. Conversion Factor (C_{fl}) = 7.5 gal/ft^3. **Find the actual application rate W_A,** • Measure the weight of a 1 yd^2 carpet (W_C). W_C = 4.0 lb. • Measure the weight of 1 yd^2 carpet and applied emulsion (W_{C+E}). W_{C+E} = 4.7 lb. • Calculate the weight of emulsion covering the 1 yd^2 carpet (W_E). $W_E = W_{C+E} - W_C$ W_E = (4.7 lb. - 4.0 lb.) W_E = 0.7 lb. • The application rate is the weight of emulsion applied per unit area (W_A). W_A = 0.7 lb./yd^2 **Convert this application rate to gal/yd^2** • Calculate the unit weight of the emulsion (γ_E) by multiplying the specific gravity of the emulsion (G_E) by the unit weight of water (γ_W). $\gamma_E = G_E \times \gamma_W = 1.010 \times 62.4$ lb./ft^3 $\gamma_E = 63.024$ lb./ft^3

Table 6-5 Field Considerations (Continued)

Binder Application Calculations	
Checking Application Rates	**Example – Checking Fog Seal Application Rate (Method A) (continued)** • Convert the unit weight of the emulsion (γ_E) 63.024 lb./ft^3 to lb./gal (γ_{Elb}) by dividing (γ_E) by (C_f 1) 7.5 gal/ft^3. γ_{Elb} = 63.024 lb./ft^3/7.5 gal/ft^3 γ_{Elb} = 8.4 lb./gal Convert W_A in lb/yd^2 to $W_{A'}$ in gal/yd^2 by dividing W_A by γ_{Elb}. $W_{A'} = W_A / \gamma_{Elb}$ $W_{A'} = 0.7$ lb/yd^2 / 8.4 lb/gal $W_{A'} = 0.08$ gal/ yd^2 • Check this value against the recommended application rates given in Table 6-1, for the given surface condition and dilution rate this application rate is acceptable. • Caltrans Standard Specifications, 2025, in Section 37-4.02A(4)(b)(iii) requires that on the first day of production that the spread rate for emulsion is tested using ASTM D 2995 to determine the spread rate in gallons per square yard.
Binder Considerations	
Checking Application Rates	**Binder – Method B (Recommended for Random Checks)** • Park the distributor on level ground and measure the number of liters or gallons of emulsion (most distributor trucks have a gauge). • Measure a distance for the test section. • Have the distributor apply diluted emulsion to the test section. • Park the distributor truck on level ground and re-measure the number of liters or gallons of emulsion. • Make necessary adjustments to volume based on temperature corrections per Standard Specifications, 2025 Section 92. • Subtract the number liters or gallons after application from the original number of liters or gallons to obtain the number of liters or gallons applied. • Divide the number of liters or gallons applied by the number of square meters or square yards covered by emulsion to give the application rate in gal/yd^2 or l/m^2. • If the distributor truck is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate throughout the project.

Table 6-5 Field Considerations (Continued)

Project Inspection Responsibilities	
Binder Application	• Is building paper used to start and stop emulsion application for straight edges? • Is the emulsion within the required application temperature range? • Does the application look uniform? • Are any nozzles plugged? • Is there streaking on the applied emulsion? • Are application rates randomly checked? • Is the speed of the distributor adjusted to match the sand spreader (if used) and to avoid start-and-stop operations? • Is the distributor truck stopped if any problems are observed?
Truck Operation	• Are the trucks staggered across the fresh fog seal coat to avoid driving over the same area? • Do the trucks travel slowly on the fresh seal? • Are stops and turns made gradually? • Do truck operators avoid driving over exposed oil?
Project Inspection Responsibilities	
Opening A Fog Seal to Traffic	• Are results from CT 342 (skid test) at least 0.3? • Does traffic go slowly - 25 mph (40 kph) or less - over the fresh seal until seal is broomed and opened to normal traffic? If not sanded, allow 2 hours before opening to traffic. • Are reduced speed limit signs used when pilot cars are not used? • Are temporary pavement markings placed after sweeping and before opening to normal traffic? • Are all construction related signs removed when opening to normal traffic?
Clean-Up	• Is all loose (excess) sand from sweeping operation removed from traveled way? • Are any binder spills cleaned up?

Table 6-5 Field Considerations (Continued)

	Removal Of Excess Binder from Surface
Sand Application	• Are enough aggregate trucks on hand to maintain a steady supply of sand to the spreader? • Is clean dry sand being used that meets the specified gradation in Section 37-4.03B (2)? • Does the sand application appear uniform? • Is sand used only once?
Sweeping	• Does sweeping begin as soon as possible after sand is applied? • Is initial sweeping done lightly with a rotary broom to distribute and set sand in surface? • Is secondary sweeping done to remove loose sand coated with excess binder?

6.6 REFERENCES

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Note: Caltrans manuals referenced above may have later editions than those cited. Refer to the latest editions of these references for the most current information.