Bitumen emulsion

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Technical bulletin

Nouryon

Introduction

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Bitumen is used as a binder in road construction and in protective coatings and adhesives used in the construction industry. In the most common processes the bitumen is heated to 100-200°C until fluid enough to mix with aggregate. The 'hot mixed' materials must themselves be stored, transported and used hot to maintain their workability.

The final strength of roadway is developed as the mixture cools. Alternatively, the bitumen is diluted with petroleum solvents like kerosene until fluid and the final strength of the material only develops when the solvent evaporates.

Bitumen emulsions provide a alternative approach in which the bitumen is liquefied by dispersing in water. Emulsions can be used with cold and wet aggregates, the final strength of the road material develops as the emulsions 'sets' – reverts to a continuous bitumen phase – and water is lost.

In many road construction applications emulsions provide a safer and environmentally friendlier system than hot bitumen since the risks of fire, burns and emissions are avoided and the processes use less energy. This booklet describes both the theory and practical aspects of bitumen emulsions.

What is an emulsion?

An emulsion is a dispersion of small droplets of one liquid in another liquid.

Emulsions can be formed by any two immiscible liquids but in most emulsions one of the phases is water

Oil-in-water (O/W) emulsions are those in which the continuous phase is water and the disperse (droplet) phase is a water-insoluble 'oily' liquid. Water-in-oil (W/O) emulsions are those in which the continuous phase is an oil and the disperse phase water. W/O emulsions are sometimes called 'inverted emulsions'. Multiple phase emulsions can be formed in which the dispersed droplets themselves contain smaller droplets of a third phase, usually the same liquid as the continuous phase.

Oil and water may form an emulsion if mixed but will quickly separate when mixing is stopped. Stable emulsions contain a third component, the emulsifier, which prevents or retards the separation of the phases.

Bitumen emulsions are normally of the O/W type although inverted emulsions based on cut-back bitumens have special applications. There is evidence that bitumen can form multiple W/O/W emulsions. Emulsions containing from 40 to 80% bitumen are brown liquids with consistencies ranging from that of milk to heavy cream. The droplets normally range from 0.1 to 20 microns in diameter.

Typical particle size distribution of bitumen emulsion droplets
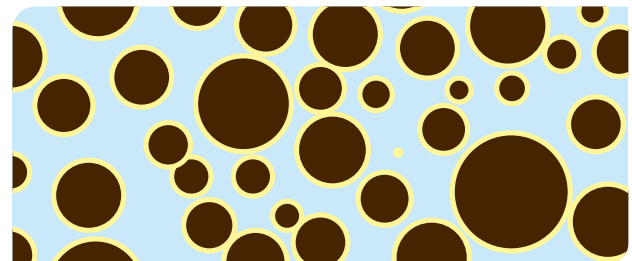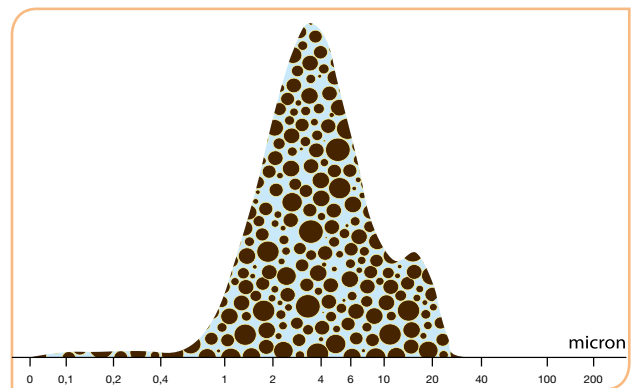
Oil-in-water emulsion
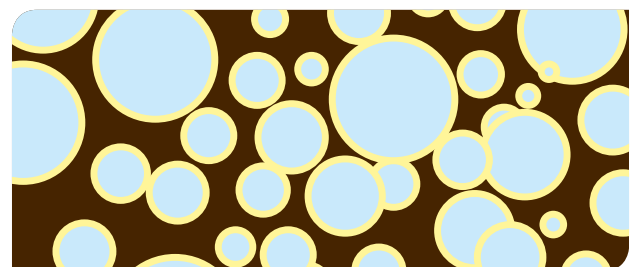
Water-in-oil emulsion

Multiple emulsion

Manufacture of bitumen emulsions

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Bitumen emulsions are usually made using a colloid mill, although other dispersion devices are possible. In the colloid mill energy is applied to the system by passing the mixture of hot bitumen and water phase between a rotating disc, cone or flywheel and a stator. The rotor as well as stator may be grooved or have teeth in order to create a turbulent flow.

Bitumen emulsion can be produced either in a batch or an in-line process plant. The batch process involves at least two process steps- water phase (soap) preparation and the actual emulsion production. The water phase is prepared in a tank into which heated water, emulsifier and other emulsion chemicals are metered and the solution properly mixed. In the emulsion production process the bitumen and the pre-made water phase are dosed to the colloid mill. If solvent is to be added to the bitumen, then a batch tank is needed for bitumen as well, or the solvent must be dosed in-line.

In the batch plant the emulsion production itself involves only a few material flows, which allows manual process control. However, proper metering of the various components are decisive for the quality of the emulsion and automatic or semi-automatic control will make the manu-facturing more efficient and reduce human error. Furthermore, the chemicals used may be hazardous as well as corrosive, which means closed dosage systems rather than open tanks and portable pumps are preferable in order to ensure safe work and environmental conditions.

In the in-line process the water heating and all material dosage are done continuously using individual dosage pumps for each material. No batch tanks are used. Instead, the water phase system must further be designed to provide sufficient reaction time for the chemicals so that

Batch emulsion plant
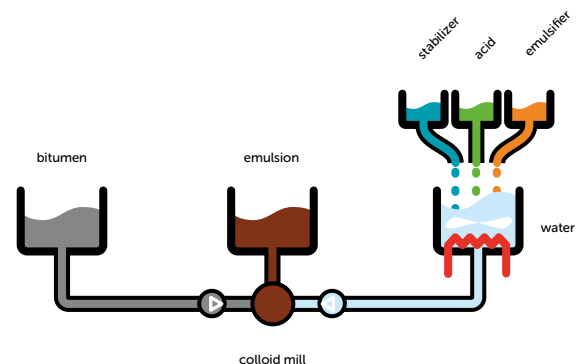
Inline emulsion plant
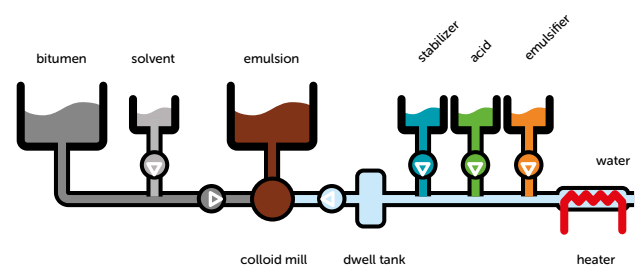
adequate neutralization and solution take place before the water phase meets the bitumen. The process needs to be automatically controlled using flow meters for all material dosage except acid, which should be controlled by the pH in the water phase.

Various special additives such as latex, SBS or bitumen dope may be used and will then require special components and technical solutions. Latex for example is shear sensitive and may coagulate in pumps and lines. SBS modified bitumens usually require the emulsion to be produced above the boiling point of water, which requires production under pressure and cooling before release to atmospheric pressure in the storage tank.

# The emulsification process

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Emulsification involves the break-up of the bitumen into droplets. This process is opposed by the internal cohesion and viscosity of the bitumen and the surface tension which resists the creation of new interface.

Droplets also have a tendency to coalesce (rejoin). To achieve a small particle size in the emulsion, it is necessary not only to apply mechanical energy in the right way in order to create small drops, but also to prevent their coalescence once formed.

The particle size of the resulting emulsion can be related to the design of the mill head, mill rotor speed, the gap between rotor and stator, the dwell time in the mill, the concentration and type of emulsifier and the emulsification temperature.
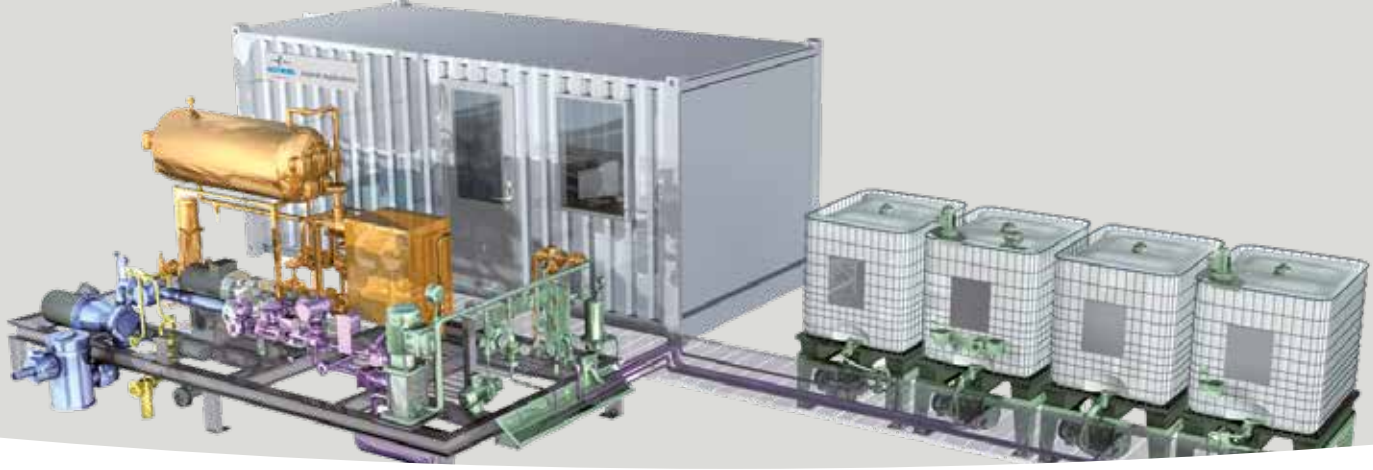
Normally the highest practical temperature is used to prepare the emulsion in order to reduce the bitumen viscosity. Bitumen is heated to 110–160°C until it has a viscosity of 500cSt or less for pumping into the mill. The water phase is also heated to 30–70°C to dissolve the emulsifiers and to achieve the required emulsification temperature after mixing with the bitumen. In colloid mills, which are not pressurized, this temperature is limited to 100°C, but in modern pressurized equipment may reach 120°C or higher. For good emulsion quality the bitumen phase should have a viscosity less than 10,000cSt at the emulsification temperature, which means pressurized systems are preferred for hard or highly polymer modified bitumens.

Function of the emulsifier

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The interfacial area between the liquid phases is greatly increased in an emulsion. One litre of bitumen emulsion may have an interfacial area of 5000m^2. It takes energy to create this interface but this energy can be reduced by the adsorption of emulsifiers. The choice of emulsifier and emulsifier concentration affects the particle size.

Once the droplets are formed they must be stabilised against coalescence which can only occur when the droplets get very close together and deform. Emulsifier adsorbed at the surface of droplets provides an electrical and steric repulsion energy barrier which helps prevent close approach. Even if this energy barrier is overcome and the droplets flocculate, the film of emulsifier on the surface still inhibits coalescence. Surface tension effects arising from the presence of the emulsifier mean that an energetic barrier has to be overcome in order for spherical droplets to deform and join together.

Stable emulsion
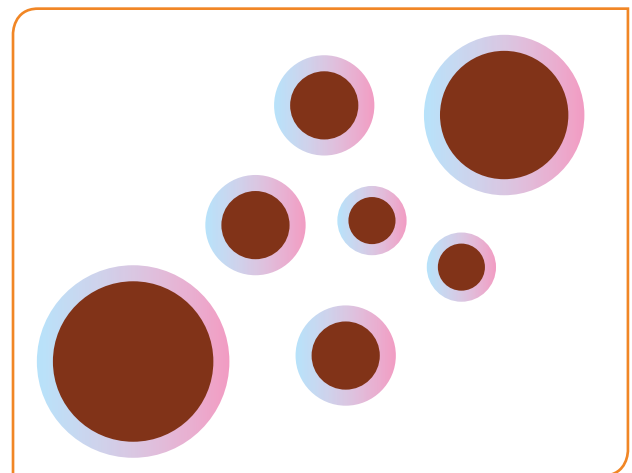
Charge on droplets prevents close approach.

Flocculation
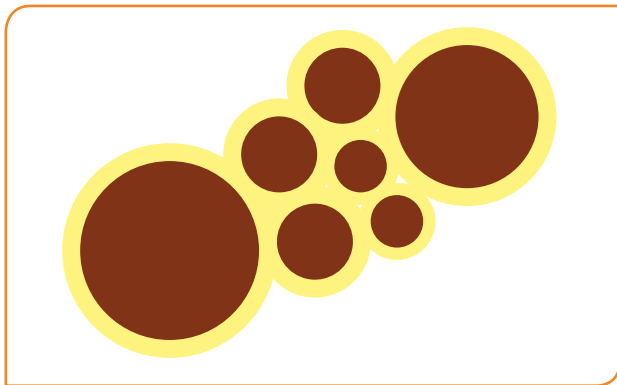
Close approach of droplets leads to adhesion between droplets.

Flocculation and coalescence can result from settlement, shear, and boiling or freezing of the emulsion. It may also be initiated by contact with minerals and are important stages in the eventual setting and curing of the emulsion.

Coalescence
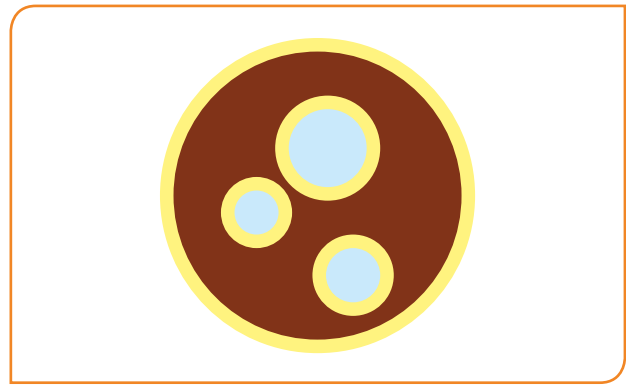
Water drains between droplets and surfactant film breaks down, Droplets fuse.

Generally more emulsifier is required to provide good stability and right performance properties than what is necessary to fill the interface. Bitumen emulsions will contain some 'free' emulsifier, which will help to prevent coalescence during emulsification, storage and transport.

Chemical nature of emulsifiers

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Concentration at the interface (surface activity) depends on the emulsifier molecule having both lipophilic (oil-loving) and hydrophilic portions (water-loving). A typical emulsifier has a hydrophilic 'head' group and hydrophobic (lipophilic) 'tail' derived from renewable materials such as fats, vegetable oils and wood. Emulsifiers such as proteins, lignins, polymers and minerals may have one or more hydrophobic and hydrophilic 'sections'. At the interface the emulsifier orientates with the hydrophobic portion(s) in the oily bituminous phase and the head group and counterions in the water phase

In order to prevent coalescence, the bitumen droplets need to be kept apart. There are two different ways to accomplish this. Ionic emulsifiers impart a charge to the bitumen droplets, when the droplets approach each other, these charges lead to a repulsive force. Because the charge on some anionic and cationic emulsifiers depends on pH, this stabilisation could be lost if the pH changes. The second stabilisation mechanism is a pure
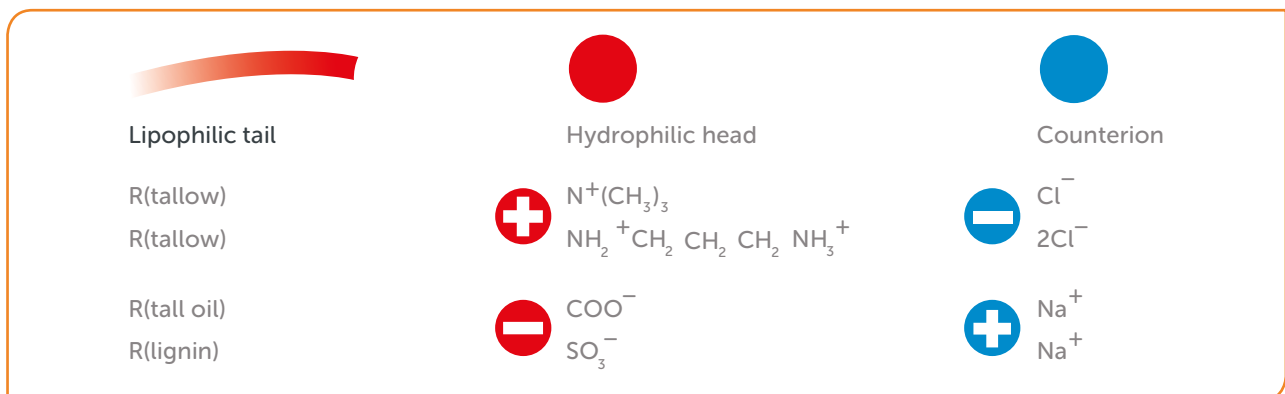
Chemical nature of emulsifiers
Continued

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physical hindrance to the close approach of the droplets. This is important for very large molecules like polymers, proteins etc. The emulsifier molecule is much smaller than a bitumen droplet and each droplet is stabilized by thousands of emulsifier molecules.

If a bitumen droplet was as large as the earth then each emulsifier head group would occupy an area of 10 square kilometers and the tail would penetrate 8 km into the earth's surface.

Many cationic emulsifiers are supplied in a water-insoluble neutral form and need to be neutralized with an acid like hydrochloric, phosphoric, acetic or sulfuric before the cationic form is generated. Similarly, some anionic emulsifiers need to be neutralized with sodium, ammonium or potassium hydroxide. Even with water soluble emulsifiers the charge on the emulsion droplets depends on pH, with acid emulsions generally cationic and alkaline emulsions generally anionic.

Typical emulsifier molecules

Lipophilic tail	Hydrophilic head	Counterion
R(tallow)	⊕ $N^+(CH_3)_3$	⊖ Cl^-
R(tallow)	$NH_2^+CH_2\ CH_2\ CH_2\ NH_3^+$	$2Cl^-$
R(tall oil)	⊖ COO^-	⊕ Na^+
R(lignin)	SO_3^-	Na^+

Salt formation

|						
RNH_2	+	HlC	=	RNH_3^+	+	Cl^-
neutral form	+	acid		water-soluble anionic 'soap'		
$RCOOH$	+	NaOH	=	$RCOO^-$	+	Na^+
neutral form	+	alkali		water-soluble anionic 'soap'		

Stabilization of the emulsion

The nature of the hydrophilic portion governs the mechanism of stabilization. Emulsifiers with large hydrophilic portions may prevent close approach of the droplets simply by their space filling properties (steric repulsion).

Hydrophilic groups may also adopt a charge in water leading to an electrostatic repulsion between droplets. Emulsifiers can be classified into anionic, cationic, amphoteric and nonionic types depending on the charge their head groups tend to adopt. The sign of this charge depends on the pH of emulsion and largely determines the charge on the bitumen droplets, although bitumen itself contains ionisable chemical groups which contribute to the droplet charge.

The size and sign of the charge on the droplets can be measured and is expressed as the 'zeta potential' of the droplet. The zeta potentials depend on pH and there is a tendency for emul-sions containing droplets with low zeta potentials (positive or negative) to be less reactive.
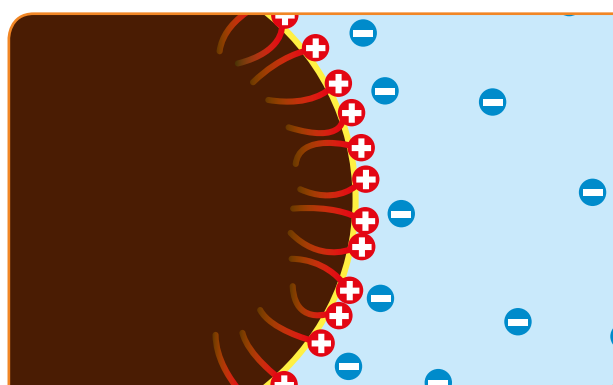
Emulsifier molecules concentrate at the interface.

Other components of the emulsion and their function

Calcium chloride

Calcium chloride or other soluble salts are often included in the water phase of cationic emulsions at level of 0.05–0.1%. Bitumen may contain salt left over from inadequate desalting of the crude oil and this salt can lead to a swelling of the droplets in an emulsion through osmosis. The result is an increase in emulsion viscosity often followed by a decrease as the salt slowly escapes from the bitumen. Calcium chloride helps reduce the osmosis of water into the bitumen and the increase in viscosity during storage. Calcium chloride can also reduce the settlement of emulsions by increasing the water phase density and in some cases improves the performance of emulsifiers.

Sodium tripolyphosphate

Anionic emulsions may be sensitive to hard water. Addition of 0.1% sodium tripolyphosphate to the formula acts as a water softener and improves emulsion quality.

Adhesion promoters

Water resistance is an important property of mixes and seals. Often anionic emulsions and occasionally also cationic emulsions may not have sufficient adhesion on aggregates, in which case adhesion promoters can be added to the bitumen before emulsification or to the finished emulsion.

Asphalt peptizer

The emulsifiability of bitumens varies. Emulsion quality can sometimes be improved by treating the bitumen with an asphalt peptizer. Improvements includes better adhesion and smaller particle size which leads to reduced settlement and higher viscosity.
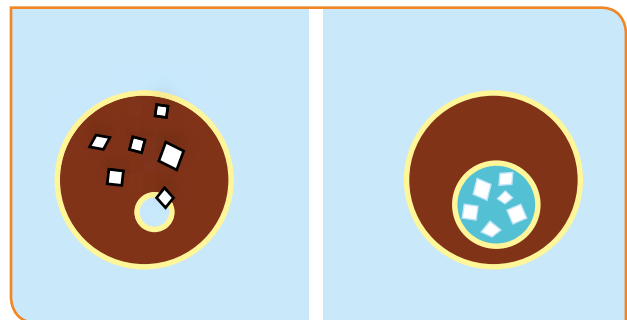
Water is drawn into the bitumen droplet leading to an increase in emulsion viscosity.

Latex

Polymer modification can improve the properties of bitumen in terms of cohesion, resistance to cracking at low temperatures and resistance to flow at high temperatures. While polymer-modified bitumens can be emulsified, latex is a water based dispersion of polymer which is particularly suited to the modification of emulsions. It can be incorporated either in the water or bitumen phase or even post-added to the emulsion. Latex comes in cationic, nonionic and anionic forms and it is important that the latex type should be compatible with the emulsion.

Thickeners

Water soluble thickeners can increase emulsion viscosity, helping to meet national standards or to reduce emulsion run-off in open graded mixes. They can be added to the water phase or to the finished emulsion typically at levels of 0.02–0.20%. Thickeners may affect the breaking and adhesion of emulsions and must be chosen with care.

	A Viscosity Engler	B settlement %	C mean particle size micron
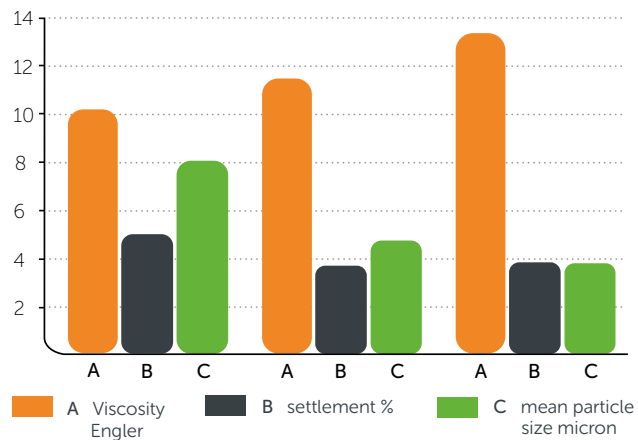
Asphalt peptizer improves emulsion properties

Typical emulsifier use level

| Emulsion type	Emulsifier level %	Emulsion pH	Typical emulsifier
Cationic rapid setting	0.15–0.25	2–3	tallow diamine
Cationic medium setting	0.3–0.6	2–3	tallow diamine
Cationic medium setting	0.8–2.0	2–5	quaternary amine
Anionic rapid setting	0.2–0.4	10.5–12	tall acid
Anionic medium setting	0.4–0.8	10.5–12	tall acid
Anionic slow setting	1.2–2.5	7.5–12	nonionic + lignosulphonate

The setting (or 'breaking') process

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Bitumen emulsions must revert to a continuous bitumen film in order to fulfil their role as a binder in road materials or as protective coatings. The speed of this setting and curing process depends on the reactivity of the emulsion, the reactivity of the aggregate and the environmental conditions such as temperature and humidity. Bitumen emulsions for road use are classified depending on their reactivity.

Rapid-setting emulsions set quickly in contact with clean aggregates of low surface area such as the chippings used in chipseals (surface dressings).

Medium-setting emulsions set sufficiently less quickly that they can be mixed with aggregates of low surface area such as those used in open-graded mixes.

Slow-setting emulsions will mix with aggregates of high surface area. Some national standards define additional super-stable emulsion grades with extremely slow setting characteristics. All aspects of the emulsion formulation can affect its classification including emulsifier type and concentration, choice and concentration of acids or base used to adjust pH, and the grade and source of the bitumen used.

Possible stages in the setting of a Cationic Bitumen Emulsion
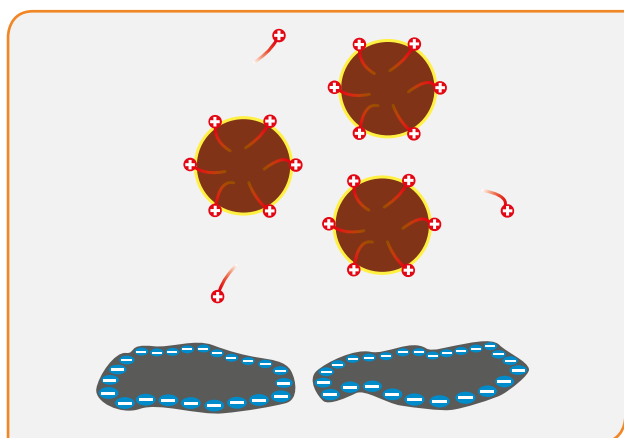
Contact of emulsion with aggregate.
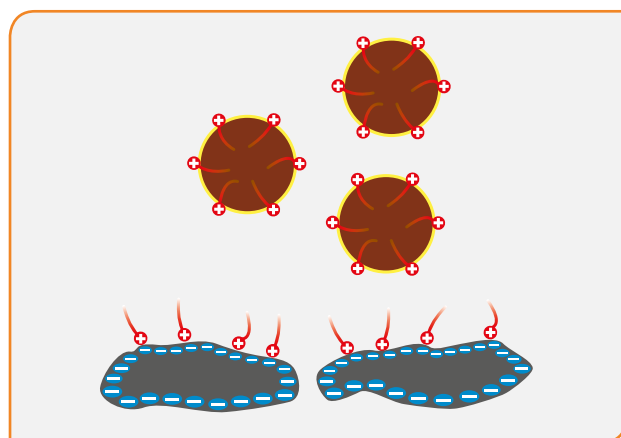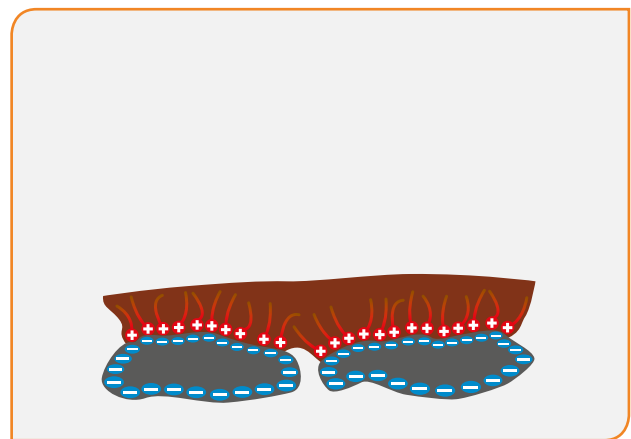
Adsorption of 'free' emulsifier.

Aggregates take up a characteristic surface charge in water which depends on pH and the nature of the minerals. So-called 'acid' aggregates high in silica tend to take up a negative charge, whereas basic aggregates like limestones can take a positive charge. As the pH is raised, all aggregates tend to become more negatively charged, while the presence of calcium salts or other cations in the water tend to make the surfaces less negative.

Generally speaking cationic emulsions react faster with an aggregate with negative surface charge, although other factors can be more important (see below).

The setting of an emulsion is a complex process which is not fully understood, and more than one factor is responsible for the break.
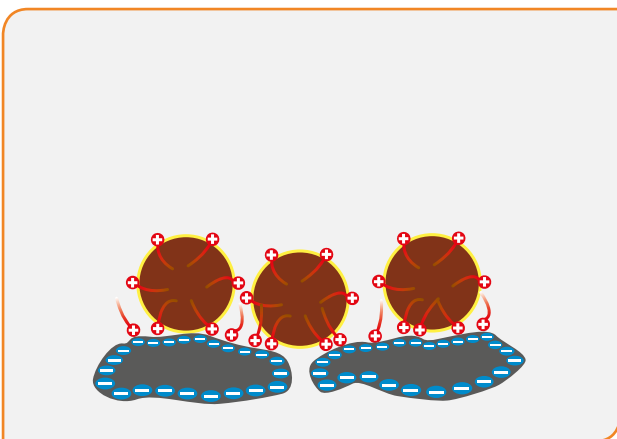
Electrophoresis of droplets to surface.

Coagulation/spreading over surface.

Some of the 'breaking' process steps may include:

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1 Adsorption of emulsifier onto the aggregate surface. Free emulsifier adsorbs rapidly; emulsifier may be abstracted from the bitumen water interface much more slowly. Removal of the reservoir of stabilizing emulsifier makes the emulsion liable to coalesce, but the effect is also to reduce or even reverse the surface charge on the aggregate, which can delay setting.Cationic emulsifiers adsorb much more strongly on siliceous minerals than anionic or nonionic emulsifiers, which explains the usefulness of cationic emulsions with acidic aggregates.

2 Movement of the emulsion droplets to the aggregate surface. The droplets of bitumen in the emulsion have a small charge and move towards an aggregate surface with the opposite charge (electrophoresis). Concentration at the surface brings the particles together leading to flocculation, coalescence and spreading over the surface.

3 Changes in pH. Some aggregates like limestones or fillers like lime or cement may actually neutralize the acid in cationic emulsion causing the pH to rise and the emulsion to be destabilized. In other cases, the aggregates may adsorb hydrogen ions leading to a less marked rise in pH, but still sufficient to destabilize. Some soluble aggregates like limestones can provide calcium or magnesium ions to the solution which tend to neutralize the charge on anionic emulsions.

4 Evaporation of water. As water leaves the system by evaporation, the droplets are concentrated, leading to coalescence. Evaporation may be the main breaking mechanism for very slow-setting emulsions.

Strong bond between bitumen and aggregate after completion of the breaking process and evaporation of the water

Testing bitumen emulsions

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National and local standards provide tests for the important features of bitumen emulsions and these tests fall into three groups:

Tests to classify the charge and reactivity of the emulsions

Emulsions need to be classified into cationic or anionic rapid, medium or slow-setting grades. The **particle charge** test is a simple electrophoresis test in which electrodes are placed in the emulsion and either the negative or positive electrode becomes coated with bitumen depending on whether the emulsion is cationic or anionic respectively.

The reactivity of the emulsion can be measured in tests in which standard aggregates are mixed with or dipped into the emulsion and the amount of bitumen deposited on the surface is determined. Alternatively, fillers such a fine quartzsand or cement are added to the emulsion in the so-called **filler index** or the **cement mix test.** The exent of coalescence or the amount of filler required to give full coalescence is a measure of the reactivity.

In other tests the emulsion is titrated with an ionically opposing solution which tends to cause emulsion breakage. Cationic emulsions are titrated with anionic surfactant, and anionic emulsions with calcium chloride. The titre gives a measure of the emulsion reactivity called the **'demulsibility'.**

The reactivity of emulsions is primarily governed by the choice and concentration of thee emulsifier and the pH of the emulsions, although manufacturing parameters can have an influence.
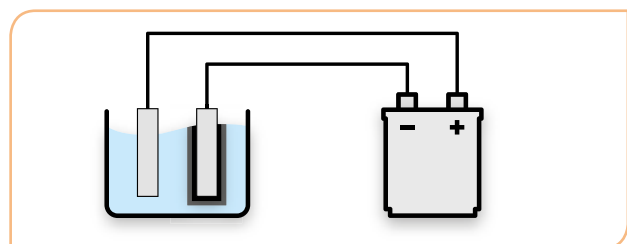
The Particle Charge Test.
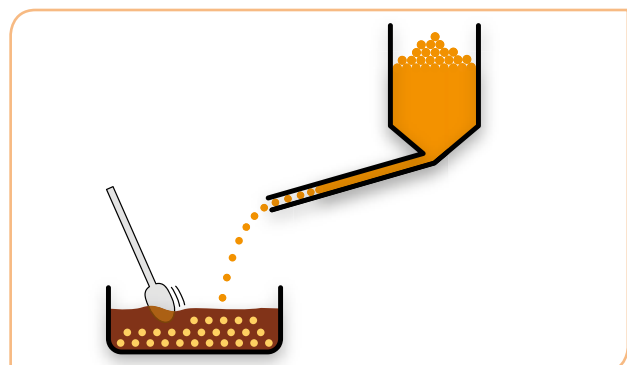
Filler Index or the Cement Mix Test.

Testing bitumen emulsions
Continued

Physical properties relevant to the handling and storage of the emulsions

The presence of large droplets in the emulsion, which could block pumps and spray nozzles, are tested by a simple screening at 150, 630 or 800 microns. The maximum **sieve residue** is specified (usually 0.1–0.2%). The sieve test may be remeasured after storage or after **freeze-thaw** to give an indication of **storage stability.**

The **viscosity** of emulsions are normally determined as the time of efflux from a flow cup with a standard orifice at a temperature relevant to the application. Saybolt Furol cups are used mostly in the Americas and a Standard Tar viscometer in Europe.

The main influence on emulsion viscosity is the bitumen content of the emulsion: the viscosity increases strongly as the bitumen content increases over 65%. An emulsion with small droplet size and a narrow size distribution will give a higher viscosity than one with a wide or bimodal size distribution. The particle size and size distribution can be influenced to some extent by the choice and concentration of emulsifier and the manufacturing conditions.

Bitumens with high salt content tend to give high emulsion viscosities because they form multiple emulsions in which some water is trapped within the bitumen drops. This may happen after the production leading to a change (increase) of the viscosity during storage.

If the density of the droplets is different from the water phase, then they will have a tendency to float or sink leading to **creaming** or **settlement** after prolonged storage. Settlement **(storage stability)** tests generally involve storing the emulsion in a cylinder, then comparing the solids content of the upper and lower layers after 1–5 days. Settlement can be reversed in many cases by stirring, but the close packing of the settled drops may lead to coalescence or irreversible flocculation.

Bitumen emulsions generally show settlement, although those with high solvent content may cream. The rate of settlement depends on the difference in densities, the size of particles, the binder content and the viscosity of the water phase. Actions which tend to equalize the densities of the two phases, such as adding solvent, adding salts, or raising the storage temperature, may reduce settlement, as do

actions which increase the viscosity such as adding thickening agents. Changes to the emulsion recipe or manufacture which reduce the average particle size will also reduce settlement.

Properties of the cured bitumen film

The **binder content** of the emulsion can be determined by simple evaporation, distillation or indirectly by the **water content.** Distillation
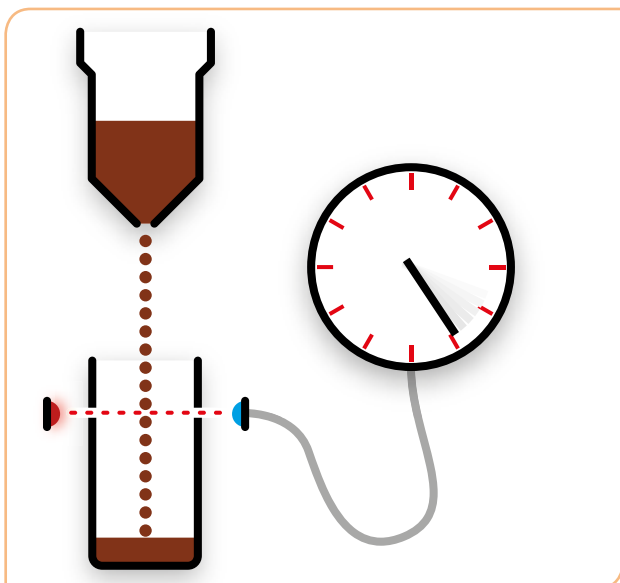
Viscosity by flow cup.
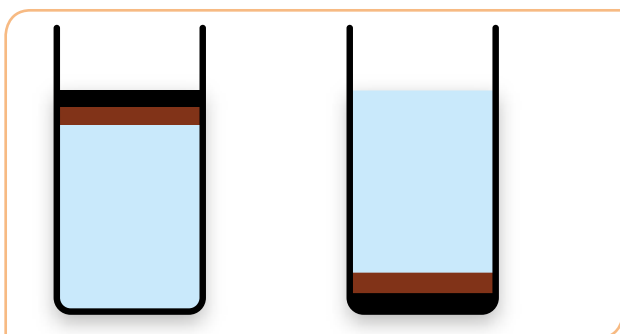
Creaming   Settlement

can also determine the content of **oil distillate** in the emulsion as well as recover the **residual bitumen** for further testwork. Some national standard tests use solvents such as alcohols and acetone to precipitate the bitumen from the emulsion without the need for high temperature heating, which could alter the binder properties. Vacuum distillation can also avoid overheating.

The viscosity of the residual binder can be determined by the standard tests used for bitumen itself such as ring and ball softening point, penetration, and kinematic viscosity. Similarly, the low temperature properties such as **breaking point to Fraas, elastic recovery** and ductility can be determined. The **float test** is specific to anionic emulsions of binders which show a reduced temperature suscreptibility. The tall oil emulsifiers used in the so-called 'high float' emulsions result in gelation of the recovered bitumen and the effect can be increased by the addition of polymers.

The **density, ash content or solubility of the residual bitumen** in toluene, xylene, or trichloroethylene may also be specified.

The water resistance or resistance to re-emulsification of the cured bitumen film is an important aspect of emulsions and can be tested by simple immersion tests on standard aggregates. Generally, cationic emulsions show better adhesion than anionic emulsions but the **adhesion** of anionic emulsions can be

improved by the addition of cationic adhesion promoters.

Specific applications such as slurry surfacings, open-graded mixes, tack coats and prime coats may demand specific tests for the emulsion.

Stability to Transport and Shear

Emulsions may appear stable in the normal storage stability tests but show coalescence during transport or pumping. In more realistic storage stability tests the emulsion is shaken or recycled through a pump and the sieve residue redetermined.

Reactivity Test

The reactivity of rapid set emulsions can be determined by using standard glass beads or standard clean aggregate chippings. The beads are covered with an excess of emulsion and the weight deposited on their surface is determined. Compared to the standard tests, the method better isolates the processes going on at the mineral surface and can identify a truly 'reactive' emulsion from a merely 'unstable' one.

The Evaporation Filtration Test

This test measures the tendency of emulsions droplets to coalesce as water is removed. Emulsions are allowed to evaporate and the amount of sieve residue is plotted against water loss. The results have been related to curing rates under field conditions.

Non-standard Tests
Particle Size and Size Distribution

The sieve residue test measures oversize particles which represent only a small proportion of the emulsion. The full particle size distribution can be measured by techniques such as light scattering, microscopy with image analysis, or the electrozone (Coulter) technique. Size and size distribution measurements are helpful in trouble-shooting problems with emulsion viscosity, storage stability and performance, as well as quality control of emulsion manufacture.

Applications of emulsions

Each application places particular demands on the emulsion.
There is a considerable amount of variation between countries on the choice of emulsion for each application, but the table summarizes the most common practice. Anionic emulsions are hardly used outside North America for road construction but may be used for some industrial coatings.

	Anionic			Cationic			
	Rapid Setting	Medium	Slow	Rapid Setting	Medium	Slow	Super-stable
Spray Applications							
Surface Dressing (ChipSeal)	•			•			
Fog Seal		•	•		•	•	•
Tack Coat	•a	•		•	•a	•	
Prime Coat			•	•		•	•
Penetration Macadam				•			
Slurry Surfacing							
Slurry Seal			•			•b	•
Cape Seal			•			•b	•
Microsurfacing						•b	
Plant Mixes							
Open Graded/Semi Dense		•a					
Dense Graded			•		•		•
RAP		•				•	•
Stockpile Mix		•a					•
Pre-coated Chips					•a	•	
Mix Paving							
Open Graded					•a		
In Place Mixes							
RAP		•a			•a	•	•
Soil Stabilization			•				•
Dense Graded			•			•	•

a) May contain solvent. b) Need to pass cement mix test.

Surface Dressing (Chipseal)

In the chipseal process binder is sprayed onto the road and chippings spread over and rolled in before the binder has cured. The process can be repeated to build up thicker layers. It is used on different classes of roadways including gravel as well as paved roads. Use of polymer modified bitumen even allows surface dressing on highly trafficked roads due to enhanced durability and prevention of chiploss. Chipseals provide exceptional surface texture and water impermeability and some resistance to cracking.

Emulsions are particularly suited to chipseals because they give good results even when chippings are damp, they more quickly develop final strength than cut-backs, and they avoid fumes and fire hazards.

Best results are achieved with hot-sprayed (50–85°C) rapid-setting cationic emulsions of high binder contents in the range 65–72%, which may also be modified with polymers. Rapid-setting anionic emulsions are used in some parts of North America, but in this case an adhesion promoter should also be used to avoid chip loss.

Applications of emulsions
Continued

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Slurry Surfacing

Finely ground dense-graded aggregate is mixed with emulsion and water to form a slurry which is spread over the road surface at thicknesses in the range 3–30mm depending on the aggregate top size. The process is usually done with a specially made mix-paver, although slurries can be hand-applied, and the emulsions used are generally cationic medium or slow-setting types. The International Slurry Surfacing Association (www.slurry.org) provides test procedures for the design of slurry surfacing.

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Depending on the choice of emulsifier, the system may provide a quick-setting slurry which can be trafficked within 60 minutes, or slower setting materials suitable for handwork. Slurry Surfacing in thick layers with quick-setting polymer-modified slurries is called

microsurfacing. For best results the emulsion reactivity should be matched to that of the aggregate, but additional chemicals may be added on the paver to adjust the setting rate.

Plant Mixes

Structural materials can be from emulsion and crushed aggregates or reclaimed asphalt pavement which meet the same demands as hot mix. Depending on the aggregate gradation, medium or slow-setting emulsions can be used. Cold mixes which combine bitumen emulsion with cement can give much improved bearing capacities.

Cold In-place Recycling

Surface courses or even the full depth of the roadway can be recycled in place either by a specially built mobile plant or by simple

equipment. Cold recycling uses bitumen emulsions either alone or in combination with cement or lime. Typically, a cationic slow-setting emulsion is used.

Soil Stabilization

Cationic slow-setting emulsions can be used for stabilization of uncrushed naturally occurring gravels and sandy soils. Generally, soils with a sand equivalence value of more than 25 (measure of clay content) can be treated with some degree of success for use as a base material for hot overlay or for minor roads where a seal coat may be sufficient. Materials of even lower sand equivalence can in some cases be treated with a combination of emulsion and a hydraulic binder such as lime or cement.

Prime Coats

Emulsion prime coats are applied to unbound sub-bases in order to seal the surface before the application of the asphalt layers. The primer seal prevents the ingress of water into the layer, loss of fines from wind or water erosion and ideally allows construction vehicles to drive over the surface without pick up on tyres. A few centimetres of penetration is readily achievable if the compacted material is not too dense but may be very difficult in practice with fine graded and highly compacted bases. Penetration can be achieved using very slow set cationic or anionic emulsions containing solvent but in some cases deep penetration can be very difficult.

However, current thinking says that deep penetration may be unnecessary as dense and highly compacted bases are already very robust and merely need to be sealed from water intrusion. A very thin primer application with minimal penetration is then sufficient. It is still important that the binder should not be picked up on the tyres of construction vehicles and this can be achieved by using a very hard grade bitumen with a rapid setting emulsion formulation.

Tack Coats

Tack coats are light application of bitumen between layers of hot mix to prevent slippage. There is considerable variation in the type of emulsion used for tack coats worldwide. In many countries slow-setting anionic or cationic emulsions are used which may be diluted with water, but Europe uses rapid-setting cationic emulsions. It is necessary for the tack coat to wet out any dust on the surface of the lower layer and this favours emulsions of small particle size and some solvent content. New developments are for tack coats based on very hard binders which cure rapidly and avoid sticking to the tires of traffic or construction equipment.

Fog Seal

A light application of diluted emulsion restores bitumen to weathered surfaces and extends roadway life at low cost.

Penetration Macadam

A rapid or medium setting cationic emulsion is applied to a compacted open-graded layer. It soaks in, binding the roadway.

Glossary of terms

Aggregate mix, dense-graded
A mix containing aggregate which is graded from the maximum size down to filler with the object of obtaining a bitumen mix with relatively low voids content.

Aggregate mix, open-graded
A mix containing little or no filler giving relatively large void spaces in the compacted mix.

Binder
General term for asphalt cement which includes bitumen, coal tar or polymer modified bitumens.

Bitumen
Residue from crude oil.
Predominately aliphatic or cycloaliphatic. Known as asphalt in the USA.

Bitumen emulsion, anionic
Bitumen emulsion in which the droplets of bitumen carry a negative charge.

Bitumen emulsion, cationic
Bitumen emulsion in which the droplets of bitumen carry a positive charge.

Chipseal
U.S. terminology for surface dressing.

Electrophoresis
Movement under the influence of an electric potential gradient.

Interfacial tension
Force acting at 90 degrees to a line in the interface experienced by molecules in the interface resulting from an imbalance of attractive forces from the two phases. Interfacial tension and interfacial free energy are measures of the work required to increase the interfacial area.

Inverted emulsion
Water-in-oil emulsion prepared from cut back bitumen and typically used for priming or tack coats.

Latex
Natural or synthetic dispersion of rubber particles in water. Usually based on natural rubber, SBR, polychloroprene or acrylates.

Micelle
Assembly of surface active molecules formed spontaneously in water.

Prime coat
Liquid binder sprayed on an unbound layer to provide a good bond for hot mix.

Reclaimed asphalt pavement (RAP)
Old pavement removed from the road surface for recycling.

Soap
Common name for surface active agent or emulsifier.

Tack coat
Also called Bond Coat. An application of low viscosity liquid bitumen or emulsion between layers of bituminous materials to prevent slippage.

Zeta potential
Measure of the charge density on a surface.

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