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# Method for controlling mean droplet size in the manufacture of phase inversion bituminous emulsions

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## Abstract

The most important factors related to the manufacture of phase inversion bitumen in water emulsions are discussed in this paper. The distribution and average droplet diameter of an emulsion depends on formulation variables such as the volume fraction, the concentration and type of surfactant and the temperature of the dispersed phase employed, the type of bitumen used, and mechanical variables as the rotational speed and time used. The emulsions for this study are prepared according to the High Internal Phase Ratio (HIPR) procedure, which requires that the initial dispersion is conducted with internal phase fractions higher than the critical packing ( $\phi > 0.74$ ). The bitumen used in this paper are 15/25, 35/50, 50/70 and 70/100. This procedure allows the manufacture of high concentration emulsions, with a small average droplet size, and narrow particle size distribution. Results show that both the droplet size and the particle size distribution obtained can be controlled by changing the parameters of the formulation. Specially one of the most important parameters to consider in the emulsion formulation if we want to obtain the smallest mean droplet size is the penetration grade bitumen used, such as the results presented in this paper.

**Key words:** highly concentrated emulsions, HIPR procedure, mean droplet diameter, storage stability, hard penetration bitumen grade

## 1. Introduction

The world production of bitumen emulsion was around 8MTn in 2013 and continues growing year by year [1]. Emulsions are dispersed systems consisting of two immiscible liquids; one of them is the continuous phase, which contains the other liquid or internal phase, dispersed as small droplets. These systems are thermodynamically unstable and have a certain kinetic stability conferred by the presence of a surfactant absorbed on the oil/water interface, which is able of lowering the interfacial tension, also facilitates dispersion of one liquid into the other.

The free energy change,  $\Delta G_{(f)}$  [kJ], during the process of forming an emulsion is given by Eq. 1 [2]:

$$\Delta G = \Delta H - T \cdot \Delta S \quad \text{Eq. 1}$$

where  $\Delta H$  is the variation in enthalpy energy (kJ),  $T$  is the temperature [K], and  $\Delta S_{(conf)}$  [kJ/K] is the conformational entropy change of the system.

The term  $\Delta H$  represents the work that needs to be given to the system to expand the interface during emulsification. Therefore, the lower  $H$  the lower is the energy to give to the system for a given interfacial area. Consequently, the use of surfactant in the formulation, which reduces substantially  $\Delta H$ , helps considerably the emulsion formation process. The term  $T \cdot \Delta S_{(conf)}$  represents the entropy increase as result of the dispersion of one component in a big number of droplets. This term is positives and promotes emulsification.

For macroemulsions (considered when droplets size is higher than 1  $\mu\text{m}$ )  $\Delta H > T \cdot \Delta S_{(conf)}$ , therefore  $\Delta G_{(f)} > 0$ , meaning that the emulsification process is not an spontaneous process. This explains why emulsions are systems thermodynamically non-stables; their stability is determined by kinetic effects [3].

Bitumen emulsions are a way to use bitumen at low temperatures. The pure bitumen is used for manufacturing at high temperatures, 140°C, which facilitates dispersion in water workability since the emulsions are flowable materials at room temperature.

There are different procedures for preparing bitumen in water emulsions. The most widely used method in the industrial process is the one that uses colloid mills for its manufacture. This

works with high temperatures, 140-170°C, high pressures, 1-3 atm, and/or high rotational speed, 5.000-10.000 rpm. In this process, emulsions are manufactured in turbulent flow produced by the colloid mill rotating at high speed around  $105 \text{ s}^{-1}$ . In the case of a conventional process carried out in an industrial reactor using values of  $\rho$  of  $1000 \text{ kg/m}^3$ ,  $v$  of  $30 \text{ ms}^{-1}$  (circumferential speed of a cylinder of radius 0,5 m and rotating at a speed of 5000 rpm),  $L$  of 0.001 m, and  $\eta$  of  $10^{-2} \text{ Pa}\cdot\text{s}$  (characteristic viscosity, at the applied shear rate, of an emulsion in which one of the phases is present in a proportion of 60% by weight), then the Reynolds number would be 3000, corresponding to a turbulent regime [4]. Emulsification generally takes place at concentrations of the dispersed phase (bitumen) between 60 wt.% -70 wt.%, or what is the same, at a volume bitumen fraction of 0.6-0.7. Above this concentration the process is not efficient since very large drop particle are obtained and emulsions have no storage stability. Moreover, the droplet size obtained by the traditional method is between 5-10 microns, being very difficult to obtain small droplet sizes [5]. Gringas et al. [6] studied the parameters influencing this procedure, namely the temperature of the aqueous phase and bitumen, the rotor speed, the dispersed phase content, the bitumen penetration grade and the emulsion flow rate were investigated, finding that the droplet viscosity during emulsification, the rotation speed of the rotor and the dispersed phase content have a significant effect on the droplet size.

Another manufacturing system used to disperse two immiscible phases is the HIPR procedure (High Internal Phase Ratio) [4,7,8]. This procedure involves the direct blend of a highly viscous phase, 1-5000 Pa·s, with a second phase immiscible on the first one and in the presence of at least one surfactant. It works with low shear, 500-1500 rpm, in laminar flow and very little time, producing a viscoelastic paste which can be subsequently diluted to the required concentration of the dispersed phase. If we consider in the process values of  $\rho$  of  $1000 \text{ kg/m}^3$ ,  $v$  of  $0.3 \text{ ms}^{-1}$  (circumferential speed of a mobile having a radius of 5 cm and rotating at a speed of 500 rpm),  $L$  of 0.002 m, and  $\eta$  of 10 Pa·s (characteristic viscosity, at the applied shear rate, of an emulsion in which one of the phases is present in a proportion of 90% by weight), Reynolds number would be 0.06, which clearly shows that the shear rate applied to the emulsions is laminar [4]. With this system it is possible to obtain stable storage emulsions with very narrow particle size distribution and small mean droplet size,  $d(0.5)$ , about  $1 \text{ }\mu\text{m}$ . This system can produce concentrated and highly concentrated bitumen emulsions, 70-95 wt.%. The droplet size of the emulsions produced by this procedure can be easily controlled by the rotational speed, formulation parameters or by the concentration of the dispersed phase used during manufacture [9,10].

The highly concentrated emulsions are characterized by volume fractions of the dispersed phase (bitumen) higher than 0.74, which corresponds to maximum packing of monodisperse spheres.

Therefore dispersed droplets are very close to each other, separated by a very thin film continuous phase formed at each point where the drops touched each other [5]. Arenas-Calderon et al. [11] showed that emulsification of highly concentrated bitumen in water is influenced by the bitumen nature and the composition of the surfactant system, enhancing or not the acceleration of the phase inversion. Masalova et al. [12] studied the rheological properties of emulsions.

Each interfacial film is subjected to a compression pressure, which is counteracted by a disjoining pressure [9], generated within the interfacial film, due to the existence of Van der Waals attraction forces and of electrostatic repulsion ones. The balance between these forces depends on the stability of an emulsion [9].

In emulsions, it is critical to control the storage stability [1,13-15] and rheological properties [15] during the formation process and thereafter during storage and transport. In fact, Tabor et al. [16] have developed a two-step model for surfactant adsorption at solid surfaces where the fast adsorption may appear to be transport-limited for organic solvents and there is barrier in aqueous systems.

By careful control of the nature and magnitude of the interaction forces between drops, properties of these systems can be controlled. The stability of an emulsion can be measured by determining the time between their formation and the complete separation of the phases.

Ideally, the concentrated emulsions (with more than 70% of internal phase) consist of an agglomeration of polyhedral droplets separated by a very thin film continuous phase of water plus surfactant (Figure 1). Three interfacial films converge to a Plateau border. The curvature of the surface of the drop at the edge of the plateau generates a pressure difference between the liquid film and the interfacial plateau edge, causing a flow of continuous phase from the liquid film to the edges of the interfacial plateau. Thus, the interfacial liquid film becomes thinner over time and may possibly break when the emulsion destabilizes. Therefore, the stability of an emulsion depends on the stability of the interfacial film liquid [17], which in turn depends on the disjoining pressure [9]. Disjoining pressure is a hydrostatic pressure inside the liquid interfacial film acting perpendicular to the surface of the droplets. This pressure opposes the contact between the droplets and therefore their coalescence. In other words, the pressure is a force disjoining per unit area, which opposes the drain of the continuous phase liquid contained in the interfacial film. The main forces acting within the liquid interfacial film, contributing significantly to the pressure of disunity are London forces, Van der Waals forces, and electrostatic repulsion forces [18,19].

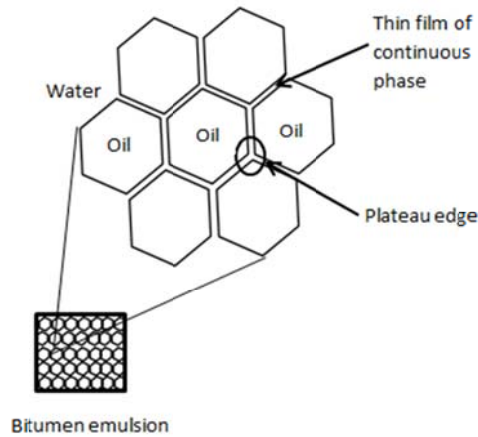


Figure 1. Polyhedral structure of the concentrated emulsion [3].

The objective of this paper is to study the control of the droplet size of bituminous emulsions prepared by High Internal Phase Ratio (HIPR) to ensure storage stability of the emulsions and good workability.

## 2. Materials and method

### 2.1. Materials

For this study a 50/70 penetration bitumen was used. Its main characteristics and the standards used for the characterization are shown in Table 1. The method used to characterize this bitumen was the penetration grade. The penetration value is a measure of hardness or consistency of bituminous material. It is the vertical distance traversed or penetrated by the point of a standard needle into the bituminous material under specific conditions of load, time and temperature. This distance is measured in one tenths of a millimeter and gives the name of the different existing bitumen. The softening temperature is the temperature at which the bitumen attains a particular degree of softening under specified condition of the test, and it is measured in °C, Also viscosity at 100°C and SARA (saturated, aromatic, resin and asphaltent) content were also measured. The SARA test separates the bitumen in functional groups of different molecular weight.

Table 1. Physicochemical characteristics of used bitumen

Characteristics	Standard	Units	15/25	35/50	50/70	70/100
Penetration	UNE-EN 1426:2007	0.1 mm	25	45	62	72
Softening temperature	UNE-EN 1427:2007	°C	61	52	51.2	50
Viscosity @ 100°C	UNE-EN 13302	mPa·s	18220	5450	4800	1416
Saturated	ASTM 4124	%	3.0	4.40	4.80	3.45
Aromatics	ASTM 4124	%	48.3	47.63	45.29	58.11
Resins	ASTM 4124	%	30	34.82	31.30	25.13
Asphaltenes	ASTM 4124	%	17	16.53	10.19	13.26

Concentrated emulsions were formulated and stabilized with cationic commercial surfactants. In this paper, an n-alkyl propylene diamine long chain, N-Tallow-1,3-propyldiamine (S1), and a propylenic alkyl polyamine, ethanol,2,2'-[[3-[(2-hydroxyethyl)amino]propyl]imino]bis (S2), with medium/fast break and with alkyl propylene diamine long chain were prepared at 50°C. In a surface treatment, after emulsion and aggregate have been applied to the road surface, the emulsion should “break” (the water should evaporate leaving the bitumen) holding the aggregate. The type of surfactant used in the manufacture of the emulsion has a big effect on the speed of the “breakage” of an emulsion. In this paper, a medium/fast surfactant was chosen because they are the most commonly used type. Surfactants were activated with acid solutions of hydrochloric acid at pH ranging between 2.0-2.5. For the emulsions formulation tap water was used adjusting its pH to 2-2.5.

## 2.2. Particle size analysis

Particle size distribution (PSD) analysis to measure the emulsion average droplet size was carried out with a laser diffractometer Malvern Mastersizer 2000

## 2.3. Emulsion preparation

The High Internal Phase Ratio (HIPR) procedure was used for emulsion preparation [20]. This procedure requires the initial dispersion to be carried out at a packing fraction higher than critical, which corresponds to 0.74. This facilitates the formation of concentrated emulsions with a very narrow distribution of drop size, and small mean droplet diameter,  $d(0.5)$ . According to this procedure emulsions with a controlled final morphology can be manufactured.

The HIPR procedure is base in the following criteria:

- The emulsion is produced in an initial volume fraction,  $\phi$ , 0.75 to 0.95. The volume fraction is the proportion of the bitumen respect the volume of surfactant diluted in water at  $\text{pH}=2\pm0.5$  used in the manufacture of the emulsion.
- A high viscosity for the dispersed phase (bitumen) is used, 1-5000 Pa·s.
- The mixing rotational speed is low, 800-1200 rpm, working in laminar regime.
- The addition of the aqueous phase to the oily phase is performed adding the entire amount of water at once, with the helix stopped, and then the mixing process starts.
- The emulsion obtained in the first few seconds is a phase inversion emulsion (W/O) changes very quickly to a direct emulsion (O/W) when in contact with the aqueous phase. Phase inversion is a process in which an emulsion changes its morphology from water-in-oil (W/O) to oil-in-water (O/W), or vice versa [11]. If the emulsification process occurs correctly there should not be free surfactant remaining in the final product.
- The emulsion is obtained in a few seconds.
- Once the emulsion is formed, a viscoelastic paste, which is diluted in water to obtain the desired relationship bitumen/water, is obtained.
- The emulsions should be stored at the required temperature, 40-60°C.

The procedure to prepare the emulsions was the following: The necessary quantity of bitumen 50/70 Pen was heated up at  $100^{\circ}\text{C}\pm2^{\circ}\text{C}$ . An aqueous solution of the surfactant to be used was prepared at different concentrations against bitumen, 1000-6000 ppm, pH was adjusted at  $2\pm0.5$  and was heated up to 40-50°C. The warm solution is added to the hot bituminous solution and is mixed between 1 to 15 min at 800-1300 rpm. Finally, the obtained emulsion is diluted adding warm water a 40-50°C until a  $\text{pH}2\pm0.5$  under gentle agitation to achieve the desired bituminous concentration. The obtained bitumen is stored at a temperature that ensures the adequate pumping and workability viscosity of the emulsion, but lower than 80°C in order to avoid boiling and breaking of the emulsion; therefore, the adequate storing temperature is between 40°C and 60°C. The parameters related to the manufacturing process are summarized in Table 2.

Table 2. Parameters used in the formulation

Parameter	Value	Units
Rotation speed	800 - 1300	Rpm
Bitumen temperature	95-100	°C
Aqueous phase temperature	40-50	°C
Volume fraction, $\phi$	0.75-0.95	---



The helix used is a helix type turbine stirring rod (Figure 2). With this type of helix the mixing material is suctioned from above. Furthermore, in the container an axial stream is generated and low shear force is generated. It is used for medium and high speeds. The characteristics of the helix are shown in Table 3.

Table 3. Parameters used in the formulation

Parameter	Value	Units
Helix diameter	660	Mm
Axis diameter	190	Mm
Axis length	400	Mm
Maximum speed	2000	Rpm



Figure 2. Helix used for the preparation of emulsions

### 3. Results & discussion

#### 3.1. Results

The influence of mixing speed on the average size of the end droplet using two different surfactants, an n-alkyl propylene diamine long chain (S1) and a propylenic alkyl polyamine (S2), was assessed. The manufacturing procedure described in section 2.3, varying the rotational speed between 800 and 1300 rpm was followed. This study has maintained a fixed surfactant concentration on emulsion of 4000 ppm and a fraction of initial volume of 0.90. The final emulsion was diluted to a final volume fraction of 0.6. With both surfactants the lowest average size droplet was obtained with a rotational speed of 1000 rpm, and at the same time, surfactant S1 reaches lower mean droplet size in the same manufacture conditions.

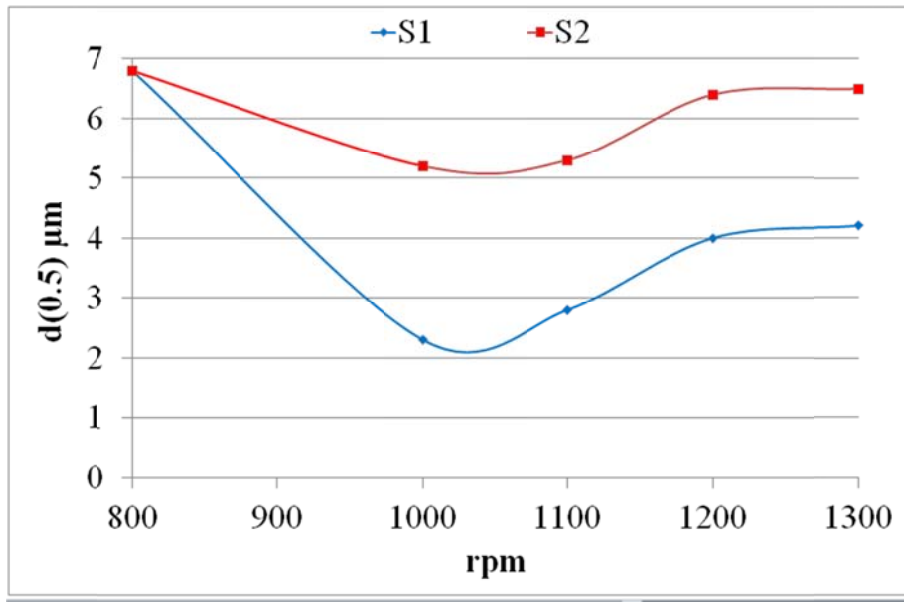


Figure 3. Influence of the rotational speed on the average emulsion droplet size.

To evaluate the influence of the mixing time on the mean droplet size, n-alkyl propylene diamine long chain S1 was used at a concentration of 4000 ppm on the final emulsion, and the emulsion was prepared at a rotational speed of 1000 rpm. As in the previous case also the initial volume fraction of 0.90 was used, and the final emulsion was diluted to a final bitumen volume fraction of 0.6. Figure 4 shows that the minimum droplet size is achieved within a few minutes, between 2 and 5 min. Later on, no smaller droplet size is obtained; on the contrary the particle size can increase after 20 min of mixing.

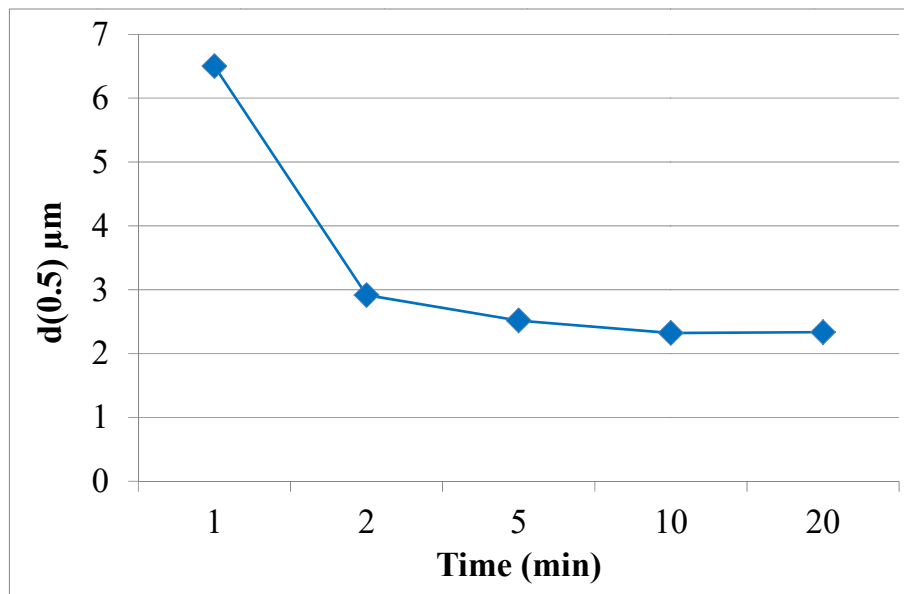


Figure 4. Influence of mixing time in the final average size of the emulsion.

To evaluate the influence of the surfactant concentration on the final mean droplet size, a constant rotational speed of 1000 rpm was used, with an initial volume fraction of 0.90. N-alkyl propylene diamine S1 concentration was varied from 2000 ppm until 6500 ppm. Again, the final emulsion was diluted to final bitumen volume fraction of 0.60. Figure 5 shows the mean droplet size decreases as a function of surfactant concentration S1 used. The smallest droplet size was achieved when a concentration of 6000 ppm of surfactant against bitumen was used during the manufacture of the emulsion.. Increasing the concentration and maintaining steady rotational speed did not further decrease the droplet size.

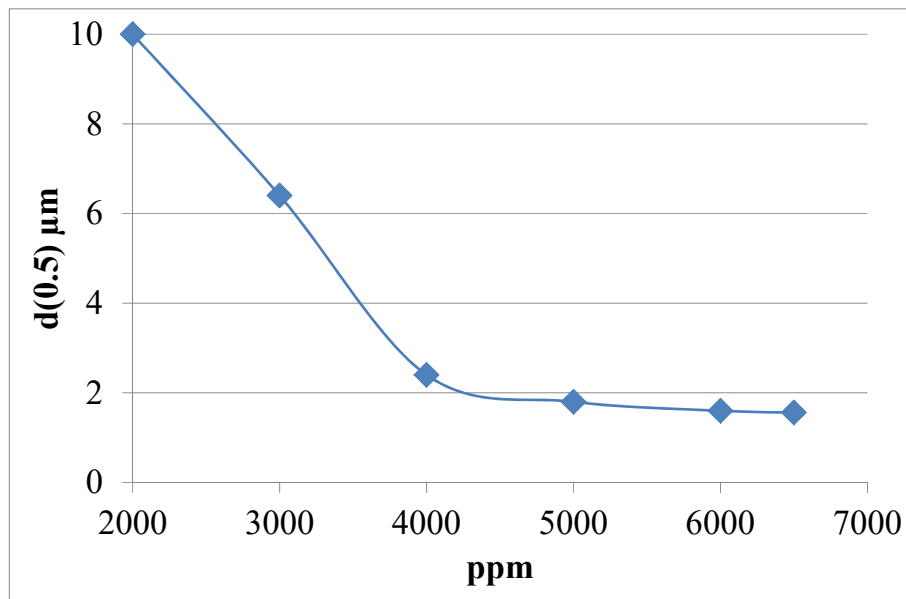


Figure 5. Influence of the surfactant S1 concentration on the average droplet size.

The different penetration grade bitumen influence in the final mean droplet size is presented in Figure 6. In this case, the emulsion was obtained with a constant rotational speed of 1000 rpm, an initial volume fraction 0.90, and a constant concentration of n-alkyl propylene diamine S1 (10400 ppm). Again, the final emulsion was diluted to a final bitumen volume fraction 0.6. The penetration was varied at 15/25, 35/50, 50/70, and 80/100.

The harder the bitumen is the lower mean droplet size obtained. In the both cases, when the concentration of surfactant S1 is 6500 or 10400 ppm, there is a linear relation with the penetration grade bitumen and the mean droplet size obtained. As the penetration grade bitumen decreases, the mean droplet size decreases too.

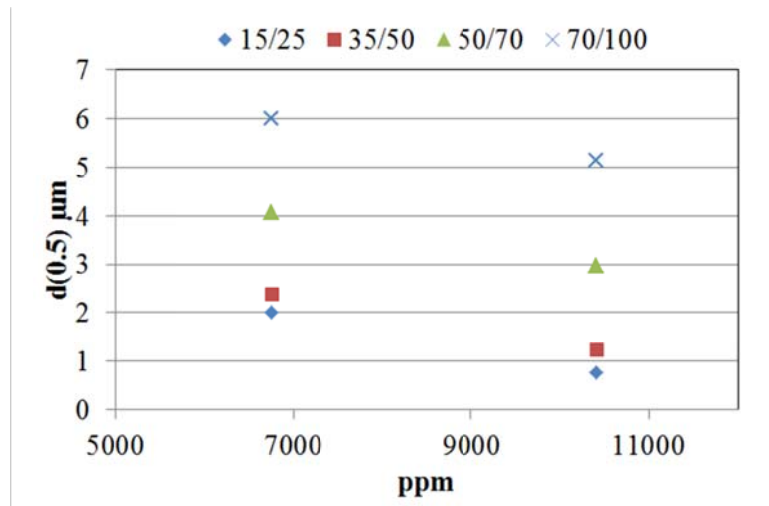


Figure 6. Influence of penetration of the bitumen in the final droplet size

Table 4 summarizes the characterization results of the emulsions produced. The same formulation parameters for the manufacture of these emulsions were used: 6000 ppm of surfactant S1 concentration and 1000 rpm rotational speed, and only the volume fraction used to formulate them was modified. As seen in Table 4, the laboratory results obtained vary as a function of the volume fraction used, even though the manufacture conditions were kept constant. The mean droplet size increases when the volume fraction used decreases. Then, the highest mean diameter size obtained is with the volume fraction 0.85. As a consequence, the storage stability is also influenced, and the lower the diameter size, the higher the storage stability. Therefore, the kinematic viscosity varies with the diameter size obtained, and the lower the diameter size reached the higher the viscosity is.

Table 4. Results of the characterization of the emulsions produced with different initial volume fraction with a surfactant concentration of  $6 \cdot 10^4$  ppm.

Property	Standard used	Units	Initial volume fraction		
			0.95	0.90	0.85
Bitumen concentration	UNE EN 1431	%	60	60	60

Efflux time	UNE EN 12846	s	56	48	42
Sieving	UNE EN 1429	%	0.01	0.02	0.02
Breaking index	UNE EN 13075-1	-	125	123	126
Storage Stability	UNE EN 12847	%	3	6	8
d(0.5)	---	μm	0.811	2.370	4.042

### 3.2. Discussion

The emulsions process formation of bitumen in water involves creating a large interfacial area. To generate this interfacial area it is necessary to decrease the interfacial free energy with the aid of a surfactant [1] and to transfer mechanical energy to the system through a suitable mixing process [21,22]. The distribution and average droplet diameter of an emulsion are dependent on formulation variables as the volume fraction, the concentration and type of surfactant and the temperature employed, as well as mechanical variables as the rotational speed used and the agitation time.

Gutierrez et al. [10] studied also this effect but using a low specific gravity viscous hydrocarbons. They used higher mixing speed than us: 1500, 2000 and 2500 rpm, but the results of the mean droplet diameter size were the same as obtained in this study, manufactured at 1000 rpm (see Figure 7). To the manufacture of the emulsions we use a very hard penetration grade bitumen which difficulties the emulsionability. Nevertheless, stable emulsions with a small diameter size are here obtained.

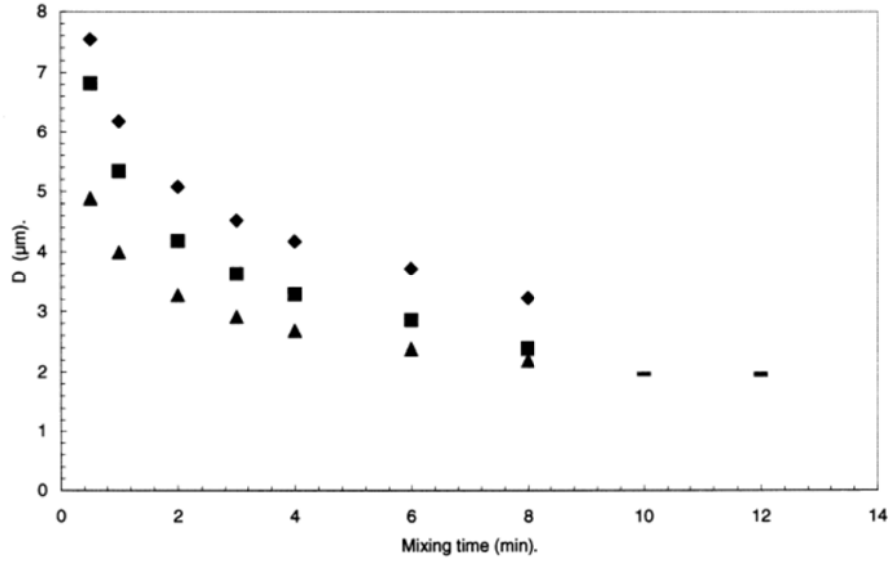


Figure 7. Mean droplet diameter vs. mixing time [10]

Mixing rotational speed: ◆-1500rpm, ■-2000rpm, ▲-2500rpm

According to the results obtained up to this point, the mean droplet size can be controlled by the rotational speed, the surfactant concentration, the penetration grade bitumen and the mixing time. To close the study, the influence of the initial volume fraction used in manufacture of the emulsion in the final mean droplet size and distribution was studied. Three emulsions were prepared with a fixed concentration of surfactant of 6000 ppm, at a speed of 1000 rpm, and varying the initial volume fraction at 0.95, 0.90 and 0.85.

Taking into account the results shown in Figure 8, the initial volume fraction used to prepare the emulsion is one of the parameters that most influence on the final mean droplet size of the emulsion. If we use a volume fraction of 0.95, holding constant the other parameters, we obtain a smaller drop size,  $d(0.5) \leq 1 \mu\text{m}$  lower than the obtained in the study of the influence surfactant concentration, where we obtained an average droplet size,  $d(0.5)$ , around  $2 \mu\text{m}$ . And if we use a initial volume fraction of 0.85, the mean medium final drop size obtained is higher than the obtained manufacturing at,  $d(0.5) \sim 4 \mu\text{m}$ .

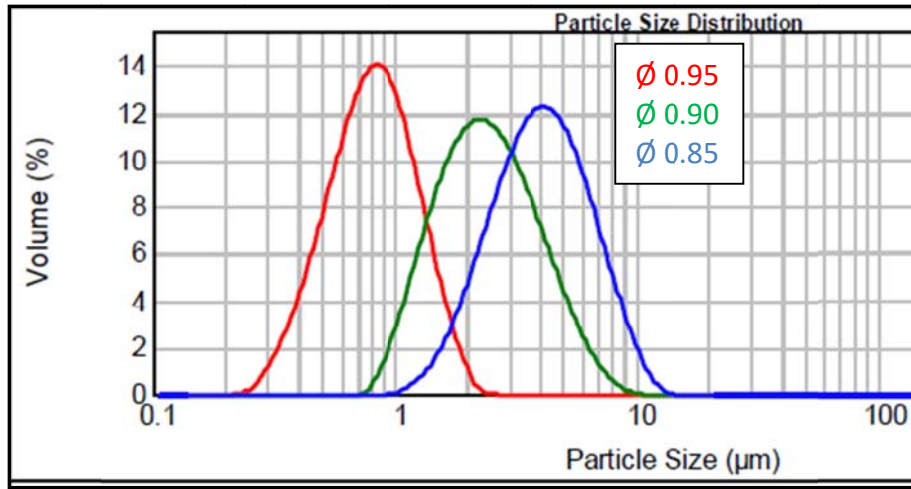


Figure 8. Influence of the initial volume fraction in the final droplet size.

Gutierrez et al. [10] studied the influence of the mixing time and the initial volume fraction in the final droplet size (see Figure 9). Figure 9a shows the droplet diameter distribution as a function of the mixing time at 2500 rpm and 65°C for the bitumen-in-water emulsions, having a bitumen volume fraction of 0.90 and mixing times of 6, 3 and 0.5 min. In Figure 9b, the authors studied the droplet diameter distributions as a function of the bitumen volume fraction of 0.95, 0.90, 0.80, and 0.75 for emulsions prepared at 65°C mixing at 2500 rpm. These results are in agreement of those presented in this paper, observing that in order to achieve a volume fraction increase, the mean droplet size should decrease. The mean droplet size obtained by Gutierrez et al. [10] is higher than that obtained in this study; although they worked at higher stirring speed and with a very low penetration bitumen grade, very soft bitumen with very low viscosity was obtained.

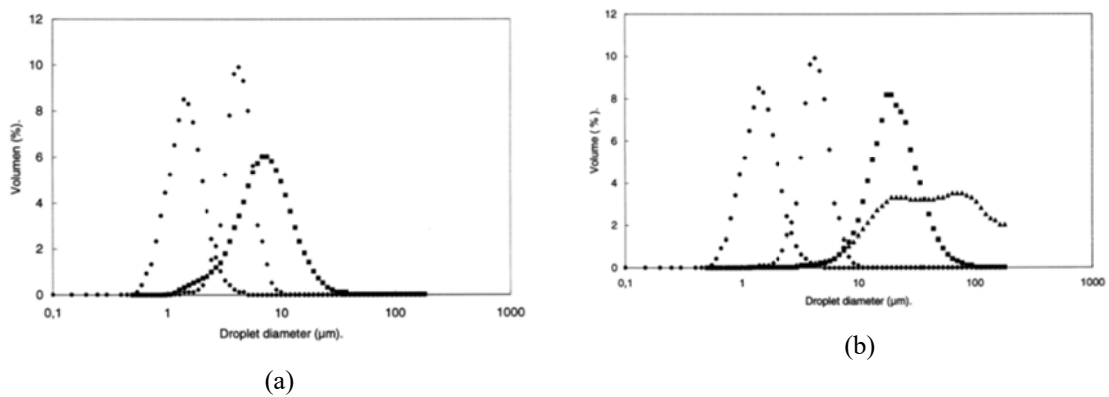


Figure 9. Droplet diameter distribution as a function of the mixing time (left) and volume fraction (right) obtained in Gutierrez et al. [10].

#### 4. Conclusions

The control of the droplet size of bituminous emulsions prepared by High Internal Phase Ratio (HIPR) to ensure storage stability of the emulsions and good workability was studied in this paper. The droplet size and the particle size distribution obtained can be controlled by changing the parameters of the formulation: rotational speed, mixing time, and surfactant concentration. The most influential parameter in controlling the final drop size is the volume fraction used in the time of manufacture and the bitumen penetration grade used. Moreover, it is possible to emulsify hard penetration bitumen residue until 15/25 x 0.1 mm, and the harder the bitumen is the lower mean diameter size obtained.

Many authors like Gutierrez et al. [10] have studied the most important parameters related with the control of the final droplet emulsion size. Specifically the authors have studied the influence of volume fraction of bitumen initially used, the mixing time or the speed revolution on, the mean droplet diameter size. But Gutierrez et al. [10] did not study the influence of the bitumen grade penetration; in fact, the authors used for their studies a type of hydrocarbon oil, with a very high penetration grade which have a high acid index. Other authors, like Gingras et al. [5] have used harder bitumen in their test but they claim that it is very difficult to emulsify hard bitumen penetration grade, and they have had a lot of problems with the formulation.

In this sense we introduced a common bitumen used in the asphalt pavement, a 15/25, 35/50, 50/70 and 70/100 penetration grade, to formulate our studies, and we have studied the influence of this type of bitumen in the mean droplet size. We could demonstrate that the harder the bitumen is, the lower mean diameter size we obtained. So, the procedure presented in the paper is favorable for hard penetration grade bitumen emulsion residue.

The results obtained in this paper focuses the objectives in the formulation of bitumen emulsion with any kind of penetration grade bitumen, even though the harder once which were until today very difficult to use in the formulation.

The procedure studied in this paper allows the manufacture of high concentration emulsions, with a small average droplet size, and narrow particle size distribution. The emulsification process is directly related to the type and concentration of surfactant used, by the presence of electrolytes, the relationship bitumen / water and the time and the mixing speed among other factors. But the parameter that influences more in the droplet diameter size and its viscosity is the bitumen ratio used in the formulation and its bitumen penetration grade used. For a fixed surfactant concentration while keeping time and the mixing speed, the average drop diameter



decreases with increasing ratio bitumen/water. A higher concentration of narrower internal phase is the droplet diameter distribution, whereby the polydispersity for such emulsions decreases. Average droplet diameter size and distribution change significant and uniformly with stirring time and mixing speed. It is conceivable that for this type of emulsions formation interfacial area occurs in a controlled manner which allows the production of emulsions with a given average droplet and a fairly narrow distribution diameter with a high degree of monodispersity and therefore reproducibility in their properties.

The emulsion stability is greatly affected by the type and concentration of surfactant, as the factors can modify the pressure disjoining and stability of liquid interfacial film. Finally, the concentrated emulsions are excellent binders for the formulation of half warm asphalt mixes when dealing with emulsions having very little water is removed almost entirely during the manufacturing process.

In future work, the possibility to use any bitumen in the manufacture of high internal phase ratio emulsions and to be able to control the mean diameter size, opens the door to the use of this emulsion as a binder in the formulation of warm mix asphalt or half-warm mix asphalt because it will be possible to equal the results obtained in hot mix asphalt mixes, where bitumen with the warm mix asphalt replacing bitumen for concentrated emulsion is used.

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