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ENVIRONMENTAL EVALUATION OF GRAVEL EMULSION

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Abstract

This paper reports the result of a study on environmental impact of road construction techniques with bitumen emulsion. This review was limited to overall indicators (GreenHouse Gas emissions, energy and natural resources consumption). Road materials with bitumen emulsion are compared with conventional techniques as Hot Mixes Asphalts. Then, three cases of road maintenance are shown (lightly or highly deformed reshaping, and structural maintenance). Several maintenance solutions are proposed that are deemed to be equivalent. Those solutions combine binder and wearing courses as necessary to compare the hot mix asphalts and cold materials with bitumen emulsion in cases of realistic use. These calculations validate favorable a priori considerations to the cold techniques, and quantify the environmental benefits regarding conventional hot mix asphalts.

1. INTRODUCTION

In a global context of reduction of the environmental impact of road construction techniques, and particularly since the Grenelle Forum on the Environment (France), cold techniques with bitumen emulsion, already known for a long time, were rediscovered. These cold techniques, avoiding heating the aggregates, achieve great energy savings during mixing in plant. As with conventional techniques (as hot mix asphalts), data from the field (production of components, mixing, implementation ...) are needed for feeding the existing environmental comparators as ECORCE (Eco-comparator for roads, construction and maintenance, [1]) and SEVE (System for evaluating environmental variants, [2]), and to quantify the environmental benefits. Some tools only take into account the global indicators (energy, greenhouse gas emissions), while other go further in quantifying the environmental impacts on aquatic environments (eutrophication, acidification, ecotoxicity) and on human health (toxicity).

As part of the IFSTTAR research programs OPTIMIRR (energy and non-renewable natural resources efficient road materials) and EPEES (assessing and forecasting of the effects on the environment of transportation infrastructure), collection of data during cold emulsion mixes projects were carried out by the IFSTTAR and CETE Ouest / LR St Brieuc staffs. These surveys have enabled the development of environmental assessment for techniques with bitumen emulsion, using the IFSTTAR software "ECORCE". From the calculations on these materials, a comparison between the cold mixes and conventional techniques as hot mix asphalts was performed on the basis of complete road maintenance scenarios.

2. DESCRIPTION OF THE METHODOLOGY AND OF THE ENVIRONMENTAL SYSTEM

The calculations detailed in this article are performed using software ECORCE whose methodology is developed in [1]. The environmental system defined for environmental data of road materials and road structures is shown in figure 1. The data basis of the software ECORCE contains data on the most common materials used for road construction : the data on the aggregates are averages from French massive rock quarries, whose impact calculations are detailed in [3] and the data on bitumen are from [4], taking into account an average European refinery (electricity production was subtracted, [1]). For materials transportation, the fuel consumption is estimated at 38 litres per 100 km (and 80% of the consumption for empty returns). The emissions of machines and trucks are then calculated with Hugrel and Joumard model, [1]. For hot mix asphalt, consumption and emissions measurement (included the consumption of a wheel loader and of the tank farm) were carrying on a TSM 17 mixing plant, heating with natural gas, [5].

For the calculation of the impact of emulsion and grave-emulsion manufacturing, a specific data gathering was carried out on an experimental site, during the IFSTTAR research program OPTIMIRR, [6]. The methodology and results of these collections is published in [7]. This project was carried out on the departmental road n°44 (Goven, France), and the manufacture and implementation of emulsion and gravel emulsion were done by the "Parc Departemental d'Ille-et-Vilaine".

Consumption of raw material were measured during emulsion and gravel emulsion manufacturing, transportation and layering. Then Greenhouse gas emissions are then calculated with the weighting factors of the IPCC method for 100 years (CO₂, CH₄ and N₂O) ,

[1], and the total energy is the sum of energies consumed (energy production having been removed).

The design of road materials with bitumen emulsion is based primarily on local experiences, there is no formalized indicator of end of life for these techniques. So a life cycle analysis with equivalent lifetime cannot be carry out to compare cold materials to conventional techniques. Therefore, we propose a comparative analysis of common maintenance scenarios for roads with low traffic volume, on the basis of French regional guides [8], [9].

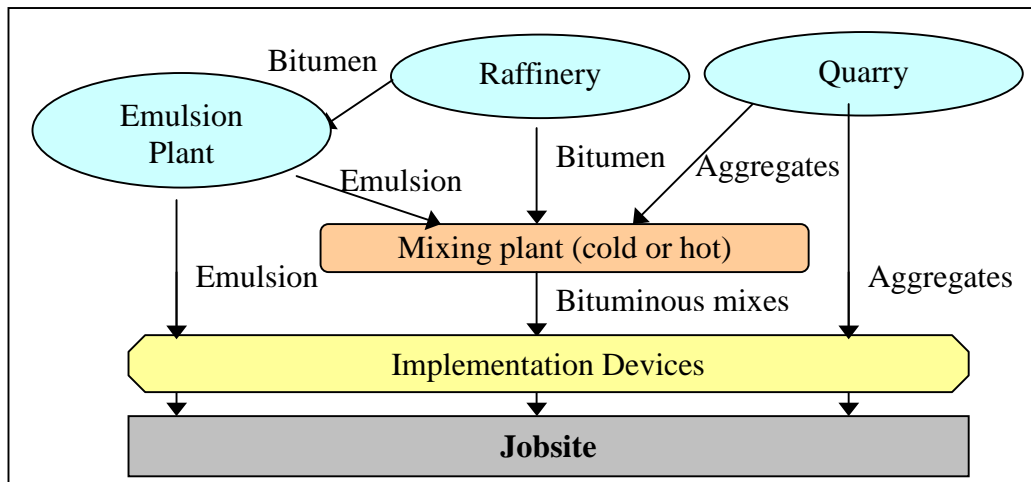


Figure 1: environnemental system (data gathering)

3. DESCRIPTION OF ROAD MAINTENANCE SCENARIOS

The environmental impact of each material was calculated for a model section with a surface of 1000 m² (200 m long and 5 m wide), similar to the departmental road n°44 (geometry, transportation distances). Bitumen emulsions used in cold mixes have been considered as a mixture of water and bitumen, whose proportions are specified for each use. Because of a lack of available data, the minor components (emulsifiers, flows) were not taken into account. For each material, standard conditions of manufacture and implementation have been taken into account (speed of spreading, compaction workshops...).

The various maintenance techniques listed below are the usual maintenance on road with low traffic volume, as the departmental road n°44. Maintenance solutions proposed were classified into 3 categories according to the disease:

- In the case of a slightly distorted road that does not require structural maintenance (case A), a few techniques allow reshaping :
 - For hot mix asphalts (HMA) which requires an implementation with a finisher, a single layer of semi coarse asphalt mix (BBSG) 6 cm thick, without binder course, can cover small deformations
 - The cold mixes as Gravel Emulsion (GE) can performed a light reshaping (about 50 kg/m²), with zero thickness in the track center line (implementation with a grader). They must be covered with a wearing course as Double Layer Surface Dressing (DSD) or Dense Cold Mix (BBF).

- Cold in-place recycling (followed by a wearing course) can also reshaping the road, by reusing existing materials.
- In the case of a highly distorted road, that does not require structural maintenance (case B), a technique for more important reshaping will be necessary (about 90 kg/m²) and will be followed by a new wearing course. For hot mix asphalt, the thicknesses are sufficient to be laid using a paver.
- In the case of a road that requires structural maintenance (case C) but with no threshold limit, an asphalt layer with significant thickness is necessary. This binder layer will be followed by a new surface course (BBSG or thin asphalt concrete (BBM)).

For each of the above cases, different structures were compared (by combining binder and wearing course if necessary), with hot mix asphalts (road base asphalt (GB), BBSG ...) or cold mixes (Gravel Emulsion (GE), road surface dressing, in-place recycling...). The design of these techniques is based on French catalogs ([8], [9], [10]) and feedbacks. The structures used are summarized in Table 1.

Table 1: Description of the structure for each road maintenance scenario

<i>Cases</i>	<i>N°</i>	<i>Description of binder / wearing courses</i>
<i>A</i>	1	Reshaping with GE (GER) (50 kg/m ²) + Double Layer surface dressing (DSD)
	2	Reshaping with GE (GER) (50 kg/m ²) + Dense cold mix (BBF) (3 cm)
	3	Cold in-place recycling (CIR) (6 cm) + DSD
	4	Cold in-place recycling (CIR) (6 cm) + Dense cold mix (BBF) (3 cm)
	5	BBSG (6 cm)
<i>B</i>	6	GER (90 kg/m ²) + Double Layer surface dressing (DSD)
	7	GER (90 kg/m ²) + Dense cold mix (BBF) (3 cm)
	8	Reshaping with BBSG (90 kg/m ²) + BBSG (6 cm)
<i>C</i>	9	Structuring Gravel Emulsion (GES) (12 cm) + DSD
	10	Structuring Gravel Emulsion (GES) (12 cm) + Dense cold mix (BBF) (3 cm)
	11	GB (10 cm) + BBSG (6 cm)
	12	GB (10 cm) + BBM (4 cm)
	13	GB (10 cm) + Double Layer surface dressing (DSD)
	14	GES (12 cm) + BBSG (6 cm)

Description of models and assumptions

The thicknesses of layers implemented are those specified in Table 1 for each materials and structures, to ensure equivalence between the different maintenance scenarios. The characteristics of the materials (formulation, implementation characteristics) are summarized in Table 2. For a realistic model of the structures, a tack layer was added under each asphalt layer (cold or hot mix), except for In-place Recycling and road surface dressing.

The transportation distance used for calculation are the distances measured on the gravel emulsion experimental site, during the IFSTTAR research program OPTIMIRR. For all materials (hot or cold mixes) the transportation distance between quarry and mix plant is set at 55.5 km, and the distance between the mix plant and the jobsite is 22.1 km. For surface dressing, the transportation distances between quarry and jobsite is set at 77.6 km.

For all materials (apart for in-place recycling), the transportation distance between the storage area of the machine (road rollers, pavers, spreaders...) and the jobsite is 22.1 km. For in-place recycling, the transportation distance between the storage area of the milling / mixing machine and the jobsite is 150 km.

For hot mixes in plant, the transportation distance between refinery and mix plant is 323 km. For cold mixes in plant, the transportation distance between refinery and emulsion manufacture is also 323 km, and the transportation distance between emulsion manufacture and mix plant is 0 km. For surface dressing and tack coat, the distance between emulsion manufacture and jobsite is 22.1 km.

Table 2: constituents and formulation of road materials

<i>Materials</i>	<i>Constituents</i>		<i>Characteristics</i>
Gravel Emulsion (GER / GES)	Emulsion: 6.05% (bitumen: 60%)	Water: 3.72%	Density: 2.580 / Compactness: 87.3%
BBF	Emulsion: 7.24% (bitumen: 65%)	Water: 2.23%	Density: 2.554 / Compactness: 87.3%
CIR	Emulsion: 2.93% (bitumen: 55%)	Water: 3.39%	Density: 2.330 / Compactness: 81.2%
BBSG / BBM	Bitumen: 5.21%		Density: 2.510 / Compactness: 94.0%
BBSG (reshaping)	Bitumen: 4.76%		Density: 2.573 / Compactness: 94.0%
GB	Bitumen: 3.85%		Density: 2.609 / Compactness: 92.0%
<i>Materials</i>	<i>Constituents</i>		
Double Layer Surface dressing (DSD)	Aggregates: 5 L/m ² + 6 L/m ² + 8 L/m ²		Emulsion: 1.5 kg/m ² + 1.5 kg/m ² (bitumen: 69%)
Tack Layer	Emulsion: 0.5 kg/m ² (bitumen: 69%)		

4. RESULTS OF ENVIRONNEMENTAL ASSESSMENTS

Comparison of bituminous mixtures:

As a first step, a structuring gravel emulsion (10 cm thick) is compared to a hot reinforcing technique (road base asphalt: GB) during manufacturing, transportation and implementation. All assumptions are kept constant (transportation distances, binder content, thickness of implementation and bulk density...).

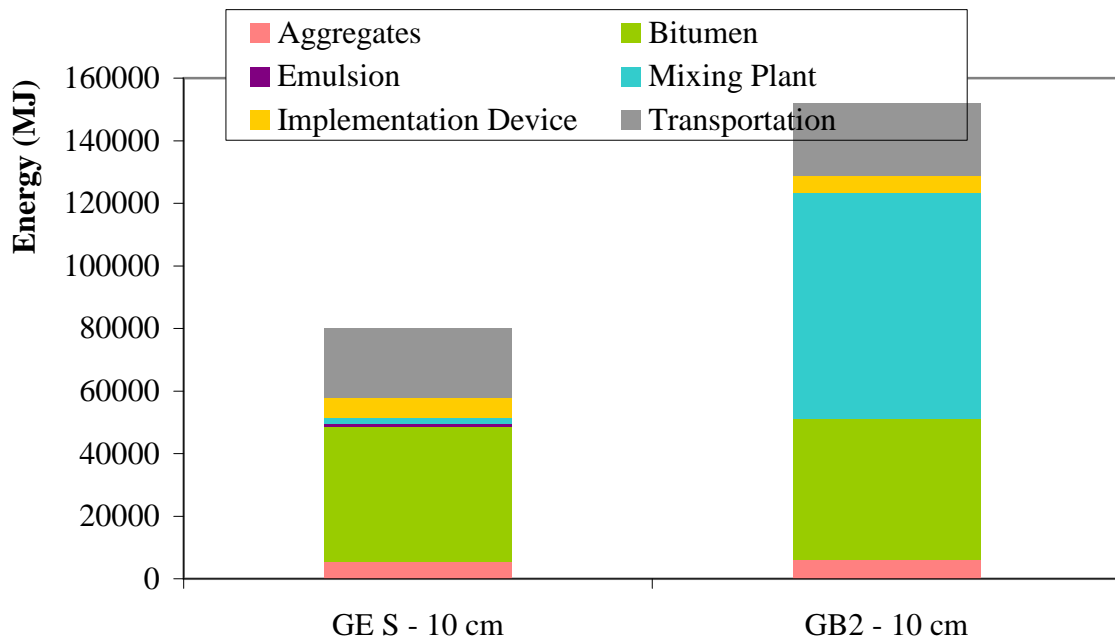


Figure 2: energy consumption for gravel emulsion and HMA (GB)

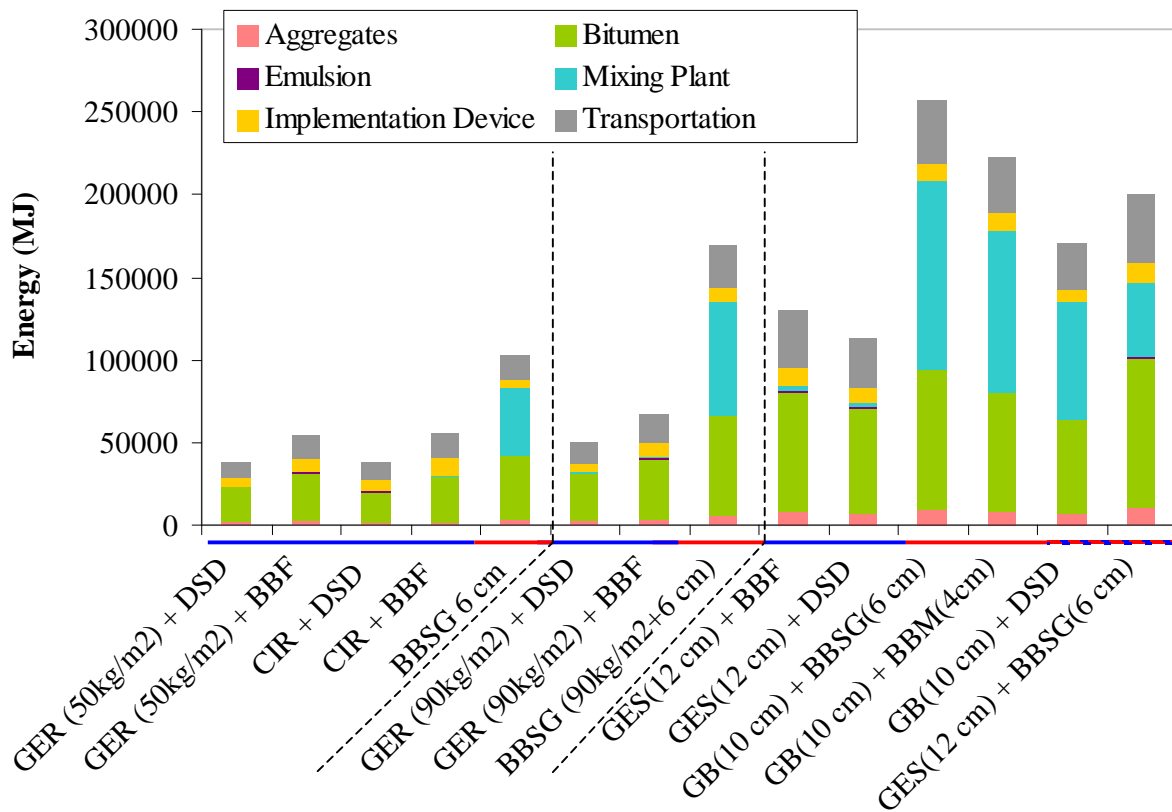


Figure 3: energy consumption (MJ) per item for the maintenance scenarios

Only the step of manufacturing in plant differentiates these 2 materials. The construction of the layer of gravel emulsion requires 80000 MJ, which is two times less energy than GB (152000 MJ) and emits 4650 kgCO₂e, or 40% less than the GB (7470 kgCO₂e). Energy consumption of both types of materials are also detailed by item on Figure 2. This graph shows that for the hot mix asphalts, manufacturing plant is the main energy user (72 000 MJ or 50% of the total energy consumption for GB). For gravel emulsion, which do not require aggregates heating, the higher consumption step is the bitumen production in refinery.

Comparison of road structures:

Differences between materials with bitumen emulsion and conventional HMA were calculated on the basis of the three maintenance scenarios detailed above: for the two global indicators (energy consumption and GHG emissions), the ranking of the structures according to their environmental impact is the same. Energy consumption of all the structures are detailed by item on Figure 3 and the values of greenhouse gas emissions, energy and materials consumption are also summarized in Table 3.

Table 3: greenhouse gas emissions, energy and materials consumption per structure

<i>Structures</i>		<i>GHG (kgCO₂e)</i>	<i>Energy (MJ)</i>	<i>Aggregates (t)</i>	<i>Bitumen (t)</i>
1	GER (50kg/m ²) + DSD	2205	38004	72	4.3
2	GER (50kg/m ²) + BBF	3218	54764	109	5.8
3	CIR + DSD	2474	40829	27	4.0
4	CIR + BBF	3368	55828	57	5.5
5	BBSG (6cm)	5077	103055	134	7.7
6	GER (90kg/m ²) + DSD	2895	50296	109	5.8
7	GER (90kg/m ²) + BBF	3908	67055	146	7.3
8	BBSG (90kg/m ² + 6cm)	8384	168959	219	12.3
9	GES (12cm) + BBF	7385	128132	316	14.5
10	GES (12cm) + DSD	6492	113133	286	13.0
11	GB (10cm) + BBSG (6cm)	12646	257163	365	17.3
12	GB (10cm) + BBM (4cm)	10976	222120	316	14.6
13	GB (10cm) + DSD	8428	169709	257	11.6
14	GES (12cm) + BBSG (6cm)	10709	200587	394	18.6

In case of light reshaping (case A), structures with cold materials (No. 1 to 4) use from 37% to 54% of the energy of structure No. 5 (a single layer of BBSG), and emit from 44% to 66% of GHG emissions from the structure No. 5.

In case of high reshaping (case B), structures with cold materials (No. 6 and 7) use from 30 to 40% of the energy of structure No. 8 (two layers of BBSG: reshaping and wearing layers), and emit from 35% to 47% of GHG emissions from the structure No. 8.

In case of reinforcement (case C), structures with cold materials (No. 9 and 10) use from 44% to 50% of the energy needed by the structure No. 11, and emit from 51 to 58% of GHG emissions from the hot structure No. 11. For GE, which does not require heating, the energy gain on the manufacturing plant compensates for the greater thickness of the structure (more energy related to the fabrication of bitumen and to the materials transportation). So the structure No.12 consumes more energy than structure No.14 (both cold and hot materials). As a consequence, transportation has a strong impact on emissions of greenhouse gases, the thickness of the structure (and thus the amount of material transported) and the quantity of bitumen used cancel the gain related to the mixing plant: the structures No.12 and 14 are equivalent in terms of GHG emissions.

These calculations show that the energy consumption needed to manufacture hot mix in plant significantly impacts their environmental performance. To reduce the GHG emission balance between the structures No. 10 and No. 11, the gravel emulsion should emit additional 6155 kgCO₂e, which means in this particular case to move the mixing plant 300 km from the jobsite. However, the benefits of the cold mixes are all the more important as the simplicity of the cold mixing plants allows them to travel in the case of major projects, and so to be closer to the jobsite.

5. CONCLUSIONS

This article is focus on the environmental assessment of emulsified asphalt mixes. Firstly the methodology and the environmental system studied are described. Secondly a description of road maintenance scenarios depending on traffic volume is presented. In a third part, results of environmental assessments based on French case studies are shown. Results obtained highlight the great benefit to use emulsified asphalt mixes for road scenarios regarding energy consumption savings and GHG reduction in comparison with mixtures manufactured at hot temperature.

These results are only valid for the assumptions made within this modelling as transportation distances which heavily depend on the local context (especially network of quarry and mixing plant). Moreover, minor components as emulsifiers were not taken into account. It requires to pursue data gathering on real sites and further action are carried out in parallel. A survey on the impact of the release into the environment by the water from breaking of emulsions, of chemical residues from emulsifiers is underway in the French Technical and Scientific Network (RST). This investigation would enable a full health and environmental assessment, with indicators of local impacts on aquatic environments (eutrophication, acidification, ecotoxicity) and on human health.

A more complete study on the in situ mechanical behaviour and life service of these materials, as part of the research program "OPTIMIRR" of IFSTTAR is also under way. These studies coincide with the specifications and tests for cold mixes standards revision, in the process of being completed for France, and in preparation at European level.

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