ENVIRONMENTAL ASPECTS OF WARM MIX ASPHALTS PRODUCED WITH CHEMICAL ADDITIVES

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ABSTRACT

The possibility to reduce the production temperature of hot mix asphalts, to produce what is called warm mix asphalts, is currently of great interest by the road industry at large. These warm mix asphalts are produced and paved at temperatures about 30 to 40°C lower than the standard hot mixtures. There are different technologies that allow a reduction of the production and paving temperature of asphalt mixtures. Among them, the use of chemical additives is one of easiest to implement. These chemical additives are based on surfactant-like molecules that interact at the mineral and bitumen interface improving the asphalt mix workability at production and paving temperatures, without modifying the final properties of the mix.

As with all the novel techniques, there may be some concerns about the possible impact of WMA additives on the mix and on the environment. In this work, environmental aspects of the chemical additives used for WMA are discussed. Comparative energy consumption and polluting emissions measurements during industrial mix production and paving are shown, demonstrating the advantages of warm mix asphalts by chemical additives. Other aspects of the use of the chemical additives on warm mixtures such as their impact on their life cycle analysis are also discussed.

Keywords: Warm mix, energy, additives, emissions reduction, environment

1. INTRODUCTION

During the last years there has been a large interest on what has been coined as Warm Mix Asphalts (WMA). These are bituminous asphalts similar to regular Hot Mix Asphalts (HMA), but produced and paved at lower temperatures. This reduction in temperature is generally between 10 and 45°C, depending on the WMA technology used. There are several technologies that allow the production of WMA on the market, which have been reviewed thoroughly in other publications [1-3].

The different WMA technologies present advantages and disadvantages since they are based on different physical principles. For example, some of them reduce the viscosity of bitumen while others are based on the production of binder foam. However, the use of certain chemical additives at low dosages is the easiest and most practical technology to use. Chemical additives for WMA are especially design products, based on surfactant-like substances that act at the interface of the mineral aggregate and bitumen during the mixing and paving steps. These allows for a better workability of the mix and consequently a reduction in temperature. [4] These chemical additives are added into the bitumen at concentrations between 0.3 and 0.5% by weight of the binder (about 150g of additive per ton of asphalt mix) and do not change the properties of the original binder (no change on bitumen grade). Previous publications had demonstrated that the resulting asphalt properties of a WMA carried out with chemical additives have similar properties as a regular HMA [4,5].

Although there is generally accepted that the temperature reduction in WMA provides several advantages, such as energy savings and polluting emission reduction, their measurement and quantification is still a matter of several studies [6,7]. In this work, environmental measurements carried out during the production and paving of two different WMAs, using a chemical surfactant additive commercialized by CECA (Cecabase® RT) are presented. Measurements on the actual gas consumption during the mix productions were taken and compared to regular HMA, demonstrating the energy savings with WMA. Measurements of air emissions at the production plant and during paving were also done for these WMAs using different analytical methods. The advantages of reducing the temperature by means of a chemical additive on the produced air emission are showed. Finally, elements of the life cycle assessment of the production of the chemical additive (cradle to gate) are shown and compared with the energy and CO_2 advantages obtained by reducing the production temperature.

2. ENERGY SAVINGS

One of the most direct advantages of decreasing the production temperature of asphalt mixtures is the reduction of the energy consumed. In the case of WMAs produced with chemical additives, the mineral aggregates are heated to a lower temperature (by about 40°C), while the bitumen is used at its standard temperature. The amount of heat reduced has a direct impact on the amount of combustible used in the process, which can be easily calculated and directly measured on the production plant.

Here are shown two examples of WMA jobs that used a chemical additive where the gas consumption was measured and compared to the same mix asphalt produced at standard temperature. The first example is an asphalt mix formulation conceived to be on a high traffic road. This formula is designed to be a thin top layer of about 3 to 4 cm thick (called *Beton Bitumineux Très Mince*, BBTM, in France). It was made with a polymer modified bitumen (PMB) as binder and it is regularly produced at 170°C (due to the higher viscosity of the bitumen). The temperature reduction was achieved by adding 0.4% of Cecabase® RT additive into the bitumen before it was mixed to the mineral aggregates. It should be noted that the bitumen temperature is the same in the WMAs and in the HMAs for all cases. The additive is a liquid that mixes easily with the bitumen. No particular mixing or solution time is required in order to use it. The additive in this case was added through a metering pump at the moment the bitumen was injected in to the mixer. This process of addition is similarly to what is currently done with some anti-stripping agents. The gas consumptions for the production of this formula at regular HMA and WMA temperature conditions were directly measured from the gas meters at the production plant. The gas consumption values for the whole production at each condition were then averaged by the total quantity of mix produced. The temperatures used, the amounts of mix produced and the consumed energy for this job are shown in Table 1.

Table 1 - Energy consumption on the production of a BBTM

	Production T (°C)	Mix produced (Tons)	Production rate (tons/h)	Energy consumption (m^3 gas/ton)
HMA	170	600	125	5.94
WMA	130	440	136	4.10
	-40°C		+9	1.84 (-31%)

As can be observed, the temperature reduction achieved was 40°C. This decrease in temperature has a direct impact on the consumed energy that is about 30% lower for the WMA. Another interesting observation of this job was that the production rate with the WMA was slightly increased with respect with the HMA. The reason for this improvement is that in order to give less heat to the aggregates, the mineral aggregates spend less time in contact with the hot air from the burner, increasing the production rate.

The second example is on a Stone Mastic Asphalt (SMA), produced in Denmark. SMA is one of the most commonly used asphalt types in Denmark and is typically applied on highways and other main roads with high traffic. In this particular case, the SMA contained 5.7% of polymer modified bitumen, fibres and granite based aggregates with a maximum size of 11 mm. The reference SMA (produced at 172°C) and the WMA SMA (produced at 135°C) were, as in the previous example, produced at the same batch plant with the same formulas except for the addition of Cecabase® RT to the WMA version. The production set-up was the same for both products except the production temperature. The reduction in temperature of 37°C was achieved by adding 0.35% Cecabase® RT additive into the bitumen. The gas consumptions during the production of a reference HMA and WMA with this formula were directly measured as in the previous example. The results, averaged by the tons of mix produced in each case, are shown in Table 2.

Table 2 - Energy consumption on the production of a SMA

	Production T (°C)	Mix produced (Tons)	Production rate (tons/h)	Energy consumption (m^3 gas/ton)
HMA	172	~ 1500	120	6.34
WMA	135	~1500	120	4.64
	-37°C			1.37 (-23%)

In this case, the temperature reduction obtained with the chemical additive is also on the order of 40°C. The energy reduction obtained in this case was of 23%.

It can be seen from these two examples that the actual amounts of energy saved by reduction the production temperature may vary between one job to the other. Many factors can play into the actual value of energy saved other than the type of formula and the WMA technology used, most of them related to the production plant [3]. For example, high moisture content in the mineral aggregates will increase the overall energy consumption during heating, reducing the percentage value of savings achieved by the additive. Nevertheless, it can be observed that the reduction in energy consumption in these examples is significant, resulting in environmental and economical advantages when WMAs are produced.

3. EMISSIONS REDUCTION

Although the emissions produced by a regular HMA are not considered dangerous or particularly toxic, it is always desirable to reduce them to a minimum. A direct consequence of reducing the temperature of an asphalt mix is the reduction of the air emissions produced by it. Here there are shown the measurements carried out during the production, truck loading process and paving of WMA prepared with chemical additives.

3.1 Emissions at production plant

Air emissions produced during the preparation of the two asphalt mixture mentioned in the previous section were measured using different methods. The measurement of both asphalt mix productions actually differ in the kind of information taken during the monitoring. For one of them, the air emissions resulting from the actual production of the mix are measured. On the other one the fumes produced during the charging of a truck at the central were measured.

For the first type of asphalt mix, the "BBTM", measurements of the fumes coming out from the chimney of the production plant were monitored to quantify the amounts of certain gases, such as carbon dioxide, CO_2, nitrogen oxides, NOx, as well as the amount of total volatile organic components (TVOC) and polycyclic aromatic hydrocarbons (PAH). The measurements were carried out by a professional and recognized institution in France (APAVE). Figure 1 shows the placement of the detector at the chimney of the production plant. The same measurements were carried out during the production of this BBTM at reduced temperature (130°C) and at regular hot conditions (170°C). The obtained values of CO_2, mix of nitrogen oxides, NOx, TVOC and PAH for each case are shown on Table 3.

It can be seen that the reduction of CO_2 and NOx, are somewhat close to the reduction in energy consumed. This is probably due to the fact the most of the CO_2 and NOx emitted during asphalt production is from the combustion of the gas consumed. If the amount of gas used during the production in reduced with the WMA, the emissions related to them such be reduced proportionally, as observed in this case. The reduction in temperature had however, a stronger effect on the TVOC and PAHs. The amounts detected on the WMA are less than half of those obtained in the HMA. The air emissions produced by hot bitumen most likely do not reduce linearly with temperature (an exponential-like relationship might be expected). This would suggest that even relatively small reduction in temperature may have a significant impact on the emission of the TVOC or PAH.

Figure 1 Placement of air emissions detectors on the chimney for the BBTM (a) and on top of the truck loading station for the SMA (b)

Table 3 - Emissions during fabrication of the BBTM

	CO_2 (Nm^3/ton)*	**Eq NO_2 (g/ton)**	**TVOC (g/ton)**	**PAH µg/ton**
HMA	14.6	6.8	80.6	78.6
WMA	9.0	5.0	14.3	35.5
Reduction	-38%	-26%	-83%	-55%

*Nm^3 are standard pressure and temperature conditions (1 bar, 0°C)

For the measurements of the second asphalt mix production, the Stone Mastic Asphalt (SMA), air emissions were done in a different fashion. In this case, the monitoring was focused on the asphalt mix, as it came out of the production plant at the instant when the trucks were filled with mix. In this case, the reduction of air emissions by burning less gas is not taken into account. The placement of the detector can be observed on Figure 1. The detector contained two different types of filters for the collection of air samples during the operation. As shown in Figure 2, the loading of a truck with HMA (picture on the left) cause the production of a significant amount of fumes (dust, aerosols, etc…) while the loading of a WMA produces almost no observable fumes.

Figure 2 Fumes generates during truck loading. Left HMA, Right WMA

The obtained measurements of dust, bitumen fumes and a "mix of pollutants" with the SMA at WMA and HMA conditions are show in Table 4. The amount of dust and bitumen fumes were determined by gravimetric measurement of the hydrocarbon soluble fractions from air samples captured by the filter. A similar determination was carried out with a different choice of filter and solvent called "mix of pollutants", which includes the bitumen fumes as well as other, unidentified, chemical components. All sampling and measurements were done by HTEK-Miljø/Sweden.

Table 4 - Emissions during fabrication of the SMA

	Dust (mg/m^3)	Bitumen fumes (mg/m^3)	"Mix of Pollutants" (mg/m^3)
HMA	1,9	1,6	1,55
WMA	0,44	0,34	0,19
Reduction	-77%	-78%	-88%

In this set of measurements, it can be seen that the effect of reducing the temperature is significant. The values obtained with the WMA were about only 25% of those obtained with the HMA. This dramatic decrease in measured fumes is well correlated to what was observed between the WMA and HMA during the truck loading (Figure 2). It is to be noted that the reduction of the bitumen fumes is similar to what was obtained with the TVOC in the first example. This would suggest that indeed the TVOC on the first measurement are probably more related to the bitumen in the mix than on the consumption of gas.

On both of the examples described above, there were significant reductions on the air emissions produced at lower temperatures by using a chemical additive with respect of those produced at regular hot temperatures. In the next section, similar measurements taken during the paving operations, are shown.

3.2 Emissions at paving site

Measurements of air emissions produced by the asphalt mix during the pavement operation of the two productions described above (BBTM and SMA) were also carried out. Again, a comparison between a WMA and HMA conditions were made.

For the first mix, the BBTM, the paving was done during the night. The asphalt mix was transported about 45 minutes before being placed and compacted. The compaction temperature for the mix produced at 170°C was 160°C on average and for that produced at 130°C was 122°C on average. In this case, measurements were carried to indentify and quantify the PAHs coming from the asphalt mixture (following methods described in NF X 43-267 and NF X 43-294). The measurement instruments were placed on three workers with different paving task. One of them was a worker on foot, placed between the two pavers used in the job. Another one was the driver of the one of the pavers. The third one was the compactor's driver. Care was taken that the workers did not smoke or were in contact with other substances that could interfere with the measurement. The same measurements, on the same persons, were done for the WMA and the HMA. The position of the three instrumented workers during the paving operation is shown in Figure 3.

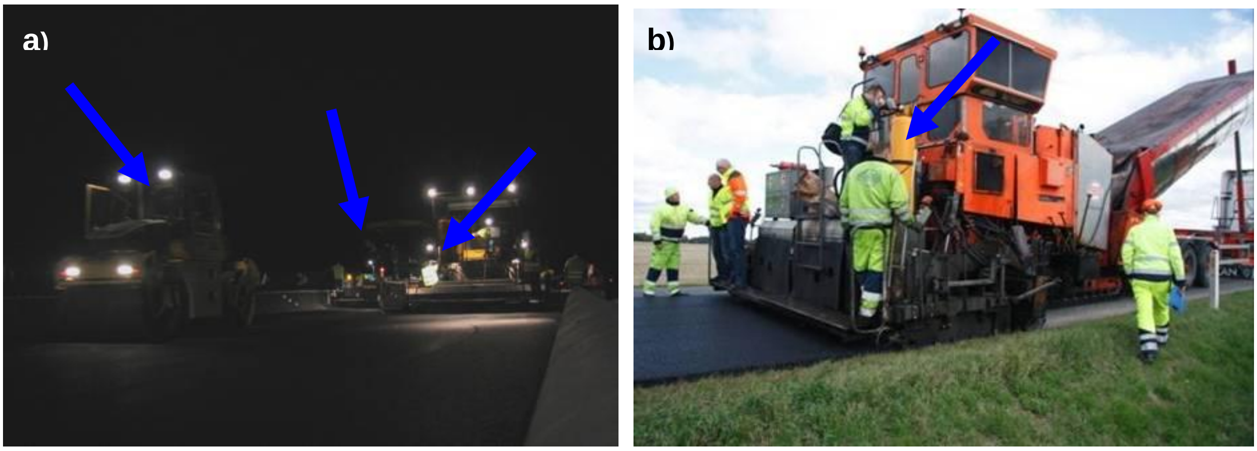

Figure 3 Placement of air emission detectors for the three different position on the BBTM example (a) and on top of the paver for the SMA example (b).

It was found that from the more than 20 molecules searched most of them were below the detection limits of the methods, showing that both mixtures, the HMA and WMA, do not produce a large amount of PAH. However, for some of the molecules tested, differences were found between the different positions of the workers and between the hot and the warm mix conditions. Table 5 shows four of the molecules that were able to be detected on most of the cases.

Table 5 Example of substances found on the paving of the BBTM

	WMA (mg/m^3)			HMA (mg/m^3)		
	Worker	Paver	Compactor	Worker	Paver	Compactor
Acenaphthylene	0.0002	0.0001	0.0002	0.0004	0.0002	<0.00003*
Fluorene	0.0002	0.0001	0.00004	0.0005	0.0003	<0.00003*
Phenanthrene	0.0001	0.0001	NA	0.0004	0.00027	NA
Naphthalene	0.0053	0.0045	0.0019	0.01549	0.0097	<0.00003*

*below detection level

As can be seen there seems to be a trend on the values of PAHs shown above. It is clear that the worker on foot, which is closer to the mix (he was next to the screw of the paver), has the higher values of exposure. The paver driver has lower levels of exposure (for some substances it was nearly half). The compactor driver has the lowest exposure, in some cases below the technique detection level. This trend is observed in both WMA and HMA paving operations. It can also be seen that the overall values for this four substances were lower for the WMA than the HMA. The reduction is actually significant since the values are reduced to about half or one third of those obtained at HMA conditions. This is true for the worker and paver driver values; however, it is not for the data obtained for the compactor driver. The values for the compactor, being the lowest (below detection levels for the HMA) may have been influenced by other factors not related to the asphalt mixture. It should be noted again that the values of PAHs for the WMA and HMA are actually very low and well below the legislation limits (for example the limit for the Naphthalene is 50 mg/m3) showing that there is no particular risk even for the HMA.

The measurements done during the paving of the SMA described above were done in a different manner. In this case, a single position was chosen for the sampling of the emissions produced by the asphalt mixture. As shown in Figure 3, the detector was mounted on the paver, just above the screw. The techniques used in this set of measurements were similar to those used during the truck loading operations. Results of the comparison between standard SMA produced at 172°C and WMA SMA produced at 135°C are shown on Table 6.

Table 6 - Emissions during the paving of the SMA

	Dust (mg/m^3)	Bitumen fumes (mg/m^3)	"Mix of Pollutants" (mg/m^3)
HMA	12	11,4	12
WMA	3,5	3,0	2,9
Reduction	-71%	-74 %	-76 %

It can be seen that in this case there were also significant differences between the HMA and the WMA. The reduction on dusts, fumes and what is called "mix of pollutants" are about 75 %. The reduction on these values is actually close to that obtained during the truck loading measurements. Please notice that the absolute results obtained at the paver should not be compared to the absolute results obtained at the loading station at the mixing plant as conditions for the measurements are different in terms of wind, temperature and distance from the point of emission.

In both of the examples shown it was found that the exposition of the workers during the pavement operation is improved by the reduction of asphalt mix temperature.

Another improvement on the working environment of reducing the asphalt mix production temperature is the comfort level of the workers during the paving. The exposure to a hot mix can become difficult after several hours of work, in particular if done on hot climates. To exemplify the reduction of temperature obtained, Figure 4 shows the thermal images taken with an infrared camera on the SMA at hot and warm mix conditions.

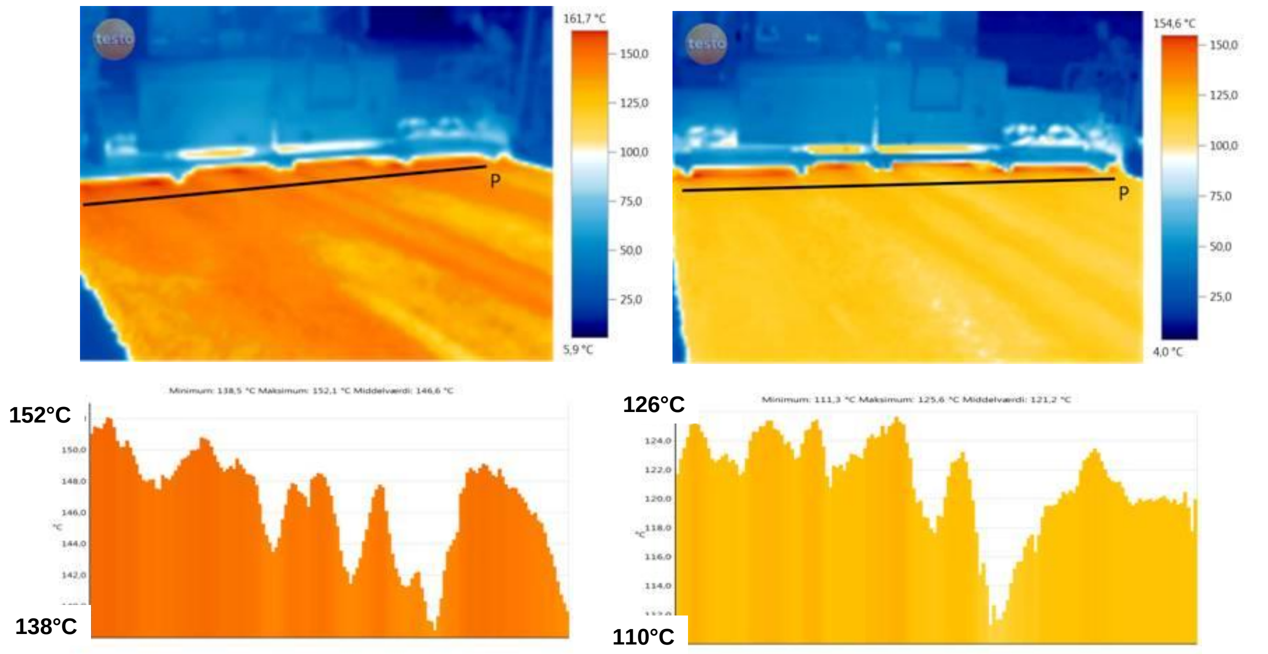

Figure 4 Thermal images and thermal profiles of the SMA during paving at regular hot conditions (left) and at WMA conditions (right)

4. LIFE CYCLE ASSESMENT OF ADDITIVE

In order to further understand the impact of a certain activity or product, there has been a strong interest on calculating or assessing all the contributions linked to such product. The life cycle assessment (LCA) is a method to estimate the impact of a certain product into the environment, taking into account all the different contributions linked to its production, use and end of life [8]. Such estimations are based on calculating, under very different hypothesis, the contributions of the production of the raw materials, the conditions of their utilisation and the different resources needed to its final disposition. This sort of calculation is most useful to make comparisons between different options of products rather than providing absolute values, since usually several hypothesis should be made in order to complete a calculation. Nevertheless, it may provide some useful information to evaluate overall impact of a certain process or material into another.

The road industry is currently working to develop this kind of calculations for the different technologies used to make roads. For example, the URSIF (an association of French road construction unions) had developed a web tool to do environmental comparisons of different kinds of pavements (SEVE) [9]. In order to include the chemical additives on the LCA of WMA, a partial life cycle assessment was carried out for the Cecabase® RT additive. The type of LCA done is what is called a “cradle to gate” LCA. This means that in the calculation it has been taken into account all the sources of raw materials and energy for its production and conditioning up to the point where it is ready for shipping to the asphalt production plant. A complete LCA of the additive should actually include its used to make a WMA, the road utilisation and final disposal or recycling, which is not the object of this paper.

The values for CO_2 equivalents and energy used for the production of the Cecabase® RT shown in this work (Table 7) were obtained through the Sigma Pro software for LCA calculations. Most of the data is based from the Ecoinvent database [10]. The infrastructures were not taken into account. The analysis method is based on the CML 2001.

Table 7 LCA parameters of the Cecabase® RT additive

Impact Parameter	Units	Value for 1kg of Cecabase® RT
Global warming (GWP100)	kg CO2 eq	4.32
Energy from Fuels (oil, gas, coal)	MJ	61.6
Other energies (biomass, solar, nuclear etc)	MJ	17.5
Total Energy (fuel + other)	MJ	79.1

It can be observed that the amount of energy needed to produce the chemical additive needed for producing a WMA is significantly lower than the energy obtained from the reduction of the mix production temperature obtained with it. To simply illustrate this statement, let's take the values from the energy consumed on the first example (BBTM). From Table 1, the gas consumption reduction by using the additive into the WMA BBTM is 1.8 m^3 of gas per ton of mix, which corresponds to approximately 72 MJ (at 1m^3 gas =39 MJ). The energy used to produce the additive needed to produce this ton (at 0.4% in the bitumen, 224g per ton of mix) equals 18MJ, which is much lower than the energy saved by reducing the temperature. The same comparison can be made for the CO_2. From the measurements taken during the production of the BBTM, a reduction of 5.6 Nm^3/ton of CO_2 was found (Table 3), which equals 11 kg of CO_2 (CO_2 density = 1.98 kg/m_3 at normal T and P conditions). The contribution of CO_2 eq due to the production of the additive is equal to 0.97 kg of CO_2, which is again significantly lower than the reduction obtained by reducing the asphalt mix temperature production. Although this is a rough comparison, as it is not completely accurate to compare directly the values from a LCA with individual measured values (amount of energy and CO2 necessary to produce the gas not consumed should also be taken into account too for example), the use of the additive is clearly advantageous to reduce the energy consumption and air emissions.

Further work will be carried out to evaluate other aspects of the LCA of the Cecabase® RT additives, such as their use in asphalt mixtures.

CONCLUSIONS

The energy savings obtained by the use of chemical additives to reduce the production temperature of an asphalt mix were demonstrated in two different asphalt mix examples. The measured savings on gas consumption were between 23 and 31% with respect of a regular hot mix asphalt.

The air emissions produced during the production of a warm asphalt mix, using the chemical additive, were also significantly reduced. The values of TVOC and HAP were the most affected by the reduction of temperature. A similar observation was found in another example where the air emissions were measured during the truck loading operation at the production plant.

The air quality during the paving was also found to be improved by the reduction of temperature. Although single PAHs were difficult to quantify, either on the HMA or the WMA, it was found that there was an effect of the position of the detectors and of the temperature reduction in the WMA. A second example, using a different air emissions measurement technique, confirmed the observed reduction in fumes and dust due again to the reduction of temperature of the asphalt mix.

A preliminary calculation of some LCA factors of the chemical additive used, Cecabase® RT, showed that the advantages obtained by reducing the temperature overcome the energy required and CO_2 emitted during the production of the chemical additive.

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