REVIEW OF WARM MIX ASPHALT NEW TECHNOLOGIES

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ABSTRACT:

Since the signature of the Kyoto Protocol, efforts in the search of processes to slow climate change down have been increased. In the case of the manufacture of bituminous mixtures, new products and procedures that allow a significant reduction of greenhouse fumes emissions and of consumption of energy resources, keeping the demanded benefits, have been developed. However, there is still some reluctance to use them, due to the ignorance of manufacturers about the changes needed in asphalt plants to adapt their technology, as well as about the economic consequences of their use. Therefore, this paper shows an analysis of the key technologies used to manufacture mixtures at low temperature that exist nowadays. Changes in plants to incorporate these new technologies are detailed, and an economical and environmental balance that compares the manufacture of these mixes with the traditional hot mixes is carried out. Everything with the aim of encouraging producers and Authorities to employ these new products, both effective, environmentally sustainable and profitable.

Keywords: sustainable development, half-warm mix asphalt, warm mix asphalt, asphalt plants, industrial adaptation, emissions, consumptions, costs, life-cycle analysis.

1.- INTRODUCCION

Since the signature of the Kyoto Protocol, researchers have investigated in order to develop new products and procedures that minimize the environmental damages caused while manufacturing and laying conventional asphalt mixes. Different bituminous mixes have been developed with this aim, such as: cold mixes, recycled mixes or rubber asphalt. Nevertheless, none of these mixes has managed to reach mechanical properties similar to those of hot bituminous mixes. However, the manufacture of bituminous mixes at low temperatures combines the care for the environment with a suitable structural response of the material.

That's the reason why the use of bituminous mixes manufactured at low temperatures constitutes an important advance for the industrial sector within the last 50 years. In this context, Ladis Csanyi, professor at Iowa's State University, is considered the forerunner of this type of mixes, as in 1956 manufactured the first bitumen foamed with steam [1].

A lot of investigations related to this topic have been developed since then both in USA, in Australia and in Europe, and it was in this last continent where in 1999 there was record of the first use of mixes manufactured at low temperature, exactly in Norway and with the Wam Foam method. In this sense, several technologies developed to manufacture this type of asphalt exist nowadays. It is estimated that more than 40 are internationally well-known, although there are others in course that look for the improvement of various aspects related with their use.

Nevertheless, it is in USA where more efforts are being made for their implementation. In this respect, more than 45 American states have actually test sections and roads where different technologies of mixes manufactured at low temperature have been employed, and the National Asphalt Pavement Association (NAPA) estimates that in five years more than a half of the mixtures laid in USA will be of this type. What's more, countries like Germany, France, Norway and Spain use this processes too, although their level of implementation is lower and usually joined to the construction of low-traffic roads or to reparations [2, 3].

One of the reasons of this situation could be the lack of specific regulations for the use of this mixtures, up to now manufactured by following the standards of hot mixes, added to the ignorance of producers and Administrations about the necessary investments that this products demand, and about the possibilities of amortization of these investments.

Therefore, a lot of research organizations are studying aspects related to manufacture and laying to develop specialized regulations. In this sense, USA, some European countries and even Andalucía in Spain have already a couple of basic recommendations [4, 5, 6]. On the other hand, relating to the required investments, this paper shows a review of the main existing technologies as well as the changes needed in asphalt plants to their development. In addition, a comparison among a traditional hot mix and three warm mixes of varied kinds is introduced, analyzing them from economic and environmental points of view.

Finally, the aim of this paper is to encourage producers and Administrations to employ these new products, both effective, environmentally sustainable and profitable.

2.- MIXES MANUFACTURED AT LOW TEMPERATURE

Bituminous mixtures can be classified according to the temperature of their manufacture. This way, within the general classification of mixes manufactured at low temperature, there are the half-warm mix asphalt, manufactured between 50 and 100 ºC, and the warm mix asphalt, manufactured between 100 y 150 ºC.

Their main environmental and social advantages facing hot mixes are [7]:

1. Decrease between 30 and 70% of greenhouse emissions during the manufacture and laying, due to the low production temperatures.
2. Saving in combustible consumption due to the low production temperatures.
3. More safety and comfortability for workers, who won't have to work at so high temperatures and who will be in less polluted atmospheres.

Moreover, the main advantages from a technical-economical point of view are [1,7]:

1. Easy adaptation of asphalt plants and compaction teams of traditional mixes, causing little initial overcosts that will be compensated with savings in other aspects.
2. They don't involve difficulties for workers, who will follow the essential patterns of hot mixes, with small variations.
3. More workability and good compactability at low temperatures.
4. Larger admissible haul time, as they cool slowlier than hot mixes, what allows increasing the field of action of asphalt plants.
5. Larger paving season and possibility of working at night due to the need for lower work temperatures, increasing productivity.
6. Possibility of achieving a better final compaction and a bigger decrease of air voids in the mix, involving an improvement of mechanical properties such as: durability, water sensitivity, rutting resistance, fatigue resistance, etc.
7. Possibility of paving with big thickness and of an early opening to traffic, what makes them suitable for repairing works.
8. Possibility of employing a big quantity of reclaimed asphalt pavement (RAP), as they provide the mix with workability.

Finally, the main existing technologies, brocken down in Table 1, can be divided into three big groups [8]:

1. Those which use organic additives.
   These additives, which can be from different origins, have a lower melting point than the one of bitumen, from which they tend to decrease its viscosity.
2. Those which employ chemical additives.
   They are usually a group of several additives that are incorporated at the same time to bitumen in order to modify properties such as its adhesiveness, its surface tension, etc., trying to promote its ability to cover the aggregates.
3. Those which foam the bitumen.
   These technologies can consist simply on the employ of mechanical equipments that inject pressurized water into the bitumen, or on the addition of products like zeolites, either natural or synthetic, that contain encapsulated water, which is released when they are put in contact with the hot bitumen. There are also other processes such as the addition of a part of the fine sand in a wet state. These processes cause that the bitumen foams during certain time, while it is able to cover easily the aggregates of the mix. In Figure 1 there are examples of each one of this kind of technologies.

MAIN TECHNOLOGIES FOR THE MANUFACTURE OF WARM AND HALF-WARM MIX ASPHALT	
ORGANIC WAX ADDITIVES	**NON-MECHANICAL FOAMING**
Sasobit	Advera WMA
Asphaltan A y Romonta N	Aspha-min
Asphaltan B	LEA (Low Energy Asphalt), EBE y EBT
Licomont BS 100 y Sübit	LEA (Low Emission Asphalt)
3E LT, Ecoflex y Ecolastic	LEAB
SonneWarmix (Ecobit)	WAM-Foam
ORGANIC VEGETABLE OR MINERAL ADDITIVES	**MECHANICAL FOAMING**
Shell Thiopave	Aquablack
Astech PER (Hydrogreen)	Double Barrel Green
TLA-X Warm Mix	LT Asphalt
Vegecol	Terex WMA
Biophalt	Ultrafoam GX
Floraphalt	Ecofoam II
MODIFIERS FROM CHEMICAL ADDITIVES	HGrant WM System
Revix (familia Evotherm 3G)	Accu-Shear
Evotherm 3G	Aquafoam
Evotherm DAT	Meeker Warm Mix
Cecabase RT	Tri-Mix Warm Mix Injection System
Rediset WMX	**ADDITIVATED EMULSIONS**
Qualitherm	Evotherm ET (with chemical additives)
Hypertherm	Ecomac (with organic vegetable additives)
Recibet	**CLASSIFICATIÓN:**
Cepsasfalt BT	Black: warm mixes
Styrelf BT	Green: half-warm mixes

Table 1. Most outstanding technologies to the manufacture of low-temperature mixes. (Source: self-made)

3.- ADAPTATION OF EXISTING ASPHALT PLANTS

Before analyzing the necessary changes, the main characteristics of the conventional asphalt plants, prepared for the manufacture of hot mixes, will be explained.

3.1.- MAIN TYPES OF ASPHALT PLANTS

There are several types of asphalt plants, which are generally adapted to the material to manufacture and to the expected production. Among the most common, 2 big groups can be found: batch plants and continuous plants.

Batch plants are characterized by the fact that aggregates and bitumen, previously heated, are mixed in appropriate amounts to manufacture one single batch of mix. Figure 2 shows the main units of these plants.

In this respect, the manufacture process starts taking aggregates in controlled amounts from their place of storage and carrying them to a dryer, where they are dried, heated and sieving in order to separate them into desired fractions, which are stored in separated bins at a constant temperature. After that, the required amount of each fraction, dosified by weigh, is taken. Filler (mineral powder smaller than 0.063 mm), is added to these aggregates into the mixer, and also the necessary bitumen, dosified and at the suitable temperature. Finally, the mixing unit is emptied after manufacturing the batch, and the operation is considered finalized.

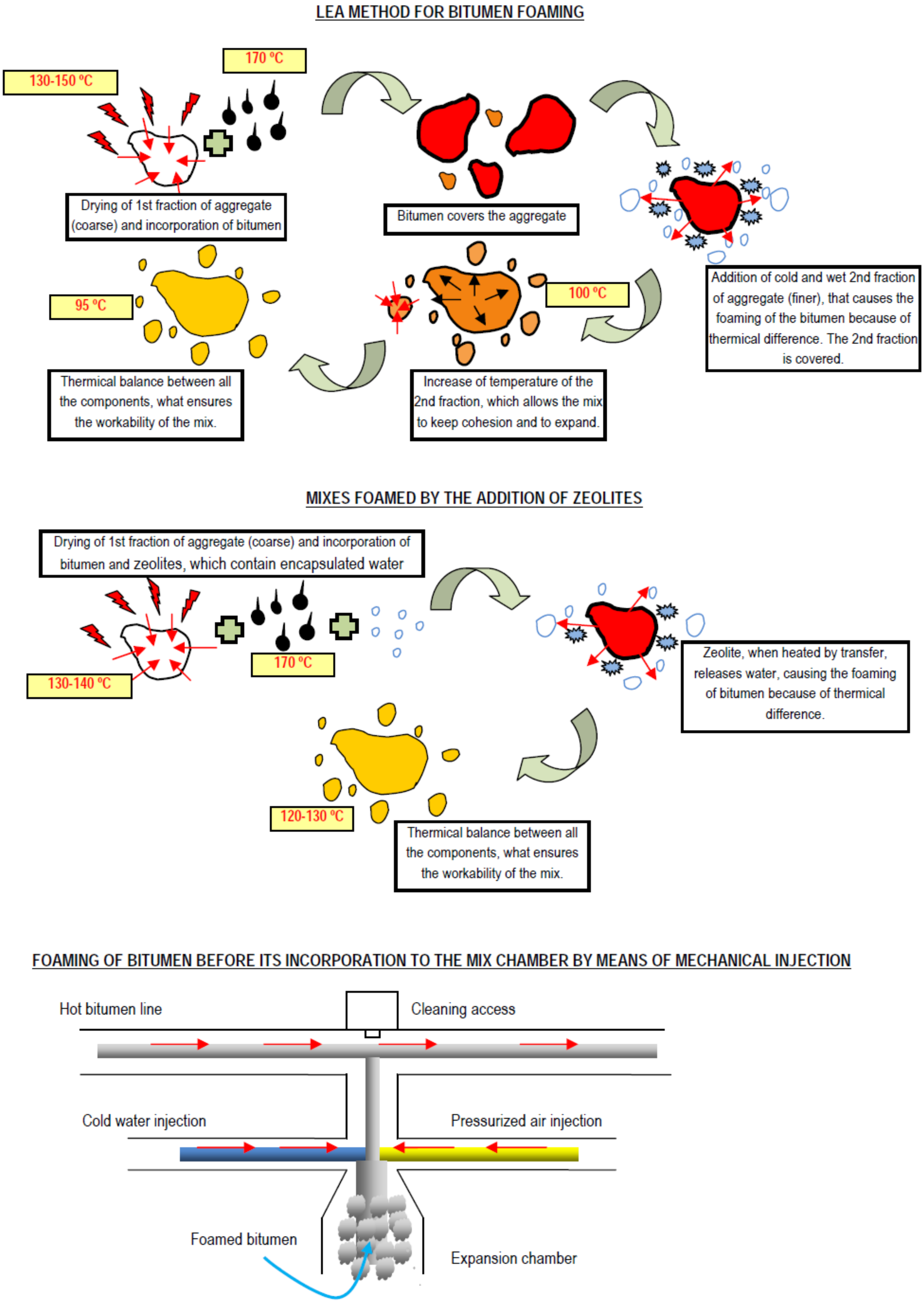

Fig. 1. Variants of foaming technologies. (Source: self-made)

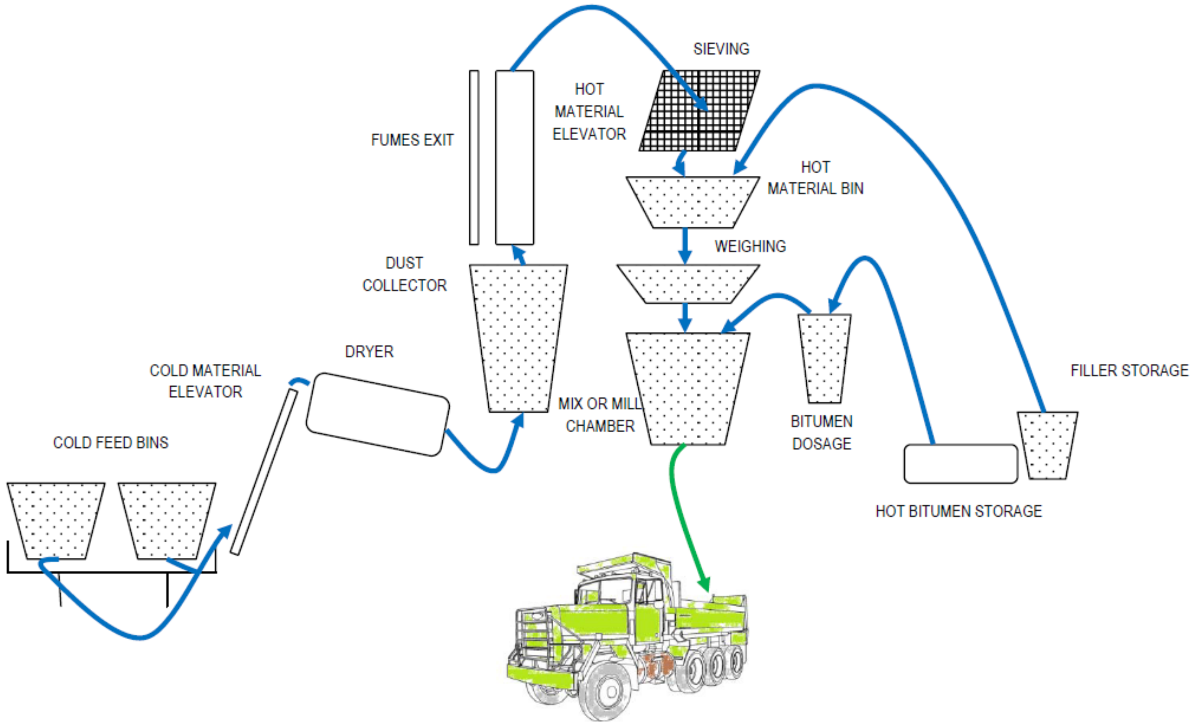

Fig. 2. Basic components of a batch asphalt plant (Source: self-made)

Nevertheless, in continuous plants like the one showed in Figure 3, the dosage of the materials is made uninterruptedly, so a continuous flow of mix is obtained. That's why they have a storage tank for the manufactured mixes. Moreover, in these plants aggregates are dried and heated in the same drum as the one where they're mixed with the bitumen.

The manufacture starts with the cold feed of the different fractions of aggregates, which is adjusted changing the transport speed of the belts of discharge. As the dosage of aggregates is cold-made, each registered weigh includes the corresponding part of humidity. That's why it's necessary to make previous laboratory tests, in order to fix its percentage and to know the real weigh of each aggregate introduced into the mix.

In addition, the employed mixers and their mode of running can be very different. One of the most common situations is that in which aggregates are introduced into the mixer through the part that is nearest to the burner, so aggregates and gases will take the same direction inside it. In this sense the bitumen, introduced at the intermediate section, is to some extent protected from the oxidation by direct contact with the burner, thanks to the physical space that aggregates take up and especially to the water that they contain, which evaporates and dampens the atmosphere.

The warning and mixing of aggregates into the drum follows a definite sequence too. In a traditional hot mix process, the internal temperature of the dryer drum mixer increases gradually. First of all aggregates are introduced, which are considered dry when this temperature is about 170-180 ºC. When 180-200 ºC are achieved, the bitumen is added. At these temperatures, the bitumen foams due to the direct contact with the humidity that remains into the drum, so it increases its volume and its capacity to wrap up.
The drum's temperature is still rising up to a point when damp completely disappears. Finally, once the mix is already manufactured, any kind of elevator at high temperature transports it to a storage tank, where it is maintained at a constant temperature until it is used.

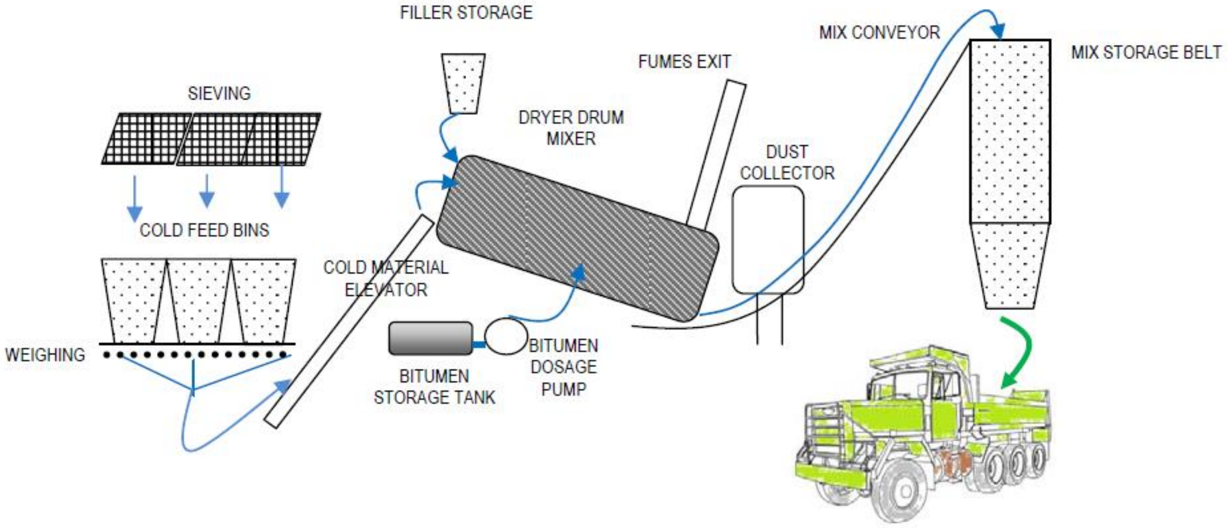

Fig.3. Basic components of a continuous asphalt plant. (Source: self-made).

3.2.- ADAPTATION TO THE TECHNOLOGIES OF MANUFACTURE OF MIXES AT LOW TEMPERATURE

Generally, the incorporation of low-temperature technologies to traditional asphalt plants doesn't demand big modifications. Only very specific processes, fundamentally of mechanical foaming of bitumen, require the installation of particular and often patented equipments.

The general aspects that must be taken into account in order to achieve an ideal result are:

1. The temperature of the exit gases after drying and/or manufacture must be maintained over their dew point in spite of the low temperatures of work, in order to prevent from obstructions. A suitable isolation, an exhaustive control of these temperatures and other measures such as preheating the baghouse filters can achieve this objective [8].
2. It is necessary to adjust the dryer's speed to manage that aggregates to achieve the desired temperature. Moreover, if mixes with a lot of fines are going to be manufactured, it's advisable to have filler preheaters.
3. Aggregates must be dry before mixing and, after that, they must result completely covered by the bitumen. If it were necessary, mixing time would be extended, or the sequence of addition of the components of the mix would be changed.
4. Production temperature and times of storage and transport must be planned with the aim of achieve the desired compaction temperature, which will be the starting point for calculations [4], as well as the room temperature. On average, at an external temperature between 10 and 20 ºC, and for a haul time of 30 minutes, the decrease of the mix temperature is about 15-20 ºC.
5. In order to maintain quality, it's not advisable to alternate in a reduced interval of time the manufacture of hot mixes with warm or half-warm mixes. Although the changes to be done are relatively simple, they must be precise, and they require of time and of a very careful organization. Different base bitumens mustn't be used either, because the mix job formulas of this kind of mixes are very exact, and any apparently little change can make room for big changes in the final product.

Besides, each technology of mix at low temperature requires changes in equipments and processes. For example, most of them involve the addition of any product that reduces the viscosity of the bitumen and that improves adhesiveness between aggregates and binder. There are a lot of ways to introduce these additives into the mix, such as:

1. In the simple case, the plant can directly purchase already-additivated bitumen from its supply center.
2. Otherwise, it will be necessary to provide the plant with any element that allows adding these components to the mix during the mixing by 2 methods, either wet or dry. In the first case, the additive is previously mixed with the binder in order to add afterwards the whole to the mix chamber. In the second case, it is introduced just before the chamber or directly into it, being mixed inside with the rest of the components. It's always necessary its homogeneous distribution.

Practice shows that the best results are obtained either buying already-modified bitumen, or adding the additives to the bitumen at the plant. Nevertheless, the introduction of these additives directly into the mix chamber, specially if they come from waxes, will be the last option [10].

On another side, additives can be supplied in liquid or solid form:

1. If in spite of the risks, making the joint of the different components into the mix chamber is chosen, at least additives in a liquid form must be employed. It will be necessary to change the mix sequence by making a previous one for more or less 15 seconds only with bitumen, fines, filler and the additive, adding afterwards the coarse aggregate. After that, the mix must be shaken for other 15 seconds. Thus, the time of manufacture per batch increases about 65 seconds [11].
   If the additives are liquid and they are added to the tank of bitumen, times don't need to be changed. This tank must have low-speed stirrers available, which will assist their distribution, and a volumetric pump which will pour them into the tank, after their dosage.

2. If additives are purchased in a solid form, most plants can use pre-existing units such as the ones for fibbers or recycled pavement addition. If they don't have them, a pneumatic feeder or a weigh bin will be enough.
   To add them into the bitumen line, they must go previously either through a melting system or through an ejector. In the first case the additive, once in a liquid state after going through the system, is poured directly in the bitumen deposit, which will be hot, and both will mix. In the second case, the ejector acts like a hydraulic pump. The bitumen to be modified is introduced in a narrow section of the pump. A vacuum arises, which generates an ascending stream in this section and which draws the additives towards the bitumen flow, helping them to distribute homogeneously. As the bitumen temperature is higher than the melting point of the additives, they solve into the liquid phase of the binder. None of the previous methods requires to increase the mixing times.

Other measures must be added to the previous ones in particular cases. For example, if emulsions are employed, such as Evotherm ET, they must be stored at 80 ºC, so the plant must have a thermally-controlled tank..

One special case are foaming technologies, as varied as their needs of adaptation.

For the foaming by using zeolites, the most common is to introduce them directly into the mix chamber, previously dosified, und before adding the bitumen. As they are supplied in a powder form, their proportion must be taken into account as part of the filler [13]. They are introduced with it or just afterwards, and the mix must be removed at least for 5 seconds before introducing the bitumen. Any dosification and feed system that already exists in the plant can be employed (Fig. 4 and 5), such as a feeder of fibbers or RAP. Only if the amount to be added is very small, it would be suitable to add them to the mix by hand. It is also possible to purchase bitumen previously modified with zeolites, but, as they distribute very easily into the bitumen, it is not usual.

The main parts of the mechanical foaming technologies are water suppliers, pumps, nozzles, etc. Producers of these technologies offer to asphalt plants complete equipments that can be easily annexed, like the "kit" in Figure 6.

As a rule, foaming nozzles must be installed in line with the bitumen feeders, which must be completed with an extra tank, a pump and a water dosifier. It is usual to set an expansion chamber for the foamed bitumen and a specific control unit to regulate the amount of water added.

Fig. 4. Feeder of fibbers for the addition of zeolites [3]

Fig.5. Feeder filling with machinery that can unload bulk bags or through a connection to a silo [3].

Fig. 6.Equipment of Terex for bitumen foaming. (Source: producer leaflet)

4.- ECONOMIC AND ENVIRONMENTAL ANALYSIS OF LOW-TEMPERATURE MIXES OPPOSITE TO TRADITIONAL HOT MIXES

Due to the wide-ranging of cases, this paper particularly analyzes usual mixes and plants of the Spanish market, such as dense mixes (with percentages of all sizes of aggregates) manufactured in batch plants. Table 2 compares the costs of a traditional hot mix with that of three mixes manufactured at low temperature that belong to each one of the big groups described in section 2. The case investigated is based on data obtained in Galicia, from a construction that demanded the manufacture and laying of about 35.000 tn of hot mixes, and where a batch plant INTRAME UM 260 T was used.

In this sense, to analyze low-temperature mixes, coincidental data have been maintained, while the particular ones of each technology have been corroborated with their producers as well as with Spanish [14,15] and North American [16, 17, 18] experiences . Average data have been used, which should be adjusted depending on factors such as the exact temperature of mixing and compaction. The cost of establishment indicated depends on the way of applying the technology, as explained, but in all cases it can be deduced from its small amount that they are easily redeemable. It is true that there are other technologies of warm and half-warm mixes that demand larger initial investments (and which usually have additional advantages), but the most don’t involve large overcosts.

It is important to stand out that the production capacity of the plant is not altered at temperatures of warm mixes, and it can slightly decrease in the case of half-warm mixes, which demand sometimes an increase in the mixing time of a few seconds in order to ensure that the binder wraps the aggregates.

From Table 2, it can be observed that the cost of production of mixes at low temperature is in the order of the one of hot mixes. Even with Evotherm, a saving of more or less 1,6 € per tn of mix can be confirmed. It is important to note that high costs of these technologies have been used, and as usual, they will decrease after their generalization.

But in order to make a complete analysis, to these costs derived strictly from production, other must be added such as the environmental and the social ones, an even the economic ones, but considered from a global point of view. In this sense exist nowadays tools based on the so-called "life-cycle analyses". In a simple way, it could be said that these analyses consist of calculating de carbon (CO_2) footprint generated in all stages of a bituminous mix manufacture, including some such as the raw material obtaining (even additives where applicable), intermediate transports and even reparation works during its useful life [18]. Some methods increase these analyses with data of energetic consumptions and of other emissions noxious for environment. They quantify them economically, obtaining a more exact comparison that that one based simply in production.

Figures 7 and 8 summarized the average results of several life-cycle analyses performed in USA to mixes similar to the ones analyzed in Table 2. In the first one it is indicated the percentage by weigh that the main operations included in a pavement construction have over environmental aspects such as global warning, fuel consumption, polluting emissions and fumes (gases with suspended particles) formation in the case of conventional hot mixes. In figure 8, with the reference of previous aspects about the whole production of hot mixes, their magnitude in the case of using low-temperature mixes is compared, and it is possible to observe differences of up to 24%. These improvements will be fundamentally gather in manufacture and laying operations, as the obtaining of raw materials will be very similar, in spite of using additives in some technologies, most of which have a vegetable or an organic origin. In the case of the chemical additives, the damage that they can cause to environment is relatively small due to their low dosage in the mix [17].

These environmental improvements can be quantified based on judgments that depend on the country and on the analyst, among others. As an example, carbon monoxide (CO) emission reaches costs between 18 and 145 €/tn, depending on if it is about a rural or an urban area [16], and methane (CH_4) emission is around 6.000 €/tn. Anyway, it is evident that the global cost of the low-temperature mixes is smaller than the cost of hot mixes, and all this without taking into account other aspects such as the increase in healthiness in the operator's work atmosphere.

MIXTURES	LOW-TEMPERATURE MIXES			TRADITIONAL HOT MIX
	ORGANIC ADDITIVES	CHEMICAL ADDITIVES (Evotherm in emulsion)	FOAMING (Aspha-min)	
Approximate cost of establishment * (€)	0-30.000	minor	0-30.000	-
Approximate cost of use licences (€)	0	0	0	-
Cost of the material of the technology (€/Tn)	1.372,80	486,00	1.029,60	-
Recommended dosage	1,5-3,0% by weigh of binder	100 % by weigh of binder	0,3% by weigh of mix	-
Approximate cost of the technology (€/Tn mix)	1,37	24,30	3,09	-
Approximate cost of technology+binder*1 (€/Tn mix)	23,87	24,30	25,59	22,50
Average savings in consumptions opposite to hot mixes (%)	20,00	50,00	30,00	-
Fuel consumption*2 (l/tn)	6,08	3,80	5,32	7,60
Fuel cost (€/l)	0,70	0,70	0,70	0,70
Fuel cost (€/tn)	4,26	2,66	3,72	5,32
Energy consumption (KWh/tn)	7,20	4,50	6,30	9,00
Energy cost (€/KWh)	0,17	0,17	0,17	0,17
Energy cost (€/tn)	1,22	0,77	1,07	1,53
Approximate cost of aggregate (€/tn)	9,03	9,03	9,03	9,03
Approximate general costs of plant (€/tn)	1,52	1,52	1,52	1,52
Approximate cost of laying (€/tn)	7,72	7,72	7,72	7,72
Total cost of the mix (€/tn)	47,62	45,99	48,65	47,62
Total savings opposite to hot mixes (%)	0,00	3,41	-2,17	-

* for a conventional batch plant. They will be similar for a continuous plant.

*1 5% of bitumen supposed as an average.

*2 for an aggregate with 2-4 % of humidity, including intermediate transports.

Table 2. Comparison of cost between hot mixes and mixes manufactured at low temperature. (Source: self-made from data provided by a construction company and by the producers of the different technologies, completed with those contained in the referenced papers).

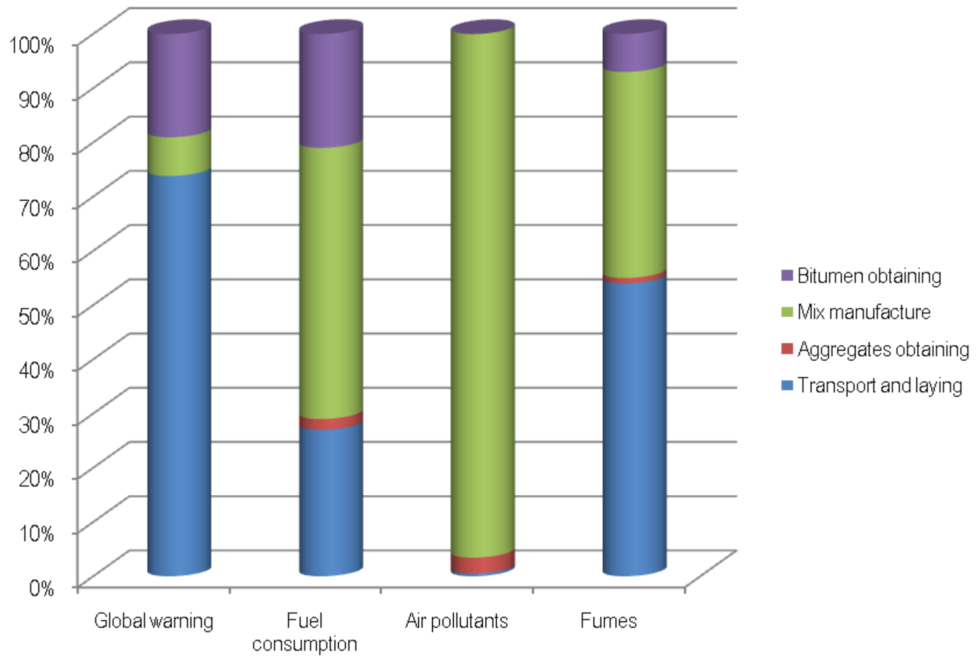

Fig.7. Environmental analysis of the different processes included in a hot mix production [16, 17]

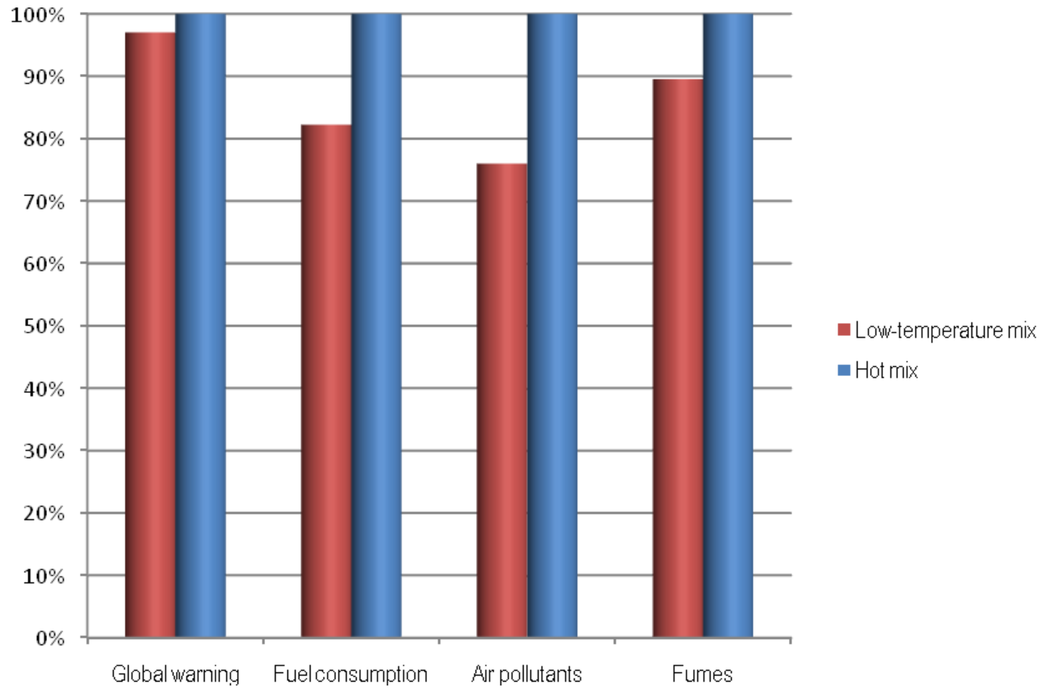

Fig. 8. Comparison of sustainability between hot and low-temperature mixes [17, 18]

5.- CONCLUSIONS

This paper shows a review of the main technologies to manufacture bituminous mixes at low temperatures. Thus, based on the results obtained during its development, the following conclusions can be drawn:

1. The incorporation of technologies to manufacture mixes at low temperature to traditional asphalt plants is a desirable and feasible process. At the expense of a small initial investment, producers could obtain short-term a lot of benefits. From an environmental point of view, emissions of pollutants and consumption of fuel would decrease. From an economical point of view, energy consumption would be reduced and the paving season could

be extended. Finally, occupational diseases would decrease, as operators would work at lower temperatures and into less noxious atmospheres as in the case of hot mixes.

2. Low-temperature technologies based on the addition of chemical products involve a smaller initial investment. Those that work with organic additives and with non-mechanical foaming would be the following. Mechanical-foaming systems have the largest costs. Moreover, they need in each particular case a specific study adapted to the plant where they will be placed. Nevertheless, they show other advantages, such as the possibility of increasing significantly the quantity of RAP admissible.

3. The operations of manufacture and laying of low-temperature mixes follow in essence the same patterns that in the case of hot mixes. The common processes must barely be changed, so the implementation of these technologies doesn't involve any difficulty for workers. Some national and international organizations are trying to specify these procedures in order to obtain mixes with better quality, but only the need of little adjustments is noticed.

4. Taking into account the cost of manufacture and laying of these mixes, those manufactured with chemical additives turn out to have one substantially smaller (3,5%) than hot mixes. Those manufactured with organic additives have a similar cost and the foamed mixes one a little larger (2%), although a more global analysis of them makes clear their suitability.

5. In the life-cycle analysis of mixes manufactured at low temperature, which takes into account the generated emissions and consumptions since obtaining their raw materials up to the moment when these mixes run out definitively, all the technologies show their advantages opposite to hot mixes. If the decrease in environmental damage is quantified and valued, they turn out to be unequivocally more economical. The social aspect should be added to those others, as the salubrity of workers increases substantially.

6. There is internationally a big interest to achieve the generalization of the use of technologies to manufacture mixes at low temperature. Thus, a greater presence of them in Spain would contribute to increase the competitiveness of national companies of the sector abroad.

6.- THANKS

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