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Evaluation of the Environmental Impact of a Dense Graded Hot Mix Asphalt (HMA)

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This research is focused on the production process of the asphalt used for roads, in order to gather the information required for developing an environmental management program in a road construction company. Life cycle analysis (LCA) methodology was used to evaluate the environmental profile of the batch production process of dense graded hot mix asphalt, in terms of its environmental impact. It was found that the environmental impact of the process is caused mainly by the stages where the asphalt binder is involved, such as heating, stock, weighing and mixing.
According to the results, three alternative scenarios were proposed for improvement, where the input of the asphalt binder to the heating process is partially replaced with three different additives (polyvinyl resin, amine-based, and a powder synthetic zeolite). The comparison of these three scenarios showed that the amine-based liquid additive is the best to decrease the environmental impact due to the asphalt binder processing.

1. Introduction

The manufacturing of hot mix asphalt consists essentially of a rotating drum mixer where the asphalt binder is mixed with aggregates (stones), at temperatures around 155 °C. To be a dense graded mix, the aggregates must meet a size distribution, according to the local standards (Go et al., 2012). The contamination generated by this mixing process is in the form of leaks that affect soil and water, and emissions due to the natural gas and diesel combustion; these contaminants affect the communities near the refineries and hot mix plants. In order to lower the mixing and laying temperatures, among other benefits, warm mix asphalt technologies have been developed, by adding additives that reduce the viscosity, so that asphalt aggregates can be coated at lower temperatures (Al-Busaltan et all., 2012). This way, the mix is easier to manipulate and can be hauled for longer distances (Hill et al., 2013). Other benefits include better performance of pavements, time and costs saving at compaction, healthier conditions for workers and lower emissions (Barthel et al., 2005). Some studies have showed the following percentage reductions: 30 % in energy consumption, 25 % in particulate material released to the atmosphere, 30 % in CO_2, 60 % in N_2O and 35 % in SO_2 emissions (Lopera, 2011).
Another technology used to lower the temperatures and energy consumptions is the cold mix asphalt emulsions. A special type of emulsified asphalt is mixed with aggregates. The emulsion used reduces the viscosity of the asphalt, making it pliable even at cold temperatures (Ying et al., 2011). The benefits are similar to those of the warm mix asphalt, since this technology requires less heating, saves energy and reduces fumes. The foamed asphalt technology consists of injecting a small quantity of cold water (usually with a mass ratio of 1 % to 5 % to the asphalt binder), together with compressed air into hot asphalt (140° C to 170° C); this way, the water becomes steam and asphalt is temporarily expanded into bubbles with a higher surface area per unit mass (Thanaya et al., 2009). Foamed asphalt can be added directly to cold

granular materials at ambient temperature (Seref et al., 2006). The addition of synthetic zeolites to asphalt causes a foaming effect that can help lower the temperatures for manufacturing hot mix asphalt.
This paper describes the assessment of the potential environmental impact of a dense graded hot mix asphalt production in a facility located in Colombia, considering four different scenarios for comparison purposes; the reference scenario is the conventional hot mix asphalt process, and the other three scenarios assess the impact of adding three different additives that help lowering the mixing temperatures.

2. Methodology

The different steps of the study are described as follows:

2.1 Goal definition and scoping (Step I)
The information gathered during the study was used as a base to define its goal and scope, the inventory analysis, the assessment of the potential environmental impact and interpretation of results. The environmental impact of the production of dense graded hot mix asphalt was assessed by following the Life Cycle Analysis (LCA) methodology, according to the ISO 14044 (Cornejo-Rojas et al., 2005)

2.2 Life-cycle inventory (Step II)
This step allows quantifying the energy and raw material inputs and environmental releases associated with each life cycle phase. The inventory analysis of the life cycle was done by gathering and calculating information related to the inputs and outputs of the process, in order to identify the hypothesis and limits of the study. Data files of the company were consulted, from January 2011 to June 2012.
Based on the inputs and outputs, mass and energy balances were verified, in order to establish the goals and scope for the LCA. Based on this information, the process was quantitatively described. Each unit of the process was associated to relevant data, while some stages of the process were excluded of this analysis. Specialized software for LCA (SIMAPRO 7.1) and several databases (Ecoinvent, Alusuisse 1992, APME report, AUMUND 1994, Bergh & Jurgens 1990, Bouwmaterialen 1993, BUWAL, CBS, CE, CHELMERS, Danish EPA, EAA report, ETH Energy version, IDEMA 2001, KEMNA, Metals and minerals, Nesa, NVE, SPIN, World resources) were used to analyze the process stages that involve most of the time and effort of the dense graded hot mix asphalt. Some limitations related to the data gathering were defined; the data excluded from this study were associated to volumetric design in laboratory, aggregates exploitation, aggregates transportation from the pit to the plant, transportation of asphalt binder from the refinery to the plant, crude oil refining for producing asphalt binder, transportation of the hot mix asphalt from the plant to the paving site, paving operations, road maintenance and road construction. There were some supplies not included in the software database; then, species with the same physicochemical properties were used in the analysis. Figure 1 shows the stages considered in this analysis.

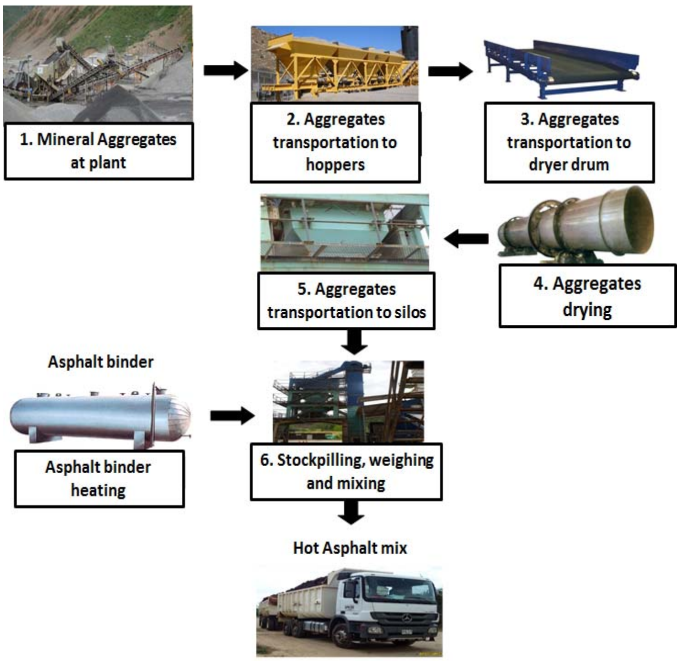

Figure 1: Process diagram for hot asphalt mix production.

2.3 Environmental impact analysis (Step III)

In this part of the environmental impact assessment (EIA), the relationships between the process stage and its environmental impacts are established. Based on the inventory analysis, the environmental loads associated to the process were identified and characterized (Martinez et al., 2007), following the methodology LCA according ISO 14040 and 14044 and introducing the information collected at the specialized LCA software SIMAPRO 7.1. The results showed the environmental impact for each stage of the process. The environmental impact categories that were evaluated are:

- Global warming (100 years).
- Respiratory effects (organics and inorganics).
- Terrestrial acidification and nitrification.
- Aquatic acidification
- Non renewable energies.
- Minerals extraction.

These impact categories were selected for comparative purposes, as described in the documents published by Swedish Environmental Research Institute (Stripple, 2001) and the Illinois Center of transportation (Leng and Al-Qadi, 2011).

2.4 Comparison of potential scenarios

Three alternative scenarios were analyzed, where each one involved the use of a different additive. These additives allow for lower temperatures during the mixing and laying processes, and this technology is known as warm mix asphalt process. The four cases studied were:

Reference: this scenario considers the process for production of conventional dense graded hot mix asphalt.

Alternative 1: this scenario considers the process to produce dense graded hot mix asphalt, where a 3% of a polyvinyl resin is added to the asphalt binder, before mixing it with the aggregates. The polyvinyl resin consists of long aliphatic chains.

Alternative 2: In this scenario, a powder synthetic zeolite is added (0.3% w/w) to the asphalt binder, before mixing it with the aggregates.

Alternative 3: In this scenario, a liquid amine-based compound is added (1% w/w) to the asphalt binder, before mixing it with the aggregates.

3. Results and analysis

The results are shown for each step described in the methodology.

3.1 Goal definition and scoping (Step I)

The goal of this study was to assess the potential environmental impact associated to the process for production of a dense graded hot mix asphalt of a batch plant located in the industrial zone of Giron, province of Santander, Colombia. The scope was defined by considering the product, the geographical and temporal boundaries, and the functional unit. The functional unit defined for this study was 3,960E3 t/month. This unit is basic for accounting the mass and energy consumptions during the process. The geographical boundary is defined by the location of the plant; the temporal boundaries for this assessment were defined by the production data, gathered from January 2011 to June 2012.

3.2 Life-cycle inventory (Step II)

As mentioned in the methodology, six stages were considered for the qualitative analysis of the process. The first stage is the heating of asphalt binder, at 155 °C during 5 h, by heat exchange from thermal oil, which is heated by a boiler that operates at 220 °C during 4 h. The oil is then transported through heating coils to the drum mixer. The second stage of the process is the transport of aggregates from the stockpiles to the hoppers. A front loader weighing 10 to 15 T, goes over 5,2 km each batch, and transports 2,676E+1 m^3/h aggregates. In the third stage, two belt conveyors transport aggregates from the hoppers to a drum dryer. The fourth stage consist of aggregates drying in the drum, where the heating is supplied by burning natural gas in presence of air, which is draught by a turbofan. Coarse aggregates are taken to a primary collector, while medium size aggregates are retained in a multi-cyclone unit, and fine aggregates are retained by a filter sleeve. This filter has an air inlet from a compressor, and the outlet is driven by an exhaust fan connected to a chimney.

The fifth stage comprises transportation of aggregates (coarse, medium and fines) by a screw conveyor to the bucket line. At the sixth stage, the bucket line transports the aggregates to the silos; then aggregates are weighed together with the asphalt to be finally mixed.

The units T, kg or m[3] were used to identify materials streams and MJ for energy inputs and outputs. Measures of mass flows and energy rates of the different streams for each stage were taken on the base of 1 T/month of asphalt mix. Table 1 shows the main streams of the process.

Table 1: In and out streams. Process for production of dense graded hot mix asphalt

Stream	Composition	Unit/month	Quantity	Stream	Composition	Unit/month	Quantity
In	Asphalt binder	T	4,90E-2	Out	Carbon Dioxide	Kg	1,01E+1
	Mineral aggregates	T	9,50E-1		Particulate matter	Kg	6,00E-3
	Energy	MJ	1,37E+1		Sulphur Dioxide	Kg	2,20E-3
	Diesel	T	1,10E-3		Nitrogen Oxide	Kg	8,80E+0
	Air	T	6,30E-1		Oxygen	Kg	5,54E+1
	Natural Gas	m^3	7,60E+0		Steam	Kg	3,80E+1
					Carbon monoxide	Kg	6,90E-2
					Dinitrogen	Kg	1,74E+2
					Asphalt mix	T	1.0E+0

3.3 Environmental impact analysis

Based on the emissions identified in the life-cycle inventory, several environmental impact categories were chosen. Impacts were determined by the characterisation provided with the LCA software. Figure 2 shows the environmental profile of the process, according to the impacts obtained for each stage.

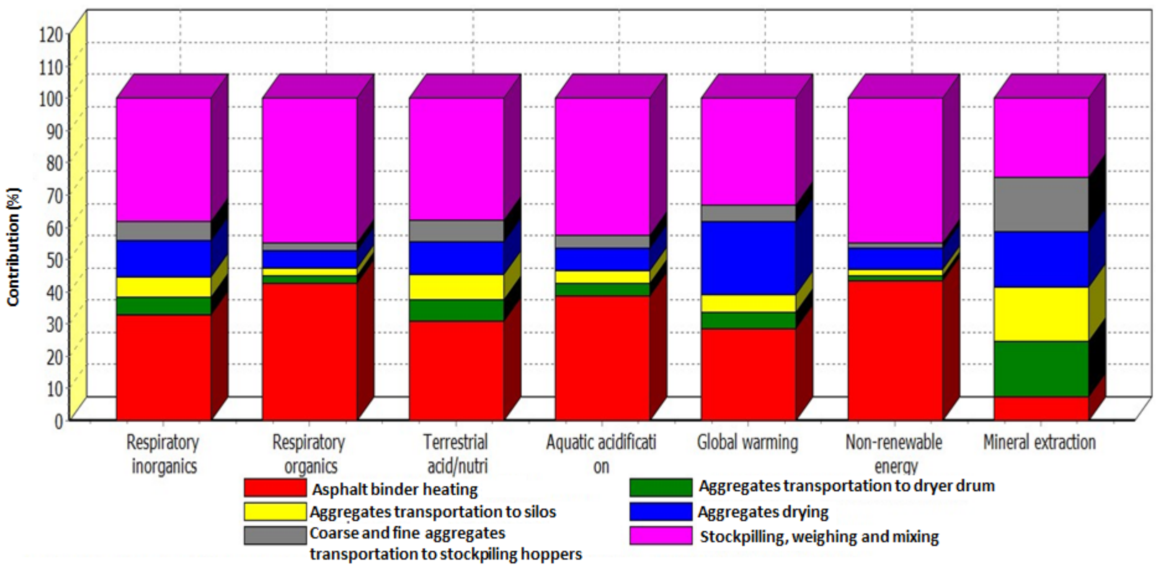

Figure 2: Environmental profile of the process for production of dense graded hot mix asphalt.

The environmental profile shows that, among the different stages of the process for production of dense graded hot mix asphalt, the heating of the asphalt binder, together with the stage of stockpiling, weighing and mixing, represent the highest contribution to the impact categories chosen for the analysis.

3.4 Comparison of potential scenarios

Three alternative scenarios were analyzed. The scenarios are described in the methodology section of this paper. The most significant streams for each scenario were quantified, in order to characterise the impact categories and determine the contribution percentages, as in the reference scenario. Table 2 shows the comparison for the proposed alternatives. According to the results obtained with the software, it is observed that the alternative III (asphalt with amine-based liquid additive), allows decreasing the global warming category from 2,25E+5 kg CO_2 eq to 1,48E+5 kg CO_2 eq; that decrease represents 35 % less of CO_2 released from the process, compared to the conventional process (reference scenario). The alternative II (asphalt with powder synthetic zeolite), helps decreasing the release of CO_2 from 2,25E+5 kg CO_2 eq to 2,12E+5 kg CO_2 eq; this means that the alternative mitigates the global warming in 6 %, compared to the conventional process.

Table 2: Characterization of the comparison between the different scenarios for the production of dense graded hot mix asphalt.

Impact category	Reference	Alternative 1	Alternative 2	Alternative 3
Respiratory inorganics [kg PM2.5 eq]	3,07E+2	3,12E+2	3,02E+2	1,99E+2
Respiratory organics [kg C_2H_4 eq]	3,31E+2	3,49E+2	3,29E+2	1,86E+2
Terrestrial acidification/nitrification [kg SO_2 eq]	6,05E+3	6,23E+3	6,00E+3	4,05E+3
Aquatic acidification [kg SO_2 eq]	2,12E+3	2,17E+3	2,10E+3	1,24E+3
Global warming [kg CO_2 eq]	2,25E+5	2,41E+5	2,12E+5	1,48E+5
Non-renewable energy [MJ primary]	2,23E+7	2,25E+7	2,21E+7	1,23E+7
Mineral extraction [MJ surplus]	6,32E+2	5,86E+2	5,83E+2	5,80E+2

The alternative III has a higher mitigating effect than the alternative II; this is due to a lower requirement of materials for producing the amine-based liquid additive used in alternative III.
Other advantages related to the use of additives are the lower requirement of asphalt binder and lower temperature for heating the asphalt binder, which helps reducing the emissions of the whole process. It can also be observed that the alternative III helps decreasing the effect due to the respiratory organics, from 3,31E+2 kg C_2H_4 eq to 1,86E+2 kg C_2H_4 eq, while the alternative I has a higher impact, and the alternative II did not show a significant decrease.

The alternatives II and III reduce other impacts, such as respiratory inorganics, terrestrial acidification/nitrification, non-renewable energy and minerals extraction. In general terms, the most beneficial effect is obtained with the addition of an amine-based enhancer.

4. Conclusions

Life cycle analysis methodology has been applied to assess the potential environmental impact of the production process of dense graded hot mix asphalt, using specialized software. The stages with the highest impact on several categories have been identified. The results showed that the heating, stockpiling, weighing and mixing are the steps with the highest concentration of green house and global warming emissions. The potential respiratory problems that would affect neighbour communities are associated to the volatile organic compounds (VOCs) and inorganic compounds that are emitted during the asphalt binder heating, aggregates drying, stockpiling, weighing and mixing.
According to the comparison of different scenarios involving the use of additives, the amine-based liquid additive shows the highest reduction on the environmental loads. The database included in specialized software shows that the contribution from the process to produce this additive has a lower input on the techno-sphere than the polyvinyl resin and the synthetic zeolite.

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