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Modeling of Polycyclic Aromatic Hydrocarbons stack emissions from a hot mix asphalt plant for gate-to-gate Life Cycle Inventory

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A B S T R A C T

Only few LCI data are by now available concerning Polycyclic Aromatic Hydrocarbons emitted by asphalt plants. Depending on the type of airborne emissions the influence of plant technology and of input materials can be significant on environmental performances of products. Then, the use of generic Life Cycle Inventory (LCI) data is not satisfying because results do not allow the comparison between technologies, and it is necessary to produce data for gate-to-gate technologies. The objective of this paper is to provide suitable LCI data for PAH airborne stack emissions of an asphalt plant equipped with a parallel drum mixer and fed with natural gas. The purpose is not to serve as a generic LCI data, but on the contrary, to serve as a first step to future comparisons to other asphalt manufacturing technologies (batch mix, counter flow drums) and to other fuels (fuel oil). The studied (and sampled) PAH are chosen from the US-EPA list of carcinogens, or expected carcinogens. Operation conditions were varied (different asphalt manufacturing temperatures and production rates) in order to obtain inventory data more representative from various working conditions. PAH values are found highly variable, probably depending on instability of natural combustion chemical reactions. An empirical model is proposed that defines a multi-linear relationship between some PAHs emissions and both the bitumen content in asphalt and the CO/CO_2 ratio. The model is discussed in terms of physic-chemical significance, limits of application and feasibility for LCA.

1. Introduction

The number of studies addressing the problem of the environmental evaluation of roads using Life Cycle Assessment has been increasing regularly over the past few years (Chowdhury et al., 2010; Gschoesser et al., 2012; Huang et al., 2009; Jullien et al., 2004; Santero et al., 2011b; Sayagh et al., 2010; Ventura et al., 2004, 2008). However, a survey of the literature (Santero et al., 2011a) reveals that very few LCI data are currently available regarding Polycyclic Aromatic Hydrocarbons (PAH) emitted by asphalt plants (Jullien et al., 2004; Lee et al., 2004; US-EPA, 2000a, 2004; Ventura et al., 2007, 2004).

Depending on the type of emission, the influence of both the plant technology and the input materials can be significant. The use of generic Life Cycle Inventory (LCI) data, indeed, is not satisfactory. They do not allow for the comparison between the different technologies (fuel, gas, continuous or discontinuous process). Consequently, more work needs to be carried out to understand the expected differences better. Assessment, therefore, is essential. If some technologies, i.e., warm mix processes, have proven to decrease energy consumption, all the improvements, however, are not always confirmed for all the emissions (Ventura et al., 2009).

PAHs are found into bitumen (CONCAWE, 1992) and in bitumen fumes (Brandt et al., 2000; Burstyn et al., 2002; Kito et al., 1997) with possible effects on health (Bonnet et al., 2000; Burstyn et al., 2003, 2007). When directly emitted from bitumen, PAH masses depend on the contact surface area between bitumen and air, the bitumen origin, and its temperature. Similarly, PAH can be generated by hot bitumen during drum mixing processes. They probably have a double origin: some steam extraction phenomena (Ventura et al., 2007) and some combustion reactions occurring within the burner's flame (Heger et al., 2001, 1999; Siegmann and Sattler, 2000; Siegmann et al., 2002).

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This paper presents the PAHs emission results obtained during the experimental campaign carried out in June 2004 using the asphalt plant of Blois (France). The objective of this research is to provide suitable LCI data regarding PAHs airborne stack emissions of an asphalt plant equipped with a parallel drum mixer supplied with natural gas. The purpose of the paper, rather than presenting a generic LCI data, is a first step for future comparisons between other asphalt manufacturing technologies (batch mix, counter flow drums) and other fuels (fuel oil). The technology studied is tested using common asphalt mix design in various operational conditions in order to obtain a representative range of PAHs emissions. The studied PAHs are chosen from the US-EPA list of carcinogens (IARC, 2010; US-EPA, 2012). Parallel drum mixing process, testing operational conditions, and sampling and calculation methods are first described. Then, the results are examined and an empirical model, developed to calculate PAHs emission factors, is presented. Finally the significance, limits and feasibility of the model within the general context of LCA are discussed.

2. Materials and methods

2.1. Parallel drum mixing technology

The Hot Mix Asphalt (HMA) plant used is a TSM-Ermont 17 from the Marini-Ermont company. The mixing principle is parallel drum mixing (Fig. 1). The burner, supplied with natural gas, is used to warm and dry aggregates. Aggregates are introduced into the drum using the main conveyor belt. The burner is located in the upper part of the drum. After drying, aggregates are mixed with hot bitumen in the lower part of the drum.

The asphalt material is a classical French bituminous asphalt mixture for base courses (GB 0/14 – class 2, NF P98-150-1 standard (AFNOR, 2010)) presented in Table 1. Bitumen is a classical 35/50 grade. New aggregates and/or reclaimed asphalt pavement mass flows are continuously measured at the dryer inlet.

Table 1
Produced Gravel Bitumen (GB) asphalt mix design.

Component	Type	Mass ratio in mix design (%)
Aggregates from La Noubleau quarry	Fraction 10/14	29
	Fraction 6/10	18
	Fraction 2/6	18
	Fraction 0/2	33.5
Fines	Limestone	1.5
Bitumen	Grade 35/50	3.75
TOTAL		103.75[a]

[a] In 2004, in France, asphalt proportions were defined as 100% of the aggregate total mass.

2.2. Choice of representative operational conditions

Production rates and asphalt temperatures are set by the operator before manufacturing process starts. During the production phase, asphalt temperature variations are usually due to some variations in the aggregate moisture content. The operator can then adjust the natural gas feeding valve if necessary.

During study, operational parameters like asphalt temperature and production rate have been varied within common ranges. Table 2 presents the characteristics of the six tests. For Tests 1 to 3, the asphalt production rate varies from 120 to 160 metric ton/hour, with a constant asphalt temperature of 160 °C. For Tests 4 to 6, the asphalt temperature varies from 140 to 180 °C with a constant production rate of 140 metric ton/hour. Test 7, on the other hand, has been conducted in unusual conditions since no bitumen was added for a "blank test". Because of its particularity, the conditions in which Test 7 was conducted are slightly different: i) the aggregate temperature is 190 °C to increase the contribution of natural gas combustion to PAH emissions; ii) for safety reasons (risk of inflammation of the air filter) the test has been run for 24 min only instead of 30 min for the other tests.

No significant changes in aggregate moisture content or atmospheric conditions (atmospheric pressure and ambient temperature) were noticed during the whole experiment. Measurement conditions, therefore, remained in accordance with the desired conditions.

2.3. PAH sampling and analytical methods

PAH sampling and analysis procedures have been carried out by a COFRAC-certified contractor. According to ISO 10-780 standard and prior to sampling, a gas velocity map inside the stack is established using a double Pitot tube connected to a micro-

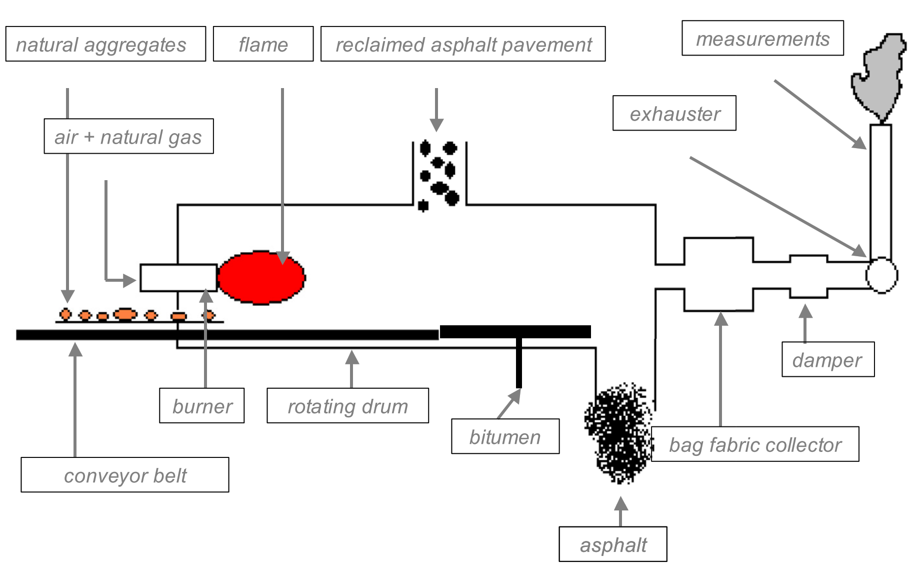

Fig. 1. Diagram of the parallel drum mixing technology.