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ENERGY EFFICIENCY AND ENVIRONMENTAL ADVANTAGES OF BITUMEN EMULSIONS: A LITERATURE REVIEW

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Abstract: This article, based on a review of scientific literature, highlights the advantages of bitumen emulsions over hot bitumen binders and hot-mix asphalt technologies. This review comparatively examines the production and application temperatures, energy consumption, and atmospheric emissions of toxic gases (CO_2, SO_2, volatile organic compounds, and polyaromatic hydrocarbons) for both technologies. The analysis indicates that bitumen emulsions, due to their application at low temperatures (20–60°C), can reduce energy consumption by 35–50%, carbon dioxide emissions by 40–60%, and sulfur dioxide emissions almost entirely (≈99.9%). Furthermore, low operating temperatures significantly reduce toxic emissions that affect the health of workers during the preparation and laying of road surfaces. The article also provides information on the main materials used in the production of bitumen emulsions - bitumen, water, emulsifiers and stabilizing additives.
Keywords: bitumen emulsion, hot asphalt, toxic gases, CO_2 emissions, energy efficiency, road construction materials

1. INTRODUCTION

As the volume of road transport infrastructure expands year after year, the demand for binding materials used in road construction is increasing significantly. Traditionally, this industry has relied on hot bitumen-based technologies, particularly Hot Mix Asphalt (HMA). However, HMA technology is characterized by high energy consumption due to its production and laying at temperatures ranging from 160-190°C. It is also associated with the emission of toxic substances into the atmosphere, such as carbon dioxide (CO_2), sulfur dioxide (SO_2), volatile organic compounds (VOCs), and polyaromatic hydrocarbons (PAHs) [9]. It has been repeatedly noted in scientific literature that these compounds negatively impact not only the environment but also the health of road construction workers [7].

Bitumen emulsions - a dispersed state of bitumen in an aqueous medium using a surfactant (emulsifier) - are proposed as an effective way to address the aforementioned problems. According to their chemical nature, bitumen emulsions are divided into anionic and cationic types, which allows for their selection based on compatibility with various mineral materials [1]. Due to their application at low temperatures, bitumen emulsions are classified as a 'cold technology' and are therefore considered a more environmentally friendly alternative to hot bitumen products.

The purpose of this article is to highlight the advantages of bitumen emulsions over hot bituminous binders, particularly hot-mix asphalt technology, based on an analysis of existing research, with a special focus on energy efficiency and the reduction of toxic gas emissions.

2. MATERIAL

Bitumen emulsions consist of several main components, each of which directly affects the stability and performance characteristics of the emulsion.

Bitumen is the main binding component of the emulsion, and petroleum bitumens with different penetration levels are used. Water serves as the dispersion medium and typically accounts for approximately 30–45% of the finished emulsion's composition [1].

Emulsifiers (surfactants) are the most important components that ensure the stability of the emulsion. According to their chemical nature, emulsifiers are divided into anionic and cationic types: anionic emulsifiers are typically produced by soaping fatty acids, derivatives of rosin, and lignin with sodium or potassium hydroxide, while cationic emulsifiers are primarily prepared based on fatty amines, polyamines, and imidazoline derivatives [1].

Additional components include acids that regulate the pH of the emulsion, electrolytes that increase stability (e.g., calcium chloride), and, if necessary, polymer modifiers [1]. In the production of bitumen emulsions, the colloid mill method or the high internal phase ratio (HIPR) method is primarily used, in which bitumen droplets are ground to a micron size in the aqueous phase [1]. Depending on the degree of stability, bitumen emulsions are divided into fast, medium, and slow-decomposing classes, which allows them to be adapted for various construction tasks (adhesive coating, cold mixtures, surface treatment, etc.) [1].

3. RESULTS AND DISCUSSION

3.1. Comparison of production and application temperatures

According to the literature analysis, asphalt mixtures are divided into the following categories depending on the production temperature: hot mix asphalt (HMA) - 160-190°C, warm mixed asphalt (WMA) - 110-140°C [2], half-warm mix asphalt - in the range of 70-95°C [3], and cold technologies based on bitumen emulsion are used at a temperature of 20-60°C [2]. It can be seen that the operating temperature of the bitumen emulsion is 100–150°C lower than that of the hot mix asphalt, as shown in Figure 1 below.

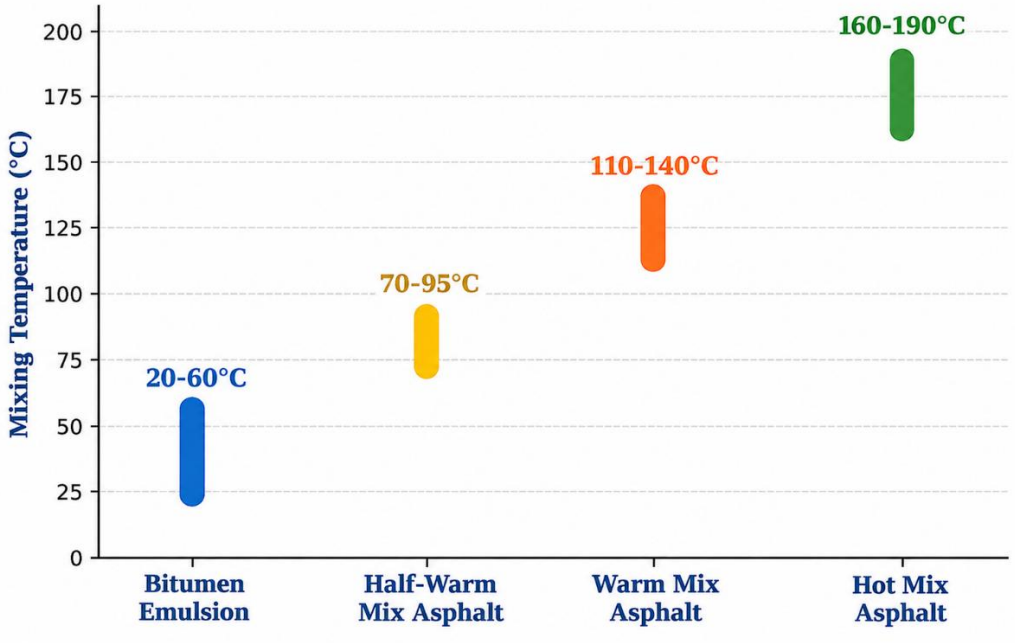


Figure 1. Comparison of operating temperatures for bitumen emulsion and hot bitumen technologies

3.2. Energy consumption

Low-temperature processing of bitumen emulsion leads to direct energy savings, as there is no need to heat the bitumen to high temperatures, and the viscosity of bitumen in the emulsion state is significantly lower than that of hot bitumen [1]. According to recent studies, cold mixing technologies (including those based on bitumen emulsion) allow for a 35-50% reduction in energy

consumption compared to hot asphalt [9]. Furthermore, it was found that reducing the production temperature by every 10°C saves approximately 1 liter of fuel per 1 ton of mixture and reduces carbon dioxide emissions by 1 kg [4, 5, 6].

3.3. Comparison of toxic gases and their impact on the atmosphere

It has been calculated that during the hot asphalt production process, an average of 53.6 kg of CO_2 emissions per 1 ton of mixture is accounted for [9]. According to the results of a study comparing hot and semi-warm asphalt technologies, reducing the production temperature to 60-100°C reduced CO_2 emissions by 58.5%, and SO_2 emissions almost completely by 99.9% [3]. ° Considering that bitumen emulsion is used at even lower temperatures (20-60°C), its potential for reducing toxic gas emissions is even higher; in general, it has been noted that cold mix technologies reduce emissions by 40-60% compared to hot asphalt [9].

It should be noted that volatile organic compounds (VOCs) and polyaromatic hydrocarbons (PAHs) formed during the production and laying of hot asphalt pose a serious risk to the respiratory tract of workers and can cause their cancer.

Table 1. Comparative analysis of bitumen emulsion and hot bitumen (hot asphalt) technologies

Indicator	Hot Bitumen / Hot Asphalt	Bitumen emulsion	Source
Production and application temperature	160-190°C	20-60°C	[1, 2]
Energy consumption	High (requires prolonged heating)	35-50% less	[1, 9]
CO_2 emissions	≈ 53.6 kg/ton (baseline indicator)	40-60% less	[3, 9]
CO_2 emissions	Relatively high	≈99.9% less (in low-temperature technology)	[3]
VOC and PAH emissions	High, poses a health risk to workers	Substantially low	[7]
Fire & Burn Risk	Upper	Low	[1]
Application season/temperature limit	Restricted (high outdoor temperature required)	Wide (even used in cold and humid conditions)	[1, 2, 8]

3.4. Other benefits and available limitations

Low-temperature processing of bitumen emulsion significantly reduces the risk of fire and burns, as well as makes its transportation and storage processes safer [1]. Furthermore, since bitumen emulsion can be used in cold and humid climates, its application period is much broader than that of hot asphalt [1, 2, 8].

At the same time, some limitations of bitumen emulsions are noted in the literature: in particular, the initial mechanical strength and viscosity are lower than that of hot asphalt, the drying

(decomposition) process takes longer, and the transportation of the emulsifier and water requires additional costs [1, 8]. Nevertheless, in recent years, research has been conducted to improve the early strength indicators of bitumen emulsions using polymer and mineral additives, which allows for a further expansion of its scope of application [8].

4. CONCLUSION

The results of the review analysis showed that bitumen emulsions have a number of significant advantages over hot bitumen binders and hot asphalt technology. Firstly, the operating temperature of the bitumen emulsion (20-60°C) is significantly lower than that of hot asphalt (160-190°C), which allows for a reduction in energy consumption by 35-50%. Secondly, and most importantly, low-temperature technologies based on bitumen emulsion significantly reduce the amount of toxic gases emitted into the atmosphere - CO_2 (up to 40-60%), SO_2 (up to ~99.9%), as well as volatile organic compounds and polyaromatic hydrocarbons, which is important for both the environment and the health of road construction workers. Thirdly, bitumen emulsion also surpasses hot bitumen products in terms of fire safety and the breadth of the application period.

At the same time, restrictions on the initial mechanical strength and drying time of the bitumen emulsion remain relevant areas for further research. In particular, obtaining bitumen emulsions based on petroleum bitumen-substituting binders obtained from gossypol resin, a waste of the oil and fat industry, is considered one of the promising research directions. This will allow for the rational use of waste and the reduction of its environmental impact.

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