



Water vapor passing through asphalt mixtures under different relative humidity differentials

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HIGHLIGHTS

- Designed experiments for Phase II water vapor diffusion under 8 RH differentials.
- Identified a linear relationship between RH differential and diffusion flux.
- Demonstrated that Phase II water vapor diffusion followed Fick's first law.
- Proved Phase II water vapor diffusivity independent of RH differential.
- Revealed much larger water vapor diffusivities in Phase II than those in Phase I.

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ABSTRACT

Water vapor diffusion in a newly constructed asphalt pavement consists of water vapor accumulating toward the asphalt layer (Phase I) and water vapor passing through the asphalt layer (Phase II). The water vapor diffusion in Phase I under different relative humidity (RH) differentials has been investigated and can be found elsewhere in literature. However, it remains unclear whether the RH differential would affect the diffusion flux and diffusivity of the water vapor passing through the asphalt layer in Phase II. This study investigated the Phase II water vapor diffusion in asphalt mixtures under a variety of RH differentials. Experimental setups were designed and assembled for the Phase II water vapor diffusion experiments. Distilled water, saturated $MgCl_2$ solution, saturated NaBr solution, and saturated KCl solution were stored in containers to provide the RH level of 100%, 36.5%, 62%, and 87%, respectively, under the asphalt mixture specimens that were sealed on top of these containers. The experimental setups were conditioned in environmental chambers to maintain a constant test temperature of 20 ± 0.5 °C and specific RH levels to establish the RH differentials between the air above and below the asphalt mixture specimen. The weight loss of the experimental setup was monitored three times a day using a high-precision scale.

A linear relationship was identified between the RH differential and the diffusion flux of the water vapor in Phase II diffusion, which demonstrated that the Phase II water vapor diffusion followed Fick's first law of diffusion. The calculated water vapor diffusivities in Phase II diffusion were significantly larger than those in Phase I diffusion and were independent of the variation of the RH differential between the air above and below the asphalt mixture specimen.

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1. Introduction

Water vapor diffusion in an asphalt pavement is an important contributor to the moisture damage of the asphalt layer [1–5]. A major driving force for the water vapor diffusion is the relative humidity (RH) differential existing between the atmosphere above

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the asphalt layer and the subgrade below the pavement structure [6,7]. The RH in air consistently changes with the weather, altitude, and other factors. In contrast, the subgrade serves as a reservoir with an RH always above 98%, which is determined using the Kelvin equation based on the fact that the total suction of the subgrade varies from 2 to 4.5 pF [8–14].

For a newly constructed asphalt pavement with an RH of approximately 0, the water vapor diffusion in the asphalt layer should consist of two major phases:

1. Phase I: water vapor accumulates toward the asphalt layer from both air and the subgrade until equilibrium, which is driven by the RH differential between air and the asphalt layer as well as the RH differential between the subgrade and the asphalt layer, as illustrated in Fig. 1; and
2. Phase II: water vapor passes through the asphalt layer driven by the RH differential between air and the subgrade, as exhibited in Fig. 2.

During these two phases, water molecules are brought into the asphalt layer and transport inside the asphalt mixtures along the easiest path (such as the air voids). Since aggregates and fillers are more prone to water molecules than asphalt binders, these water molecules inside the asphalt mixtures act as debonding agents for the aggregate-binder interface, which leads to moisture damage in the asphalt mixtures. Furthermore, when the pavement temperature drops at night, water molecules brought into the asphalt layers by water vapor may condense into liquid water, which will then develop pore water pressure under traffic loading. The cyclic pore water pressure will further facilitate stripping of the asphalt mixtures, which is the separation of the asphalt film from the aggregate or filler surfaces. These facts indicate that it is very difficult to avoid moisture damage, even for asphalt layers impermeable to liquid water.

In a previous study, the researchers investigated the water vapor diffusion in Phase I under different RH differentials and quantified the effect of the RH differential on Phase I diffusion [15]. Linear relationships were identified between the RH differential and the water vapor diffusivity in Phase I under 1 atmosphere.

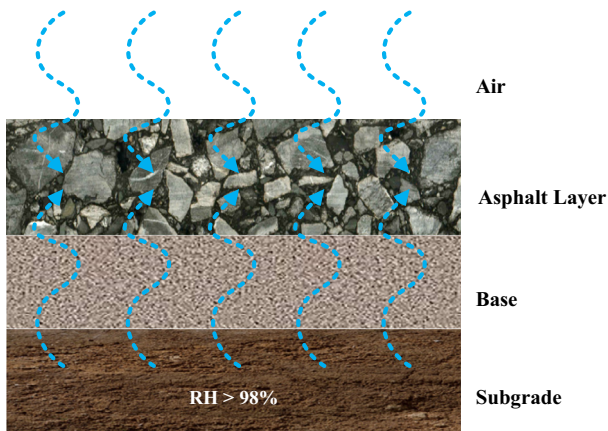


Fig. 1. Phase I of water vapor diffusion in a newly constructed asphalt pavement.

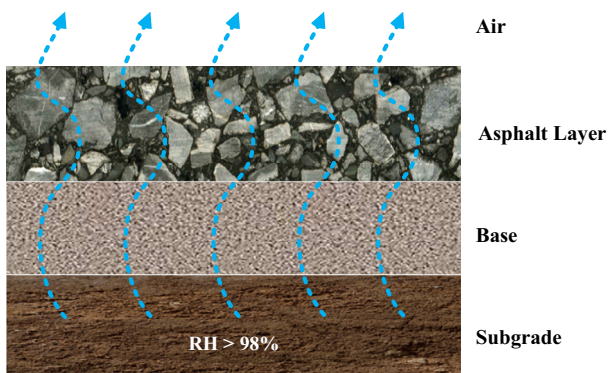


Fig. 2. Phase II of water vapor diffusion in a newly constructed asphalt pavement.

However, the water vapor diffusion in Phase II under different RH differentials has not been studied; it remains unclear whether a change in the RH differential would also result in variation of the diffusion flux and diffusivity of the water vapor passing through the asphalt layer.

To address this research need, this study investigated the Phase II water vapor diffusion under different RH differentials. The next section describes the design of the Phase II water vapor diffusion experiments as well as the precise control of the RH above and below the asphalt mixture specimen. The following section details the step-by-step procedure of the Phase II water vapor diffusion tests under a total of eight different RH differentials. The subsequent section presents the analysis of the test data and the determination of the diffusion flux and diffusivity under each RH differential. The final section summarizes the major findings of this investigation.

2. Experimental design of Phase II water vapor diffusion

2.1. Design of experimental setup

An experimental setup was designed according to the standard method specified in ASTM E96 [16], as illustrated in Fig. 3. In this experimental setup, an asphalt mixture specimen was sealed on top of a container storing a specific solution. The RH in the enclosed container was controlled by the solution and was designated as RH_1 . The entire setup was then placed in an environmental chamber that provided a specific RH (specified as RH_2). Therefore, an RH differential was established between the air above and below the asphalt mixture specimen. This RH differential could be varied by selecting different solutions and/or changing the RH in the environmental chamber.

2.2. Control of RH_1 : Selection of saturated solutions

To achieve a series of levels of RH_1 in the container, four solutions were selected. The first solution was distilled water that was able to provide a constant RH_1 of 100%. The other three solutions were prepared using $MgCl_2$, NaBr, and KCl, which were supposed to provide RH levels of around 33%, 59%, and 85%, respectively [17]. These chemicals, with 99% purity, were used to make corresponding saturated solutions. A monitoring setup was then assembled to determine the actual RH levels provided by these saturated solutions.

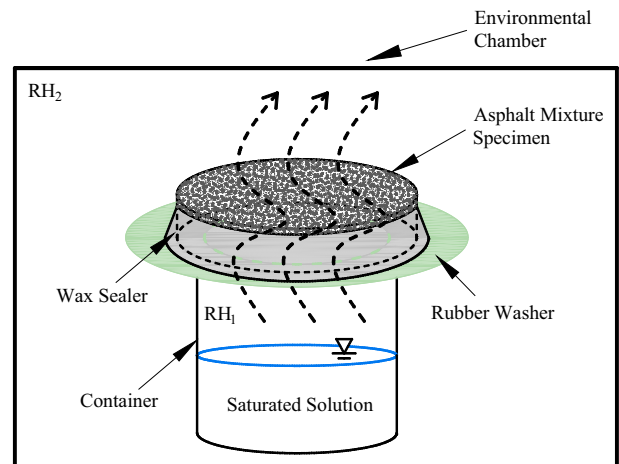


Fig. 3. Illustration of experimental setup.

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