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Original Research Paper

Investigation into the ship motion induced moisture migration during seaborne coal transport

Wei Chen *, Jian Chen, Kenneth Williams, Craig Wheeler

Centre for Bulk Solids and Particulate Technologies, The University of Newcastle, Callaghan 2308, Australia

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ABSTRACT

The inherent moisture in a coal cargo constantly migrates under the dynamic ship motion during maritime transport. The moisture often builds up at the bottom of the cargo. The accumulated water, if not removed sufficiently by the bilge well, can cause safety concerns during a voyage and difficulties during cargo unloading. The study presented in this paper aims to develop a program to investigate the moisture migration within coal cargoes in order to assess and eliminate shipping risks. The moisture migration phenomenon is initially modelled by adopting the classic infiltration theory, and considering the ship motions experienced by bulk carriers. An experimental method is developed to empirically characterise the moisture migration of a coal sample under simulated shipping dynamics. A predictive model is also developed to estimate the total moisture migration in a full size cargo by properly scaling up the experimental results. The model was validated by bilge well log collected from actual coal shipping voyages from Australia to international destinations.

1. Introduction

The inherent moisture within bulk material is not static during its storage, handing and transport. In fact, there is a propensity under dynamic motions for moisture to be liberated from the particle assembly and becomes mobile [1,2]. This is particularly evident during prolonged maritime transport processes. In many cases, the migrated moisture tends to accumulate at the base of a cargo hold under the dynamic ship motion. Fig. 1 demonstrates the excessive moisture build-up from moisture migration after shipping voyages.

There are two major hazards associated with moisture migration during shipping. Firstly, the formation of a wet base during the voyage can cause vessel instability and inherent safety concerns [3,4]. Under the International Maritime Solids Bulk Cargo Code, it is emphasized that the likelihood of formation of a wet base must be declared prior to loading onto a vessel [5]. A wet base in a coal cargo may have considerably less yield strength, and cargo shift may be triggered when significant rolling of the vessel occurs during shipping [6]. Secondly, the wet base can cause handling difficulties when discharging with a grab. The excessive water at the base transforms the solids material into a fluid state, which interrupts the unloading using the grab. Although the bilge pump is often fitted under the cargo body to enable the removal of the water drained to the base, it is critical to estimate the total amount of drained water to ensure the pumping operation is effective, in which an understanding of the moisture migration is required.

The moisture migration mechanism is closely related to the intrinsic properties of the material [7]. The infiltration theories [8–11] are often utilised to model the macroscopic moisture movement in unsaturated material (shown in Fig. 2(a)), such as soils and minerals. Nevertheless, these models are static state based without considering the influence of applied dynamic motions. Under external motions, the hydraulic conductivity of the unsaturated material will alter and it is difficult to accurately quantify based on the current model development. Alternatively, from a microscopic view, the dynamic response of liquid bridges and capillary bonds in-between particles (shown in Fig. 2(b)) under the influence of the external accelerations determine the moisture movement within a sample [12]. However, it is still challenging to scale up the microscopic model to describe the macroscopic moisture migration due to the size and shape of the real granular particles. Therefore, an experimental approach remains a more direct and robust method for investigating the moisture migration mechanism.

Based on the forgoing comments, this research aims to develop an experimental program to characterise the moisture migration in

* Corresponding author.
E-mail addresses: wchen3@uon.edu.au, w.chentbs@gmail.com (W. Chen).

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Fig. 1. Migrated water builds up at the base of the cargo hold after a shipping journey.

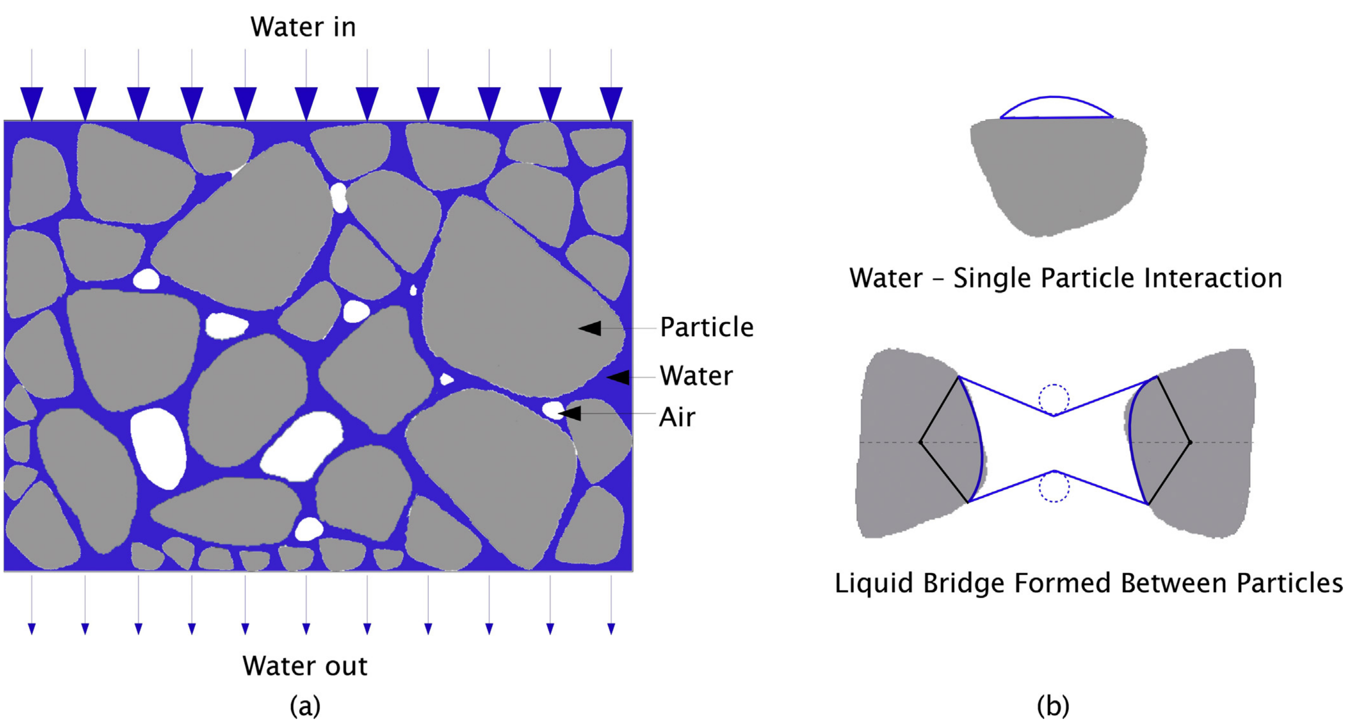

Fig. 2. Macroscopic moisture migration in bulk solids (left) and microscopic moisture-particle interactions (right).

coal materials under ship motions. The obtained moisture migration characteristics enable accurate assessment of the water draining behaviour when bulk carriers transport coals cargoes in practice.

2. Moisture migration modelling – an infiltration theory

The process of the moisture migrating within a partially saturated bulk solids may be described using the classic infiltration theory [13,14]. As shown in Fig. 3, considering an element within the bulk material, the speed of the moisture flowing through the element is defined as a moisture migration rate (infiltration rate). This moisture migration rate is depending on the following material parameters:

- The moisture content of the material – θ_i,
- The hydraulic head above the element – h_0,
- The hydraulic conductivity of the material at such moisture content – $K(\theta_i)$,
- Particle and material properties such as the particle density, particle size distribution, tortuosity and porosity.

The moisture migration rate of the element is predominantly determined by its hydraulic conductivity. The hydraulic conductivity of the material element is defined as [15],

$$K = k\frac{\rho_w g}{\mu} \tag{1}$$

where

- k is the permeability of the material,