論文の内容の要旨

Abstract

Experimental study on the effect of the air - water interface created at wall surface on water flow in narrow gaps.

(壁面に形成された気液界面が狭小空間中の水の流れに与える影響に関する実験的検討)

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Water flow in narrow gaps characterized by porous surfaces has been observed to breed air bubbles that stay strongly fixed on the surface of water flow. Water flow in porous media or between parallel plates is well understood, through equations and simulations. However, there have been some limitations to this understanding, based on the findings of this research and some previous research. Flow between parallel plates or porous media attempts to cater to the varied material characteristics such as material roughness by incorporating a material factor. In reality, and especially for narrow gaps of water flow, the surface over which water flows could be modified due to the interaction between water and the surface over which it flows. Therefore, water seizes to flow directly over the surface in such a case. By this research, the flow surface could be enveloped by air bubbles, and the properties of the surface would then become completely different from those previously envisaged. A new surface, whose overall area could now be more than that of the primary material, now, determines the properties of flow.

Unlike in closed interfaces, a direct water flow observation technique has been adopted to simulate actual water flow in narrow gaps. A transparent glass panel bound to a study material, while leaving a narrow gap between the two, is used as a set-up to

observe water flow directly. This set-up is connected to a continuous water supply container, and resembles the set-up of the water pass test for crack self-healing concrete. With this kind of specimen set-up, and other aids such as good lighting, and video recording, a lot of data can be collected about water flow. The flow rate can be measured, and visual observations made.

In self – healing concrete testing, this observed effect of air bubbles creation and growth could be mistaken for actual self-healing products deposition within crack interstices. This is because it mimics the actual water flow reduction effect due other well-known mechanisms of self – healing concrete. In this research, the contributory effect of air bubbles in the initials stages of water supply during self – healing testing concrete has been clarified. The mechanisms of air bubble growth too have been investigated. The effect of water supersaturation, presence of nucleation points on the water flow surface, plus continuous water flow are necessary conditions for air bubble growth. Minus any of these, bubble growth becomes stagnated. These mechanisms however, are only of an accelerating role for air exchange at the air – water interface. Different materials possess different surface characteristics and thus different potential for the air bubble effects and water flow, when bound in narrow gaps of water flow. In this research, concrete, pumice, wood, glass, Styrofoam, aluminium, plastics have been investigated and compared for their ability to cause air bubbles contribute to water flow reduction mechanisms when bound in narrow gaps.

Water flow over a solid surface experiences drag resistance due to the non-slip boundary condition. Micro air bubbles have been used in several applications to reduce surface friction, for example in ship propulsion. In the cases where this is utilized, the air bubbles are not fixed on any surface; they are released near the surface that experiences drag. In this research however, consideration is made for micro and nano air bubbles that are created and fixed at the surface of water flow within narrow gaps. Here, the bubbles do not serve to reduce flow drag (from the results and observations of this research). Once the air bubbles are hinged, or fixed on a surface of water flow, their effect becomes quite apparent. In narrow interfaces, the water flow braking effect of surface anchored micro and nano air bubbles is well pronounced based on the findings of this research. It has been found that this effect is capable of reducing water flows by an average of about 15%. If the water is air – rich, and the micro and nano bubbles have been formed, they have the potential to grow into large millimeter size air cavities. These would then further block water flow and contribute to further water flow reduction. At this point, flow could be constricted by more than 60% depending on the ambient conditions, gap size, and other flow parameters.

The effect of large air bubbles blocking water flow was largely understood in related research, and initially thought to be the main cause of water flow reduction. However, with continuous observations, and within smaller time intervals of water flow measurements, it was observed that water flow reduction continues to take place even in the absence of large millimeter size air bubbles. The water flow reduction in this case is due to micro and nano air bubbles that are fixed or anchored at the wall surface of water flow as could be observed by a microscope. The mechanism of water flow reduction by these surface anchored micro and nano air bubbles is by water flow braking by the fixed air – water interface. In this research, a hypothesis about the nature of the water surface is proposed. Although current knowledge of the air – water surface is largely understood in terms of surface tension (surface energy), a microscopic clarification of the behaviour of the air – water interface is necessary. It is further hypothesized in this research that water molecules at the air – water interface adopt a fixed arrangement in which molecular rotation is restrained. This fixed and structured molecular layer interacts with both the freely flowing bulk water molecules on one side, and the freely moving air molecules on the opposite side. The zone of influence of this restrained water layer gradually extends only into the bulk liquid. In this research, this fixed molecular layer plays a role in dampening water flow in narrow channels. Away from the interface and into the bulk, water molecular rotation is gradually allowed, and flow (rotation) speed becomes faster. In relatively large channels, the effect of this mechanism is almost negligible, but cannot be underlooked in smaller interfaces.

In order to strengthen this theory, an experimental approach has been adopted still utilizing the visual observation technique. In this experiment, an air – water interface is created, in a relatively narrow gap (about 2 – 3 mm), and observations are made at this interface. Unlike most water interfacial research, where a static liquid layer is studied, in this study, the interface created between air and moving water is studied to reflect the perspective of this research. Air is trapped in a bubble within a narrow gap, creating an air phase over which water continuously flows. The vibration of the interface; dampening of a spinning floatable sphere connected to an air bubble with the flow path; persistent adsorption and retention of luminescent molecules at the interface despite continuous water flow (only observable in UV-light); and the conveyance of luminescent molecules by rising air bubbles, all help to reinforce the said hypothesis, as observed in this experimental approach. With this understanding and hypothesis, several of the dominant mechanisms or observed phenomena involving water flow through narrow gaps could be explained.

The nature of the air – water interface is still complicated, and several researchers are attempting to better understand its behaviour in order to find areas of application and also to propel science forward. In concrete technology for example, where water permeation through the dense micro pore structure determines material durability, understanding these water flow mechanisms is important in finding lasting solutions for our infrastructure. It is hoped that this research could help shed more light on several water ingress related mechanisms at a smaller scale of focus.