6. Школяр С. П., Новописьменний С. А. Створення центру інтелектуальної власності в рамках Стратегії економічного розвитку територіальної громади. Управління навчально-виховним процесом нової української школи в контексті національно-патріотичного виховання молоді: матеріали Всеукр. наук.-практ. конф. молодих науковців (учнів, студентів, магістрантів, аспірантів) (6 квітня 2021 р., м. Полтава) / за заг. ред. М. В. Гриньової ; Полтав. нац. пед. ун-т імені В.Г. Короленка. Полтава : ПП Астрая, 2021. С. 258–259.

CAMPHOR BOAT TRANSPORTS LIQUID MARBLE

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1 Introduction.

Autonomous motion of solid and liquid objects, called also self-propelling, driven by various physico-chemical (mainly interfacial) phenomena attracted considerable attention from researchers in the last decade (Pimienta and Antoine, 2014, Abbott and Velev 2016). A self-propelling particle moves on its own by converting energy from the environment (e.g., chemical, electrical, thermal) into mechanical motion with respect to the surrounding fluid or solid media (Bico and Quere, 2002, Sharma et al. 2012, Ismagilov et al. 2012, Kühn et al. 2015)

Various mechanisms of self-propelling have been introduced, including the use of gradient surfaces (Daniel et al. 2001, Daniel et al. 2004, Zheng et al. 2008); involving hot and cold Leidenfrost effects (Linke et al. 2006, Lagubeau et al. 2011, Agapov et al. 2014a, Agapov et al. 2014b, Kruse et al. 2015, Li et al. 2016); soluto- and thermo-capillary Marangoni flows (Paxton et al. 2006, Chen et al. 2009, Jin et al. 2012, Zhao and Pumera 2014, Ban and Nakata 2015, Bormashenko et al. 2015, Ooi et al. 2015, and exploiting micro- and nano-structured surfaces (Lagubeau et al. 2011, Kruse et al. 2015, Li et a. 2016).

The interest in self-propelling systems arises from numerous fundamental problems and applications, including guiding of self-assembly processes (Ismagilov et al. 2012, Mendelson et al. 2000), understanding mechanisms of the motion of bacteria and other microswimmers (Elgeti et al. 2015, Maass et al. 2016), lab-on-chip systems (Zhao and Pumera, 2014) drug delivery and microsurgery (Ghosh and Fischer, 2009).

One of the most fascinating self-propelled objects is a camphor boat (Kohira et al. 2001, Nakata and Matsuo, 2005, Nakata et al. 2014, Suematsu et al. 2014). Our paper reports towing of a floating liquid marble by a camphor boat. Liquid marble represent a kind of non-coalescence droplet, exposed to the intensive research recently (Derjaguin and Prokhorov, 1993, Neitzel and Dell'Aversana 2002) .

2 Experimental Procedures.

2.1. Manufacturing of liquid marbles

Two kinds of liquid marbles coated with lycopodium and fumed fluorosilica powder were prepared. Lycopodium (the average diameter of particles was about 30 μm) was supplied by Fluka. The average diameter of particles, specified above, was established with SEM imaging, carried out with high resolution SEM (JSM-6510 LV). Distilled water (with the electric conductance of 0.6 mS) was used for manufacturing the lycopodium coated liquid marbles.

The primary diameter of the fumed fluorosilica particles is 20-30 nm and they originate from hydrophilic silica after reaction with tridecafluoro-1,1,1,2-tetrahydrooctyltrimethoxysilane. The residual silanol content on their surfaces is 50% and the fluorine content is 10.9% (see Binks and Tyowua, 2013).

Marbles coated by lycopodium were filled with bi-distilled water (resistivity 2 MΩ cm as measured with LRC-meter Motech MT 4090). Marbles coated by fumed fluorosilica powder were filled by a 70 vol.% aqueous solution of ethanol, supplied by Bio-Lab Ltd, Liquid marbles were prepared according to the protocol described in detail in our previous papers (Bormashenko et al. 2008, Bormashenko et al. 2012).

2.2. Imaging of the self-propulsion

The motion of the marbles driven by camphor particles was registered by the epy-video imaging using a Therm-App infrared camera. After capturing the video, the movie was split into separate frames by the Video to JPG converter.

3 Results and discussion.

Consider first the behavior of liquid marbles coated by lycopodium, filled with water driven by camphor boats. Liquid marbles, shown in Fig. 2 are non-stick droplets encapsulated with micro- or nano-scaled solid particles. Since liquid marbles were introduced in the pioneering works of Quèrè et al. (Aussillous and Quéré, 2001, Aussillous and Quéré, 2006), they have been exposed to intensive theoretical and experimental research (McHale et al 2009, Tian et al 2010, Dandan and Erbil 2009). Actuation and micro-transport of liquid marbles by various stimuli (pH, UV and IR) were reported (Dupin et al 2009, Nakai et al 2013a, Nakai et al 2013b, Paven et al 2016). It was shown that liquid marbles remain stable for dozens of minutes when placed on liquid/air interfaces (Bormashenko et al. 2009a). Marbles do not coalesce with the supporting liquid due to the air layer separating a marble from water, similarly to the Leidenfrost droplets situation (Bormashenko et al. 2009b, Linke et al. 2006).

The typical graph of the temporal dependence of the velocity of the center mass of a liquid marble transported by a camphor particle

Now, consider the mechanism of the self-propulsion in detail. The typical time dependence of the velocity of the center of mass of the boat is depicted in Fig. 3. A maximal velocity of the center mass of the boat was registered as high as $\left|\vec{v}_{cm}^{\max}\right| = 0.1\frac{m}{s}$. The characteristic time of the boat motion was *ca*. 5s. The equation describing the motion of the boat is:

$$m\frac{d\bar{v}_{cm}}{dt} = F_{fr} + \alpha L^2 \nabla\gamma = -\chi L\eta\vec{v}_{cm} + \alpha L^2 \nabla\gamma \quad , \tag{1}$$

where *m*, *L* and $\vec{v}_{cm}$ are the mass, characteristic dimension and velocity of the center mass of the boat correspondingly, α and χ are the dimensionless coefficients depending on its shape, γ and η are the surface tension and the viscosity of the supporting liquid correspondingly [31].

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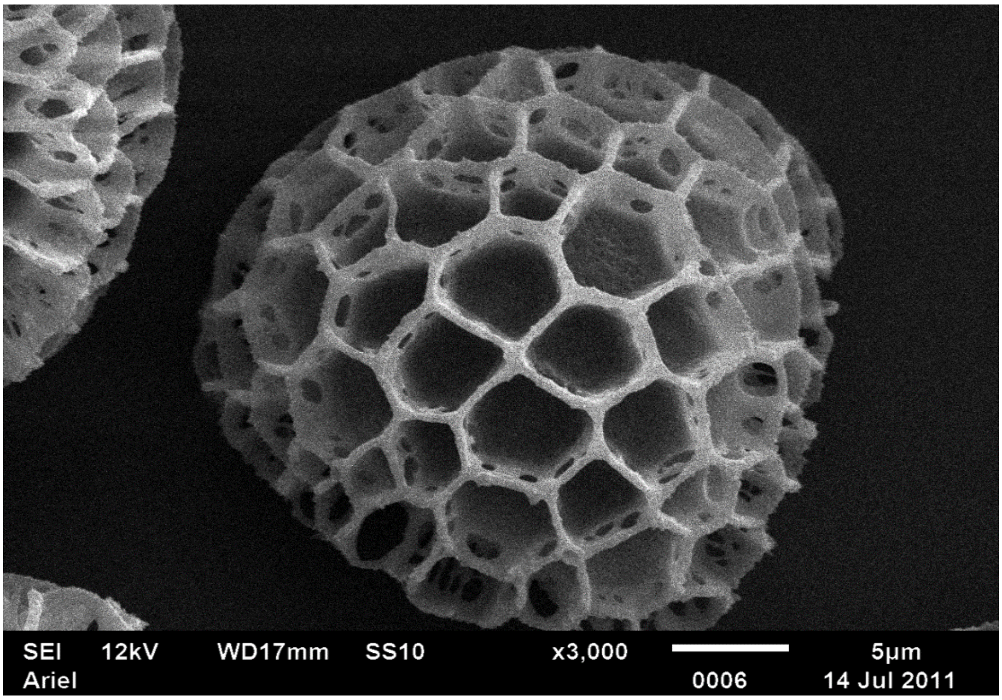

Figure 1. SEM image of the lycopodium particle 5µm.

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