The dynamics of non-contact and non-reciprocal interacting Propylene Glycol (PG)-Water binary droplet

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Motivation:

Once the binary droplets of Propylene Glycol (PG) and water mixtures are deposited on a wetting surface, the droplets exhibit interesting chaotic collective motion through “unknown” interaction even if they are not in contact. A series of experiments are conducted to probe how the pair of PG-water droplets interact.

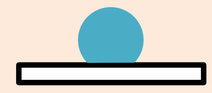
Background:

Spreading parameter (S),
a parameter describes the degree of wettability

$$S \equiv \gamma_{SV} - (\gamma_{SL} + \gamma_{LV})$$

γ: surface tension
V: vapor L: liquid S: solid

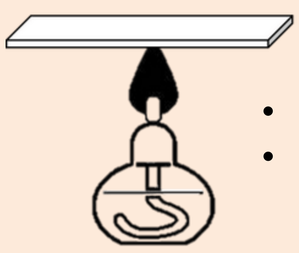
$S > 0$
Fully wetted



$S < 0$
Partially wetted

Experimental setup and method

Substrate surface treatment:

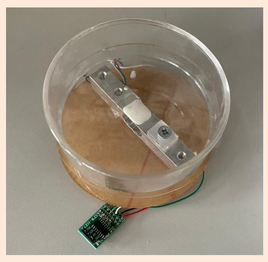


- Slide glass
- Alcohol burner

PG-water solution:

- DI water
- Propylene glycol (Guan Yi)
- Colors dye < 0.1% (優奇食品)

Evaporation rate (ε):

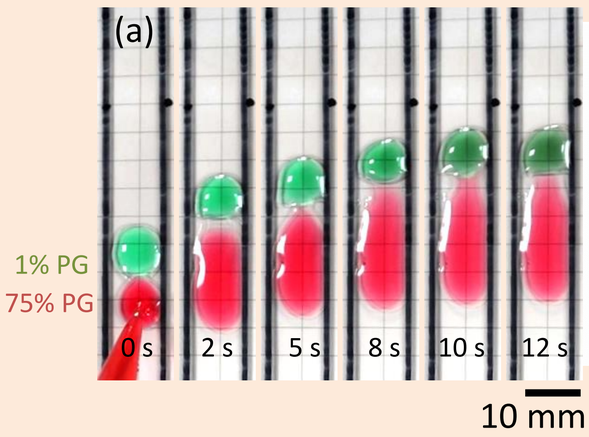


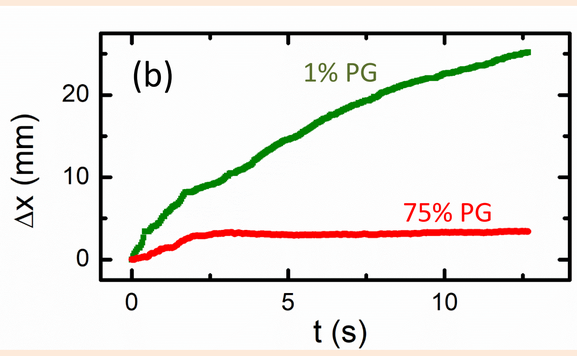
- PG solution
- 100 g load cell
- Petri dish
- HX711 ADC

PG fraction (w.t. %)	1%	25%	50%	75%
Evaporation rate, ε [$ng/(s \cdot mm^2)$]	19.3	19.2	6.1	~1.9

Results and discussions:

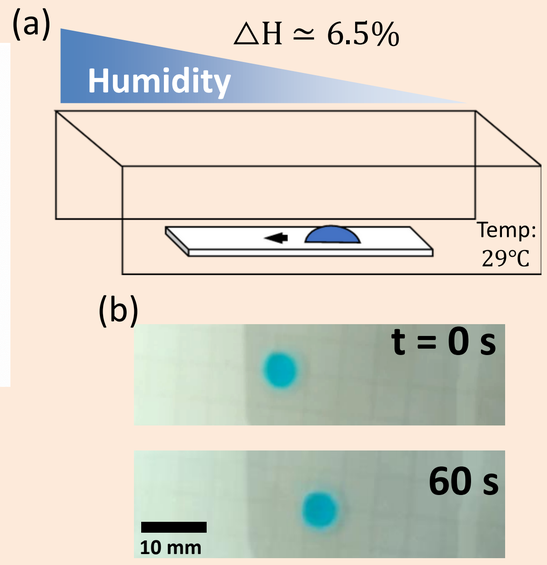
The motion of a pair of interacting droplets:

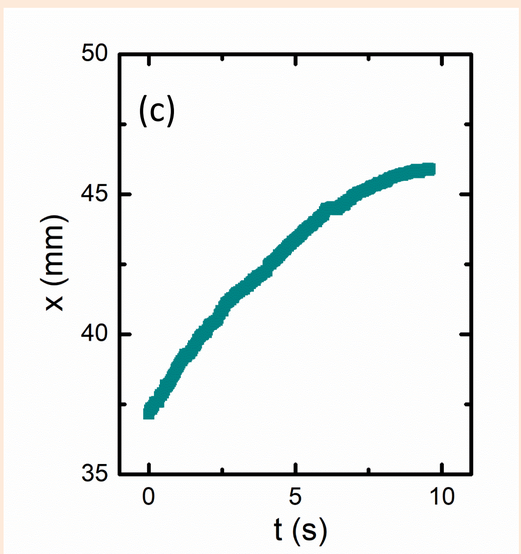




(a) Time series of spontaneous droplet motions of a pair of non-contact PG-water droplets, 1% (green) and 75% (red). They move in the same direction, revealing that their interaction is non-reciprocal.
(b) The quantitative evolution of droplet displacements.

Interaction through evaporation?

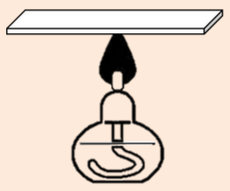




(a) A tunnel with a humidity gradient (6.5% R.H. at 29 ^{o}C) is constructed to test how the evaporation difference affects the droplet motion.
(b) The snapshots to evidence induced droplet motion.
(c) The quantitative evolution of droplet position of a 25% PG fraction droplet. This experiment evidences that the droplet motion is neighboring droplet.

Factors affecting droplets interaction:

(a) Substrate treatment



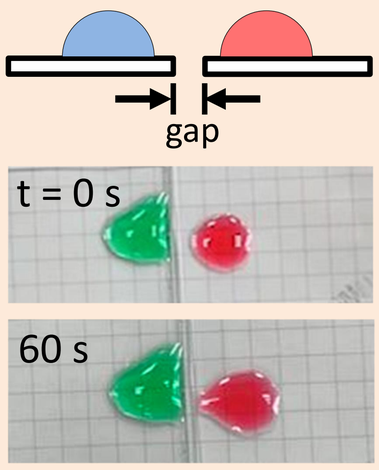
Burning enhanced substrate wettability is necessary.

(b) Post-treatment duration

last~ 

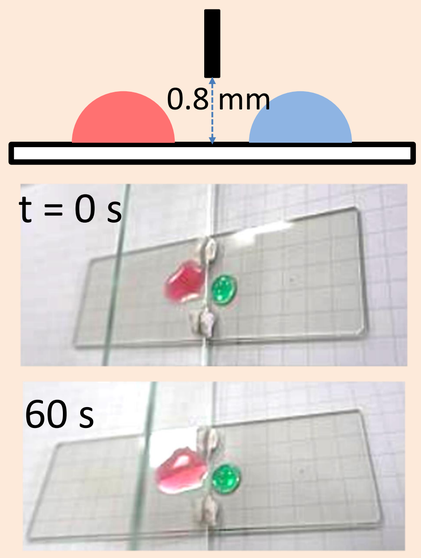
The surface treatment can last over 15 min.

(c) Separated substrate



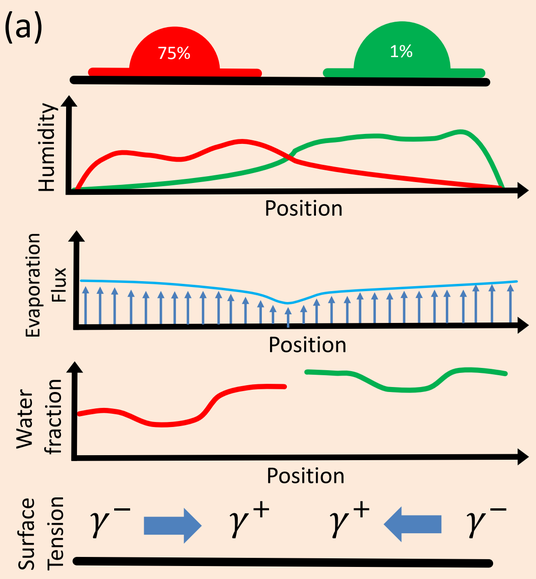
The droplets still interact even the substrate is separated.

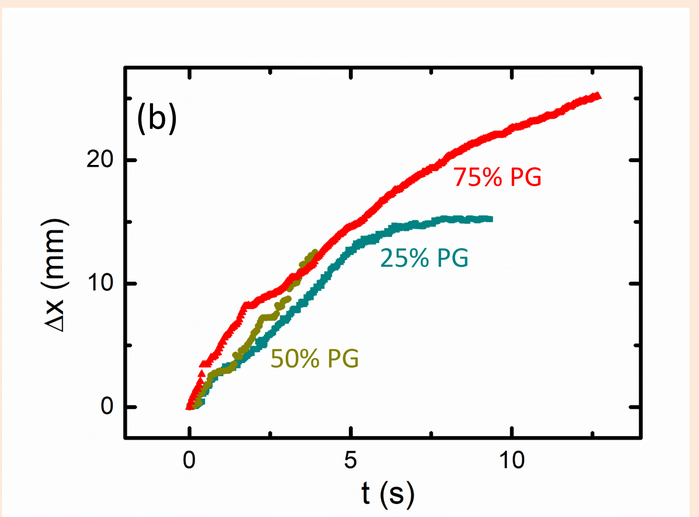
(d) Partition



The droplets no longer interact once shielded by a partition (with a 0.8 mm raised height).

The non-reciprocal interaction of different PG solutions





(a) The scenario of droplet interaction. The (water) evaporation generates a humidity gradient suppressing the evaporation of the neighboring droplet. The uneven evaporation leads concentration difference, then the corresponding surface tension (γ) difference drives the droplet approaching each other.
(b) The displacement of the 1% PG droplet pushed by 75%, 50%, 25% PG droplet.

Conclusion:

- PG-Water droplets on wetting surface exhibits fantastic behaviors
- Their interaction is non-contact and non-reciprocal
- The droplet interaction is mainly contributed by the surface tension difference induced by mutually affected evaporation difference

Reference: [1] N. J. Cira, A. Benusiglio & M. Prakash, Nature 519, p446 (2015)
[2] P.-G. de Gennes, Capillarity and Wetting Phenomena, Springer