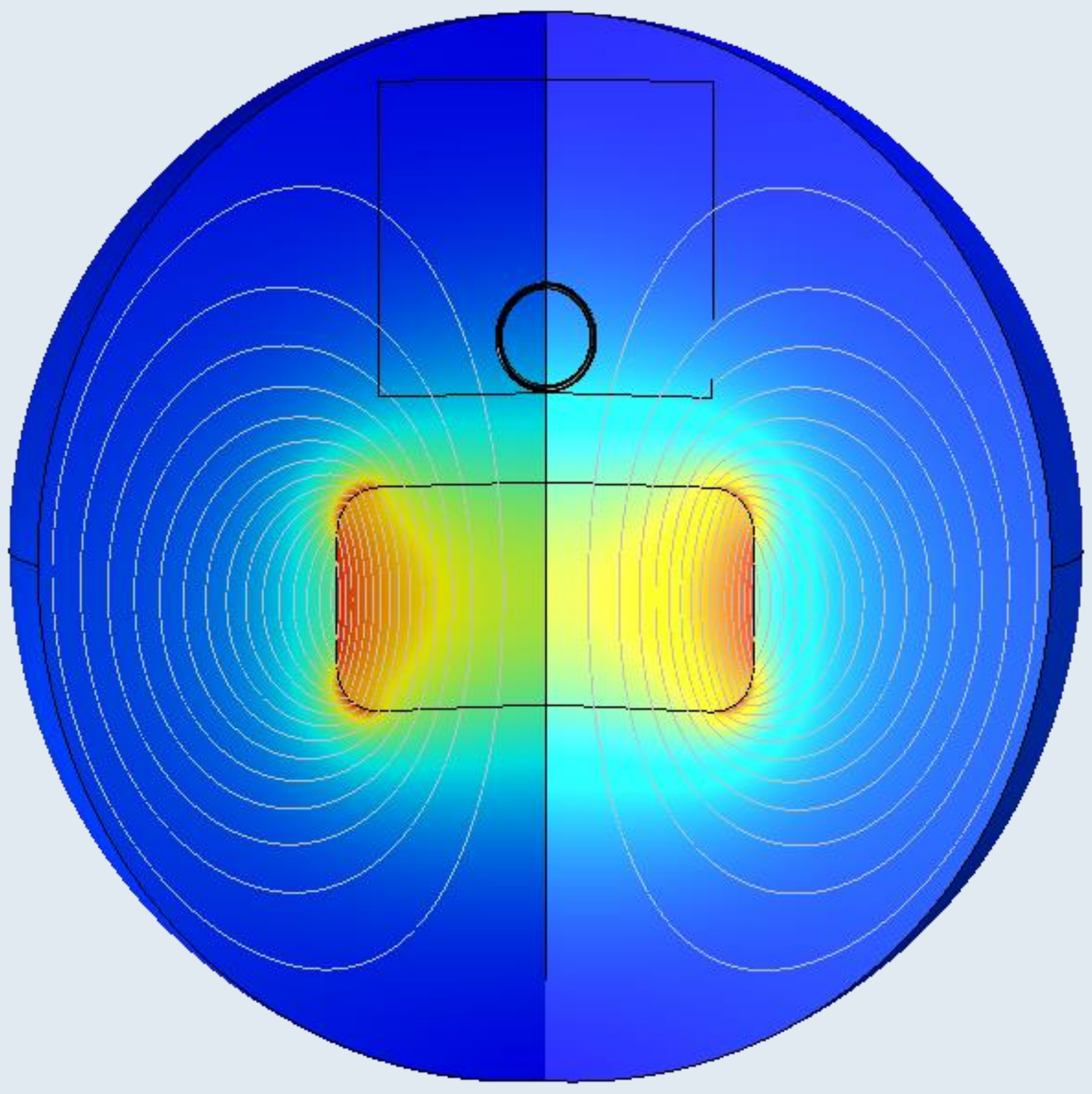

Effect of a magnetic field on the impact dynamics of ferrofluid droplets

This work investigates the influence of a magnetic field on the thermal transport characteristics of impinging ferrofluid droplets.

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Abstract

This study explores the impact of a magnetic field on ferrofluid droplets hitting a heated solid substrate. Ferrofluids contain magnetic nanoparticles in a nonmagnetic liquid, and the magnetic field influences their behavior. It increases the spreading diameter and contact time of the droplet, improving overall heat transfer. These effects can be controlled by adjusting the magnetic force. COMSOL Multiphysics has been used to numerically model the multiphase flow phenomena involving magnetic field, interface tracking using phase field model, fluid flow and heat transfer modules. The findings of this study offer insights into the manipulation of ferrofluid droplets in external force fields, with potential applications in various industries such as electronics, cooling systems, and microfluidic devices. By harnessing magnetic forces, it becomes possible to enhance heat transfer efficiency and optimize fluid dynamics, opening up new avenues for innovation and improved performance in a range of engineering applications.

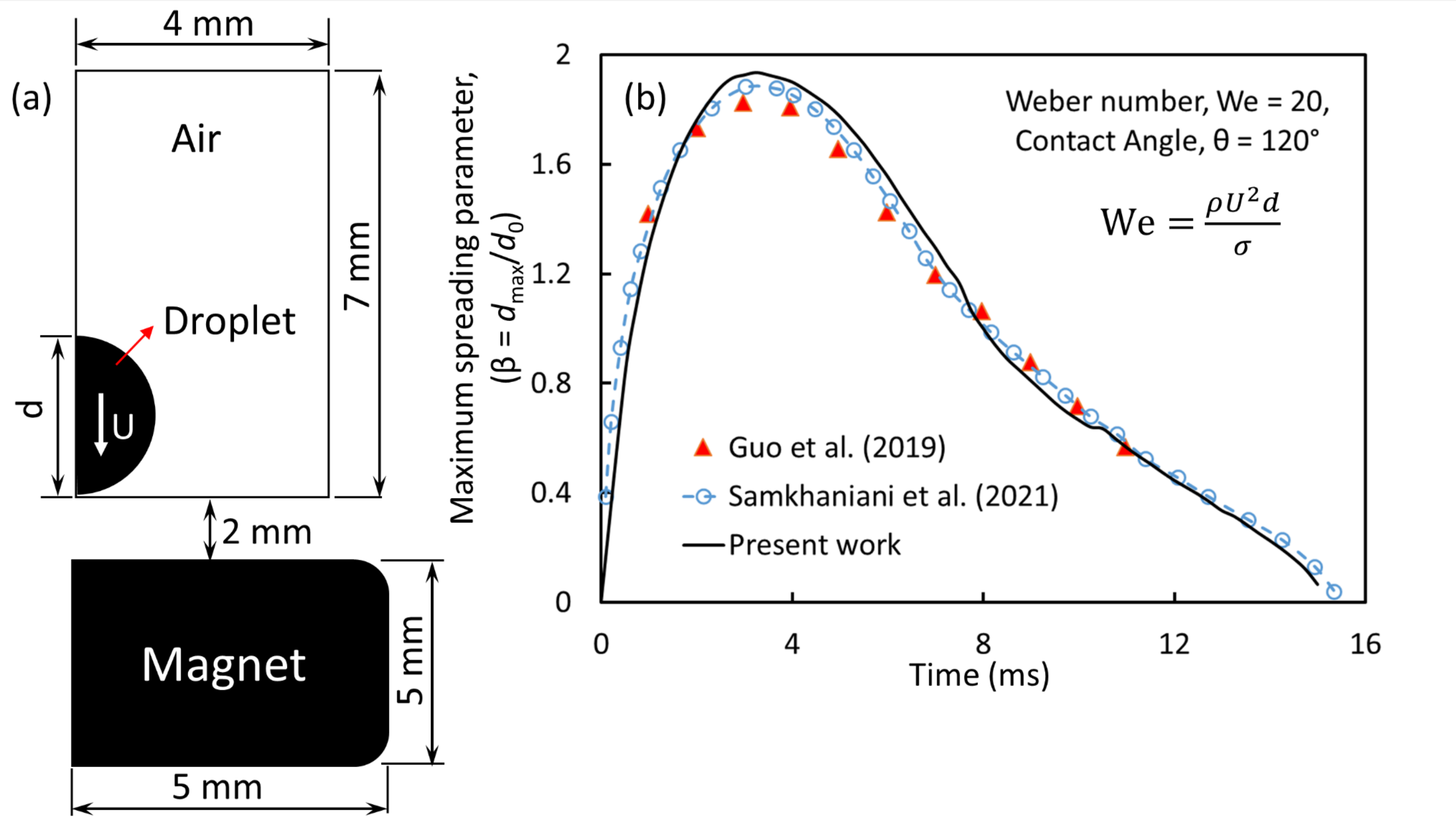

Figure 1: (a) Schematic of the simulation setup with relevant dimensions (magnet and droplet are shown) (b) Validation of present work with numerical and experimental results of Samkhaniani el. al. (2021) and Guo et al. (2019), respectively, for maximum spread diameter for a water droplet in no magnetic field case of shown parameters.

Methodology

Figure 1(a) shows the schematic of the simulation setup consisting of a droplet, air and magnet domains. Simulations are conducted to model the effect of a magnetic field on impinging ferrofluid droplets using the following modules and submodules of COMSOL Multiphysics:

AC/DC (Magnetic Field physics): To simulate an external magnetic field created by a cylindrical permanent magnet (NdFeB). Fluid flow, Phase field and Heat transfer modules: To simulate the interfacial evolution of impinging ferrofluid droplets and their heat transfer interactions with the heated substrate in a magnetic field.

Triangular mesh elements are used with a maximum element size of 0.01×Drop diameter, as per recommendations of various studies [1]. Simulation results of present work for water droplets without magnetic field are validated against numerical and experimental results of Samkhaniani el. al. (2021) and Guo et al. (2019), respectively, and they are in excellent agreement, as seen in Figure 1(b).

Results

Validation of the present work is shown in Figure 1(b). The magnetic field induces an attractive magnetic force in ferrofluid droplets. This force suppresses the bounce of droplets, a commonly occurring phenomenon in the case of hydrophobic and superhydrophobic substrates having contact angles > 90°.

As seen in the comparative Figures 2(a) and (b), and plots of 2(c), the magnetic field prevents the bounce of ferrofluid droplets, which is observed in no field case for a contact angle of 120°. It also increases maximum spreading diameter and contact time with the hot surface maintained at 60°C, resulting in enhanced thermal transport compared to no magnetic field case under identical conditions. The jump off of the droplet for no field case can be observed at 20 ms in Figure 1(a).

The effect of contact angle on maximum spreading diameter is shown in Figure 2(d). As expected, maximum spreading is observed for hydrophilic cases of 45° and 60°.

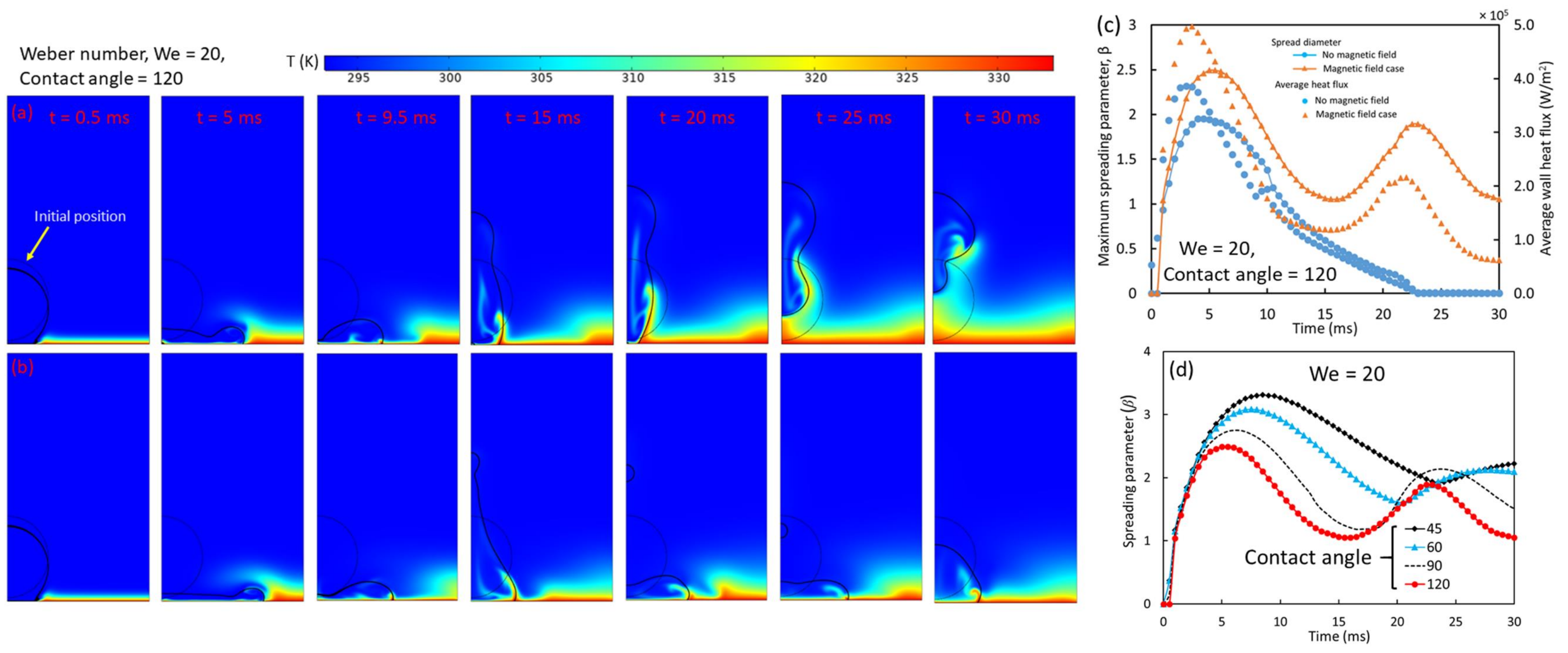

Figure 2: Temporal evolution of droplet and resulting temperature distribution for (a) no field (b) magnetic field cases for We = 20 and contact angle = 120 (c) Maximum spreading diameter (β) and avg. wall heat flux for the same case (d) effect of contact angle on maximum spreading diameter. At We =20 in the presence of the magnet

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