Liquid micro-droplet effects in a plasma

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Ionised gases, usually referred to as plasmas, are present in a wide range of naturally-occurring and industrial cases. These plasmas often contain micrometre-scale droplets, particularly in technologically-important applications such as plasma spraying and vapour decomposition for materials processing, condensation of droplets in semiconductor fabrication plasmas, and droplet blowoff in plasma arc cutting and welding devices. Additionally, droplets are found in ionospheric and fusion reactor plasmas. The primary purpose of my PhD project is to investigate the stability and dynamics of these droplets, and substantial progress has already been made. In particular, we have three manuscripts in preparation for submission to various academic journals which summarise most of the completed work. This report gives a brief overview of the progress achieved so far; full details will be provided in the forthcoming publications.

The first paper is a computational study of the charging of non-spherical objects in a plasma, which is already with the referees. This acknowledges the numerous processes which lead to droplet deformation, such as rotation, electric fields and flows past the droplet. The results extend the existing theories for spherical and cylindrical objects, and reveal that the spherical charging approximation is reasonable for a considerable range of droplet shapes. Besides droplets, this work is applicable to non-spherical solid particles in a plasma; examples include astrophysical dust, ice grains in noctilucent clouds, and fractal aggregates in semiconductor fabrication plasmas.

The second manuscript is concerned with the stability of a rotating droplet which is either charged or in an electric field. New results are derived analytically and agree well with existing studies of stability against individual electrostatic and rotational effects, while making interesting predictions for when these effects are simultaneously present. Although this work was motivated by its application to droplets in a plasma, it is also relevant in non-plasma cases such as thunderstorm clouds, inkjet printing and electrospraying.

The final manuscript describes the stability of droplets in plasmas for some specific examples. The cases described are plasma-enhanced chemical vapour decomposition, where droplets may be electrostatically destroyed, plasma arc cutters, where droplets may be broken up by strong plasma flows, and fusion plasmas, where centrifugal breakup may occur. In all three examples the breakup of droplets is beneficial, so these mechanisms can be used to optimise the various applications of droplets in plasmas.

There remains much work to be done, particularly regarding experimental studies of droplets in plasmas. I have just started looking at images from the Joint European Torus fusion plasma experiment, which appear to show the breakup of droplets which might be accredited to centrifugal breakup. Furthermore, the dusty plasma experiment at Imperial College is currently being renovated, providing the possibility of droplet injection under similar conditions to vapour decomposition plasmas, and a collaborative project to study droplets in plasma Hall thrusters is being planned with the University of Southampton. I also hope to develop a computer simulation of droplets in a plasma flow over the next year in order to improve the model for droplet breakup in plasma arc cutters; this simulation could then be easily adapted to the problem of melting and formation of droplets from a surface in contact with a plasma.