# Diesel fuel droplet impingement on heated surfaces

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### Introduction

The impact of droplets on a solid surface is important in a number of industrial applications such as IC engines, fire suppression, thermal power plants and ink printing, among many others. Several parameters, such as droplet velocity, diameter and angle of impact [1], liquid physical properties [2], surface conditions [3], wall surface temperature ($T_w$) [4]and ambient pressure [5] are of key importance for the deformation of droplets upon impact and thus, define the impact outcome. Previous investigations show that the dynamic of droplet impact on a heated surface is different from those observed on a cold surface. in the present study, the impact of Diesel fuel droplets on a heated surface within a gaseous (air) environment at 1 and 2 bar has been investigated for a wide range of Weber number and surface temperature values employing both high speed visualization and CFD modelling.

### Material and methods

The experimental setup and the image processing technique is shown in Figure 1 and comprises from the pressure chamber, the droplet generation system, the heated surface, the optical shadowgraphy system and the data acquisition system.
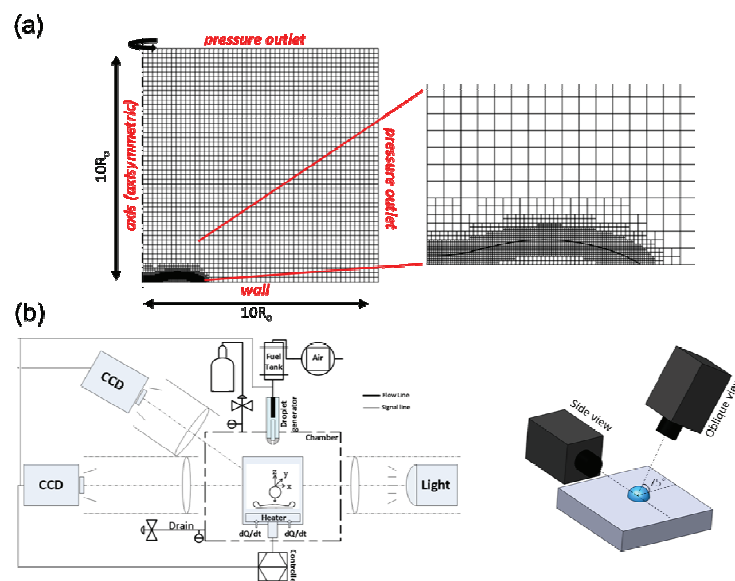


**Figure 1: (a)** 2D-axisymmetric computational domain and boundary conditions used for the simulation of Diesel droplet impingement and grid refinement of the liquid-gas interface **(b)** Schematic illustration of the test rig set-up utilised

The liquid used in this study was standard summer Diesel fuel with properties ρ=833 kg/m3, σ=28.9 mN/m and μ=2.7 cP at 25 °C. Droplet generation was achieved by a delicate electromagnetic injection system. Droplet injection and size was controlled from the compressed upstream air pressure and the opening time of the injector anchor; the achieved droplet size and velocity were in the range of 250-500 μm and 0.5-9 m/s, respectively. These correspond to impact Weber and Reynolds numbers in the range of 15-1000 and 91-1256, respectively. A transparent high pressure chamber equipped with three quartz glasses for optical access was utilized while experiments were performed at pressures of 1 and 2 bar; nitrogen was used to pressurize the chamber. The employed CFD model solves the Navier-Stokes equations for mass and momentum conservation, while it employs the VOF methodology to capture the liquid-gas interface. The energy equation coupled with a species transport equation for the vapour and a local evaporation model are utilized to simulate phase change [6]. The evaporation rate is based on the kinetic theory of gases, where

the driving force is the difference between the saturation conditions at the interface and the conditions on the vapour side.

## Results and Discussion

In general, under the designated operating conditions, essentially six different macroscopic outcome regimes can have been identified, termed as: stick, splash, rebound, partial-rebound, breakup and breakup-rebound as illustrated in Figure 2.
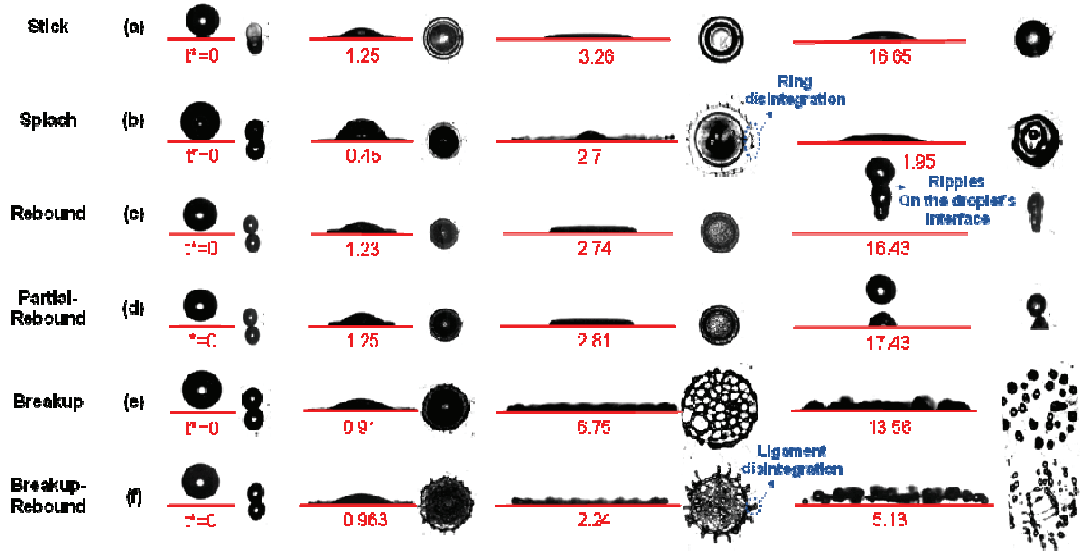


**Figure 2:** Temporal evolution of Diesel fuel droplet during impact on the heated flat aluminium surface for different values of Weber number and wall temperature; (a) stick regime at We=65, $T_W$=170°C; (b) splash regime at We=490, $T_W$=180°C; (c) rebound regime at We=65, $T_W$=350°C; (d) partial rebound regime at We=65, $T_W$=340°C; (e) breakup at We=490, $T_W$=340°C; (f) breakup-rebound regime at We=202, $T_W$=370°C

The impact outcomes are categorized and inserted into a non-dimensionalized map to identify the droplet impact based on the droplet Weber number (=$\rho U_0^2 D_0/\sigma$) and the surface temperature for the (Figure 3). Critical (We, T) pairs have been identified, which signify the transition to the breakup, splash and rebound regime.
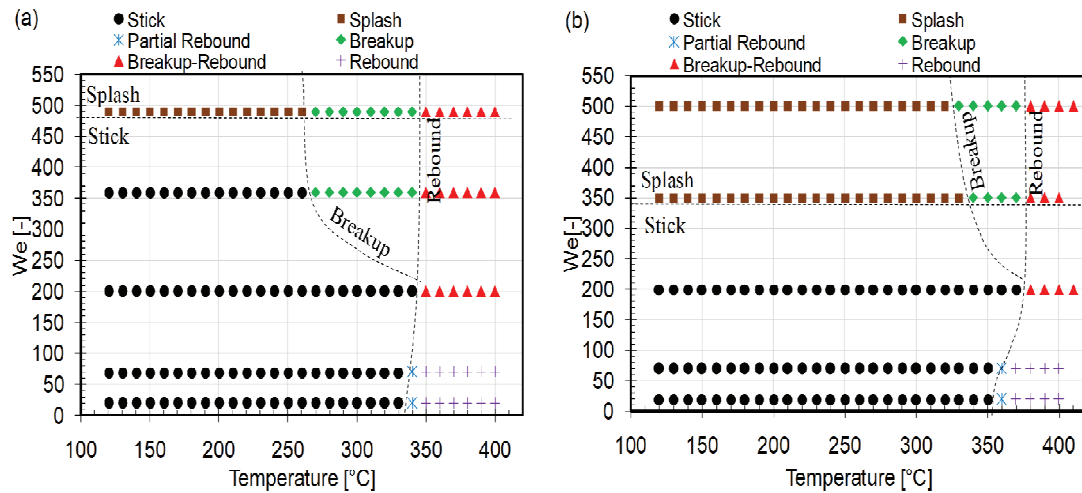


**Figure 3:** We-T regime diagram of Diesel fuel droplet impact on a heated aluminum surface at (a) P=1bar and (b) P=2bar

The effect of wall surface temperature and impact Weber number on wetting spreading factor and dynamic contact angle have been numerically and experimentally assessed (Figure 4 and Figure 5).

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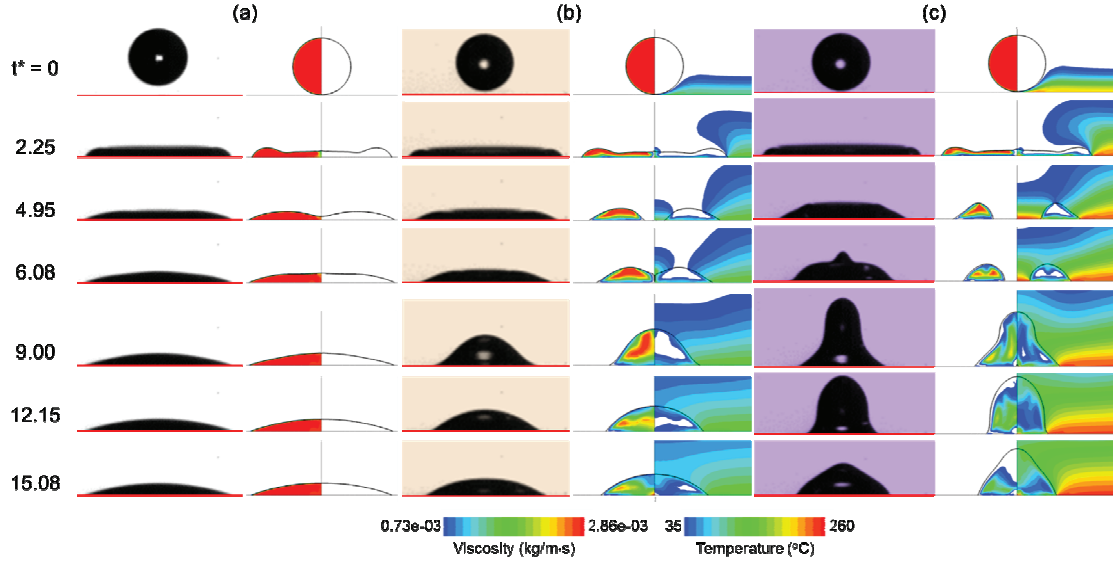
**Figure 4:** (a) Sequential images (experiment and simulation) of Diesel fuel droplet impact on a heated luminium surface for We=65 and P=1 bar: (a) $T_W$=25°C, (b) $T_W$=140°C and (c) $T_W$=260°C. For the simulation results, values of viscosity and temperature below



the lower contour level are cut-off.
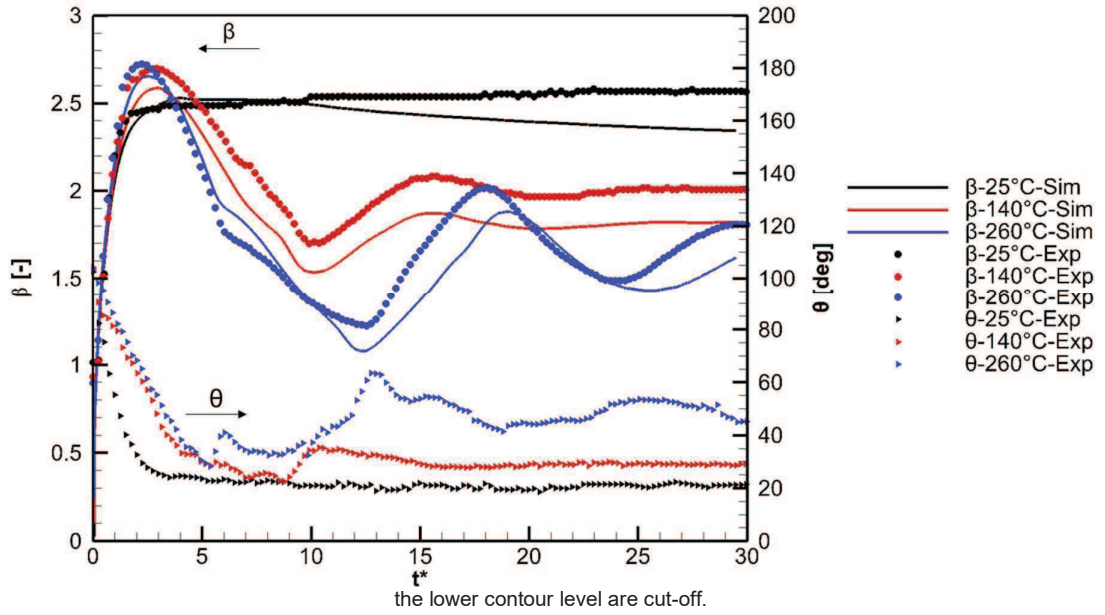
**Figure 5:** Effect of surface temperature on time evolution of dynamic contact angle and spreading factor for We=65 and 1 bar chamber pressure at $T_W$=25, 140, 260°C

It has also been confirmed that by increasing wall-surface temperature, the droplet exhibits a strongly oscillating behaviour during the expansion and recoil phases, due to a reduction of liquid viscosity in the bulk of the liquid at higher surface temperature (Figure 6). This stronger recoiling behaviour also increases the value of the dynamic contact angle with the solid surface.

The effect of air pressure is quite insignificant on the wetting dynamic (Figure 7), however a weak suppression of the droplet spreading at P=2bar is observed, since the spreading factor obtains a lower value at P=1bar. This can be attributed to the increased aerodynamic drag effect at the triple contact point, as the density of the ambient air is doubled at 2 bar air pressure compared to atmospheric condition.
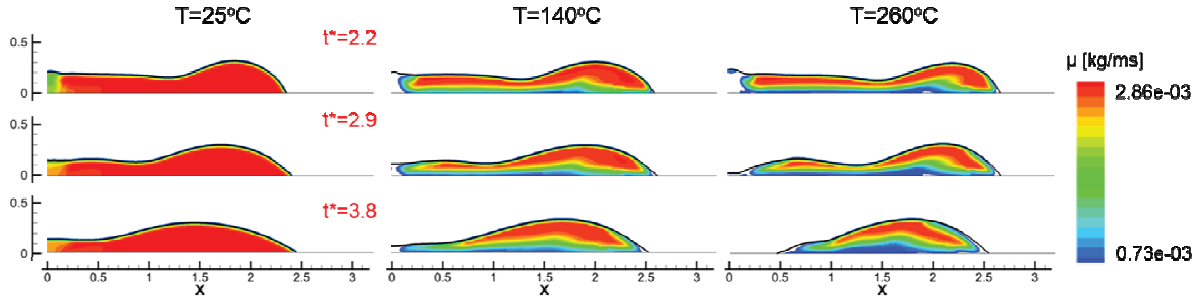
**Figure 6:** Droplet rim motion at 3 time instances (hysteresis and recoil) for 3 different surface temperatures of $T_W$=25, 140, 260°C,
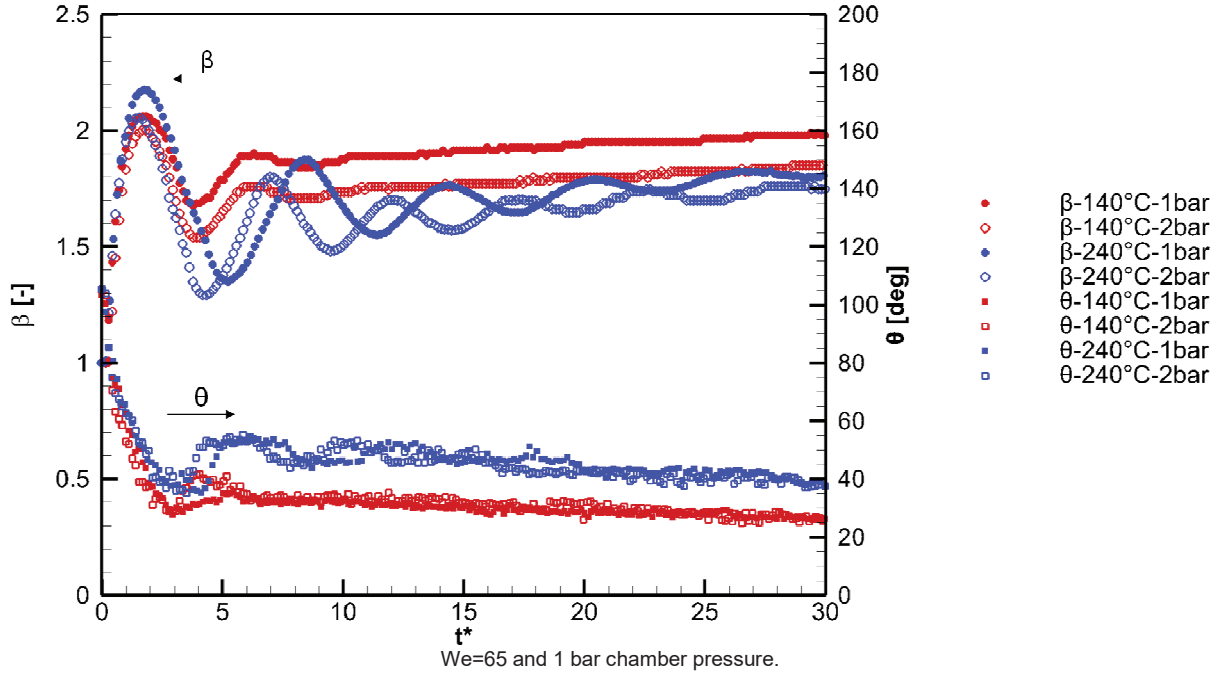


We=65 and 1 bar chamber pressure.

**Figure 7:** Temporal variation of (a) the dynamic contact angle θ and (b) spreading factor β for We=19 at TW=140 and 240°C

### Nomenclature

| | | | | |
|---|---|---|---|---|
| $T_L$ | Leidenfrost Temperature [°C] | | t* | Dimensionless time (t×$V_0$/$D_0$) |
| $T_W$ | Wall surface temperature [°C] | | We | Weber number (ρ$V_0^2$$D_0$/σ) |
| P | Ambient pressure [bar] | | $V_0$ | Impact velocity [m/s] |
| ρ | Density [kg/m$^3$] | | $D_0$ | Droplet diameter at impact time [m] |
| σ | Surface tension [N/m] | | μ | Viscosity [mPa.s] |

### References

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