Test-case number 26: Droplet impact on hot walls (PE)

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1 Practical significance and interest of the test-case

Fuel droplet impingement on a hot surface is encountered in many practical processes, ranging from various types of internal combustion engines. Droplets impacting on a hot wall in a diesel combustor engine usually experience wall temperature in the range $200-300^{o}C$, which means that they exhibit typical Leidenfrost phenomenon. Evaporation and hydrodynamic deformations are accompanied by heat, mass and momentum transfers that still require some fundamental investigations. Here we present experimental results for the thermal and dynamical behavior of the droplets before and after impact. To reproduce the experimental data is a challenge for any numerical method as it means taking into account properly the impact of a droplet with the Leidenfrost phenomenon that usually rely on pressure building in thin vapor layer ranging down to the micrometer. In addition to this scale, the phase change in a non-condensable gas, the effect of roughness on the vapor flow during the Leidenfrost, *etc.*, may also request small-scale description for the mass diffusion layers.

2 Definitions and physical model description

The experiment consists on a droplet generator based on Rayleigh instability that generates perfectly calibrated droplets at given frequency and velocity. This generator is vertical and flowing droplets downward as can be see on figure 1, for some other experiments, the generator can flow droplet upward (figure 2). The droplets are then impacting on an inclined hot plate. Thanks to this device, all droplets have the same history. The relevant parameters are:

- Incident normal Weber number: $We = \dfrac{\rho_l V_{i,n}^2 D_l}{\sigma}$
- Reynolds number: $Re = \dfrac{\rho_l V_{inc,n} D_l}{\mu_l}$
- Ohnesorge number: $Oh = \dfrac{\mu_l}{\sqrt{\rho_l D_l \sigma}}$

All quantities with subscript l are related to the liquid. We give in the table 1 the physical properties of the liquid, namely ethanol in our experiments.

3 Test-case description

For this test case, the droplet chain is ascending according to figure 2. Θ is the angle between the plate and the vertical. We summarize in the table 2 the initial conditions for this case.

For that case, we observe perfect rebound of the droplet. However, due to hot wall, part of the droplet is evaporating. We give in the table 3, the surface temperature of the droplet measured by infrared techniques as described in detail in (LeClercq *et al.* , 1999b), the diameter of the droplet measured by image processing and the velocity measured by Phase-Doppler techniques at a location 12 mm after rebound. The duration of impact is of order $5\ 10^{-4} s$.

It should be noticed for this test case, that the roughness of the hot wall is around 1 micrometer. The numerical simulation for this case must take into account evaporation. It will be supposed that physical properties like surface tension, dynamic viscosity do not depend of the temperature. In order to get the proper gas temperature field in the neighborhood of the heated wall, a preliminary computation of the thermal boundary layer must be done with an imposed temperature on the wall given by table 2. As a suggestion, the computational domain for this calculation could be a rectangular box of 0.1 m by 0.04 m the length of the wall is 12 mm. We give on figure 3 an example of such calculation (LeClercq *et al.* , 1999a).

In order to show the dynamic of the physical phenomenon, we show in figure 4 a snapshot of the chain droplets impact for a descending droplet stream. The droplets diameter is 174 μm, the wall temperature is 623 K. The wall angle is $\theta = 15^\circ$, the droplet velocity is 3.68 m/s.

4 Relevant results for comparison

This test-case is today a very difficult one. The main challenge of such a test is first to get results with a CFD code, and second to obtain these results with physical and numerical descriptions that stand the mesh refinement needed to achieve numerical convergence with respect to the spatial discretization.

Once simulation results are successfully obtained, it is possible to compare with the experimental results. In this stage, the main features to be reproduced are the size and velocity of droplets after the rebound. It is also possible to compare the other experimental values given in table 3, but the droplet surface temperature will be highly sensitive to the physical wall roughness effect on the impact feature. Therefore this last quantity is probably more an indication of the quality of the physical model than a test-case for the numerical method used.

Liquid density ρ_l, kg/m^3	777.95
Surface tension σ, kg/s^2	0.0221
Dynamic viscosity μ_l, kg/m s	0.001052
Boiling temperature T_b, K	351.5
Critical temperature T_c, K	561.25
Leidenfrost temperature T_L, K	458

Table 1: Physical properties of liquid

Droplet diameter D_l, μm	210
Frequency f, Hz	7500
Initial velocity $\vec{V_l}$, m/s	4.9
Initial normal velocity $V_{i,n}$, m/s	1.268
Initial temperature T_i, K	297
Wall temperature T_w, K	623
Plate angle Θ_i, degree	14
Incident normal Weber number	11.88

Table 2: Initial conditions

Droplet diameter D_{rb} 10 mm after rebound, μm	192
Velocity after rebound $\vec{V_{rb}}$, m/s	3.97
Normal velocity after rebound$V_{i,n_{rb}}$, m/s	0.75
Surface temperature after rebound T_{rb}, K	317
Angle after rebound Θ_{rb}, degree	11

Table 3: Experimental results after bouncing

References

LeClercq, P., Estivalezes, J.L., & Lavergne, G. 1999a. Drop impact on a heated wall: Global models and experimental results comparison. *In: ILASS Europe*. Toulouse, France.

LeClercq, P., Ravel, O., Estivalezes, J.L., & Farre, J. 1999b. Thermal and dynamical characteristics of droplets after impact on heated wall. *In: ILASS Europe*. Toulouse, France.

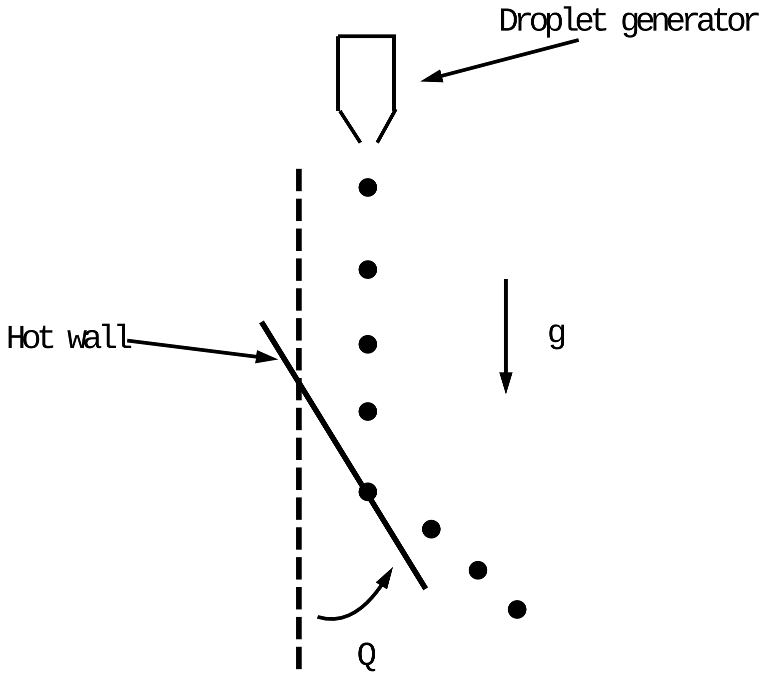

Figure 1: Experimental set-up, descending droplets

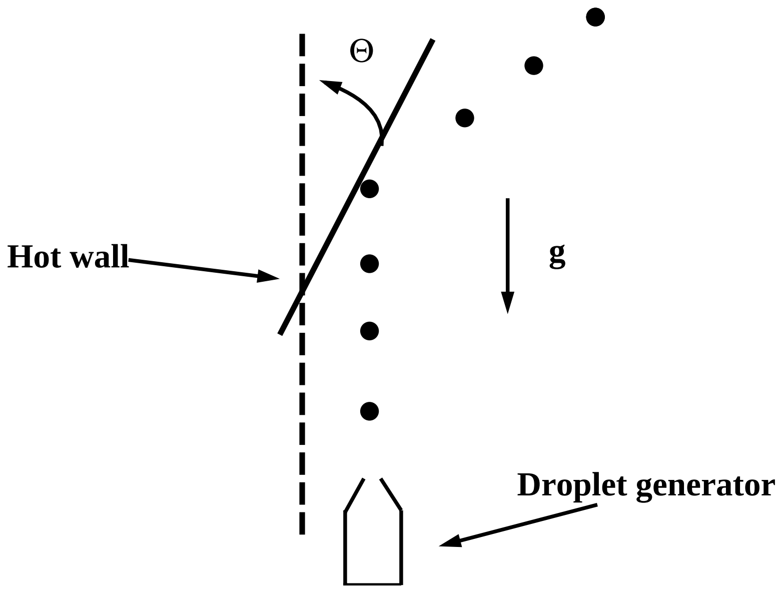

Figure 2: Experimental set-up, ascending droplets

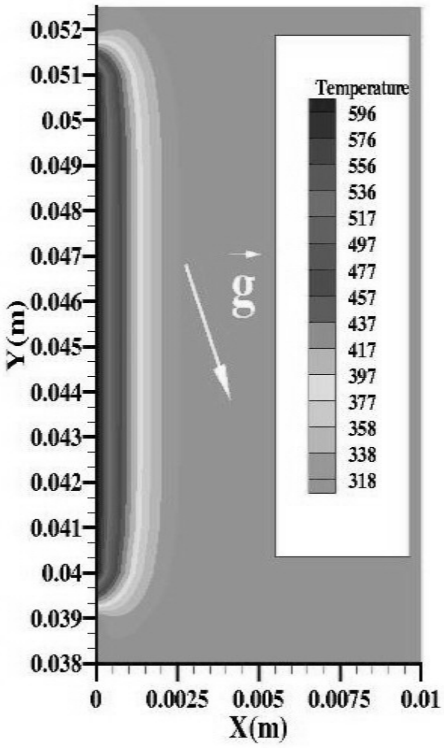

Figure 3: Computed gas thermal field, the heated wall goes from y=0.04 m to y=0.052 m

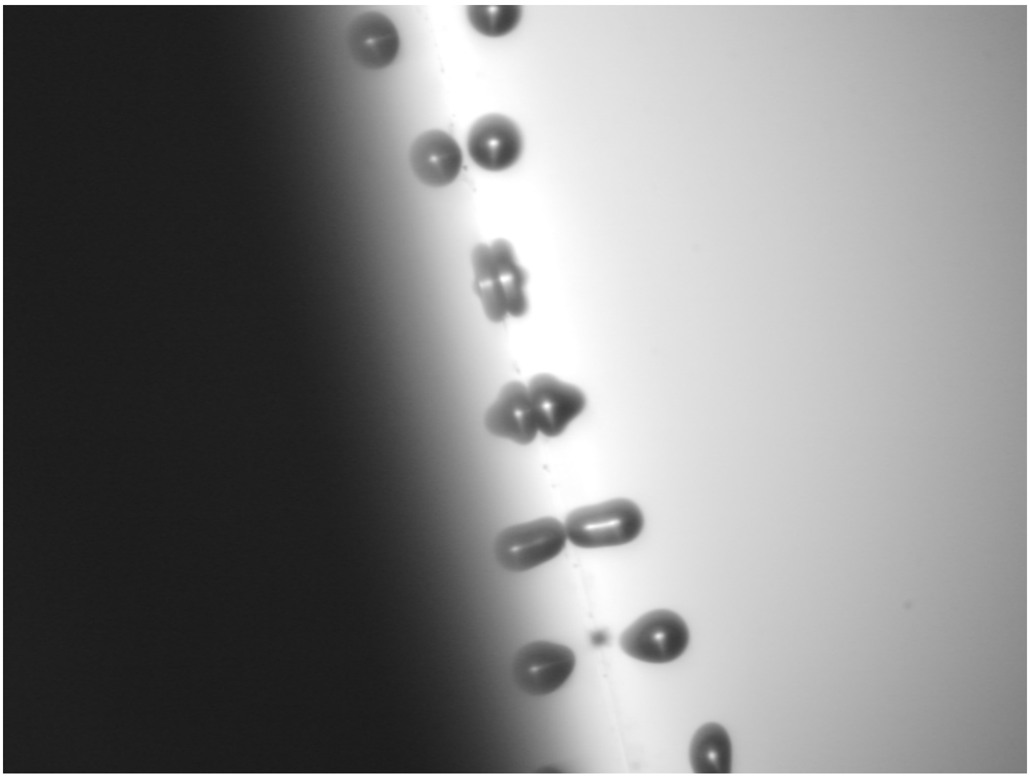

Figure 4: Experimental result for descending droplets stream