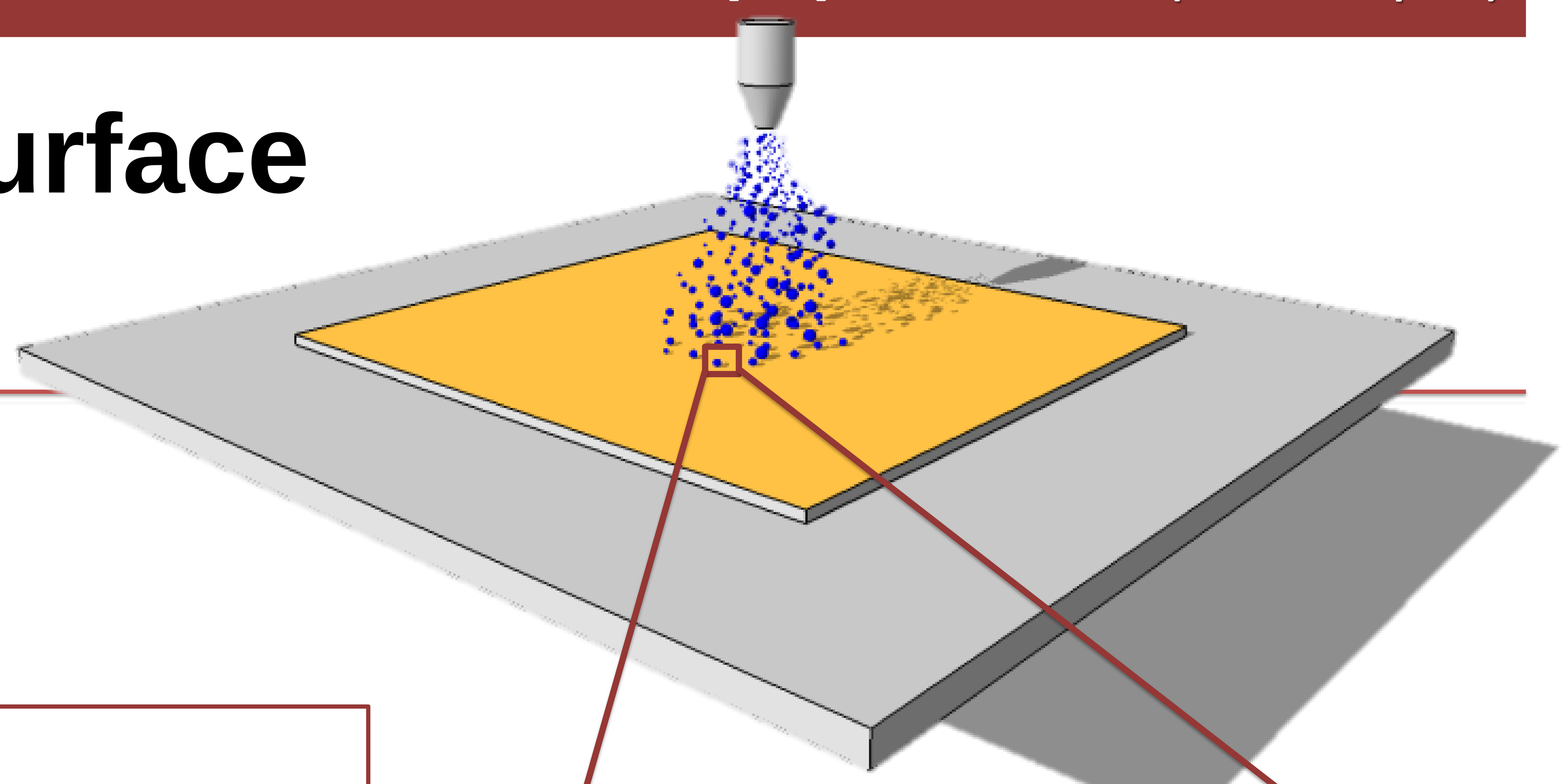
Dynamics of liquid nitrogen cooling process of solid surface at wetting contact coefficient.



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Background

Liquid cryogens cooling by direct contact is very often use as a method to drop the temperature of the devices or equipment i.e. HTS cables. Local heat flux value within HTS cables could increase even to 10^6 W/m^2. Heat dissipation by pool boiling get some limits regarding to its characteristic. That because the spray cooling (SC) method, which is one of the best way to dissipate the high heat amount from a surfaces, is taken into consideration, to develop increase of heat transfer efficiency.

This study shows influence of hydrodynamic and thermal issues of single liquid nitrogen droplet during the time of impact, and how its contribution to overall heat transfer rate.

Objectives

- Increase of heat flux removal from hot surface in required temperature range,
- Increase of efficiency of heat transfer by liquid nitrogen,
- To analyze the impact of wetting contact coefficient on the heat flux.

Small scale analysis

Hydrodynamic and thermal influence of the droplets onto flat surface are coupled and dependent on each other. Droplets created in the sprays are reached the surface and form the contact interface between heated surface and liquid in the short period of time, with a highly complicated process, depends on a kinetic energy of the droplet during impingement. A process of shape formation depends mostly on a inertia forces, viscosity and surface tension forces. To compare different behavior of droplets, the dimensionless Weber number was implemented, which determines the ration between inertia forces to surface tension forces of the droplet.

$$We = \frac{\rho_l d_0 v_0^2}{\sigma}, \qquad (1)$$

where: ρ_l – liquid density; d_0 – initial droplet diameter; v_0 – initial droplet velocity; σ - liquid surface tension. In small-scale (for the single droplet), the coefficient of wetting contact surface (WCC) could be introduced. This coefficient defines area occupied by spread liquid to initial diameter of the droplet treated as an ideal sphere:

$$\beta = \frac{D_r}{d_0}, \qquad (2)$$

D_r – imaginary diameter of the wetting circle, on which droplet interacts; d_0 – initial droplet diameter.

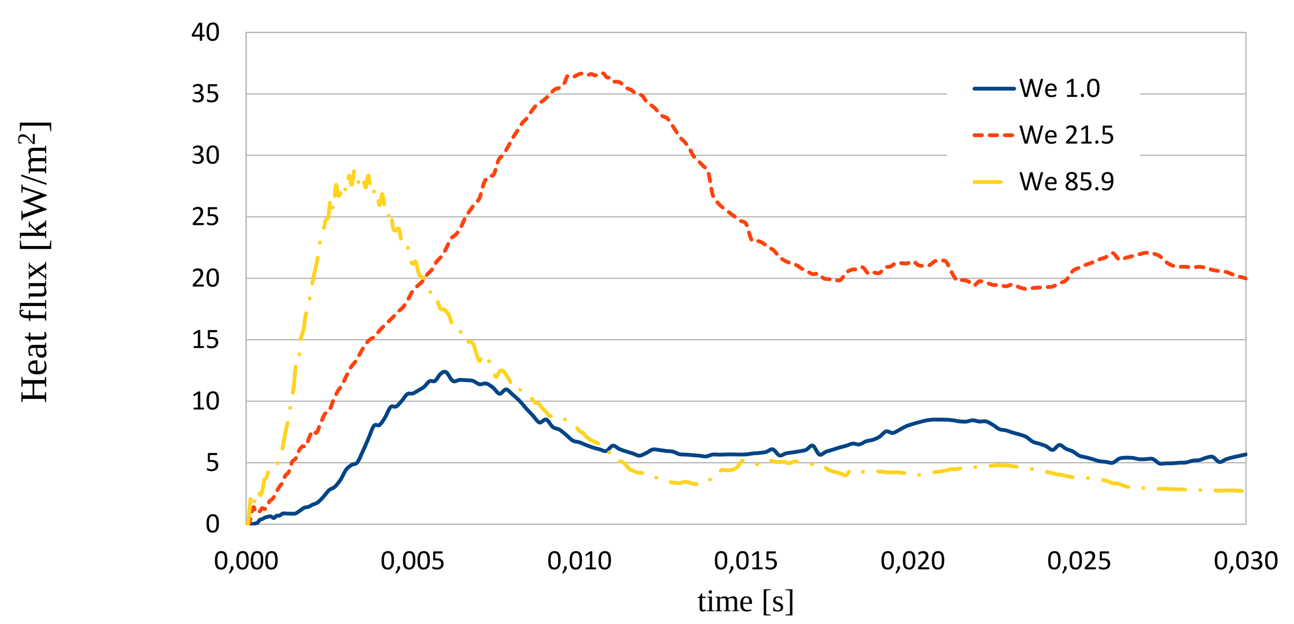
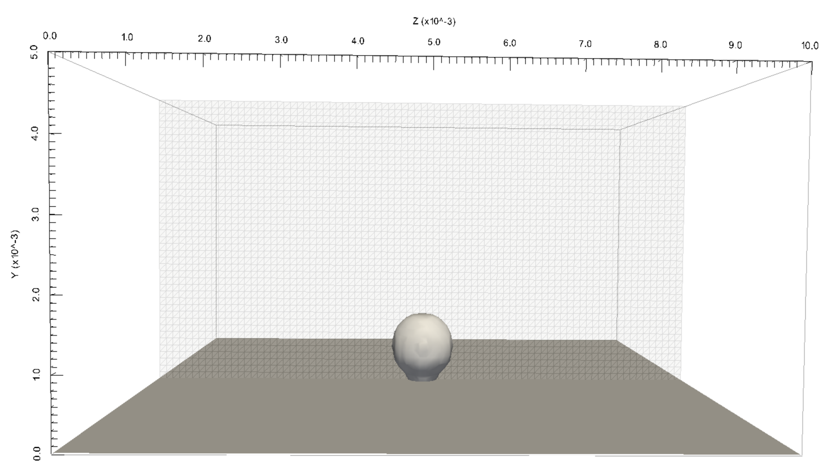


Figure 1. Heat flux during the time of impact for different *We* numbers.

Numerical model

The numerical model was performed by using two-phase Volume of Fluid (**VoF**) method of surface tracking between phases. All the simulations were carried out using the ***OpenFOAM 2.3.0*** toolkit environment.



Symulation assumptions:

- flat and perfectly smooth surface of impact,
- liquid nitrogen droplet diameter of 1.0 mm**,**
- direct numerical simulation (DNS) type of fluid flow,
- evaporation occurs in nucleate boiling regime,
- Incompressible type of fluid flow.

The one-dimensional pseudo-conjugate heat transfer was developed to determine the temperature profile on the hot surface, during simulation time.

$$\rho_m c_{p_m} \frac{\partial T}{\partial \tau} = k_m \frac{\partial^2 T}{\partial x^2} - \dot{q}, \qquad (3)$$

Energy equation of phase transition is shown below:

$$\frac{\partial T}{\partial \tau} + \nabla \cdot (\boldsymbol{U}T) = DT\, \nabla^2 T - \frac{\dot{q}}{\rho\, c_p} \qquad (4)$$

$$\dot{q} = \begin{cases} -\dot{m}_{lv}\, L & for\ evaporation \\ \dot{m}_{lv}\, L & for\ condensation \end{cases} \qquad (5)$$

Two-phase properties were defined as weighted average parameters, wherein the weight ratio of the parameter corresponds to the function of the liquid fraction in two-phase system.

$$\rho = \alpha\, \rho_{liq} + (1-\alpha)\rho_{gas} \qquad (6)$$
$$\mu = \alpha\, \mu_{liq} + (1-\alpha)\mu_{gas} \qquad (7)$$
$$c_p = \alpha\, c_{p_{liq}} + (1-\alpha)c_{p_{gas}} \qquad (8)$$

Results

- Dynamics of liquid spilling significantly affect the removal of heat transfer from the surface,
- Heat flux rate change is proportional to wetting contact coefficient,
- Cooling of the surface occurs immediately after the particle collision on the flat surface,
- Impact of the highest heat flux values are characterized by the instances at which the Weber number reaches values of 21.5 or 85.9 – in this regime fragmentation of a single droplet occurs, which significantly enlarge the sphere of the influence (β above 2).

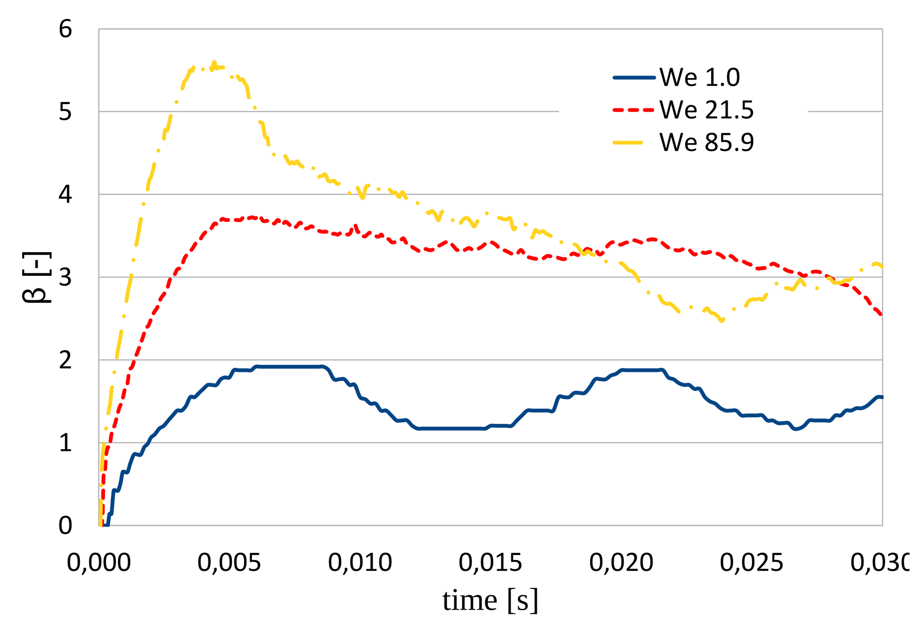


Figure 2. Wetting contact coefficient during the time of impact for different We numbers.

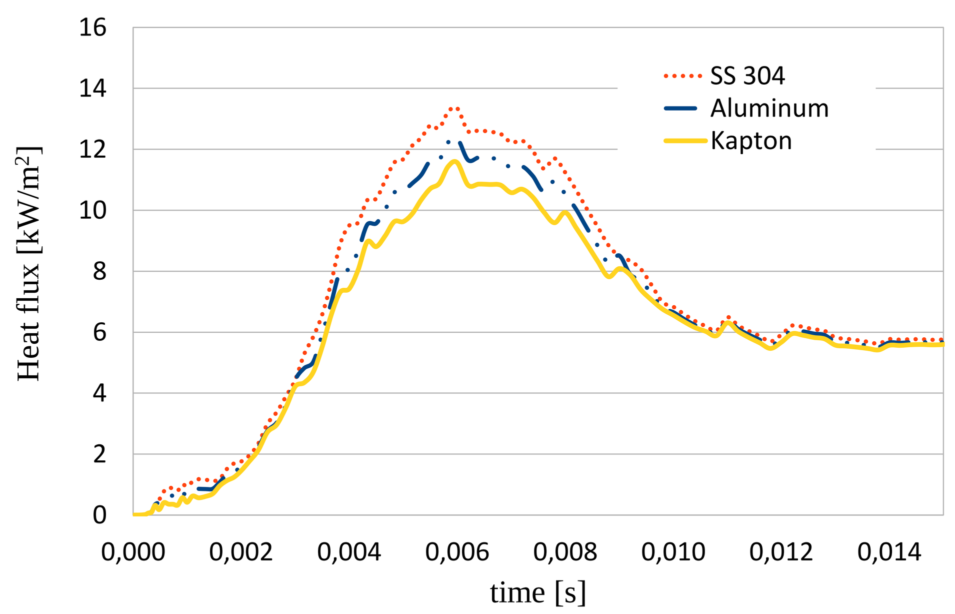


Figure 3. Peak heat flux for different materials declared as a boundary condition.