Franco-British INTERREG IIIa (Project Ref 162/025/247)
Final monitoring meeting: 11 June 2007

# A kinetic algorithm for modelling the droplet evaporation process in the presence of a heat flux and background gas

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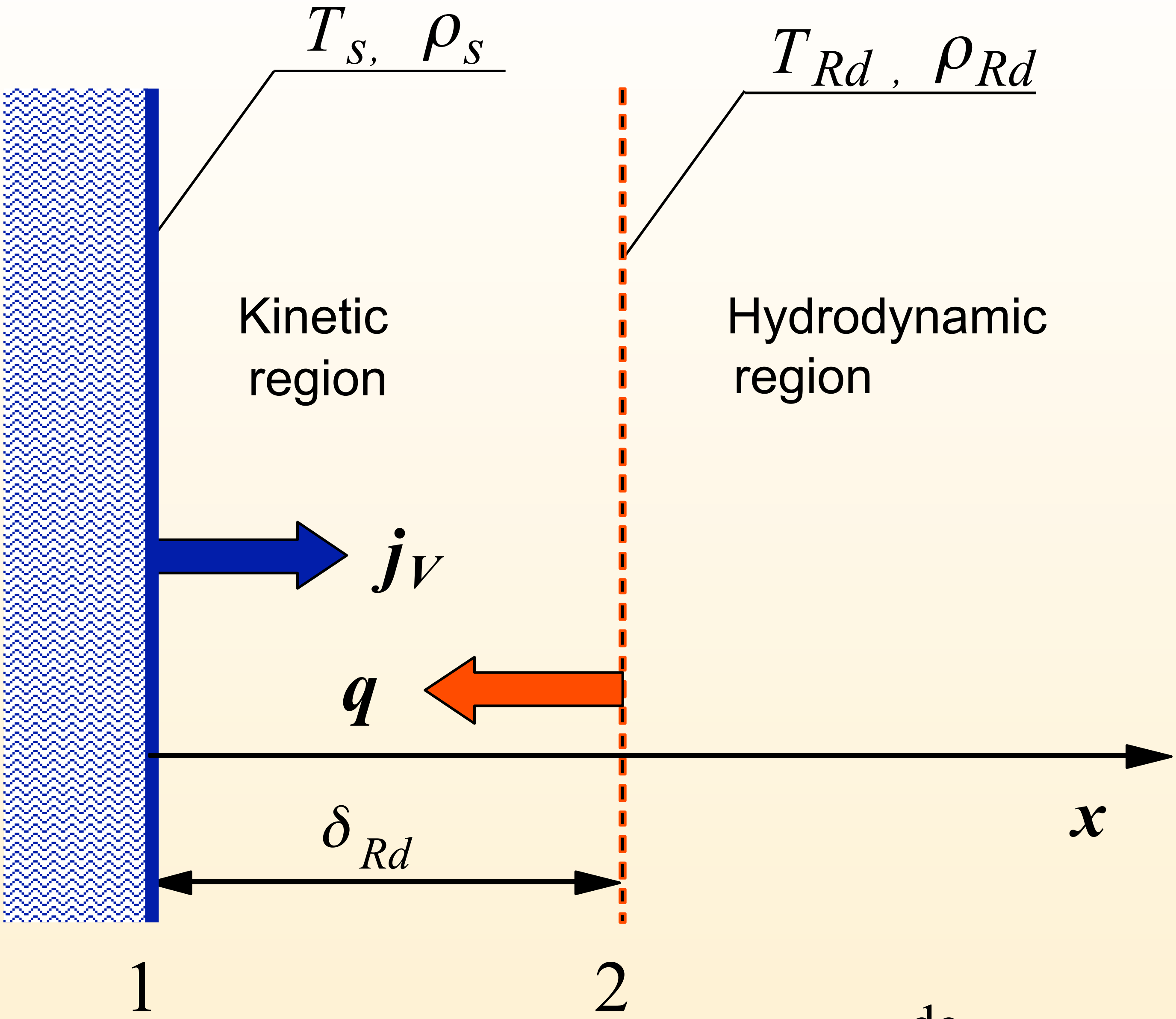
# Background

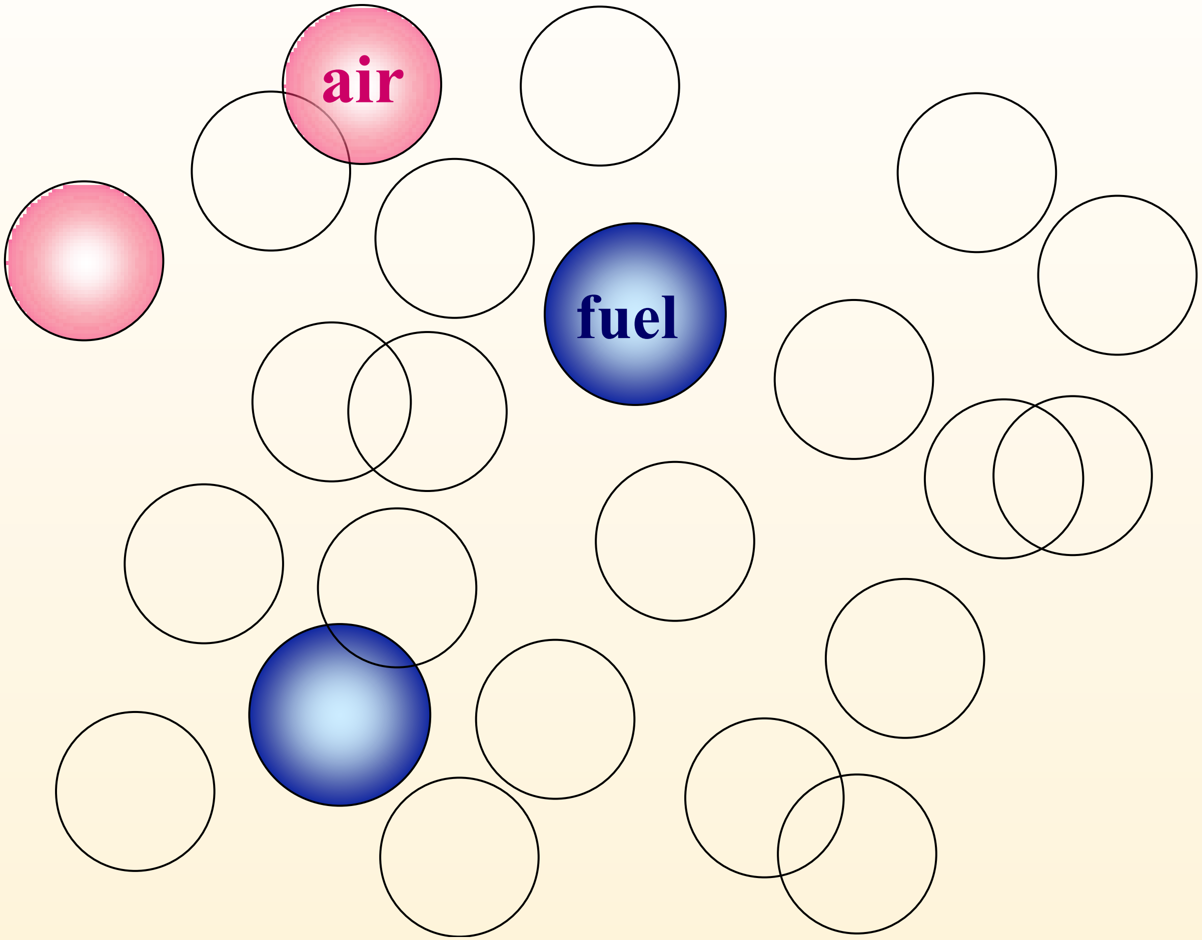
Kryukov, A.P., Levashov, V.Yu. and Sazhin, S.S. (2004)
Evaporation of diesel fuel droplets: kinetic versus hydrodynamic models, *Int J Heat Mass Transfer* 47 (12-13), 2541-2549.

Shishkova, I.N. and Sazhin, S.S. (2006) A numerical algorithm for kinetic modelling of evaporation processes, *J Computational Physics*, 218 (2), 635-653.

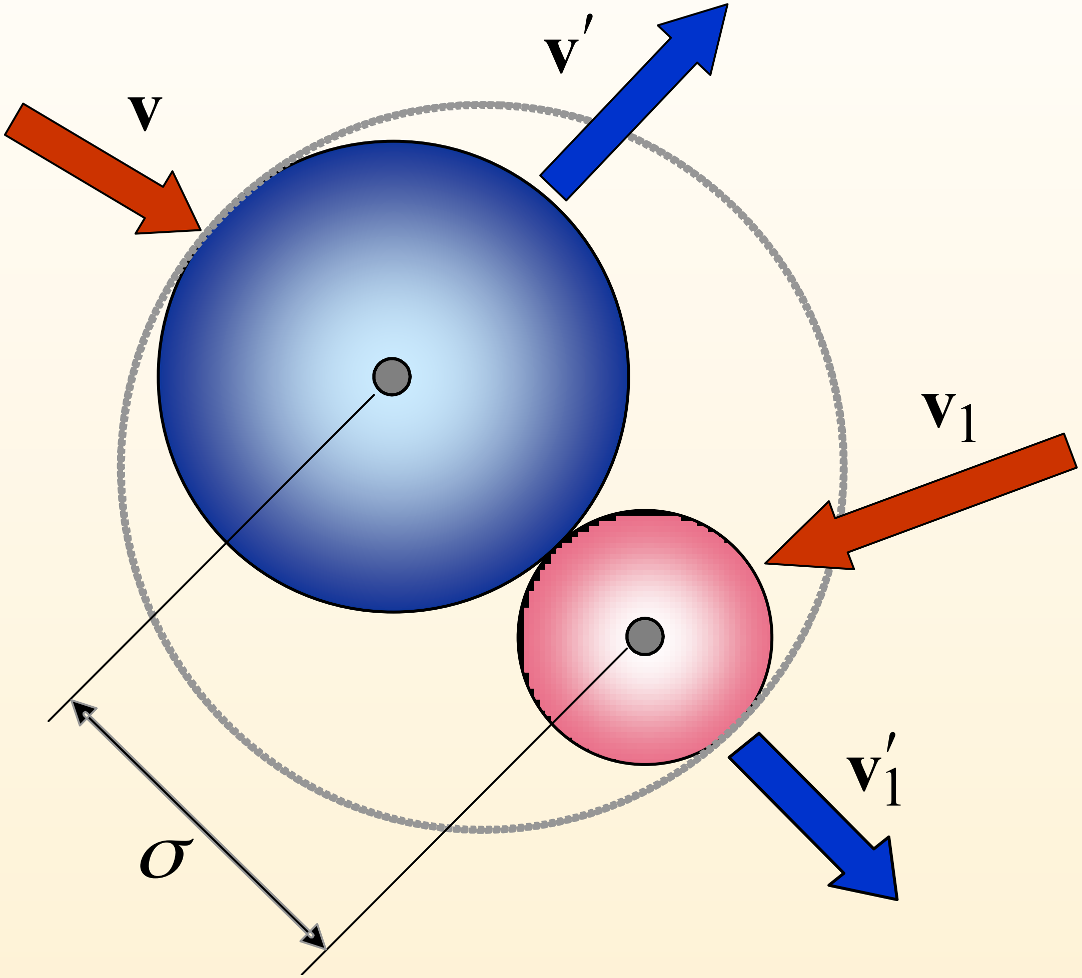
Sazhin, S.S., Shishkova, I.N., Kryukov, A.P., Levashov, V.Yu., Heikal, M.R. (2007) Evaporation of droplets into a background gas: kinetic modelling, *Int J Heat Mass Transfer* 50, 2675-2691


$T_{s,}\ \rho_s$
$T_{Rd}\ ,\ \rho_{Rd}$
Kinetic region
Hydrodynamic region
$j_V$
$q$
$x$
$\delta_{Rd}$
1
2

de


air
fuel

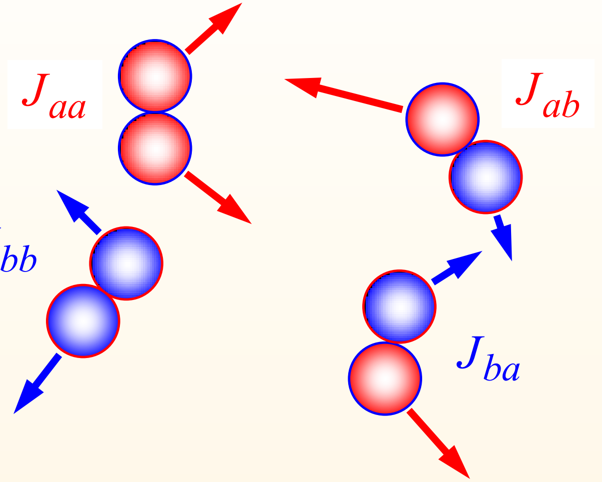
# Collision of molecules



# Boltzmann equations

$$\frac{\partial f_a}{\partial t}+\xi_a\frac{\partial f_a}{\partial x}=J_{aa}+J_{ab},$$

$$\frac{\partial f_b}{\partial t}+\xi_b\frac{\partial f_b}{\partial x}=J_{ba}+J_{bb},$$



$$f_a=f_a\left(t,x,\vec{\xi}_a\right)$$

$$f_b=f_b\left(t,x,\vec{\xi}_b\right)$$

$$n_i=\int\!\!\!\int_{-\infty}^{\infty}\!\!\!\int f_i\,d\vec{\xi}$$

$$n_i u_{ix}=\int\!\!\!\int_{-\infty}^{\infty}\!\!\!\int f_i\xi_x^i\,d\vec{\xi}\qquad i=a,b$$

$$T_i=\frac{1}{3Rn_i}\int\!\!\!\int_{-\infty}^{\infty}\!\!\!\int\left(\vec{\xi}_x^i-\vec{u}_{ix}\right)^2 f_i\,d\vec{\xi}$$

# Evaporation coefficient

$$\beta = \frac{j_{es}}{\rho_{vs}\sqrt{\frac{R_v T_s}{2\pi}}} = 1$$

# Hydrodynamic equations (stationary droplets)

$$q_s = h(T_g - T_s)$$

$$j_v = \frac{\rho_{\mathrm{mix}} D_{va}}{R_d} \ln(1 + B_M)$$

$$\frac{dT_s}{dt} = \frac{3}{\rho_l c_l R_d}(q_s - j_v L)$$

$$\mathrm{Nu} = hR_d / k_g$$

$$B_M = \frac{Y_{vRd}}{1 - Y_{vRd}}$$

$$\mathrm{Nu} = 2\frac{\ln(1 + B_T)}{B_T}$$

$$B_T = \frac{c_{pv}(T_g - T_s)}{L(T_s) - (|\dot{q}_d| / \dot{m}_d)}$$

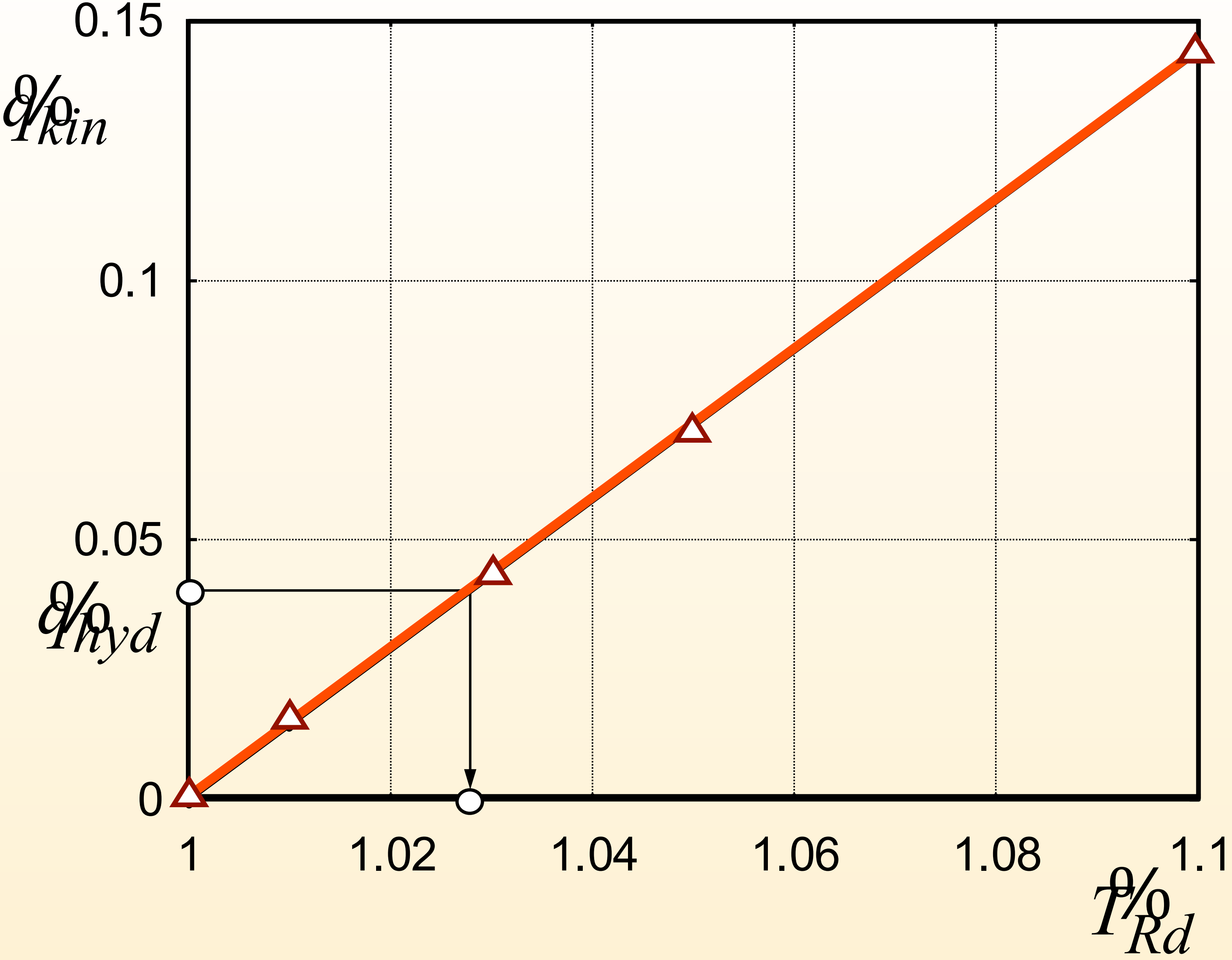
## Thickness of the kinetic region

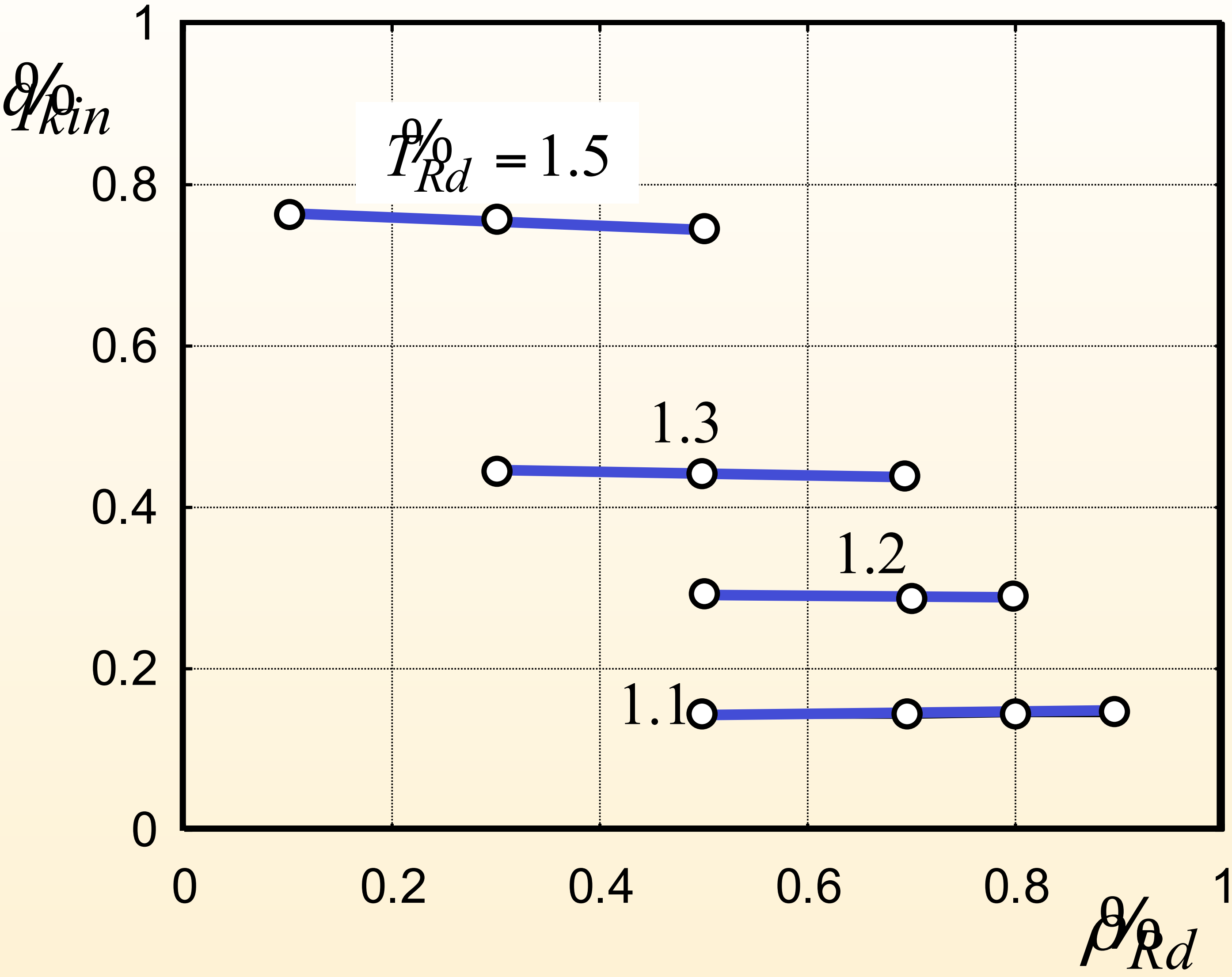
$$\delta_{Rd} = 10\,\lambda_c$$

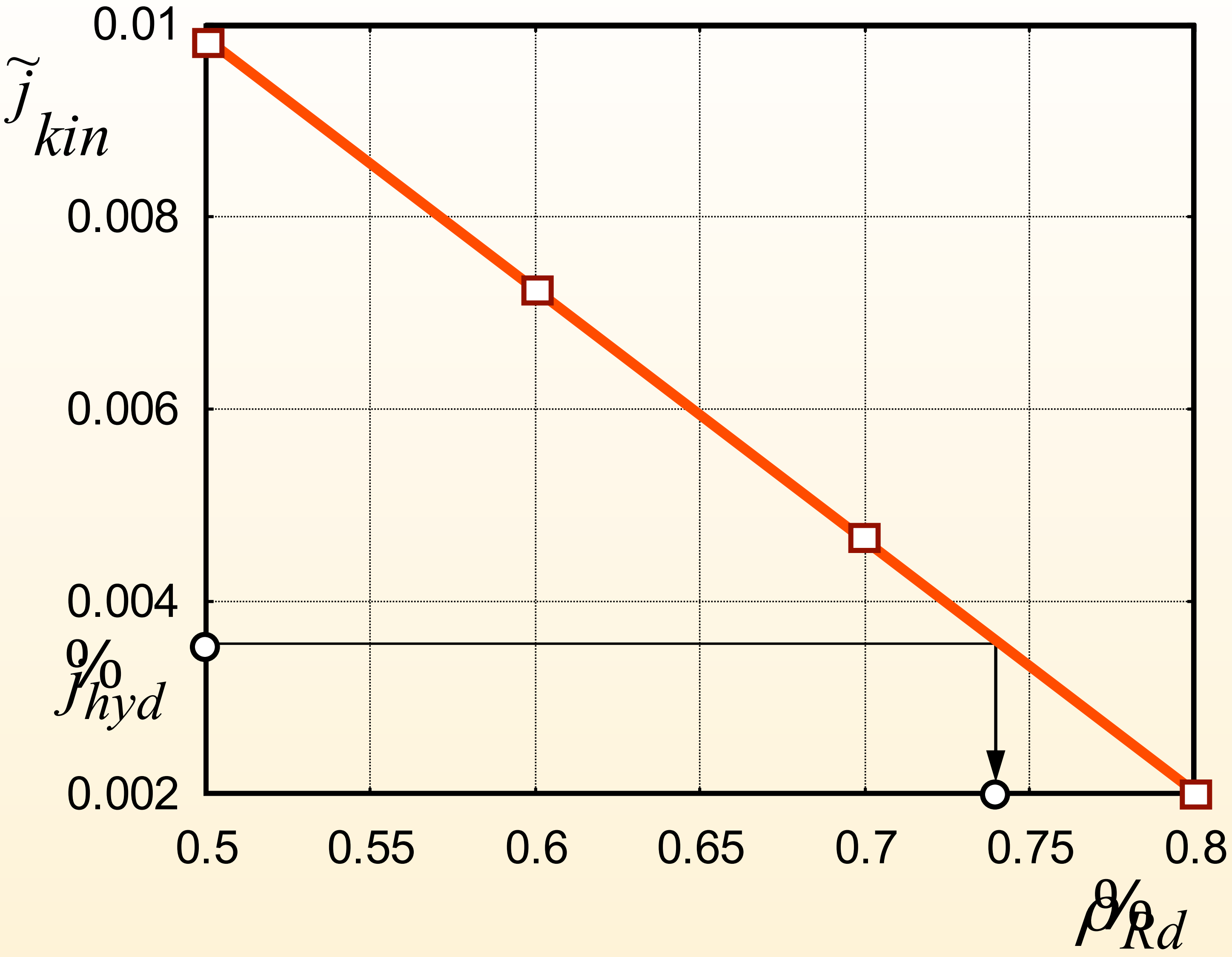
## Matching conditions

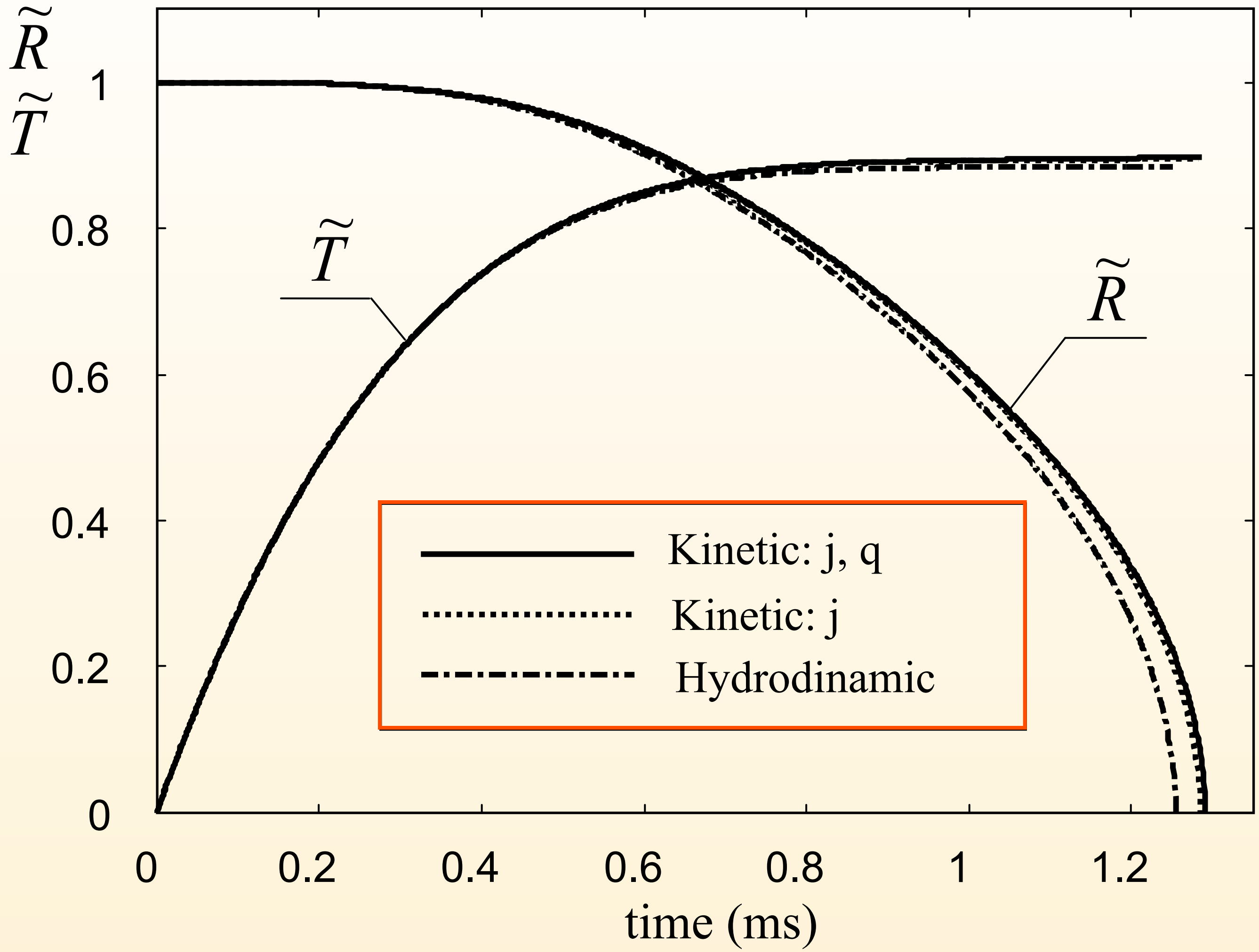
$$j_{kin} = j_{hyd}$$

$$q_{kin} = q_{hyd}$$

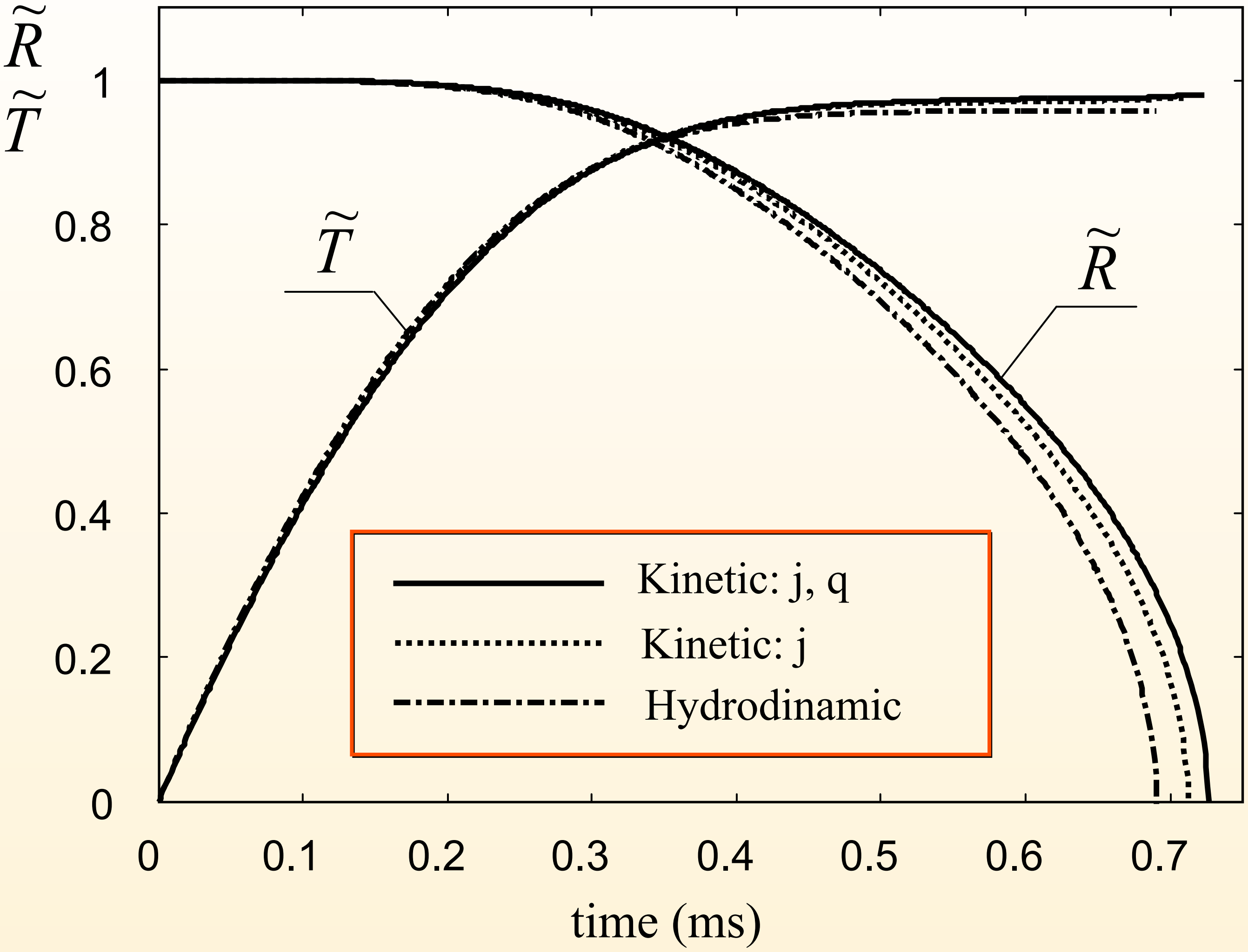

0.15
0.1
0.05
0
$\tilde{q}_{kin}$
$\tilde{q}_{hyd}$
1
1.02
1.04
1.06
1.08
1.1
$\tilde{T}_{Rd}$


$\tilde{q}_{kin}$
$\tilde{T}_{Rd} = 1.5$
1.3
1.2
1.1
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
$\tilde{\rho}_{Rd}$

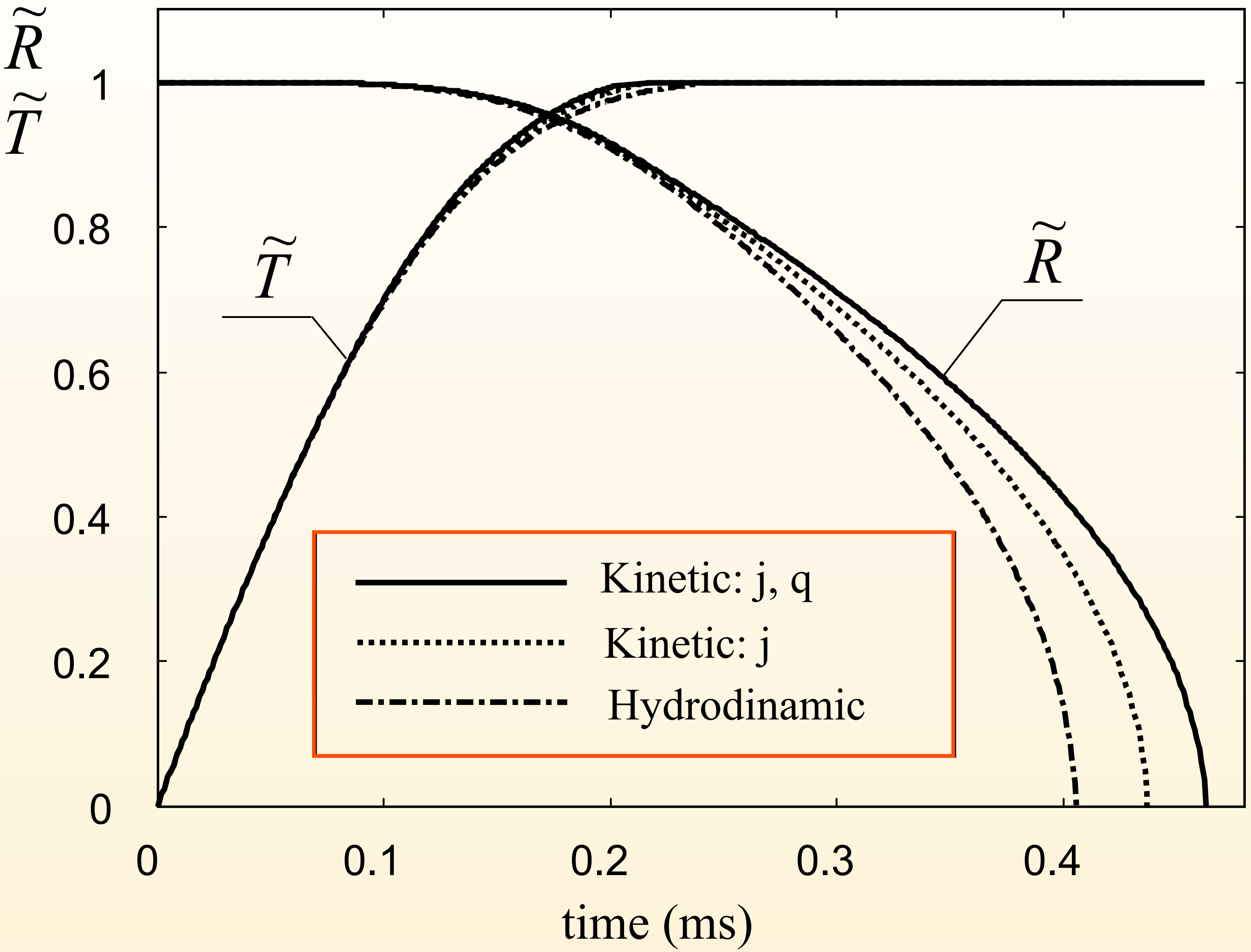

0.01
0.008
0.006
0.004
0.002
$\tilde{j}_{kin}$
%
$j_{hyd}$
0.5
0.55
0.6
0.65
0.7
0.75
0.8
%
$\rho_{Rd}$



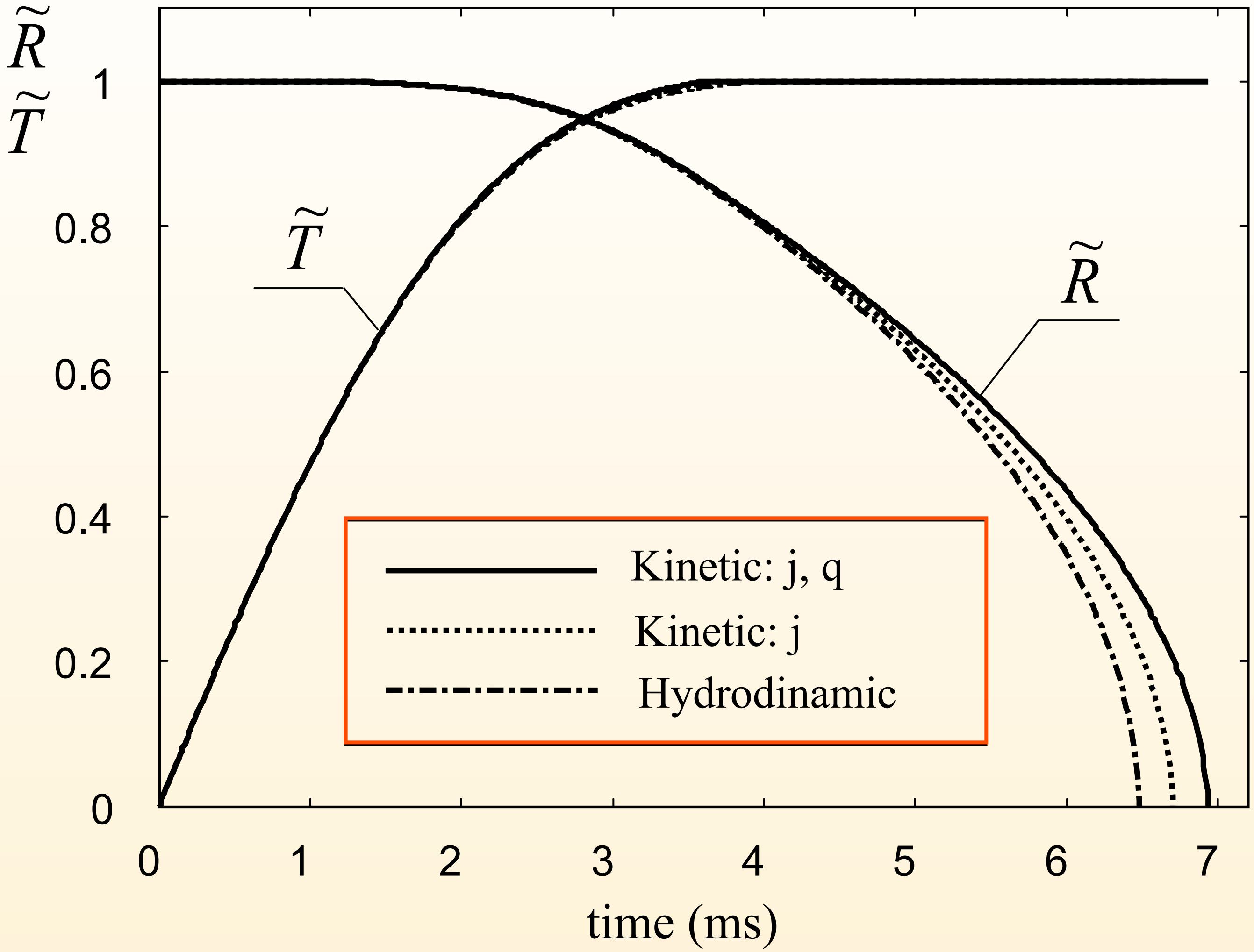
$$R_{d0} = 5\,\mu\text{m};\ T_g = 750\,K;\ \tilde{R} = R_d / R_{d0};\ \tilde{T} = (T_s - T_{s0})/(T_{cr} - T_{s0})$$



$$R_{d0} = 5\,\mu\text{m};\;\; T_g = 1000\,K;\;\; \widetilde{R} = R_d / R_{d0};\;\; \widetilde{T} = (T_s - T_{s0})/(T_{cr} - T_{s0})$$



$$R_{d0} = 5\,\mu\text{m};\quad T_g = 1500\,K;\quad \tilde{R} = R_d / R_{d0};\quad \tilde{T} = (T_s - T_{s0})/(T_{cr} - T_{s0})$$



$$R_{d0} = 20\,\mu\text{m};\;\; T_g = 1500\,K;\;\; \tilde{R} = R_d / R_{d0};\;\; \tilde{T} = (T_s - T_{s0})/(T_{cr} - T_{s0})$$

# Conclusions

- A new kinetic model for droplet heating and evaporation into a high pressure background gas (air) is suggested. This model is based on the introduction of the kinetic region around evaporating droplets, where the dynamics of molecules is described in terms of the Boltzmann equations for vapour and air. Both mass and heat transfer processes in this region are taken into account.

- The model is applied to calculation of heating and evaporation of fuel droplets in Diesel engine-like conditions.

- The kinetic effects are important in the case when the gas temperature raises to 1000 K and 1500 K. In this case, for droplets with initial radii 5 μm the predicted evaporation time in the presence of the heat flux in the kinetic region is about 14% longer than predicted by the hydrodynamic model.

# Unsolved problems

- The value of the evaporation coefficient
- The contribution of inelastic collisions
- The validity of the Boltzmann equation for dense gas

# **Thank you for your attention**

*Any comments or suggestions*

*would  be highly appreciated*

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