MULTI-SCALE CONDENSATION IN IMPACT-PRODUCED VAPOR CLOUDS. D. de Niem, *Institute of Space Sensor Technology and Planetary Exploration, German Aerospace Center, Berlin, Germany, (detlef.deniem@dlr.de)*.

In hypervelocity impacts of asteroids or comets on the surface of a planetary body, depending on the impact velocity, part or all of the projectile material and some of the target material can be vaporized and expands as a dense gas cloud [6, 8]. Purely hydrodynamic treatment using an equation of state valid for thermodynamic equilibrium [9] does not cover the case when the vapor is quenched into a metastable state before condensation sets in. During the expansion, density and pressure fall by many orders of magnitude, making it difficult to treat the process with conventional hydrodynamic algorithms. Here, for expansion into vaccuum, an analytical solution due to Zeldovich and Raizer [3] is used to approximate hydrodynamics. In the presence of an atmosphere, a numerical solution based on a second-order accurate Godunov method with van der Waal's equation of state is constructed.

After the poineering work of Raizer [1] who investigated the fate of condensation products of an iron meteroite expanding into vacuum, only few authors have studied the problem of condensation in impacts (e.g. O'Keefe and Ahrens [2]). Qualitatively, the main theoretical results of Raizer stayed unchanged. The conventional view of the order of events during condensation is as follows (see [3], e. g.):

- the adiabate of the vapor reaches the coexistence curve, the vapor becomes saturated, further expansion along the gas adiabate leads to supercooling
- at some critical degree of supercooling, the nucleation rate becomes high enough that a large number of critical nuclei of the new phase forms
- nucleation terminates, and clusters grow into droplets of macroscopic dimensions, the gas pressure drops
- at some moment, the flux of molecules at the surface of the droplets is so low that the degree of condensation freezes, a non-zero mass fraction of gas remaining

In this work, a numerical solution of the kinetic equations for moments of the size distribution of growing droplets and of the energy equation is presented. It is demonstrated that the above order of events is a too simplistic scenario and that nucleation events in impact-generated vapor appear several times at different temporal and spatial scales. The degree of supercooling follows a complicated oscillating pattern on a logarithmic time scale, see fig. 1. In this way, several 'generations' of droplets are formed, with very different final dimensions. The distribution of sizes such is no more dominated by a single scale, but rather characterized by several 'generations' of droplets of different characteristic sizes (each time a new 'generation' appears, the r.m.s. size of droplets decreases, because the older and large drops are outnumbered by finer, newly-formed droplets, see fig. 2).

Thermodynamic conditions at the moment of the various nucleation events are very different, in terms of temperatures

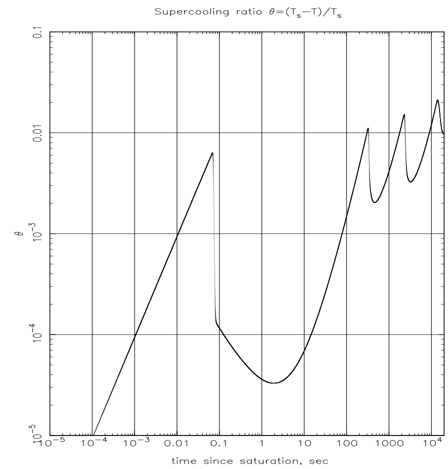

Figure 1:

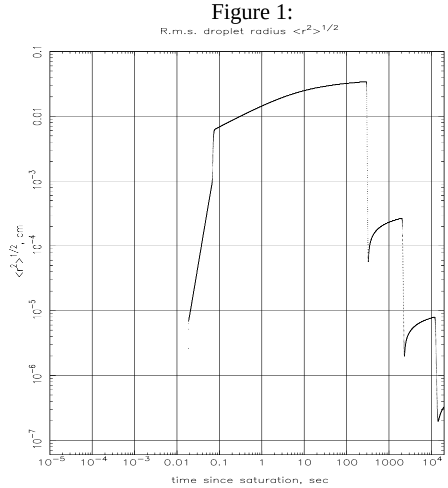

Figure 2:

and pressures. The density distribution is the only input required for the kinetics and adiabatic evolution of the liquid-vapor mixture, since no back-reaction of condensation on hydrodynamics is assumed. This is justified, if the degree of condensation reaches large values at rather late times, only. If an atmosphere exists, more detailled considerations are necessary because of the density gradient in the atmosphere and the role played by the atmospheric shock. Condensation begins in a layer near the boundary of the original vapor material with the swept-up atmospheric gas (the shock wave is travelling ahead of this zone). The geometry of shock-wave propagation in the atmosphere is complicated (see fig. 3), because the vertical density gradient hinders lateral propagation and leads to acceleration vertically upward, see Newman et al. [7], e. g. Here, Lagrangean tracer particles are used to derive the comoving mass density and the temperature where the coexistence curve is crossed, these variables being the input for the nucleation kinetics, and no back-reaction of condensation on the further hydrodynamic evolution is assumed. No detailled model for the release of gases in the course of crater formation is made, however, since the density and pressure scales in the crater and in the expanding vapor are too different to allow a combined treatment. Results are available for different sizes of impactors, to investigate scaling properties. The kinetic equations used here follow from the classical Becker-Döring-Zeldovich theory of nucleation (e.g. Frenkel [4], or Abraham, [5]). A system of ordinary differential equations is obtained, that gives the time evolution of the degree of condensation and of several moments of the droplet size distribution. The kinetic equations are in a form that allows to incorporate more general droplet models (other than the capillarity approximation used by Zeldovich and Raizer [3]).

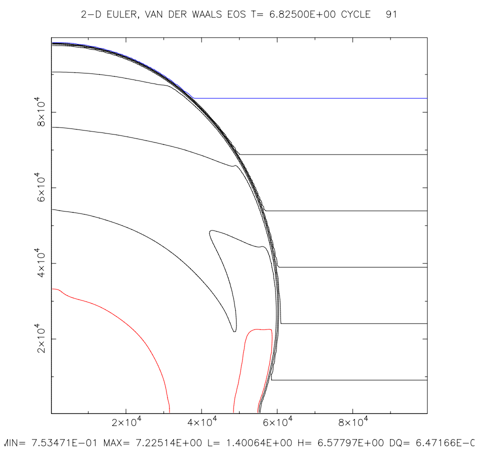

Figure 3: Logarithmic pressure contours, at $t = 6.825s$. $log_{10}P$ in Pascal. Contour interval $\sim$ factor of 4.4377. Initial conditions: uniform hemisphere of 5 km radius, specific energy corresponding to [9], isothermal (exponential) atmosphere. Note the excellent resolution of the shock wave by the Godunov method.

References

[1] Raizer, Yu. P. 1959: *On Condensation of a cloud of vaporous matter expanding into vacuum. Soviet Phys. JETP 37 No. 12 ,1741-1750.*

[2] O'Keefe, J. D., Ahrens, T. J. 1982: *The interaction of the Cretaceous/Tertiary extinction bolide with the atmosphere, ocean and solid earth, Geol. Soc. Amer. Special Papers, 103-120.*

[3] Zeldovich, Ya. B. , Raizer, Yu. P.: *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena, Academic Press, New York, San Francisco, London, 1967.*

[4] Frenkel, Ya. I.: *Kinetic theory of liquids. Oxford University Press, 1946.*

[5] Abraham, F. F.: *Homogeneous Nucleation Theory. Advances in Theoretical Chemistry, Supplement 1, Academic Press, New York, London, 1974.*

[6] Melosh, H. J.: *Impact Cratering. A Geological Process. Oxford University Press, 1989.*

[7] Newman, W. I., Symbalisty, E. M. D., Ahrens, T. J., and Johnes, E. M. 1999: *Impact Erosion of Planetary Atmospheres: Some Surprising Results. Icarus 138, 224-240.*

[8] Pierazzo, E., Kring, D.A., Melosh, H. J. 1998: *Hydrocode Simulation of the Chicxulub impact event and the production of climatically active gases. J. Geophys. Res. 103, 28607-28626.*

[9] Melosh, H. J., Pierazzo, E. 1997: *Impact vapor plume expansion with realistic geometry and equation of state. 28th Ann. Lunar and Planet. Sc. Conf., p. 935.*