

Interactive comment on “On condensational growth of clusters and nanoparticles in sub-10 nm size range” by T. Nieminen et al.

T. Nieminen et al.

tuomo.nieminen@helsinki.fi

Received and published: 30 April 2010

We thank the referee for his comments and suggestions on improving the manuscript. Our response to the comments are given below. In this response all references to equation numbers etc. are based on the manuscript version published in ACPD (not the revised manuscript).

The key point of the paper is interesting and publishable, but the paper should not be more than a short note. It should be shortened significantly. Also, there are some misleading statements that need to be corrected.

We have moved the material related to Equations 3–8 in section 2.1 into Appendix in the revised version of the manuscript. This shortens the main text, while still leaving

C2278

the necessary details easily available for the reader.

What I found most interesting about this paper is that the effect of neglecting the size of the condensing molecule is larger and extends to larger sizes than I expected. I would think that this point should be emphasized in both the abstract and conclusions. I suspect that underestimating the errors due to the usual approximation is a factor in its continued use. The title should be reconsidered with this in mind. The present title is uninformative and a bit redundant.

We revised the title to “Sub-10 nm particle growth by vapor condensation - effects of vapor molecule size and particle diffusional motion”.

The abstract and the heading for section 2.1 refer to an “exact” solution. But equation (1) is not exact. It is based on the assumption of hard, unpolarizable spheres. When dispersion forces are taken into account, there is a more complex dependence on both particle size and collision energy. Also, the use of condensed phase density to estimate the size of a single molecule is not exact and most molecules are not spheres. I am not asking that these factors be included, only that it be acknowledged that the equations used are still not exact.

We agree with referee that our equation is not exact in the strictest sense. Therefore we modified the heading of section 2.1 and the abstract accordingly. The heading 2.1 is revised to “Equation for particle growth rate due to vapor condensation”. We also added an explanation of the assumptions made into the beginning of section 2.1: “Here we derive an expression for the particle diameter growth rate resulting from condensation of single component vapor. We assume the particle to be spherical, and do not take into account any interaction forces between the particle and vapor molecules.”

There is no need for equation (10). Equation (11) can be obtained much more directly from equation (9). In proceeding from equation (9) to the usual simplified expression, two approximations are made: replacing the collision diameter with the particle diameter and replacing the reduced mass with the vapor molecule mass. If only the second

C2279

approximation is made, one immediately obtains equation (11) from equation (9). The approximation to the reduced mass made in obtaining equation (10) results in a cubic term that is dropped in passing to equation (11). The justification for not using reduced mass is simple. For the conditions referred to in the text preceding equation (11) (equal densities, $dv = 0.2 \cdot dp$ and $dv = 0.5 \cdot dp$), the errors in neglecting $1/mp$ in equation (9) are, respectively, 0.4% and 6.1%. The errors given in the text, 0.6% and 9.4%, seem to be overstated as a result of comparing one approximation to another (it looks like the errors in the two approximations are in opposite directions).

We agree with the referee that there are also other ways of deriving the approximation in Equation 11. However, we decided to retain our original derivation and error analysis leading to Equation 11.

The claim is made, both in the abstract and at the end of section 2, that the equation used here accounts for particle motion. As explained above, it does not. It only accounts for the effect of the size of the condensing molecule. This claim must be corrected.

It is true that Equation 11 (which is referred to as an approximate analytical expression in the abstract) doesn't account for the particle motion anymore, as in the derivation this effect is shown to be quite small even in the sub-10 nm size range. However, in Equation 9 (which is the starting point of our approximation leading to Equation 12) both the vapor molecule size and particle diffusional motion are accounted for. We revised the text in the abstract accordingly, stating that from the two effects discussed in this work the effect of particle diffusional motion is much smaller than the effect of vapor molecule size.

Equation (9) includes a Fuch-Sutugin correction factor, γ , and this is retained in equation (12), creating the false impression that equation (12) is not restricted to the kinetic limit. But γ is treated as a constant in doing the integration; this is only true in the kinetic limit. So γ in equation (12) should be replaced with the mass

C2280

accommodation coefficient. Doing so does not reduce the utility of the result, since the effect would seem to be of interest only of concern in the kinetic limit.

The referee is correct that γ introduced in Equation 5 is not constant. However, for particle sizes below 100 nm it does not differ considerably from the mass accommodation coefficient (which has been assumed unity in this manuscript). We replaced γ with mass accommodation coefficient in Equation 12, as this approximate equation is derived for particle size smaller than 10 nm.

Equations (2) through (8) should be deleted since they ultimately serve no purpose in this paper. I don't see the point of including equation (13). It adds no insight and it does not seem to be used.

We moved the material related to Equations 3–8 into Appendix in the revised manuscript. This way the reader can still easily access the necessary details in these equations. Equation 13 is an earlier relation between condensable vapor concentration and particle growth time, published by Kulmala (1988). It is used in Table 1 of this manuscript when comparing the results of this work and the previously used approaches.

Figures 4 through 7 don't add anything important and get in the way of the main point. The conclusion from Figure (4) that "The highest growth rate is obtained when the condensing vapor has a large molecule mass and a small liquid phase density" is obvious from inspection of either equation (9) or the standard formulation. Figure 5(a) would be interesting if the maximum is real and if an explanation were provided for it. But I think it must be an error. If the core is unchanged, only its size should matter, not its mass (since particle motion has been neglected). Figures (6) and (7) add little, as indicated by the perfunctory discussion of them.

We decided to remove Figures 4b and 5–8 from the revised manuscript, in order to keep the manuscript more focused on the enhancing effect on particle growth rates of including vapor molecule size and particle diffusional motion.

C2281

C2282