

### **Detail Reply to the reviewers' comments**

Thanks for the reviewers' comments and constructive suggestions. We appreciate the time and effort all the reviewers put into reviewing our manuscript. We have revised the original manuscript according to the comments given. For easy tracking, we colored the revision according to reviewers: red for referee #1 blue for referee #2 and purple color for last referee Dr. Michel Attoui.

#### **Referee #1 :**

\*I am still unclear about how the multiphysics modeling in COMSOL was complemented by MATLAB. There is not just one trajectory of particles entering and leaving the CPC but the particle flux density into the CPC follows the flow velocity profile. Was MATLAB used for an ensemble of released particles? Was it done in a different way? In understand COMSOL is capable to represent particles that change their physical properties during their travel through the system. Why were the particles not modeled fully within COMSOL.

#### **Reply:**

Thank you for pointing it out. In our study, COMSOL was used to calculate the steady-state velocity, temperature and vapor concentration fields in the flow channels of sMCPC. The local transport and thermodynamic conditions experienced by particles during their growth process can be found from the calculated fields. Instead of using COMSOL itself, MATLAB was used to solve the growth and trajectories of particles when they were transported through the fields.

The counting efficiency of sMCPC was not derived either from a single discrete particle trajectory, or from explicitly tracking an ensemble of individual particles. Instead, particle flux at the CPC's inlet were represented in a continuous manner through the radial velocity distribution  $w(r)$  and the particle concentration distribution  $N(r)$ . The product,  $w(r)N(r)$ , gives the local particle number flux density. The activation/counting efficiency was then obtained by integrating the activated particle flux over the corresponding inlet radial range.

We did not use COMSOL to model the growth of particles because of the continuous coupling of particles with the velocity, temperature and vapor concentration fields. The coupling substantially increases both the model complexity and computational time, especially for reported parametric investigation.

To clarify this point, we revised the original manuscript to explicitly describe how the particle activation/counting efficiency was calculated from the flux-weighted integration, rather than from explicit tracking of individual particles. The revised text, in L212-217, now reads as follows:

In this study, COMSOL Multiphysics and MATLAB were used to calculate the activation and condensational growth of particles in sMCPC. COMSOL was first employed to obtain the steady-state velocity, temperature, and vapor concentration fields in the flow channels of sMCPC, from which the local thermodynamic and transport conditions can be obtained for the particle growth. With the resolved fields, MATLAB was then used to solve the particle growth equations (Eqs. 5–9). The adoption of this combined approach was primarily to save the computational time for efficiency calculation.

\*Figure 2 has a lot of white space at the moment; the data are only a detail. Please explore showing the results more clearly. A panel that stretches the information horizontally (a zoom in horizontal direction only) could be a viable option. The labels of the color legend should be enlarged.

Reply:

Thank you for the suggestion. Accordingly, we revised Figure 2 to improve its clarity and readability.

\*I appreciate the model verification regarding the mesh quality and the external corroboration with measured temperatures. While further comparison to experimental data would be welcome, I am convinced about the general value of the developed model.

Reply:

Thank you for your positive comments on the mesh-quality verification and the corroboration with measured temperatures. Your recognition of the overall value of the developed model is very appreciated.

**Referee #2:**

\*In the current manuscript it is not clear how the solved fields from the COMSOL simulations have been transformed into counting efficiency curves. In the conclusion, the authors mention that it is calculated from particle trajectories, but it remains unclear how this was done.

Reply:

We appreciate the comment. Accordingly, we included the detail description in the revised manuscript.

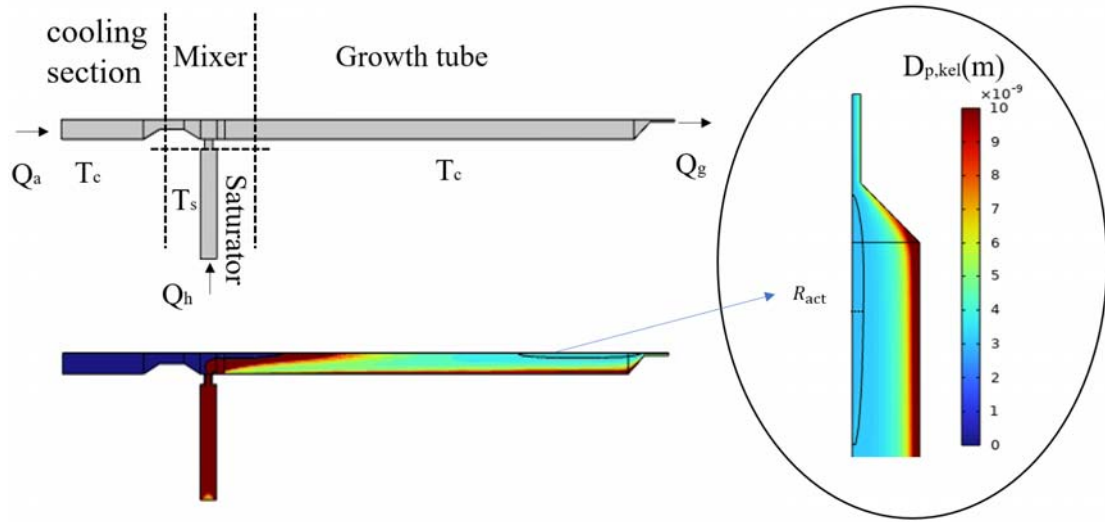
In this work, COMSOL was first applied to obtain the velocity, temperature and vapor concentration fields in the flow channel of sMCPC. The local supersaturation distribution was then determined from the calculated fields. From the local supersaturation distribution, the minimum activation diameter  $D_{p, \text{kel}}$  was calculated by Eq. (2). This parameter defines the activation condition for the particle growth at each location in the flow channel of sMCPC.

$$D_{p, \text{kel}} = \frac{4\sigma v_m}{k_b T \ln S_r} \quad (2)$$

The activation region was further identified as the region where the growth of particles with a given diameter can be activated, and the corresponding radial boundary of this region,  $R_{\text{act}}$ , represents the outermost radial position within which the particle growth can be activated (illustrated in Fig. 2).

The counting efficiency of sMCPC was lastly determined by the integration of particle number flux over the activated region. Specifically, the activation efficiency was calculated by Eq. (3):

$$\eta_{\text{act}} = \frac{\int_0^{R_{\text{act}}} 2\pi r w(r) N(r) dr}{Q_a N_0} \quad (3)$$



**Figure 2.** Computational domain for modeling the sMCPC performance and a typical distribution of the equilibrium Kelvin-diameter

where  $w(r)$  is the axial velocity profile and  $N(r)$  is the local particle number concentration. The product,  $w(r)N(r)$ , gives the local particle number flux density. The radial integration over the activated region corresponds to the total activated particle flux. The CPC's counting efficiency curve is, therefore, not either calculated from a single discrete particle trajectory, or from an ensemble of particle transport.

To clarify this point, we revised the original manuscript to provide an explicit description on how the counting efficiency curves were calculated from COMSOL-resolved fields. The revised text in L148–156 now reads as follows:

The counting efficiency was derived from the COMSOL-resolved fields by the flux-based method. In the method, the local supersaturation distribution was first obtained from the calculated temperature and vapor concentration fields. The corresponding minimum activation diameter  $D_{p, kel}$  was then calculated using Eq. (2). The activation region for the particle growth was identified as the region, defined by the outermost radius,  $R_{act}$ , in which the growth of particles in a given size can be activated. Assuming that particles entering this region undergo condensational growth, the activation efficiency was calculated by integrating the particle number flux over the activated region by Eq. (3). Note that local particle flux, which is the product of the axial velocity profile  $w(r)$  and the local particle concentration  $N(r)$ , is used in Eq. (3).

\*The authors give a homogeneous nucleation equation which they claim to use for the calculation of the homogenous background in the CPC. They do not report any values of this later on and even more importantly; it is typically well known that homogenous nucleation rates from classical nucleation theory by far underestimate the real nucleation rates. It is therefore not clear if CPCs under the tested temperature conditions would be feasible or suffer from high background.

Reply:

Thank you for the comment. Indeed, homogeneous nucleation shall be avoided in the CPC operation and the nucleation rates estimated by the classical nucleation theory underestimate the rates in practice.

The main objective of this study is to investigate the particle activation and condensational growth behavior in the sMCPC. The inclusion of homogeneous nucleation rate calculation in our modeling is to offer the general guidance for the selection and limit of the temperature settings for sMCPC. Neither was the homogeneous nucleation rate the focus of our modeling, nor was it used to accurately predict the CPC background. The exact temperature setting will be experimentally determined.

Accordingly, we revised the description to clarify the limited role of the homogeneous nucleation analysis in the present study. The revised text in L170–173 now reads as follows:

*I is the local homogeneous nucleation rate to evaluate the risk of self-nucleation under different temperature settings. Note that the homogeneous nucleation analysis in the modeling is to offer the general guideline for the temperature setting range in sMCPC operation, not to accurately predict the nucleation rate.*

\*It is not clear if the sMCPC which is simulated here corresponds to a real-world instrument or not. As it seems that the simulated sMCPC is not a commercially available instrument, geometric considerations would also be a big added value to this study. What happens in the simulations when the dimensions of the instrument are slightly

varied? In addition, I wanted to remark that the authors cite a pending patent application from China. If so, the involved co-author should specify his conflict of interest.

Reply:

Thanks for your comment. During the conduction of this modeling work, the prototype sMCPC was not available. The objective of this work is to establish a general guideline for the R&D of sMCPC, not to reproduce the performance of a specific CPC commercially available.

For this study, we simply constructed a simplified prototype using the key dimensions of sMCPC studied in this work for the model validation. A good agreement between the modeled and measured temperature distributions was obtained. We are currently working on the development of sMCPC prototypes. We will be happy to present the experimental performance of sMCPC once its development is complete.

This work is focused on analyzing the potential performance of sMCPC under different operational conditions, not to promote any commercial or existed CPC. Regarding the cited patent, the inventors are major authors of this manuscript, and this relationship has been disclosed for transparency.

Under the above-stated circumstances, we don't think the issue of conflict-of-interest exists. We would be happy to provide the formal conflict-of-interest statement if it is required by the journal.

\*Line 59: The authors cite Vanhanen et al. (2011) here, but the PSM is not a laminar-flow CPC. They cite it in the next paragraph again correctly, so I would modify the statement here.

Reply:

Thank you for pointing this one out. Accordingly, we deleted the citing Vanhanen et al. (2011) from Line 59.

\*Line 63: I would end the paragraph with some word on the usage of other working fluids in CPCs (especially as testing different working fluids is a major result of the

manuscript). There have been many new developments in that area e.g. Wlasits et al. (2024)

Reply:

Thanks for this suggestion. We agree that recent developments on alternative working fluids in CPCs are highly relevant to this work. Accordingly, we have added a discussion at the end of the paragraph and included a reference to Wlasits et al. (2024), which highlights the influence of working fluid selection on CPC performance.

The revised text in L61–63 now reads as follows:

Recent studies have also demonstrated that the choice of working fluid can significantly influence the CPC performance, particularly in reducing composition-dependent counting efficiencies (Wlasits et al., 2024).

\*Line 77: What does “offer enhanced mixing” mean?

Reply:

We appreciate the reviewer’s request for clarification. The term of “enhanced mixing” in the original manuscript was not clearly defined and has now been clarified.

In a MCPC, “enhanced mixing” refers to the intensified convective mixing of both aerosol and vapor flows in a confined space. Compared with laminar flow CPCs, where heat and mass transfer are primarily governed by diffusion across flow layers, a MCPC promotes rapid interaction of two streams due to strong velocity gradients and impingement. As a result, a MCPC enables faster establishment of supersaturation conditions required for the particle activation than laminar flow CPCs. Therefore, “enhanced mixing” in this context specifically describes the increased efficiency of heat and mass transfer processes.

To clarify this point, we revised the manuscript accordingly. The revised text in L76-81 now reads as follows:

Compared with laminar flow CPCs, MCPCs enhance convective mixing between the aerosol and vapor streams, which promotes heat and mass transfer and facilitates fast establishment of supersaturation conditions required for particle activation. In addition,

the reduced particle residence time prior to growth would suppress the particle loss due to Brownian diffusion and reduce counting errors associated with wall condensation (Sgro & de la Mora, 2003).

\*Line 93: Introduce the abbreviation sMCPC here.

Reply:

Thanks. The abbreviation “sMCPC” is now defined at its first occurrence in the manuscript (Line 98).

\*Line 309: “It is attributed to the elevated vapor pressure results in the enhanced vapor loss at the high temperature”. Not quite clear to me what the authors want to say here. Please try to reformulate.

Reply:

Thank you for the comment. Accordingly, we clarify it as the following (L343-347):

For the cases with the same temperature difference ( $\Delta T = 35^\circ\text{C}$ ), increasing both  $T_s$  and  $T_c$  leads to a reduction in the maximum supersaturation. This is because, although the local vapor pressure  $p$  was increased by increasing the temperature setting, it significantly increased the saturation vapor  $p_s(T)$  at the same time. The increase in  $p_s(T)$  outweighs the increase in  $p$ , resulting in the decrease of supersaturation ratio.

\*Line 309-316: This is similar to what Barmounis et al. (2017) and Wlasits et al. (2020) found for laminar flow types. Could be mentioned here.

Reply:

Thank you for the suggestion. We agree that the observed trend for sMCPC shows qualitative consistency with that reported in previous studies on laminar flow CPCs (Barmounis et al., 2017; Wlasits et al., 2020). However, the sMCPC convectively mixes the hot vapor of working fluid with cool aerosol flow. The supersaturation ratio created by the convective mixing would be different from those in laminar flow CPCs. Therefore, the above consistency is in general trend, not in quantitative equivalence.

To address the comment, we have revised the manuscript to include the suggested references and to clarify the difference between the sMCPC results and previous laminar CPC studies.

The revised text in L353–355 now reads as follows:

The observed trend is qualitatively consistent with that reported in previous studies on laminar flow CPCs (Barmounis et al., 2017; Wlasits et al., 2020) although the studied sMCPC involves convective mixing processes, which is different from that in laminar CPCs.

\*Line 329: The authors speak of a broadening of the effective activation zone. This is not shown. In general, radial distributions such as in Fig. 2 could be helpful to understand better why the curves are sometimes steeper and sometimes are not.

Reply:

Thank you for this valuable comment. Accordingly, we have included a new Fig. 8 to show the difference in the activation regions of particles in the same diameter under different temperature settings. The new figure shows that by increasing the temperature difference from  $T_s = 35\text{ }^{\circ}\text{C}$  and  $T_c = 5\text{ }^{\circ}\text{C}$  to  $T_s = 40\text{ }^{\circ}\text{C}$  and  $T_c = 5\text{ }^{\circ}\text{C}$ , the activation region was enlarged, which provides direct explanation for the steepness change of the activation curves. The corresponding discussion has been revised accordingly (L371-379).

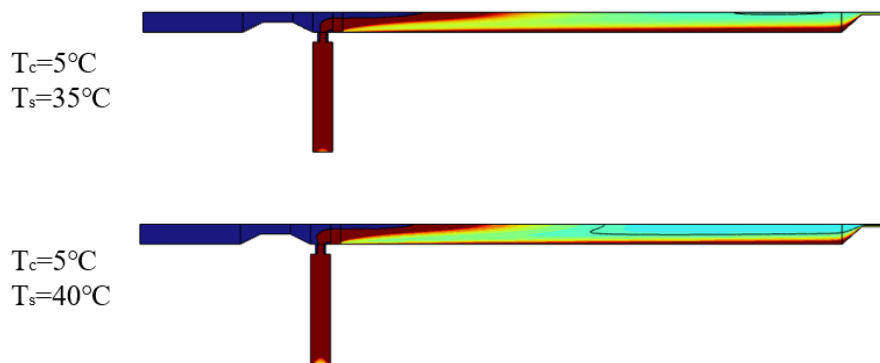


Figure 8. Comparison of activation regions for particles with the same diameter in the sMCPC under different temperature settings

\*7.: The steepness of the activation curves is what makes MCPCs in my opinion valuable compared to laminar flow type CPCs. This should become very clear in this manuscript and could be further emphasized (supported by the above mentioned 2D considerations) and a proper explanation on how the activation curves were obtained (see major comment).

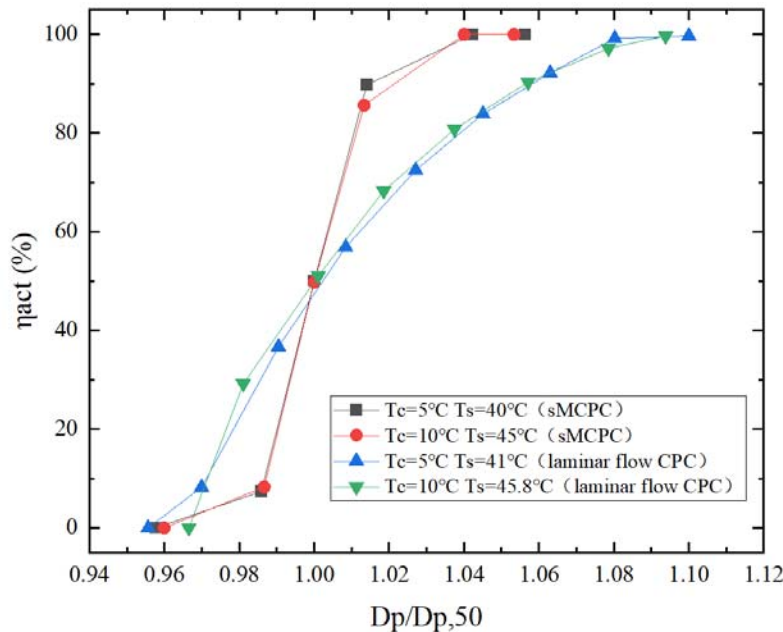
Reply:

Thank you for the comment. Accordingly, we have added a separate subsection in the revised manuscript to directly compare the calculated activation efficiency curves of the sMCPC and laminar-flow CPCs. In this new subsection, the steeper transition of the sMCPC activation curve and its implication for particle activation behavior are emphasized and discussed.

The detailed procedure used to obtain the activation curves has also been clarified in our response to the major comment concerning the transformation of the COMSOL-resolved fields into counting-efficiency curves.

The revised text in L471–484 now reads as follows:

### 3.4 Comparison of $\eta_{act}$ between the sMCPC and laminar flow CPC



**Figure 13.** Comparison of the activation efficiency curves for sMCPC and laminar flow CPC

As shown in **Fig. 13**, the activation efficiency curves of the sMCPC were compared

with the laminar flow CPC data, reported by Hao et al. (2021), (as a function of  $D_p/D_{p,50}$ ). The sMCPC activation curves exhibited steeper change in the vicinity of  $D_p/D_{p,50} \approx 1$  than the laminar-flow CPC curves, indicating that the activation of particle growth in laminar flow CPCs occurred over a wider size range compared to that of sMCPC and demonstrating the difference in the transition characteristics from non-activated particles to fully activated particles between the two types of CPCs. By comparison with laminar flow CPCs, the sMCPC showed a narrower activation transition region and a sharper activation cutoff. This modeling result indicates that the sMCPC can provide a more efficient activation environment near the critical activation diameter than a laminar flow CPC, which offers a higher size resolution.

\*6: What is Z0 on the x-axis?

Reply:

We thank the reviewer for pointing this out. The notation “Z/Z<sub>0</sub>” was not clearly defined in the manuscript. In the revised manuscript, it has been replaced by “Z (mm)”, which represents the axial distance along the flow direction measured from the inlet of the cooling section.

\*Line 402-406: The lower saturation vapor pressure of some working fluids however has the advantage that the Delta T can be even more enhanced (see the standard PSM settings), which at least for the PSM enables the detection well below 2 nm. This could be discussed here or even tested.

Reply:

We thank the reviewer for this insightful comment. A working fluid with low saturation vapor pressure allows for large temperature differences ( $\Delta T$ ), which is beneficial for enhancing the supersaturation and has been applied in instruments such as the PSM for detecting sub-2 nm particles.

The present work, however, focuses on the design of a compact sMCPC, where practical constraints need to be considered. In particular, increasing  $\Delta T$  significantly

would lead to high energy consumption and, more importantly, the high  $\Delta T$  would be very challenging to realize in a miniature configuration of sMCPC due to the limited room for thermal insulation. These factors limit the extent to which  $\Delta T$  can be increased in practice.

For these reasons, the present study considers a range of operating conditions that are representative of practical compact sMCPC designs.

**Michel Attoui:**

\*This versatile tool will certainly be of great value to the mixing instrument community. It represents, to my knowledge, the first functional turbulent mixing CPC with a cold growth tube, whereas previous efforts have largely focused on laminar models. I suggest, however, that the authors cite the work of Fisenko et al. (2007): <https://doi.org/10.1016/j.ijheatmasstransfer.2006.10.046>

Reply:

Thank you for this positive evaluation and for drawing our attention to the relevant study. Accordingly, the revised text in L91–96 now reads as follows:

However, most previous modeling studies have focused on laminar-flow CPCs, while studies specifically addressing the performance of mixing-type CPCs remain limited. A related work is on mixed-flow particle magnifiers (Fisenko et al., 2007). In the work, vapor condensation and heterogeneous droplet growth were analyzed, highlighting the roles of mixing, supersaturation formation, and transport processes in the determination of instrument performance.

\*The authors should clearly distinguish between the mixing chamber (characterized by turbulent flow) and the cooled down growth tube (laminar conditions) throughout the manuscript, rather than using the generic term 'MCPC'. As the MCPC is a combination

of both components, precise terminology is essential for clarity. Furthermore, strictly speaking, a mixing CPC is not followed by a cold tube (see Wang et al.2002 cited in the paper and Wehner et al., 2011: <https://doi.org/10.5194/amt-4-823-2011>).

Reply:

Thank you for this comment. Accordingly, we have revised the relevant descriptions throughout the manuscript to clearly distinguish between the mixing chamber and the growth tube, rather than using the generic term “MCPC”. The corresponding text has also been modified accordingly for improving the clarity and accuracy.

\*The air is assumed to be saturated upon entering the mixing chamber. The saturator schematic lacks clarity; specifically, the purpose of the central hatched area should be defined. Furthermore, unlike the sample line and growth tube, the mixing chamber appears to lack temperature control. Is it thermally isolated (adiabatic mixing) from the environment and from the other parts of the CPC?

Reply:

Thank you for this valuable comment. In the revised manuscript, we have improved the clarity of Fig. 1 by adding annotations to the hatched region in the saturator. This hatched central area represents the porous media containing the working fluid, whose function is to provide sufficient liquid–gas contact area so that the carrier gas can be saturated before entering the mixing chamber.

In addition, the annular regions surrounding both the saturator and the mixing chamber are heated and thermally insulated to maintain the required thermal conditions. The mixing chamber is not directly exposed to the ambient. Instead, it is thermally isolated from both the cooling section and the growth tube. Therefore, the mixing process in this region occurs under a thermal-protected condition, which minimizes undesired heat exchange with adjacent components and its surroundings.

We have clarified these points in the revised figure.

\*Line 78: I would suggest using '**minimize**' instead of '**suppress**' regarding diffusion

losses, as these losses can be reduced but rarely eliminated entirely.

Reply:

Thanks. We have revised it (Line 79).

\*Line 40: The parameter  $R_{act}$  within the integral is difficult to interpret, define, or calculate. Could you clarify how it is determined? Further details would be greatly appreciated

Reply:

Thank you for the question. The parameter  $R_{act}$  represents the outermost radial boundary of the activation region in the sMCPC. In this work, Eq. (2) was used to determine the spatial region where particles with a given Kelvin diameter can be activated (as illustrated in Fig. 2). Based on the COMSOL-resolved field distribution, the boundary of this activation region can be directly identified, and  $R_{act}$  is defined as the maximum radial coordinate  $r$  of that region. In other words, it corresponds to the outermost radial position at which particle activation can occur under a specific condition studied.

\*Line 154: The mathematical definition of the integral of over the chamber volume is unclear. Specifically, could you clarify the functional relationship between the nucleation rate and the spatial coordinates of the chamber? Furthermore, please distinguish between the local nucleation rate (per unit volume) and the total (integrated) nucleation rate. It would also be helpful to explicitly state the differential element ( $dV$ ) used in the expression.

Reply:

Thank you for the comment. In this study, the quantity  $I$  in Eq. (4) was used to calculate the local homogeneous nucleation rate to assess the likelihood of homogeneous nucleation under a given temperature setting. We did not integrate the local nucleation rate over the entire chamber volume. Accordingly, we have revised the corresponding text in the manuscript to clarify this point:

The revised text in L170–173 now reads as follows:

Here,  $I$  is the local homogeneous nucleation rate to evaluate the risk of homogeneous nucleation under different temperature settings. In this study, homogeneous nucleation analysis is used as the reference for the selection of the temperature settings.

\*Line 162 :  $D_v$  the diffusion coefficient of the vapor molecules appears in equation 5 but not in the list of symbols. The list of symbols gives the *diffusivity*.

Reply:

Thank you for your comment. The symbol  $D_v$ , representing the diffusion coefficient (diffusivity) of working fluid vapor molecules, has already been defined in the Symbols List at Line 649 and is used in Eq. (5).

\*Line 164: in the text  $p$  is the surrounding vapor pressure. In the list of symbols:  $P$  is the partial pressure of the condensing vapor [Pa]. Can you clarify?

Reply:

Thank you for this comment. In the present study, the “surrounding vapor pressure” in the text and the “partial pressure of the condensing vapor” listed in the Symbols List refer to the same physical quantity. To avoid confusion, we have revised the wording in the manuscript accordingly (Line 183).

\*Line 165: Same thing for  $p_d$ . Please choose one name or definition in the text and in the list of symbols.

Reply:

Thank you for this comment. The definition of  $p_d$  has been revised and unified in both the main text and the Symbols List for consistency (line 184).

\*Ligne 174: Could you please clarify the purpose of Equation 8? It defines the droplet surface temperature ( $T_d$ ), yet this value is neither calculated nor utilized elsewhere in

the text. Is it related to potential droplet evaporation? It needs some clarification. The temperature of the flow  $T$  in the same equation requires further clarification too. What is the value of  $T$  since the axial temperature profile is not constant?

Reply:

Thank you for this question. Eqs. (5-9) are solved together to model the growth of particles. The particle diameter  $D_p$ , the droplet surface temperature  $T_d$ , and the particle location are calculated in a coupled manner. Eq. (8) is used to calculate the droplet surface temperature which could evolve along with the particle growth, rather than being simply assumed to be equal to the surrounding gas temperature. The value of  $T_d$  is then used in Eq. (6) to determine the equilibrium vapor pressure at the droplet surface.

Eq. (8) is not specifically introduced to describe the droplet evaporation, but to account for the thermal state of a growing droplet during condensation. Regarding the temperature  $T$  in Eq. (8), it represents the local gas temperature surrounding the particle (i.e., away from the particle surface). This temperature is not constant along the axial direction. In our calculation,  $T$  is obtained from the COMSOL-calculated temperature field. In other words, particles at different locations in the flow channel are with different local gas temperatures.

To avoid confusion, we have revised the text to clarify that Eqs. (5-9) are coupled and solved, and that  $T$  in Eq. (8) denotes the local gas temperature, position-dependent, obtained from the COMSOL temperature field.

The revised text in L189–195 now reads as follows:

To account for heat transfer during condensational growth, the droplet surface temperature ( $T_d$ ) is introduced herein and calculated together with the particle growth, Eq. (5). Because the latent heat is released during vapor condensation and exchanged between the droplet surface and the surrounding gas ( $T$ ), the droplet surface temperature,  $T_d$ , would not be equal to the local gas temperature (away from the droplet surface). The evolution of  $T_d$  is therefore described by an energy conservation equation that considers both the latent heat of condensation and conductive heat transfer between the droplet and the surrounding gas.

\*Ligne 175: What is the density  $\rho_v$  of the droplet? Is it the density of the working fluid or the density of the seed particle? What is the difference between  $\rho_v$  and  $\rho$  the density of the fluid given in the symbols list? The list of symbols says  $\rho_v$  is the density of the vapor.

Reply:

Thank you for this comment. In Eq. (8),  $\rho_v$  refers to the density of condensed working fluid in a growing droplet, not the density of the seed particle. In contrast,  $\rho$  in Eq. (14) is the fluid density in the continuous gas phase used in the macroscopic heat-transfer equation. Thus, the two symbols correspond to different phases and different governing equations. We acknowledge that the notation may be confusing because  $\rho_v$  is often used to denote the vapor density.

\*Ligne 181: Could you say few words to argue why  $a_t = 1$

Reply:

Thank you for this comment. In our modeling, the thermal accommodation coefficient  $\alpha_T$  was assumed to be 1 for the simplicity in the modeling of aerosol droplet heat transfer (Line 202). It corresponds to complete thermal accommodation at the droplet surface, i.e., gas molecules are assumed to be in thermodynamical equilibrium with the droplet surface upon the collision. Because the objective of this model is to describe the overall droplet growth and thermal evolution in flow channel of sMCPC (not to describe the interfacial molecular energy exchange in detail),  $\alpha_T = 1$  is considered reasonable.

\*Ligne 190: Here you have to say *mixing chamber* rather than MCPC

Reply:

Thank you for this comment. This has been revised accordingly, and “MCPC” has been replaced with “mixing chamber” in the manuscript (Line 209).

\*Line 207: What is  $F$  given in the equation (11) for the present model and instrument ?

Reply:

Thank you for pointing this out. In the present model,  $F$  denotes an additional volumetric body force term in the momentum equation. Since no extra external body force was applied in this study,  $F$  was set to zero. For simplicity, we have deleted  $F$  from Eq. (11).

\*Line 220: The term 'local saturation' is somewhat ambiguous in this context and requires clarification. Given that the carrier gas is assumed to be saturated upon exiting the saturator and before entering the mixing chamber, it would be more precise to refer specifically to the 'mixing chamber' rather than the 'MCPC'. Indeed, the MCPC encompasses the entire system, including the saturator, mixing chamber, and growth tube.

Reply:

Thanks. In our discussion, it refers “mixing chamber”, not entire CPC. Accordingly, we have revised the revised text in L252–254 as:

The temperature distribution in the mixing chamber significantly influences the local saturation vapor pressure, thereby affecting the supersaturation field. The heat transfer in the flow is modeled using the steady-state energy conservation equation:

\*Line 226:  $q_{turb}$  is missing in the symbols list.

Reply:

Thank you for your thorough reading and pointing out this omission. The symbol  $q_{turb}$  has been added to the symbols list.

\*Line 283: Could you please provide more details regarding the temperature measurement method? Specifically, was a thermocouple inserted from the outlet of the growth tube, or were measurements taken through sealed ports at various positions

along the tube?

Reply:

Thank you for the comment. The temperature was measured using a thermocouple probe inserted into the flow channel from the outlet of the growth tube. The probe was moved step by step along the axial direction to measure the temperature at different locations along the tube axis (Line 317-318).

\*Line 302: Fig 6 not Fig 5.

Reply:

Thanks. It has been corrected.

\*Line 618:  $v_m$  the molecular volume of the water has nothing to do in the paper since you have not used water.

Reply:

Thank you for pointing this out. It has been corrected to “molecular volume of the condensable vapor” in the revised manuscript.

\*Line 612:  $T_s$  and  $T_c$  are inverted in the list of symbols. You should correct.

Reply:

Thank you for pointing this out. The definitions of  $T_s$  and  $T_c$  in the list of symbols have been corrected in the revised manuscript.

\*Line 632: Could you please give the numerical values of:  $\sigma_k$ ,  $\sigma_\omega$ ,  $\beta^*$ ,  $\gamma$ , and  $\beta_0$ ?

Reply:

Thank you for the suggestion. Accordingly, in the revised manuscript, we have clarified that  $\sigma_k$ ,  $\sigma_\omega$ ,  $\gamma$ , and  $\beta_0$  are not treated as fixed constants, but are obtained through the standard SST blending relation

$$\phi = F_1\phi_1 + (1 - F_1)\phi_2$$

where  $\phi$  represents  $\sigma_k$ ,  $\sigma_\omega$ ,  $\gamma$ , or  $\beta_0$ . In contrast,  $\beta^*$  is taken as a constant. The numerical values used in this study are the default COMSOL SST constants:  $\sigma_{k1} = 0.85, \sigma_{k2} = 1.00$ ;  $\sigma_{\omega1} = 0.50, \sigma_{\omega2} = 0.856$ ;  $\gamma_1 = \frac{5}{9}, \gamma_2 = 0.44$ ;  $\beta_{01} = 0.075, \beta_{02} = 0.0828; \beta^* = 0.09$ .

The revised text in L245–250 now reads as follows:

where  $P_k = \mu_t S^2$  is the turbulence production term,  $S$  is the mean strain-rate magnitude, and  $\mu_t = \rho k / \omega$  is the eddy viscosity.  $F_1$  is the blending function of the SST model. The parameters  $\sigma_k$ ,  $\sigma_\omega$ ,  $\gamma$ , and  $\beta_0$  are calculated using

$$\phi = F_1 \phi_1 + (1 - F_1) \phi_2 \quad (14)$$

while  $\beta^*$  is a constant. The default COMSOL values used in this study are  $\sigma_{k1} = 0.85, \sigma_{k2} = 1.00, \sigma_{\omega1} = 0.50, \sigma_{\omega2} = 0.856, \gamma_1 = 5/9, \gamma_2 = 0.44, \beta_{01} = 0.075, \beta_{02} = 0.0828$ , and  $\beta^* = 0.09$ .