14th ETH-Conference on Combustion Generated Nanoparticles
August 1st – 4th 2010
Poster-Abstract

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Title: An experimental device for growth of the submicron particles through heterogeneous condensation in order to separate them from gases with a conventional method

The use of heterogeneous condensation as a preconditioning technique has been studied **[1, 2]** to enlarge the particles diameter over Greenfield gap **[3]** in order to allow the use of conventional separators for the capture of submicronic particles with higher removes efficiencies and reduced costs.
In above cases the supersaturated atmosphere, necessary for heterogeneous condensation, is achieved by mixing two flows, saturated water vapours and the polluted gases with entertained particles, at different temperatures.
This paper presents an experimental device, called growth tube (see fig. 1) to study the growth of the submicron particles through heterogeneous condensation where the supersaturation region is achieved in a cylindrical tube, in the which the gas with particles flows and where a water film, on the inside the wall, produces the vapour necessary for condensation. With this method the resulting degree of supersaturation achieved is greater than that for simple mixing, increasing so the efficiency of the process **[4]**. The elevated temperature of the wetted walls produces a high concentration of water vapour, while the cooling arises from the entering sample air flow. In fact in this scenario the diffusion of water vapour from the walls to the centreline is faster than the warming of the flow. How can see from fig. 1, after growth tube the gas, with particles so enlarged, has passed in three traps, i.e. Drechsel, in order to removal them by inertial forces. The figure 2 shows the removal efficiency of particles obtained by experimental plant. The measurement of size distribution is performed with DMA.
We can see that the removal efficiency increase with diameter and with temperature. This behaviour can be explained as follows: the condition for the formation and the growth of droplets by condensation is that the degree of supersaturation is greater than the critical supersaturation, S_{cr} (the supersaturation corresponding to nucleation rate equal to 1), which decreases with the increase of particle size, then, vapour condensed on the surfaces of bigger particles firstly, and the collection efficiency of particles increases with the increase in particle size. This effect is overdrew by increasing of the temperature. But increasing particle size, the temperature seem became non influential on the removal efficiency.
Obviously needs further testing, but the simplicity of the growth tube proposed make it suitable for future industrial applications.

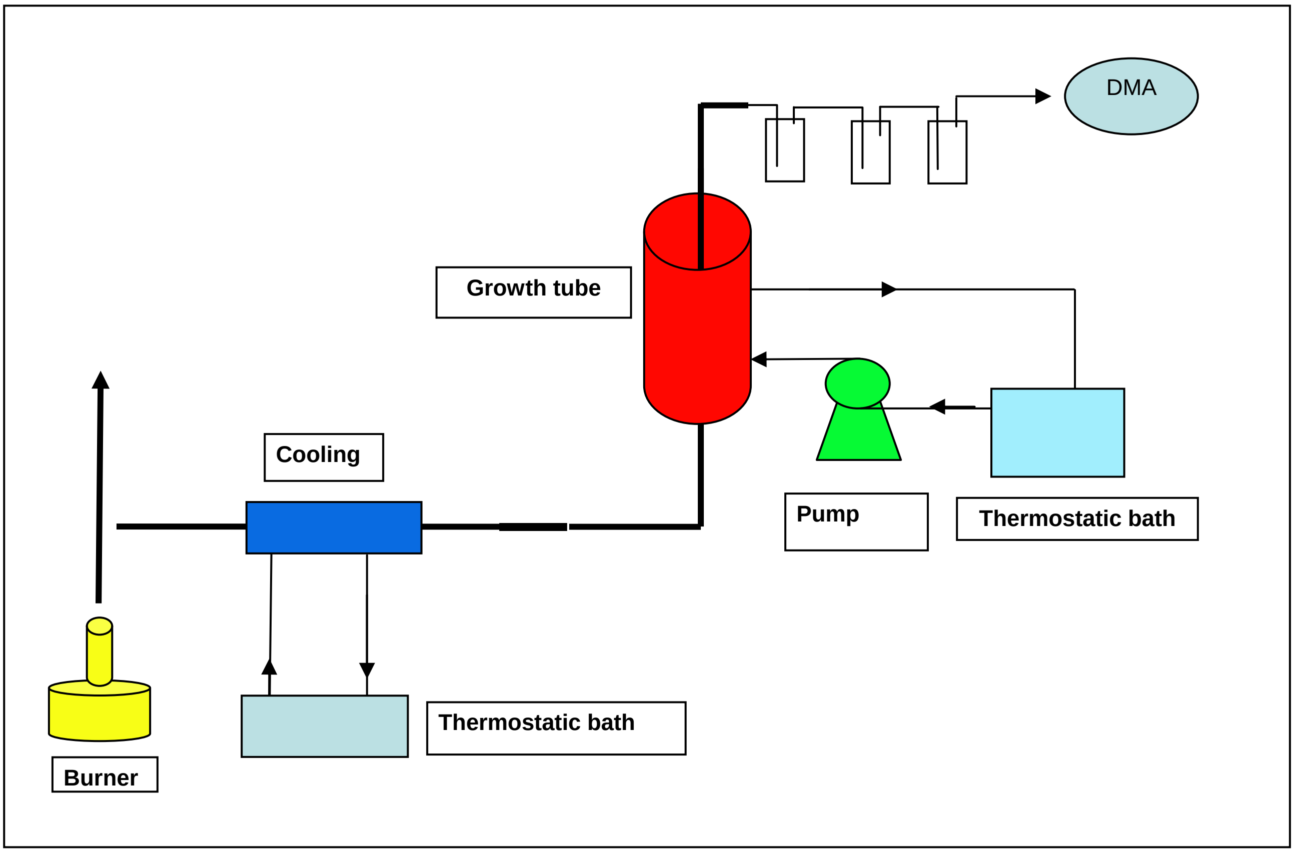

Fig. 1 – Experimental apparatus

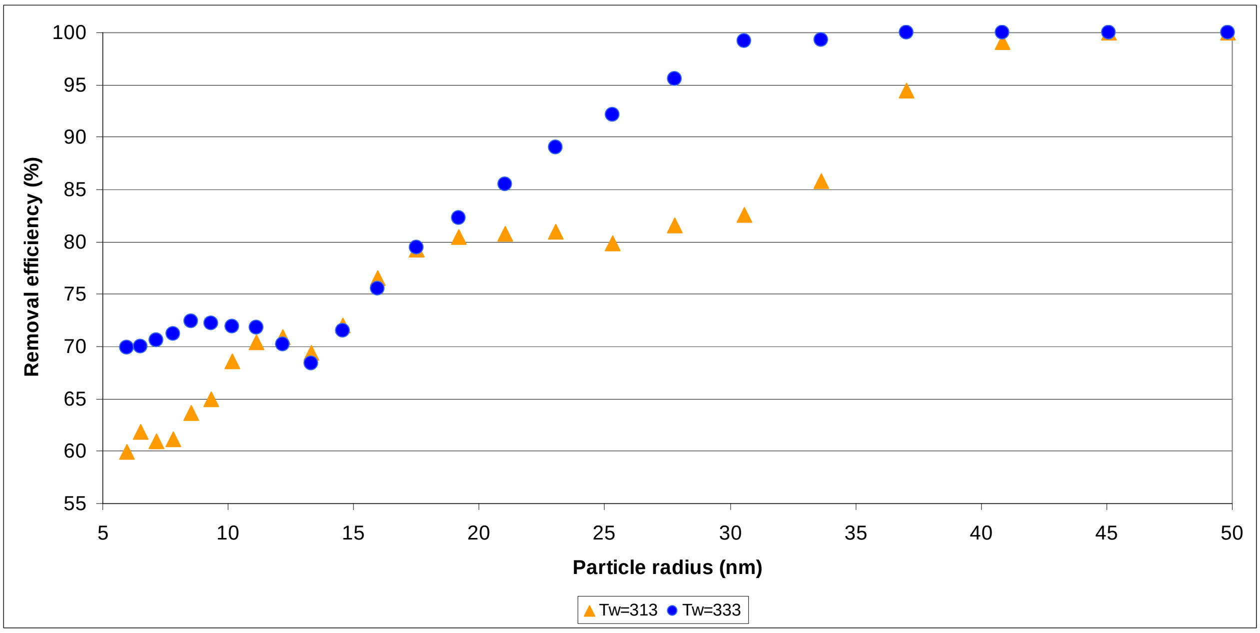

Fig. 2 – Removal efficiency vs particle radius at two different wall temperatures

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Experimental device for growth of the submicron particles through heterogeneous condensation in order to separate them from gases with a conventional method

Eng. Marco Tammaro; Prof. Amedeo Lancia; Eng. Francesco Di Natale; Dr. Antonio Salluzzo

INTRODUCTION

Submicronic particulate emission poses a serious problem for environmental pollution, human health and possible affects on climate **[1].** The use of heterogeneous condensation as a preconditioning technique to enlarge the particles diameter over Greenfield gap **[2]** in order to allow the use of conventional separators for the capture of submicronic particles with higher removes efficiencies and reduced costs has been studied **[3-5]**. In above cases the supersaturated atmosphere, necessary for heterogeneous condensation, is achieved by mixing two flows, saturated water vapours and the polluted gases with entertained particles, at different temperatures. This paper presents an experimental device, called growth tube (see fig. 2) to study the growth of the submicron particles through heterogeneous condensation where the supersaturation region is achieved in a cylindrical tube, in the which the gas with particles flows and where a water film, on the inside the wall, produces the vapour necessary for condensation. With this method the resulting degree of supersaturation achieved is greater than that for simple mixing, increasing so the efficiency of the process **[6]**. The elevated temperature of the wetted walls produces a high concentration of water vapour, while the cooling arises from the entering sample air flow. In fact in this scenario the diffusion of water vapour from the walls to the centreline is faster than the warming of the flow.

HETEROGENEOUS CONDENSATION

Heterogeneous condensation of a sub-micrometric particle is an energetically unfavourable process because, the liquid free surface increase causes a free energy rising **[6, 7, 8]**. In order to overcome the energetic barrier, then to activate condensational growth, the vapour must be oversaturated. That is the ratio, **S**, between partial vapour pressure $\mathbf{P_v}$ and equilibrium vapour pressure, **P°(T)**, at the flow temperature **T**, must exceed unity **[6, 7, 8, 9, 10]: $\mathbf{S = P_v/P°(T)}$**. The smaller the particle the higher the supersaturation required to activate condensational growth. This is because the equilibrium vapour pressure over a droplet is higher than over a flat surface as a result of the droplet surface tension **[6]**. This effect is described by the Kelvin relation **[10]**, $\mathbf{D_K = (4\sigma M)/(\rho R_v T \ln S)}$ which associates the equilibrium vapour supersaturation to the diameter of a droplet composed of that condensed vapour, $\mathbf{D_K}$, where **M**, **ρ**, and **σ** are the molecular weight,

EXPERIMENTAL ACTIVIES

The particles were produced by burning natural gas using a Bunsen burner. The flow gas was cooled to 297 k and introduced in the growth tube (fig. 1-2); water vapour supersaturation is experimental achieved into a growth tube (fig. 2) whose the temperature is lower than that of the growth tube wall. The walls are actively wetted to maintain a partial pressure of water vapour at the walls near the equilibrium vapour pressure at the wall temperature. The distribution of particles, first and after treatment, were measured by means of DMA (Differential Mobility Analyzer) (fig 3). How can see from fig. 1, after growth tube the gas, with particles so enlarged, has passed in three traps, i.e. Drechsel, in order to removal them by inertial forces. The figure 4 shown the removal efficiency for two different temperature of the growth tube wall.

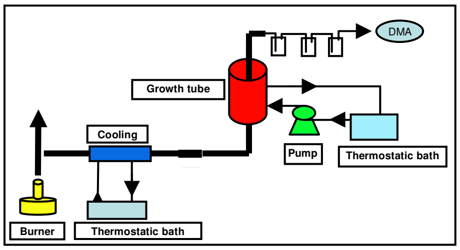

Fig. 1 – Experimental plant

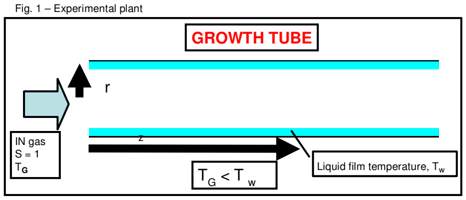

Fig. 2 – Particular of Experimental plant: Growth tube

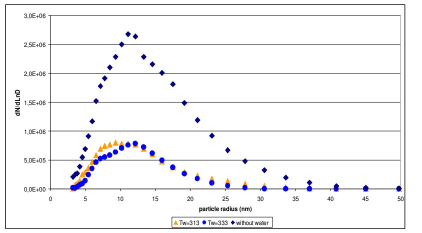

Fig. 3 –Size distribution analized by DMA

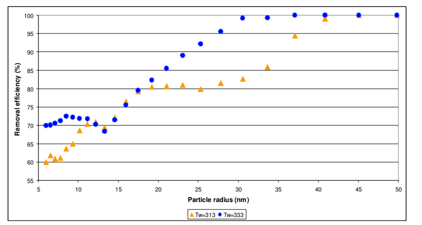

Fig. 4 – Removal efficiency vs particle radius at two different wall temperatures

MODELLING

HEAT AND MASS PHASE GAS BALANCE

For the cylindrical geometry (fig. 2) the profile of T and P_v throughout the growth tube, are obtained by solution of follow equation

$$2U\left[1-\left(\frac{r}{R}\right)^2\right]\frac{\partial T}{\partial z}=\alpha_t\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) \quad (1)$$

$$2U\left[1-\left(\frac{r}{R}\right)^2\right]\frac{\partial Pv}{\partial z}=\alpha_v\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial Pv}{\partial r}\right) \quad (2)$$

Each equation is solved by separation of variables

where
R: radius of tube (fig. 1)
U is the average flow velocity (m/s)
$\boldsymbol{\alpha_t}$ is thermal diffusivity of gas
$\boldsymbol{\alpha_v}$ is the vapour mass diffusivity

Assumptions
•Fully developed parabolic flow profile
•Axial thermal conduction is ignored
•Constant temperature at the wall
•Pressure and temperature entering profile constant

DROPLET GROWTH MODELLING

The following equations shows the balance of mass (1) and energy (2) **[14].** The (3) is the definition of I. The (4) shown to the simplified model of growth of the layer of liquid around the solid particle after embryo formation.

$$I=\frac{4\pi r_d MD}{RT}\left(P_{v,a}-P_v\right) \quad (1)$$

$$T_d=T-\frac{IL}{4\pi\lambda r_d} \quad (2)$$

$$I=-\frac{dm_d}{dt}=-4\pi r_d^2\rho_l\frac{dr_d}{dt} \quad (3)$$

$$r_d=\sqrt{r_{d,o}^2+\frac{2MD}{\rho_l R_v T}\left(P_v-P^o(T_d)\exp\left(\frac{2\sigma M}{R_v T_d\rho_l r_{d,o}}\right)\right)t} \quad (4)$$

where

m_d: mass of a single droplet; T_d: temperature of a single droplet; $r_{d,o}$: initial droplet radius; t : time; r_d: droplet radius; M: molar mass; D: vapour mass diffusivity; T_d: droplet surface temperature; I: mass flux; L: specific latent heat of condensation; λ: thermal conductivity: $P_{v,a}$: droplet surface vapour pressure

RATE OF FORMATION OF EMBRYO MODELLING

The rate of formation of critical embryos which can then develop into macroscopic droplets (fig 5) is given by equation (1) **[11-13]** where K is a kinetic constant and it is somewhat uncertain and depends in detail upon the nucleation situation ΔG^* and is the free energy of formation of a critical embryo (eq. 2); f(m,x) is a "geometrical factor" **[12].** In figure 6 is showed J vs time.

$$J=4\pi K R_p^2\exp\left(-\frac{\Delta G^*}{kT}\right) \quad (1)$$

$$\Delta G^*=\frac{8\pi M^2\sigma^3}{3\left(R_V T\rho\ln S\right)^2}f(m,x) \quad (2)$$

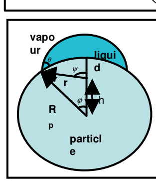

Fig. 5 – Schematic representation of a liquid on a spherical particle (R_p); r, radius of embryo; Θ: contact angle

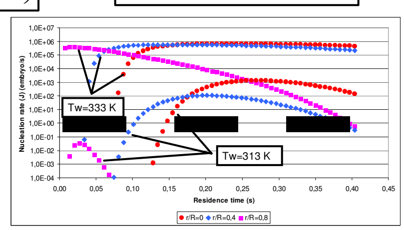

Fig. 6 – Rate of formation of embyo vs S, at T=313 K. The dashed line indicates the critical condition, that is J=1 (1/s),

Critical Supersaturation, S_{cr}, indicates ambient saturation at which a particle will promote almost immediate nucleation and condensation :

$$J=1\ (1/s) \rightarrow S_{cr}=\exp\left[\frac{1}{RT\rho}\sqrt{\frac{8\pi M_W^2\sigma^3}{3\Delta G^*}f(m,x)}\right] \quad (3)$$

ACKNOWLEDGMENT

I would like to thank Prof. A. D'Anna and Eng. M. Sirignano for their valuable assistance in the experimental activity.

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