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Influence of Particle Evaporation on Shock - Wave Induced Coagulation

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Introduction

The usual source for coagulation of aerosol particles is Brownian motion. Additionally, particle collisions can occur due to relative particle motion induced by gravity or flow fields. Examples are coagulation in sedimentation chambers, in turbulent flows or in acoustic waves. Other examples are shock waves running with supersonic velocities through an aerosol. The associated shock-induced fluid flow can also cause particle coagulation due to the acceleration of particles in the relaxation zone behind the shock wave. Under such conditions lighter particles are faster accelerated than heavier ones and collisions can occur. More details about the physical situation is described in /1/. In the present case a model based on the General Dynamic Equation (GDE) was developed assuming spherical particles with a bimodal size distribution. The particle collision model used is based on a modification of the kinetic theory of gases. Collisions between particles of different size including the resulting agglomerates were taking into acount. The collision efficiency was assumed to be 1. The velocities of the agglomerates formed were assumed to be equal to the velocity of the large particles before their collision. Interaction between gas- and particle phase was described by a model published in /2/. Additionally, heat transfer and evaporation of small particles were considered.

Coagulation- and Evaporation Model

The GDE /3/ was used to simulate the shock-wave induced particle coagulation. For stationary one-dimensional conditions neglecting particle diffusion and external force field and assuming the shock-wave induced coagulation to be the only relevant source term, the GDE for the number concentration n_k results in:

$$n_k \cdot \frac{dv_{p_k}}{dx} + v_{p_k} \cdot \frac{dn_k}{dx} = \left[\frac{dn_k}{dt}\right]_{coag\ s} \quad ; k = 1...6. \qquad (1)$$

To solve this equation it is necessary to determine the source term and the particle velocity. The coagulation source term is the product of the collision cross-section of the participating particles, their number concentrations and relative velocity, respectively.

The other unkown quantity is the particle velocity v_{p_k}. The deceleration of the particles in the relaxation zone behind the stationary shock wave is caused by viscous drag. For spherical particles Newton's law of motion formulated in /4/ can be used. The particle velocities mainly depend on the relative motion between gas and particles and the drag coefficient.

The particle diameter d_{p_k} of size class k can be calculated from the evaporation equation:

$$v_{p_k} \cdot \frac{d}{dx} d_{p_k}^2 = - K_k \quad . \qquad (2)$$

K_k represents the evaporation coefficient, which depends on the *Sherwood* number as well as on particle surface temperature T_{p_k} and vapor pressure. Equations for the gas phase mass, momentum and energy equations complete the system.

Results

A system of seventeen differential equations for the particle and gas phase properties were formulated. Fig.1 shows the typical example obtained for the number concentration of KBr_2 particles of two different initial size classes calculated at Mach number $M = 4.5$. The opened symbols represent the behavior of the small particles, the closed ones that of the large particles, respectively. Calculated results taking gas-particle interaction and the present coagulation model into account are represented by full lines with triangels. The effect of evaporation is represented by the curves identified by squares. The dotted lines were obtained from calculations neglecting both coagulation and evaporation. It is obvious that the particle number concentration is much lower without evaporation compared to the complete model. Due to this fact the coagulation efficiency calculated for both models and plotted in Fig. 2 decreases with increasing Mach number from 53% to 2%.

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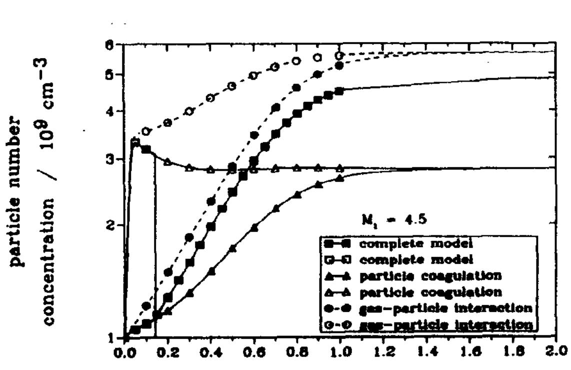

Fig. 1: Number concentrations calculated with particle sizes $d_p = 90$ nm and $d_p = 810$ nm, respectively.

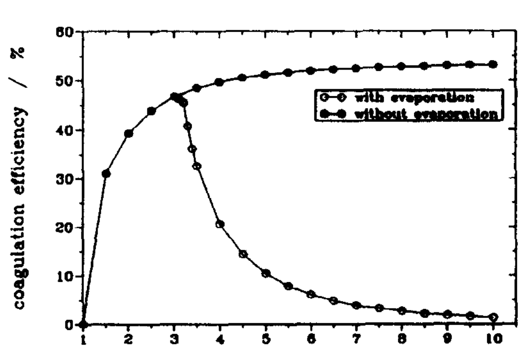

Fig. 2: Coagulation efficiency calculated with the gas-particle interaction model with and without regarding evaporation of the small particles.