The Effects of Droplet Collision, Evaporation, Gravity and Turbulent Dispersion on the Droplet Size Distribution of an Aerosol Cloud under Icing Conditions

László E. Kollár, Masoud Farzaneh
NSERC/Hydro-Québec/UQAC Industrial Chair on Atmospheric Icing of Power Network Equipment (CIGELE) and Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE) at the Université du Québec à Chicoutimi, Chicoutimi, Québec, Canada, G7H 2B1
http://www.cigele.ca

***Abstract*—The droplet size distribution (DSD) of an aerosol cloud is one of the most important factors which affect ice formation on overhead transmission lines. The size and distribution of the droplets are influenced by several processes during their movement in the air. The effects of droplet collision and coalescence, evaporation and cooling, gravitational settling, and turbulent dispersion are examined in the present paper. In order to achieve this goal, two-phase air/dispersed water spray flows are simulated both theoretically and experimentally. Natural aerosol clouds are modeled in the experiments by spraying droplets into a cold air flow inside an icing wind tunnel. A theoretical model has also been developed, which simulates the two-phase flow created in the wind tunnel considering the above mentioned processes. The significance of these processes regarding their influence on DSD is evaluated by computing their time scales which depend on ambient conditions and vary in space.**

I. Introduction

THE characteristics of the aerosol cloud in the proximity of a transmission line is a fundamentally important factor influencing atmospheric icing. One of the most significant properties of the aerosol cloud is its droplet size distribution (DSD) which undergoes modification due to several phenomena. Thus, the processes and parameters which govern these phenomena should be considered when modeling icing of transmission lines. In laboratory modeling, water is injected into cold air flow, and an icing object is exposed to the resulting two-phase flow. Similarly to natural aerosol clouds, the characteristics of artificially produced sprays are modified due to dissimilar thermodynamic parameters describing the two phases. These dissimilarities are most significant at injection time, because the thermodynamic parameters of the two phases become stabilized in the test section. The processes influencing spray characteristics are the interactions between the two phases, the mutual interactions in the dispersed phase, and the effects of external forces. The intensity of these processes depends on the level of turbulence which also plays a key-role in the formation of aerosol cloud in wind-tunnel experiments.

A theoretical model of two-phase air / dispersed water flows was presented in [1] together with experimental observations obtained in a cold wind tunnel. The theoretical model was applied for simulating the evolution of DSD in the flow inside the wind tunnel. The role of droplet collision, evaporation and gravitational settling in such models was studied in [2]. That paper examined how each of these three processes influences droplet size in the simulations when thermodynamic parameters are varied in the range describing icing conditions. The present paper also investigates the effects of these processes; however, it considers an additional important factor, the turbulence dispersion of droplets, and provides qualitative and quantitative dependence on atmospheric parameters by determining time scales for the four processes considered. Ambient parameters vary with icing conditions and with location inside the wind tunnel; therefore time scale analysis is carried out for two significantly different icing conditions describing in-cloud icing and freezing drizzle, and for two locations inside the wind tunnel, in the settling chamber and in the test section. Before defining time scales and carrying out time scale analysis, the four processes of interest and the model constructed in [1] will be described briefly.

II. Modeling Two-Phase Flows

This section is devoted to the two-dimensional model of two-phase flows, which is applied in this study. First, a brief description of the processes considered will be given, and then the procedure of computation will be presented.

A. Four Processes Influencing Spray Characteristics

The following four processes are included in the model and will be described in this section: (i) droplet collision and coalescence, (ii) evaporation and cooling, (iii) gravitational settling, and (iv) turbulent dispersion of droplets.

The model of binary droplet collisions was constructed in [3]. This model considers five possible outcomes of collisions: (i) coalescence after minor deformation, (ii) bouncing, (iii) coalescence after substantial deformation, (iv) reflexive separation, and (v) stretching separation. The boundaries between the collision regimes are determined in terms of three non-dimensional parameters: (i) Weber number, *We*, (ii) impact parameter, *B*, and (iii) droplet size ratio, Δ. The criteria for stretching separation, reflexive separation and bounce are provided by the following equations:

$$We > \frac{4.8}{B^2}\frac{\left[1+\gamma^2-\left(1+\gamma^3\right)^{2/3}\right]\left(1+\gamma^3\right)^{11/3}}{\gamma^6\left(1+\gamma\right)^2} \tag{1}$$

$$We > 3\left[7\left(1+\Delta^3\right)^{2/3}-4\left(1+\Delta^2\right)\right]\frac{\Delta\left(1+\Delta^3\right)^2}{\Delta^6\eta_1+\eta_2} \tag{2}$$

$$We > \frac{\Delta\left(1+\Delta^2\right)\left(4\phi'-12\right)}{\chi\left(1-B^2\right)} \tag{3}$$

where

$$\gamma = 1/\Delta\,, \quad \eta_1 = 2\left(1-\xi\right)^2\left(1-\xi^2\right)^{1/2}-1\,,$$

$$\eta_2 = 2\left(\Delta-\xi\right)^2\left(\Delta^2-\xi^2\right)^{1/2}-\Delta^3\,, \quad \xi = \frac{1}{2}B\left(1+\Delta\right),$$

$$\chi = \begin{cases} 1-\left(2-\kappa\right)^2\left(1+\kappa\right)/4 & \text{if} \quad \kappa > 1.0 \\ \kappa^2\left(3-\kappa\right)/4 & \text{if} \quad \kappa \le 1.0 \end{cases}, \quad \kappa = \left(1-B\right)\left(1+\Delta\right),$$

and ϕ' is the shape factor with proposed value of 3.351. The boundary between coalescence after minor deformation and bounce is represented by a line joining two points. One of these points separates the regime of bounce from that of coalescence after substantial deformation for head-on collisions, while the other point is the one where the Weber number is zero and the impact parameter is unity. This collision model provides the outcome of collision as well as the size, velocity and temperature of post-collision droplets, according to the conservation of mass, momentum and energy, respectively.

The formulation for constructing a model for evaporation and cooling are based on [4] and [5]. The model calculates the rate of droplet mass, *Δm*, which is evaporated during the time interval, *Δt*, as follows:

$$\frac{\Delta m}{\Delta t} = -\frac{\pi d D_f\left(e_w\left(T_d\right)-RH_a e_w\left(T_a\right)\right)}{R_w T_f\left(1-\dfrac{e_f}{p_{st}}\right)}Sh \tag{4}$$

where d is the droplet diameter, $e_w\left(T_d\right)$ and $e_w\left(T_a\right)$, the pressures of saturated water vapor at droplet temperature, T_d, and air temperature, T_a, respectively, RH_a, the relative humidity of air, *Sh*, the Sherwood number, R_w, the gas constant for water vapor, p_{st}, the static pressure of air, and where the subscript *f* refers to film formation on the evaporation surface involving droplet temperature and air temperature. The cooling of droplet temperature, ΔT_d, during the time interval, *Δt*, is obtained from the heat balance equation:

$$c_w m\frac{\Delta T_d}{\Delta t} = \alpha d^2\pi\left(T_a-T_d\right)+L_{ev}\frac{\Delta m}{\Delta t} \tag{5}$$

where m is the droplet mass, c_w, the specific heat of water, L_{ev}, the latent heat of vaporization of water, and where the heat transfer coefficient, α, is determined by the following expression:

$$\alpha = \frac{Nu\lambda_a}{d} \tag{6}$$

where *Nu* is the Nusselt number, and λ_a is the thermal conductivity of air at the temperature of droplet surface. The variable T_d is the droplet temperature at the beginning of the time step, and $\Delta m/\Delta t$ is obtained from (4). The Sherwood number and the Nusselt number which are defined by the Reynolds number based on air velocity, and the temperature dependences are given in [1].

The effect of gravity is not negligible in natural atmospheric icing processes under low wind conditions and in low-speed wind tunnels, especially in the presence of large droplets. Gravity is responsible for the vertical separation of droplets of different size; therefore, its effect is included in the droplet equation (see Section II.B).

The effect of turbulence on droplet motion is considered by adding a fluctuating component, $\mathbf{u}'$, chosen randomly from a Gaussian probability distribution, to the mean gas velocity, $\overline{\mathbf{u}}$, in the droplet equation. The value of the fluctuating component is changed at the beginning of each droplet – turbulent eddy interaction, which lasts until the break-up of turbulent eddy or until the droplet traverses the eddy. The eddy lifetime, t_{ed}, is determined as follows:

$$t_{ed} = \frac{l_{ed}}{\left|\mathbf{u}'\right|}\,, \quad \text{with} \quad l_{ed} = \frac{C_\mu^{0.75}k^{1.5}}{\varepsilon} \tag{7}$$

where C_μ = 0.09, and ε is the turbulent dissipation, whereas the transit time, t_r, is obtained from the following formula:

$$t_r = -\tau\ln\left(1-\frac{l_e}{\tau\left|\mathbf{u}-\mathbf{v}\right|}\right) \tag{8}$$

where $\tau = 4\rho_d d/\left(3\rho_a C_D\left|\mathbf{u}-\mathbf{v}\right|\right)$, ρ_d and ρ_a are the droplet and air densities, respectively, C_D, the drag coefficient, and **v**, the droplet velocity. When $l_e/\left(\tau\left|\mathbf{u}-\mathbf{v}\right|\right) > 1$, (8) does not have a solution, therefore it is assumed that the time of droplet – eddy interaction is equal to the eddy lifetime, t_{ed} [6].

B. Theoretical Model

The two-dimensional model of two-phase air / dispersed water flows applied in the present study will be described in this section. First, the air velocity field is determined by the commercial software CFX, which solves the Navier-Stokes equations iteratively by using the finite volume technique. These data together with turbulent parameters serve as input for the model which solves the droplet equation, tracks droplet trajectories, and calculates droplet parameters considering the effects of the processes described in Section II.A.

The droplet trajectory code is based on the droplet equation:

$$\frac{\pi}{6}d^3(\rho_d+0.5\rho_a)\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t}=\frac{\pi}{6}d^3(\rho_d-\rho_a)\mathbf{g}+3\pi d\mu_a f(\mathbf{u}-\mathbf{v}) \tag{9}$$

where $\mathbf{v}$, $\mathbf{u}$ and $\mathbf{g}$ are the droplet velocity, gas velocity, and gravity vectors, respectively, ρ_d is the density of the droplet, ρ and μ are the density and dynamic viscosity of the gas, respectively, while f deals with the Stokes drag. The non-dimensional equation that describes droplet motion is obtained after introducing the following non-dimensional parameters, $\mathbf{U}=\mathbf{u}/u$, $\mathbf{V}=\mathbf{v}/u$ and $T=tu/l$, where $u=|\mathbf{u}|$, and l is the horizontal distance between the nozzles and the icing object in the tunnel:

$$\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}T}=\frac{l}{u^2}\mathbf{g}+\frac{18\mu l}{\rho_d d^2 u}f(\mathbf{U}-\mathbf{V}). \tag{10}$$

Since f is time-dependent, (10) is integrated numerically by using the Euler scheme in a predictor-corrector mode:

$$\mathbf{V}_*=\mathbf{V}_j+\left.\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}T}\right|_j\Delta T\,, \tag{11a}$$

$$\mathbf{V}_{j+1}=\mathbf{V}_j+\left(\left.\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}T}\right|_j+\left.\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}T}\right|_*\right)\frac{\Delta T}{2}\,, \tag{11b}$$

where ΔT is the non-dimensional time interval, the subscripts j and j+1 stand for quantities at the beginning and at the end of the time increment, respectively, while the subscript * refers to an intermediate value. The droplet position at the end of the time increment is obtained by applying the trapezoidal scheme:

$$\mathbf{X}_{j+1}=\mathbf{X}_j+(\mathbf{V}_j+\mathbf{V}_{j+1})\frac{\Delta T}{2}\,, \tag{12}$$

where $\mathbf{X}$ is the dimensionless droplet position vector.

In the first step of computation, the commercial software CFX determines the air velocity field by using air velocities measured at the inlet and outlet of the simulated domain as input data. The air velocity field thus obtained is used as input in the droplet trajectory code. Since there are too many droplets to follow individually, they are collected into parcels. Each parcel contains the same number of droplets of identical size, velocity and temperature. These droplet parameters at the beginning of the computational domain are also prescribed. Further input parameters are the ambient conditions, which are assumed to be constant over the computational domain, and turbulence data, *i.e.* the level of turbulence and size of turbulent eddy.

The droplet trajectory code tracks parcels in space and time as if they were single droplets with the size, mass, velocity and temperature of one droplet from that parcel. The fluctuating component of air velocity is modified after each time interval describing the droplet – turbulent eddy interaction and added to the mean air velocity computed by CFX. Then, the position and velocity of droplets are determined by applying (11)-(12), and the droplet size and temperature are modified due to evaporation and cooling. If the droplet is evaporated completely, then the corresponding parcel is withdrawn from further computation. The parcel size is considered larger according to the mass of droplets carried in one parcel when seeking for colliding droplets. If the distance between two parcels is less than the sum of their radii, they will collide. The outcome of collisions and the size, velocity and temperature of post-collision droplet or droplets are determined by utilizing the composite collision outcome model. If coalescence occurs, then either parcel is modified to represent the post-collision droplet, while the other one is withdrawn from the simulation. This process is continued in the next time steps until the termination condition of the simulation is satisfied.

C. Experimental Model

Experiments were carried out at the CIGELE atmospheric icing research wind tunnel (see [1] for details). This facility is a closed-loop, low-speed icing wind tunnel, including a 3-metre-long test section with a rectangular cross-section 46-cm high and 91-cm wide. Water is injected into the cold air stream through air-assisted nozzles located on a horizontal spray bar. The nozzles are manufactured by Spray System Co. and incorporate stainless steel fluid cap 2050 and stainless steel air cap 67147. The pressures and the flow rates of the water line and air line together with the nozzle characteristics determine the resulting DSD at the nozzle outlet. This DSD serves as input for the droplet trajectory code, while droplet size measurements at different heights in the middle of the test section are used to validate the output of the model. A droplet pattern was obtained on a small slide covered by collargol on either side; and then droplet diameters were measured by using a Scienscope microscope. The input air velocities for CFX calculations were measured by Omega anemometer, while turbulence data at the spray-bar and in the middle of test section were obtained using a TSI hot-wire anemometer IFA300.

III. Time Scales

This section presents the time scales of the processes described in Section II.A.

A. Binary Droplet Collision

Two parcels collide when the distance between their centers is less than the sum of their radii. Thus, the time step should be small enough to avoid that two parcels “jump” each other. Accordingly, the collision time scale is determined by the following formula

$$\tau_c=\frac{\sqrt{n_p}\,d}{v_r} \tag{13}$$

where n_p is the number of droplets in a parcel, and $v_r=|\mathbf{v}_r|$ with $\mathbf{v}_r$ denoting the relative velocity of colliding droplets. Since the model is two dimensional, the area of a droplet parcel is assumed to be equal to the sum of the areas of droplets in that parcel, and thus, the parcel diameter is $\sqrt{n_p}\,d$. In order to provide a lower limit for the collision time scale and determine a maximum value for the time step in numerical simulations, the diameter of the smallest droplet and the highest possible value of the relative velocity have to be substituted in (13). It should be clear, however, that the time scale given by (13) is smaller than the average time between two collisions. Thus, one may refer to (13) as the numerical time scale, while the time scale which describes the physical process itself may be calculated as the inverse of the collision frequency. While references [7] and [8] calculated the collision frequency of droplets of particular sizes, this paper will compute the average collision frequency of all the droplets as it varies along the streamwise direction.

B. Droplet Evaporation

The time scale for evaporation of a droplet of diameter, *d*, is related to the droplet mass and the rate of evaporated droplet mass (4), and may be expressed as follows

$$\tau_{ev} = \frac{\rho_d d^2}{6D_f \dfrac{\left(e_w(T_d) - RH_a e_w(T_a)\right)}{R_w T_f \left(1 - \dfrac{e_f}{p_{st}}\right)} Sh} \tag{14}$$

This formula shows that small droplets have shorter response time to evaporation. It also shows that air temperature, droplet temperature and relative humidity of air affect this process, while the effect of air velocity is less important. These observations are in agreement with the results of sensitivity tests presented in [2].

C. Gravitational Settling of Droplets

The time scale of gravitational settling of droplets is determined by the ratio of a characteristic length and the vertical velocity of droplets, v_y . Reference [9] used the thickness of dry air where the droplet penetrates and the droplet terminal velocity to determine the time scale for sedimentation of cloud droplets. Since droplets move in an air flow in the cases considered in this paper, the vertical velocity of droplets differs from their terminal velocity. An appropriate choice of the characteristic length is the droplet diameter, *d*, so that the time scale takes the following form

$$\tau_s = \frac{d}{v_y} \tag{15}$$

It may be deduced by studying the droplet equation (9) that after the transient state the vertical component of droplet velocity may be approximated as $v_y = u_y + g\tau$ where u_y is the vertical component of gas velocity and $g = |\mathbf{g}|$.

D. Turbulent Dispersion of Droplets

The turbulent time scale is defined by the time of interaction between the droplet and the turbulent eddy. Therefore, turbulent time, τ_t , is defined as the minimum of eddy life time, t_{ed} , and transit time, t_r , which are defined by (7) and (8)

$$\tau_t = \min(\tau_{ed}, \tau_r) \tag{16}$$

IV. Time Scale Analysis for Two Specific Conditions Describing In-Cloud Icing and Freezing Drizzle

The flow of dispersed water droplets in cold air stream was simulated for two specific conditions by applying the model described in Section II and by laboratory experiments. Table I shows the atmospheric parameters which were chosen in order to reproduce typical aerosol clouds under in-cloud icing and freezing drizzle conditions. The droplet temperature and droplet velocity near the spray bar were chosen as 20 $^\circ$C and 20 m/s, respectively. Turbulence data at the spray bar and in the test section were obtained from measurements. The turbulence levels at those two locations are 7.8 % and 0.7 %, respectively, for in-cloud icing; while the same parameters take the values of 7.9 % and 0.6 % for freezing drizzle. The sizes of turbulent eddies were measured as 10.4 cm and 3.9 cm for in-cloud icing, whereas 11.8 cm and 4.3 cm for freezing drizzle. The decay of turbulence between the place of droplet injection and the test section was assumed according to a decreasing power function. The values of all physical and numerical parameters are provided in [1] together with a detailed discussion of computed and measured DSDs at different heights in the test section. In what follows, a time scale analysis is carried out; more precisely, it is discussed how the significance of the processes listed in Section II.A changes with ambient conditions and with location inside the tunnel.

TABLE I
ATMOSPHERIC PARAMETERS ASSUMED IN SIMULATIONS

Atmospheric parameters	In-cloud icing	Freezing drizzle
Air temperature ($^\circ$C)	-10	-5
Air velocity (m/s) (test section)	20	10
Relative humidity of air (-)	0.95	0.8
Median volume diameter (μm) (settling chamber)	27	62

In order to calculate time scales, some parameters which change during the simulation should be estimated. First, all the time scales depend on droplet size, therefore they are presented as functions of droplet diameter. Other parameters, which vary during simulation and appear in the formulae (13)-(16), are the relative velocity of colliding droplets, v_r , air velocity, u , vertical component of air velocity, u_y , gas-droplet relative velocity, $|\mathbf{u} - \mathbf{v}|$, fluctuating component of gas velocity, $|\mathbf{u}'|$, and droplet temperature, T_d . The effects of different processes are of particular interest in the settling chamber, close to the spray bar where the imbalance between the phases is still significant; and in the test section where a stable two-phase flow is already formed. Therefore, the extreme values of these variables, which occur close to the starting point of simulations, are substituted into (13)-(16) to calculate time scales near the spray bar, while their average values are determined from simulations for computing time scales in the test section. The fluctuating component of air velocity is approximated for this computation by the product of air velocity and measured turbulence level. Since the vertical component of air velocity may be positive or negative with low magnitude (usually less than 0.3 m/s), 0 m/s is taken as average and the time scale of gravitational settling is determined by predicting the vertical component of droplet velocity as $v_y = g\tau$. Further parameter values are shown in Table II for in-cloud icing and freezing drizzle conditions.

TABLE II
PARAMETER VALUES FOR COMPUTING TIME SCALES (SB – NEAR SPRAY BAR, TS – IN TEST SECTION)

Parameters	In-cloud icing		Freezing drizzle	
	SB	TS	SB	TS
v_r	3.5	0.5	7	0.25
u	7.8	20	3.9	10
$\lvert\mathbf{u}-\mathbf{v}\rvert$	2.5	0.5	4.5	0.3
T_d	20	-10	20	-6

Fig. 1 presents time scales of the four processes considered for the two atmospheric conditions, and at the two locations in the wind tunnel. The vertical lines are drawn at the values of the median volume diameter (MVD) in each particular case at the mid-height of test section. The main observations are summarized in what follows.

- The most influencing parameter on time scale of droplet collision is the relative velocity of colliding droplets. Since this parameter decreases as the flow approaches the test section, the collision time scale is greater in the test section than in the settling chamber. The time scale obtained at the MVD in the test section is greater for freezing drizzle than for in-cloud icing, whereas these values are in the same range near the spray bar for the two atmospheric conditions.
- The time scale of evaporation depends on many parameters, but the effects of air temperature and droplet temperature, or their arithmetic mean, T_f, are the most considerable. This parameter decreases between the settling chamber and the test section; thus, droplet evaporation becomes less important and the corresponding time scale increases. Comparing time scales for the two atmospheric conditions, they are in the same range in the test section, and time scale is greater for freezing drizzle near the spray bar.
- The decisive factor on the influence of gravity is the gas-droplet relative velocity. The diminution of this relative velocity leads to lower time scale in the test section. The time scale for droplets of the same diameter in the settling chamber is slightly greater for freezing drizzle; this relation is opposite, however, if time scales at MVDs are compared, because droplets are larger under freezing drizzle conditions and the effects of gravity become more significant. Due to the same reason, the curves obtained for the test section lie close to each other for the two conditions, but the value at the MVD is greater for in-cloud icing.
- The parameter which has the greatest influence on time scale of turbulence is the fluctuating component of air velocity. Since it decreases toward the test section, the time scale is greater in that part of the tunnel. The turbulence level does not change significantly at the same location for different atmospheric conditions, and the air velocity is higher for in-cloud icing, therefore so is the fluctuating component. This fact causes more considerable turbulence and lower time scale for in-cloud icing. It should be noted that this time scale does not depend on droplet diameter, because droplet size affects transit time only, but the eddy life time is smaller than the transit time for the cases and droplet sizes considered.

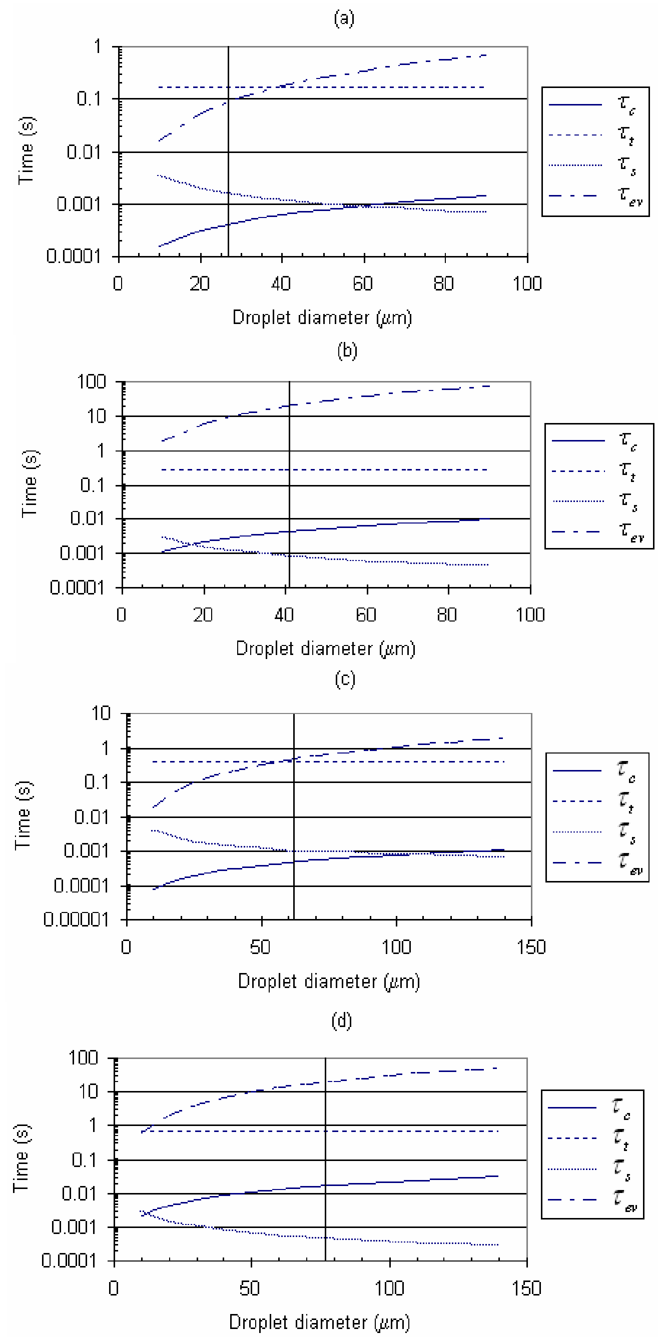

Fig. 1. Time scale of collision, turbulence, gravitational settling and evaporation, (a) in-cloud icing conditions, settling chamber, (b) in-cloud icing conditions, test section, (c) freezing drizzle conditions, settling chamber, (d) freezing drizzle conditions, test section

Time scales of the same processes for different conditions and locations were compared in the previous paragraph. Now, a comparison of different time scales for the same conditions and for the same locations follows. It can clearly be seen that droplet collision and gravitational settling have the smallest time scales in all the four cases. The corresponding curves intersect each other, because droplet collision is the most influencing process for small droplets, and gravitational settling becomes more and more significant as droplet size increases. For both atmospheric conditions, droplet collision is associated with the smallest time scale close to the spray bar, while time scale of gravitational settling is the smallest in the test section, considering time scales obtained at the MVDs. Consequently, the time step in the simulations is determined by the time scale obtained for droplet collision considering the smallest particles. The time step was taken to be slightly smaller than the collision time scale calculated with the smallest particle size and an upper limit of relative velocities, which is the air velocity.

It should be noted that the numerical time scale was considered in this discussion for binary droplet collisions in order to obtain a criterion for the time step in the numerical computation. However, if the goal is to describe the physical process, the collision time scale should be determined as the inverse of collision frequency which may be obtained from simulations. The collision frequency is shown in Fig. 2 as a function of streamwise direction in the wind tunnel. It may be deduced from this figure that the collision time scale obtained as the reciprocal of collision frequency is 0.003 s and 0.043 s near the spray bar and in test section, respectively, for in-cloud icing conditions; whereas these values are 0.0015 s and 0.257 s for freezing drizzle conditions. These values are greater than the numerical time scales obtained for the MVDs; however, the difference is not greater, in general, than one order of magnitude. The comparison of this time scale to that of gravitational settling leads to the conclusion that the influence of binary droplet collision and that of gravitational settling are approximately the same near the spray bar, but that gravitational settling is more significant in the test section.

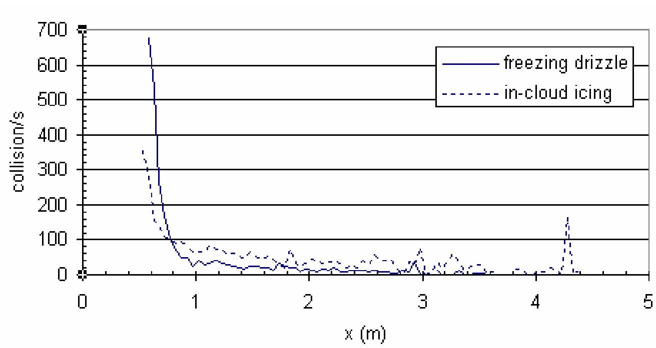

Fig. 2. Collision frequency along streamwise direction in the wind tunnel

V. Conclusions

Time scale analysis of four processes influencing droplet size and droplet motion in two-phase flows has been carried out in this paper. These processes are namely (i) binary droplet collision, (ii) droplet evaporation, (iii) gravitational settling of droplets, and (iv) turbulent dispersion of droplets. The effects of these processes are examined for two different atmospheric conditions describing in-cloud icing and freezing drizzle, and in two different locations inside an icing wind tunnel: in the settling chamber close to the spray bar and in the test section.

Results of time scale analysis show that the most influencing processes are droplet collision and gravitational settling for all the cases investigated. Droplet collision is more frequent near the spray bar and for small droplets, while gravity becomes the most important factor in the test section and for large droplets. The effects of evaporation are considerable near the spray bar, while thermodynamic imbalance exists between the two phases. The importance of turbulence lies in the fact that it modifies droplet trajectories, and thereby intensifies droplet collision.

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