ELECTRICALLY STIMULATED AGGLOMERATION AT AN EARTHED SURFACE

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Abstract

With the aid of a microscope and a video camera settling particles have been observed when passing a classical point-plate arrangement and, because of the deflection in the electrical field, impacting on the wall. As the cinematographic studies can show the arriving particles are forming agglomerate-chains orientated along the electrical field lines and growing up to a critical length which is dependent on the electrical operation conditions. In the video tapes it is clearly to see that agglomerate chains of critical length are pulled off by the electrical forces. The observed agglomeration phenomenon is decisively governed by the particle material itself, in particular particle resistivity. Graphite and limestone particles and glass spheres as well in the size range around 30 µm have been investigated. In order to illustrate this electrically stimulated agglomeration process a video tape will be shown.

Introduction

In electrical precipitation it is well known for a long time that the electrical resistivity of the dust particles undergoing precipitation process is an important variable. Roughly, materials with resistivity below 10^4 Ωcm are sometimes difficult or impossible to precipitate /1/. As possible explanation for that behaviour it is to read already in the early book of Rose and Wood: "The general conclusion appears to be that, on making contact with the collector electrode, particles of low resistivity rapidly part with their charge and acquire a heavy charge of the same sign as that of the electrode; whereupon they are projected into the gas stream, or even as far back as the corona wire" /2/. Hereby another important but opened question is: do particles coming into contact with collecting plate leave it again as individual particles or might it be possible that an agglomerate of particles is pushed off?

In addition in quite another context this phenomenon of bouncing particles came again into discussion recently: cleaning the exhaust gas of diesel engine vehicles. The principal of electrostatic precipitation was applied to agglomerate diesel soot particles which are extremely small in size (about 100 nm) /3/. As experiments have shown it is possible to clean diesel exhaust gas by a two stage process: firstly the soot particles are agglomerated in the electrostatic separator. These agglomerates that have a size of more than 5 µm can be collected in a cyclone /4/. Although these experiments were successful it was not yet understood how the agglomerater works; do turbulence level and flow field structure induce the agglomeration process, how important is the electrode design, or does the process completely happen at the wall?

Therefore an observation of the particles impacting on the collecting plate would elucidate this complex situation. Since the general phenomenon should be independent of the absolut particle size, the basic idea was an observation of the wall behaviour with optical methods by using larger particles in a classical point-plate arrangement and materials with different electrical resistivity.

Experiments

Experimental Set-Up

For studying particles driven by a corona field towards a collecting plate a classical needle-plate arrangement was chosen (Fig. 1). The steel needle used for creating a corona discharge had a diameter of 0.80 mm and the distance between its sharp end (radius of curvature 35 µm) and the collecting plate was

Evaluation of Video Pictures

Compared with 16 mm high speed cinematography the high speed video technique is easy and quick to handle, i.e. the process can be observed online and immediately after the experiments the pictures can evaluated. In total all recorded parameter settings fill video tapes of about six hours, therefore it is an extremely extensive and almost impossible work to analyze all the pictures taken. Only a completely automated process would be able to overcome this task. Therefore a certain preselection of picture sequences was made by human eye and some pictures within these sequences (intervall 5 s) were digitalized and transferred to a Macintosh computer. These selected pictures were analyzed by an image processing software /5/ and Fig. 3 principally illustrate the evaluation procedure.

The picture of the clean steel sphere on the clean plate electrode serves as reference for all evaluations (marked white in Fig. 3). The image processing software is able to measure distances by mouse-clicking and to calculate the equivalent diameter of a marked area; from this results "particle size" and "lengths" of agglomerate chains given in the following sections with a local uncertainity of a few micrometers. Evaluated quantities are:

- *Mean thickness of the dust layer D* on the surface of the steel sphere: the thickness is taken under five angles a (45°/67.5°/90°/107.5°/135°) and averaged, this procedure was made each 5 s; starting with a clean surface means D = 0.
- *Mean length of agglomerate chains L*: measured is the distance between the sphere surface and the far end of the chain; all agglomerates "chains" occuring between a = 45° and 135° were taken and averaged.
- *Mean migration velocity* w_y: measured is the displacement of individual particles or agglomerates respectively within 5 ms when moving towards the sphere surface or when leaving it (y-direction); one mean value consists of displacement measurements on five different particles having the same eqivalent diameters; starting the process at t = 0 s the velocities taken occur between 30 s and 60 s.
- *Mean sedimentation velocity* w_x: same procedure as before but results are not discussed here.

Parameters

Beside the applied voltage U or the pseudohomogeneous electrical field strength E respectively the main interest was directed to the behaviour of different dust materials. The experiments were performed with graphite and limestone particles and two fractions of glass beads. Quantities to characterize the different materials were given in Table 1. The particle size distributions were measured with a laser diffraction spectrometer (Helos) and the given values $d_{p,i}$ refer to the cumulative volume distribution. Beside the solid density ρ_{solid} the bulk density ρ_{bulk} as well as the porosity ε are listed; the last ones refer to a pot-like measuring device for electrical resistivity which is described in /6/. While $\rho_{el,solid}$ is the solid resistivity /7, 8, 9/ $\rho_{el,bulk}$ is the result of the measuring device at a temperature T and a relative humidity rH of the air passing through the bed. For a visual comparison Fig. 4 illustrates these measured electrical dust resitivities. Remarkable is the difference in resistivity of the two glass bead beds; obviously their chemical composition must be of different nature which is also indicated by a significant high value of relative humidity in Table 1 compared to the others.

Results

Phenomenological Description

Before going into more details a first information is gained from looking on selected and cutted, however characteristic video sequences /10/. Unfortunately the pictures which may be viewed by the reader in Fig. 5 can only give a weak impression of the dynamic process happening at the wall, but the pictures are able to characterize the different behaviour of the dust materials investigated. Which phenomena are typical for the different dusts?

Graphite: most of the arriving low resistivity particles are focused onto the edges of particles deposited before, thus forming a ramification structure which is continously growing. This is probably caused by the distortion of the electrical field creating a stronger flux density of electrical field lines at edges. Since the graphite particles have plate like shape, the structure growing up is reminding to branches of a tree. It is clearly to see how the orientation of these branches is determined by the electrical field lines. From time to time an agglomerate of particles is leaving the earthed surface with high velocity in direction of the electrical field lines.

From observing a lot of video sequences the conclusion results that there are probably two reasons for the detachment of an agglomerate. First and main reason is of electrical nature: the conductive particles bear immediately after touching the collecting plate charges of the same sign as the earthed surface itself resulting in a repelling force. When the branches of particles reach a critical size this repelling force is able to overcome the adhesive force between a particle-particle contact. The location of the detachment is more likely for small contact areas and for contacts closer to the collecting plate. As second reason for detachment it is to observe the impact of arriving high velocity particles diving into the ramification to a certain degree and tearing off a particle branch.

Glas I: this fraction of glas beads is characterized by a surprisingly low resistivity values and this fact must finally be the deeper cause why these glas beads do form particle chains. With that respect the behaviour is similar to that one of the graphite particles: continous deposition of individual particles at the top end of particles deposited before. These particles show almost the same potential than the earthed surface there the electrical force tries to tear them off the plate. But with Glass I we do not observe a ramification structure but extremely regular chains. This difference in deposition structure is probably caused by the difference in particle shape. Since two contacting spheres are easily movable one upon the other (compared to irregular shaped particles) the electrical field is able to stretch more than two spheres into a chain-like form.

Furthermore the surface of the glass beads is relatively smooth compared to the graphite particles, therefore the adhesive force between the glass beads is certainly higher than between graphite particles. This is presumably the reason why the electrical force is not able to detach the particle chains from the collecting plate and the chains can become very long. All detachments which are to observe are clearly caused by the impact of arriving individuals with high velocity as an intensive visual analyze of the video tapes may show.

Glass II: the measured electrical dust resistivity shows the highest value of all materials investigated and moreover glass shows the highest elasticity module. High resistivity means that these particles keep their charge for a relatively long time after coming into contact with the earthed surface, and obviously their is no repelling electrical force, but only an attractive one. It is to observe, however, that these Glass II particles are not deposited on the collecting plate, they are bouncing off the plate immediately after contacting. Thrown back into the corona field they are accelerated again towards the plate, thus hopping down along the plate. Since Glass II particles are larger in diameter by a factor about two they have higher masses (factor eight) and reach higher migration velocities (factor two). In total the kinetic energy of these particles has to be expected higher by a factor of 32! Such a high kinetic energy (of relatively elastical spheres in particular) must obviously be able to overcome the attractive electrical forces which try to clasp the particle on the collecting plate.

Because of the reasons mentioned above Glass II particles show almost no deposition on the collecting plate and, of course, no agglomerates can be

Glass I. As to see the process of ag
only E > 2 kV/cm and the particle c
As previously mentioned the exp
agglomerate structure at all.

Concerning the layer thickness
particles is suddenly starting at val
steeply increase at 3 kV/cm. The G
of around 1 kV/cm and presuma
limestone and glass because of pa
one should be careful because of re

Growth Behaviour

Fig.8 represents for the three dust
time dependence of L and D within
clean surface. According to Fig.6,
each dust was chosen which showe

The simplest behaviour is to obse
tinously growing in time, i.e. no
Looking at the dust layer thicknes

merate formation even starts at values of
ins can be longer by a factor of about two.
nents with limestone did not show any

: precipitation process with limestone
; of 1 kV/cm, while the values for Glass I
phite layer already forms at lower values
' its structure is less dense than that of
:le shape. Comparing the absolut values
ons mentioned above.

terials Graphite, Glass and Limestone the
e first 120 s, i.e. t = 0 means starting with
proximately that operation condition for
he strongest effects.

e with limestone: the dust layer is con-
of the particles precipitated do detach.
of the Glass I particles it is obvious that

Migration Velocity of Arriving Particles

Fig.9 exemplarily shows a sequence of pictures evaluated in order to derive the migration velocity. Depicted is the migration of an agglomerate of graphite particles at E = 3 kV/cm in time steps of 5ms. These pictures clearly illustrate the obvious problem of characterizing such a particle by a "diameter". Therefore in the following diagrams only isolated flying particles have been evaluated avoiding such extrem sizing problems. In spite of all that an influence of particle shape exist which has been ignored in all reflections following, especially with graphite.

Fig.10 shows the measured migration velocities for individual particles of approximately same (equivalent) size as function of the applied electrical field strength. Independent from the dust material it is to observe a steady increase of velocity when increasing E. The increase of Limestone is rather steep compared to that one of Graphite which even becomes almost zero for E > 1 kV/cm, while that one of Glass I sets in earlier and increases weaker than Limestone but stronger than Graphite. The absolute values are the highest for Glass I especially at electrical field strengths ≤ 1 kV/cm. At 1.5 kV/cm Glass I and Limestone particles get comparable velocities in the order of 0.2 m/s.

Additionaly a comparison with calculated values was made. The calculation was made according to the well known formula for field charging process /1/ resulting from a balance of forces and assuming the validity of Stokes' Law (abondoning Stokes' Law should lead to even lower velocity values because the c_w(Re)-function):

$$w_y = \left[1 + 2\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\right] \cdot \frac{\varepsilon_0}{\eta} \cdot E^2 \cdot d_p$$

The electrical permittivity of the dust materials is given in Table 1. Since Glass I shows a electrical resistivity close to that one of Graphite the value $\varepsilon_r = 1000$ was chosen instead of tha classical one of glass.

The comparison in Fig.10 shows that all theoretical values lie below the measured velocities. For Graphite it is only a factor of about two while the difference for Glass I and Limestone is about four to five. Even when a factor two is conceded to the uncertainity of the evaluation procedure the obvious conclusion must be that particles migrate faster than common theory predicts. The explanation of that phenomenon should be a goal of further studies.

Conclusions

These investigations showed that the electrical conductivity of particles decisively influences the structure of the dust layer deposited in an electrical field. Conductive particles, for example graphite, grow dendritically on the collector electrode. The length of the dendrites is limited by electrical forces. Thus the detachment of particle clusters is possible and agglomerate formation occurs.

Acknowledgements

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Table 1: Dust parameters (material constants according to /7, 8, 9/)

Dust	$d_{p,10,3}$ µm	$d_{p,50,3}$ µm	$d_{p,90,3}$ µm	T °C	rH %	ρ_{solid} g/cm³	E_{elast} N/m²	ρ_{bulk} g/cm³	ε	$\rho_{el,bulk}$ Ωcm	$\rho_{el,solid}$ Ωcm	ε_r
Graphite	18,4	33,5	54,2	26,4	39,6	2,3	$2{,}2 \cdot 10^{10}$	0,42	0,81	$2{,}85 \cdot 10^{5}$	10^{-1}	∞
				25,6	40,3			0,65	0,71	$4{,}39 \cdot 10^{5}$		
Glass I	22,3	40,8	65,7	26,2	40,3	2,5	$7{,}8 \cdot 10^{10}$	1,56	0,37	$7{,}71 \cdot 10^{7}$	10^{18}	(10^{3})*
				26,4	39,5			1,70	0,30	$9{,}36 \cdot 10^{7}$		
Glass II	42,9	58,2	80,5	26,5	48,3	2,5	$7{,}8 \cdot 10^{10}$	1,56	0,37	$8{,}23 \cdot 10^{12}$	10^{18}	5
				26,4	47,2			1,65	0,29	$8{,}58 \cdot 10^{12}$		
Limestone	12,9	25,2	52,3	25,0	40,5	2,7	$7{,}0 \cdot 10^{10}$	1,36	0,50	$5{,}21 \cdot 10^{10}$	10^{5}	8,45
				25,5	41,0			1,42	0,47	$7{,}21 \cdot 10^{10}$		

* This value was taken for the calculation of the particle charge and the migration velocity, respectively.

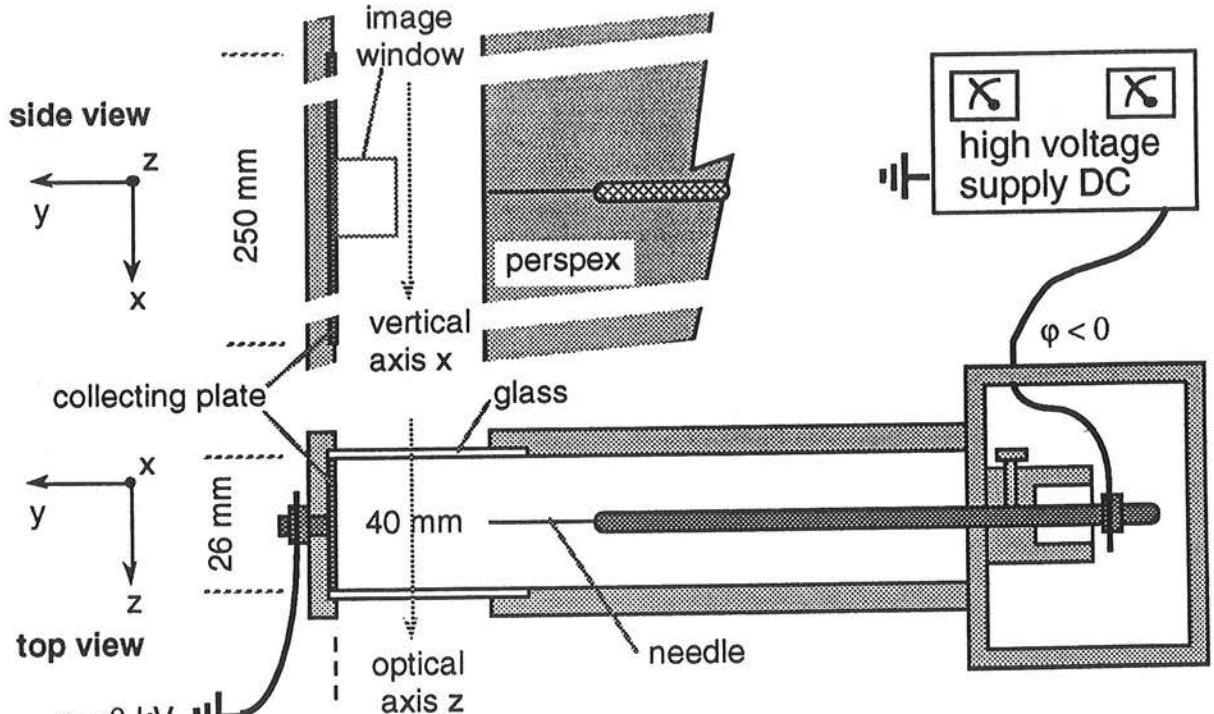

Fig. 1: Point-plate arrangement realized.

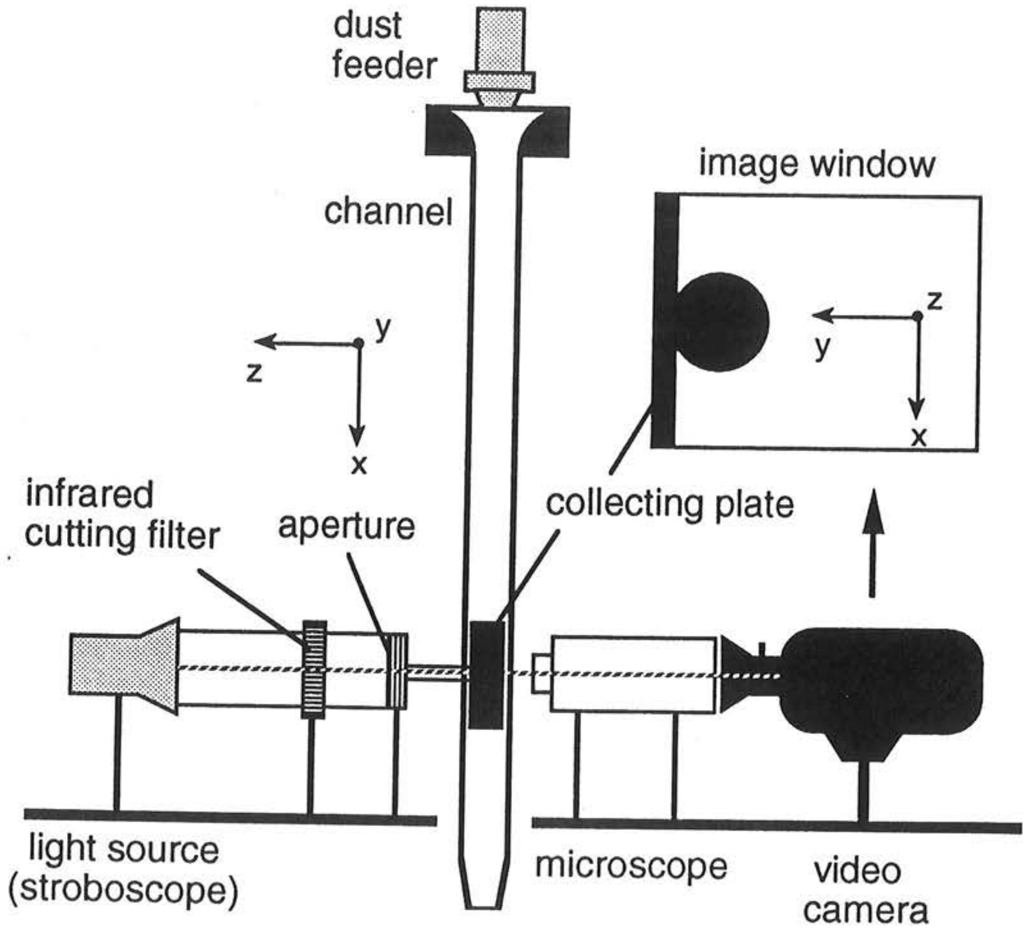

Fig. 2: Experimental set-up to observe behaviour of settling particles in a point-plate arrangement.

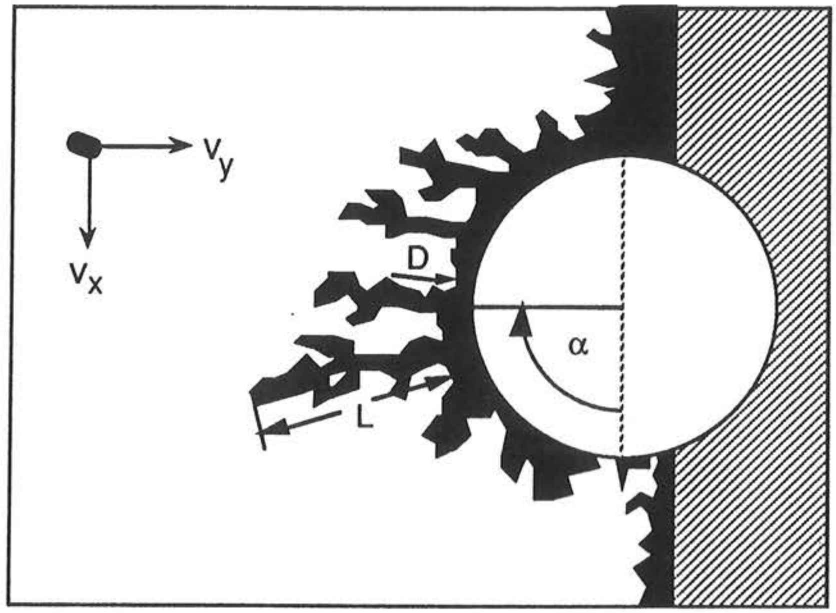

Fig. 3: Schematic illustration how digitalized video pictures were analyzed.

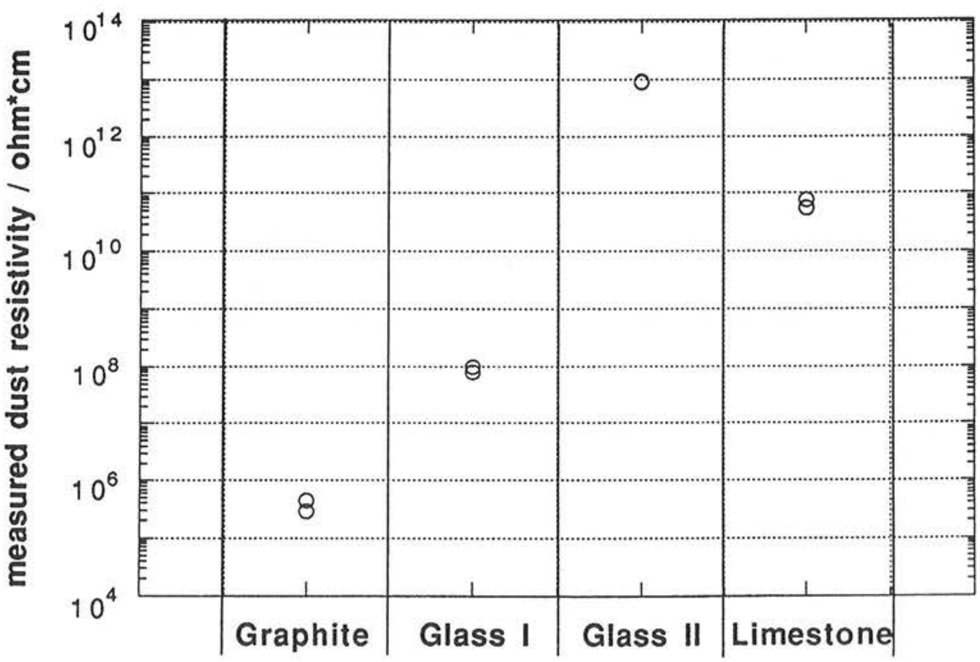

Fig. 4: Measured electrical resistivity of dust beds of the materials investigated.

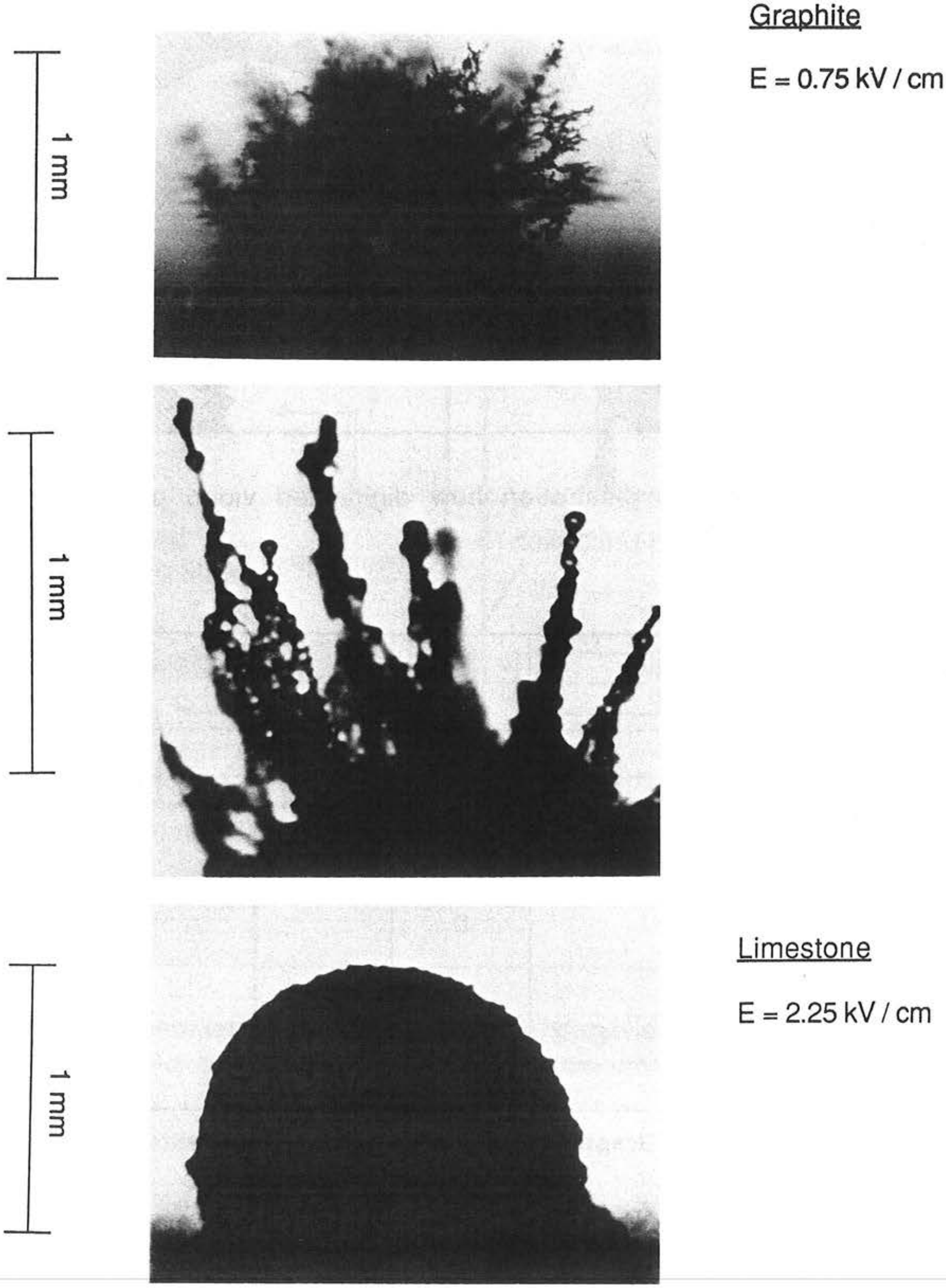

Fig. 5: Each picture represents a typical situation for the different dust materials investigated.

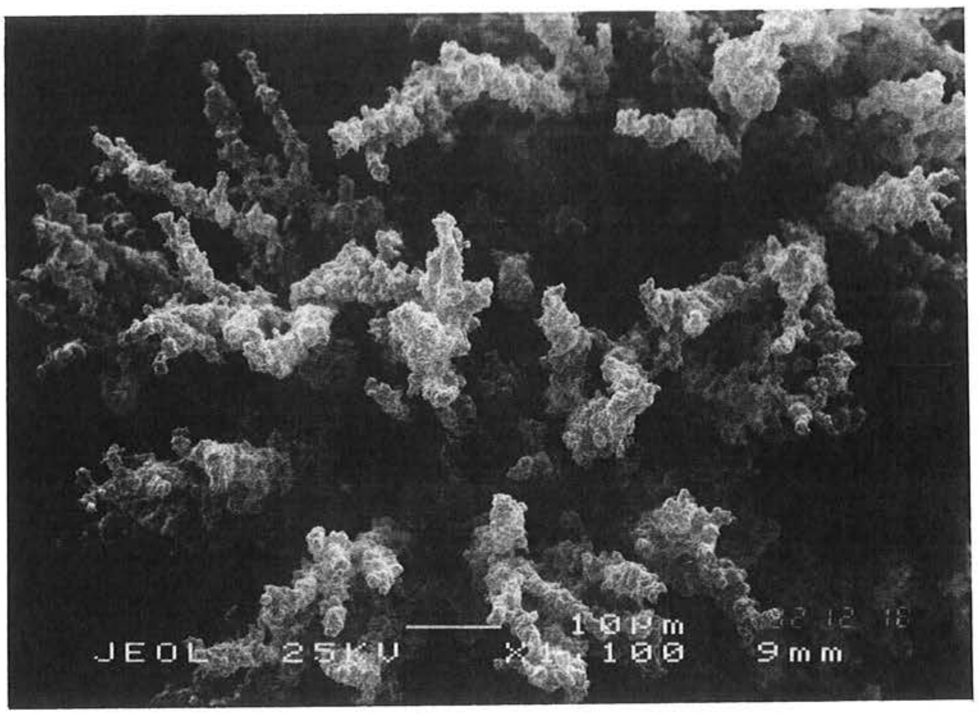

Fig. 6: Soot particles deposited on a collecting electrode in a needle-plate arrangement, flow velocity 5 m/s, magnification 1100 x.

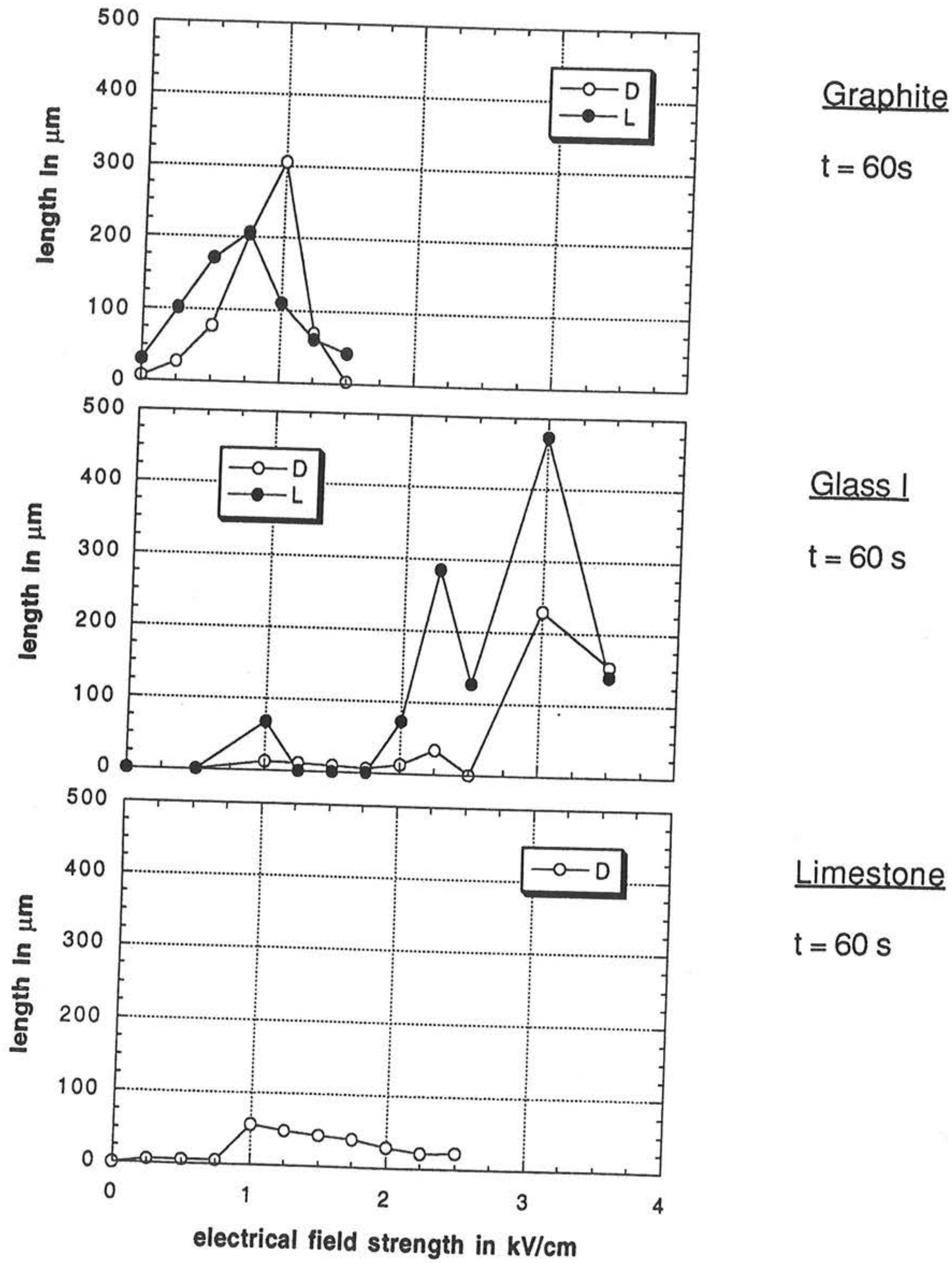

Fig. 7: Thickness of dust layer D and length of agglomerate chain L as function of the pseudohomogenous electrical field strength E for the three dust materials Graphite, Glass I and Limestone.

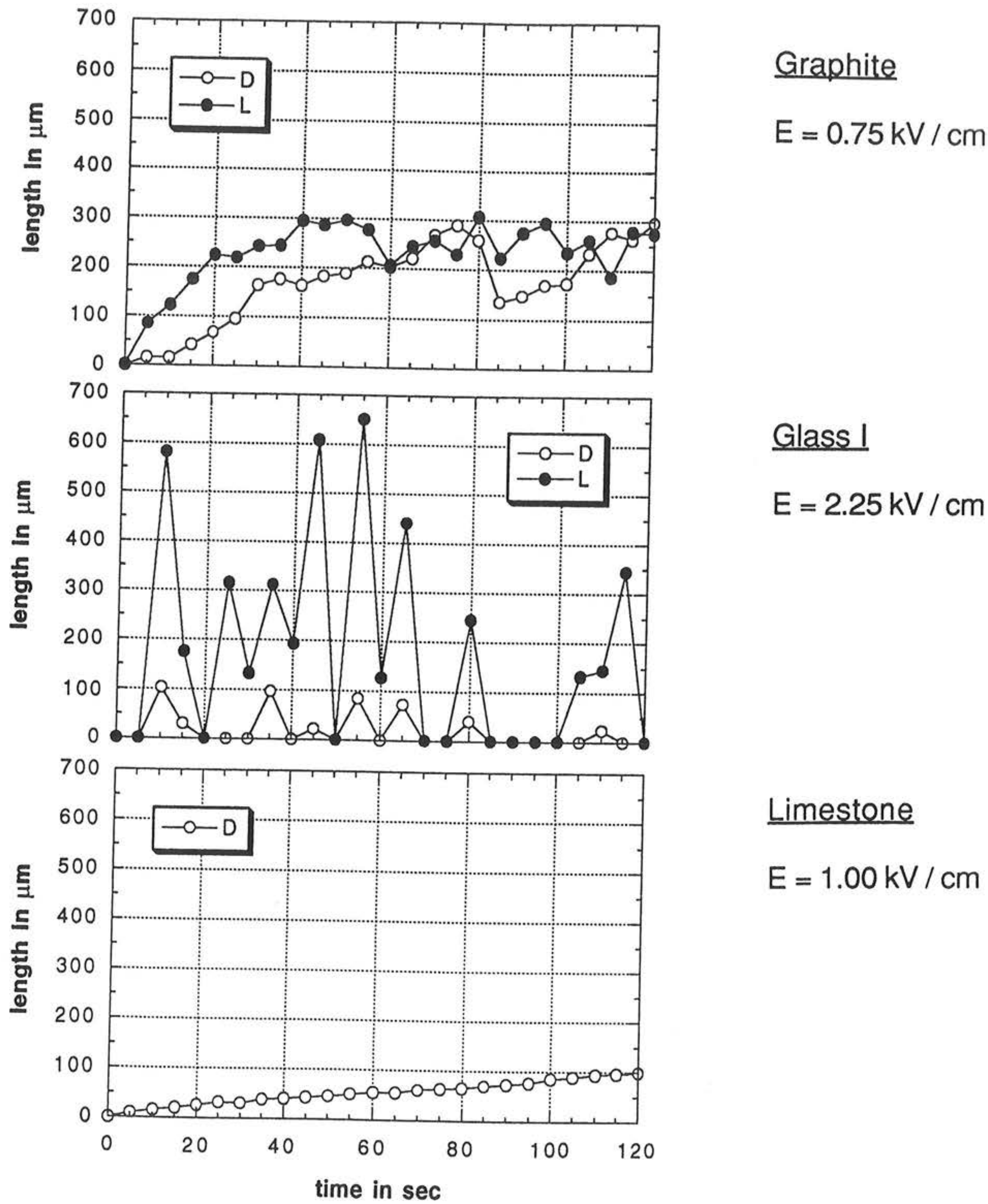

Fig. 8: Thickness of dust layer D and length of agglomerate chain L as function of time for the three dust materials Graphite, Glass I and Limestone; t = 0 means clean collecting surface.

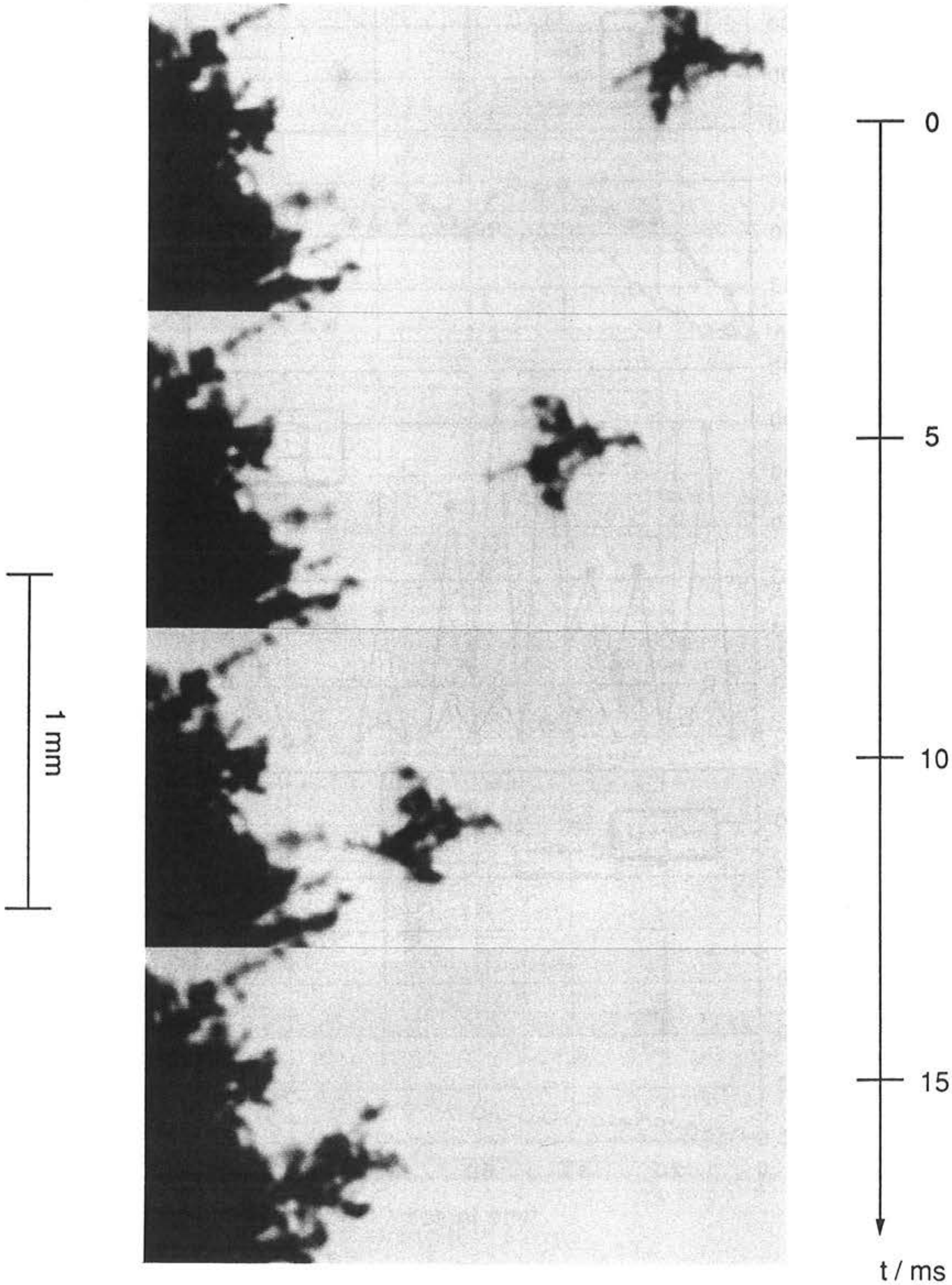

Fig. 9: Sequence of pictures showing an agglomerate of graphite particles moving towards the collecting electrode; time interval between pictures 5 ms.

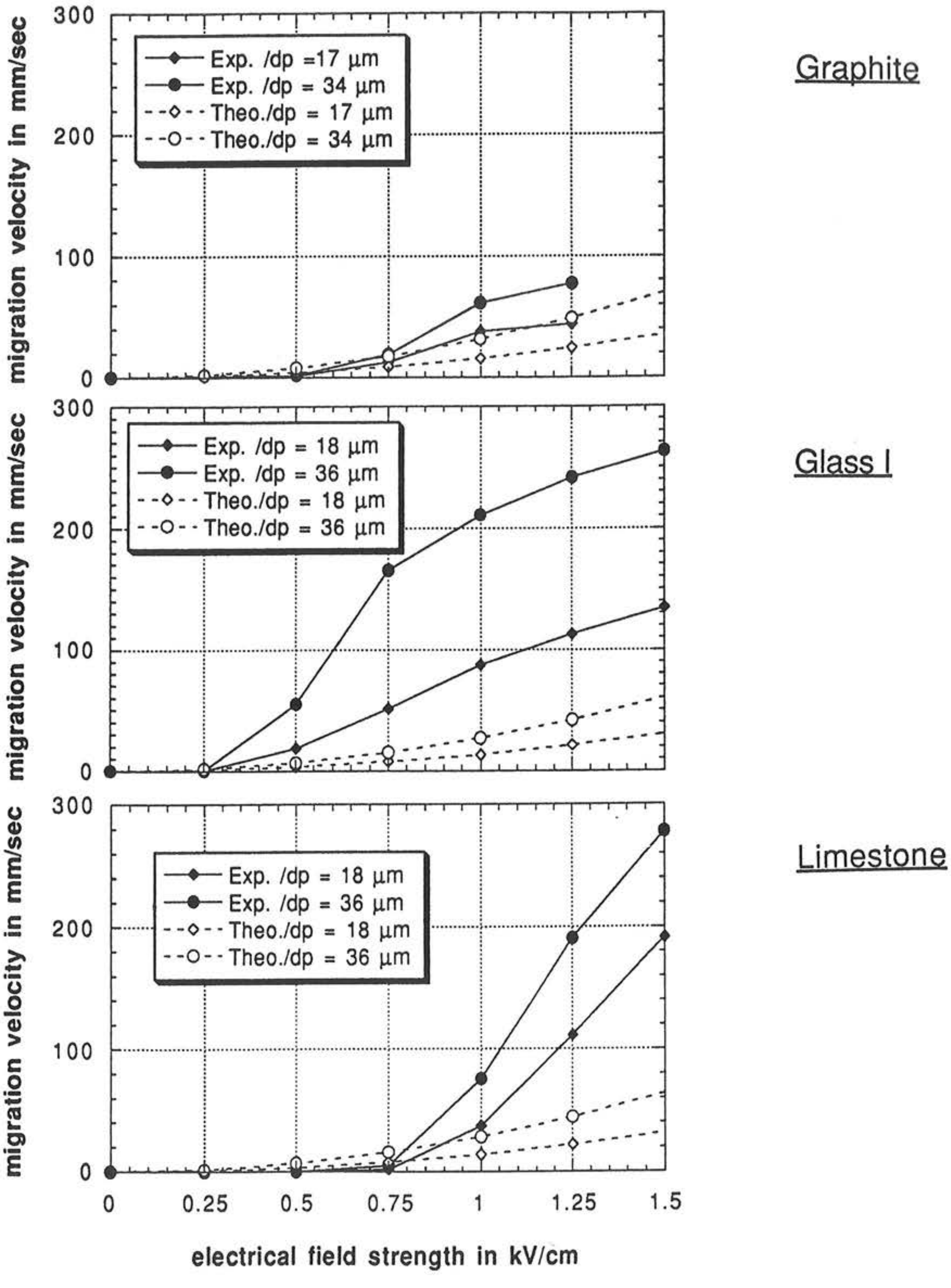

Fig. 10: Migration velocity w_y of individual particles as function of the pseudohomogenous electrical field strength E for the three dust materials Graphite, Glass I and Limestone.