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ELECTROSTATIC BENEFICIATION OF COAL

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QUARTERLY TECHNICAL PROGRESS REPORT

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1. INTRODUCTION

From previous study, we know that oxidation of the coal surface will decrease the efficiency of electrostatic beneficiation by increasing the negative charge of the carbon particles. The polarity and magnitude of charge acquired by the nonconducting particles varied depending on the state of "oxidation" of the surfaces and the work function relative to the metal surface. The formation of oxide layer on the coal particles are rather rapid, therefore, the grinding and charging processes are need to be carried out in a nitrogen or argon atmosphere.

It is clear that impaction efficiency between coal particle and charger will decrease with decreasing particle size and particle velocity. So, it is necessary to charge small particles in a different process. We plan to size classify the coal particles into three size fractions: 1)fine (<40μm). 2) medium (40~100μm). 3) coarse (100~200μm). Static mixer and a new designed charger (powder pump connected with a circular tubing) are used in the experiment. And we planned to measure the charge to mass ratio distributions as a function of the particle size distribution on the separator plates.

2. DETERMINATION THE CHARGE TO MASS RATIO DISTRIBUTIONS AS A FUNCTION OF PARTICLE SIZE DISTRIBUTION

The present coal particles used in our studies are mixture ground in the size range up to 200 μm. We plan to classify the ground coal particles in three size groups (<40μm, 40~100μm and 100~200μm) by using sieves or size classifier. The charging efficiency of different size particles with several types of tribocharging processes: (1) static mixer (as a function of air velocity and concentration), (2) milling against copper beads (as a function of bead size, milling time, etc.). (3) New designed electric static charger. Through experiment, we will establish most efficient charging methods for each size group, both with fresh and oxidized coal powder. A series experiments is planned to process at a nitrogen atmosphere (Fig. 1).

2.1 Separation of coal particles in the atmospheric environment

First we are using a small hand grinder (Gilson Co., Model LC-80) to grind Illinois #6 coal. The coal powder then will be size classified into three size groups (<40μm, 40~100μm and 100~200μm) by using sieve or size classifier. The coal powder will be transported into the electric charger through vibrate feeder. As for the electric charger, we are going to use static charger, milling against copper beads or powder pump connected with circular tubing to charge the particles. The construction of parallel plate separator has been illustrated in previous report. The two electrodes are connected to two HV power supplies. After the coal and pyrites have been separated on to the separator plates, we are going to take the samples at the different locations of the plates, and analyze their charge over mass ratio with size distribution. The charge over mass ratio will be measured by Faraday Cage.

2.2 Separation of coal particles in the nitrogen environment

We are going to use the sealed bags to perform the grinding, feeding and charging processing at the nitrogen environment in order to avoid the oxidization of coal surface by oxygen in the atmosphere. As for the transportation of the ground powder samples between the sealed bags, we are going to use the sealed box filled with nitrogen gas. Then we will measure the charge over mass ratio along with the size distribution on the separator plates. Compare the results with that in the atmospheric environment.

3. METHOD TO MEASURE THE MASS, CHARGE AND SIZE OF THE PARTICLE

One of the project objectives is to develop instrumentation used for particle size and charge analysis for particles in the size range 1 to 100 μm diameter. Therefore, we will do the following: (1) Computation of the electric field of an isolated toroidal electrode raised to potential V with respect to distance points. (2) Simulation of charged particles in three dimensions in the oscillating electric field of a toroidal electrode in the presence of an external air flow. (3) Measurement of particle size, charge and mass based on their response to the oscillating electric field of a toroidal electrode.

1). Electric field of a toroidal electrode

The electric field of a toroidal electrode is to be obtained by the substitute charged method. The approach is to replace the actual toroidal with a set of ideal linear ring charges within the volume of the toroidal. Placement of the ring charges is illustrated in Fig.2 for four ring charges. The number N of ring charges and their position are related initially and

considered to have uniformly distributed charges q_j, j =1, 2, ..., N. Then the charges q_j are calculated such that the potential at N selected points on the surface of the toroidal due to the set of ring charges, has the correct value. The number and /or position of the substitute ring charges is varied to find a suitable set, i.e. one which gives the potential at any point on the toroidal surface correctly to 0.001% variation for modeling the field of the toroidal.

Let the center of a substitute charge ring of radius a be located at position (x_0, y_0, z_0) with respect to axis (x, y, z) parallel to the x-y plane (i.e., z is same for all points of the ring) (Fig.3). Then, a point on the ring is located at coordinate where

$$x'=x_0+a\cos j,\ y'=y_0+a\sin j,\ z=z' \tag{2}$$

The element of charge dq on a segment of the ring of length l is

$$dq=ldl=\frac{q}{2\pi a}adj=\frac{q}{2\pi}dj \tag{3}$$

where $$dj=\frac{2\pi}{M} \tag{4}$$

and $$j=(\frac{2\pi}{M})k,\ k=1,2,3,...,M \tag{5}$$

Where φ $(0<\varphi<2\pi)$ is an coordinate around the ring, λ is the linear charge density on the ring and q is the total ring charge. The constitution of the ring segment to the electric potential at field point p(x, y, z) is

$$dV=\frac{1}{4\pi\varepsilon_0}\frac{dq}{[(x-x')^2+(y-y')^2+(z-z')^2]^{1/2}} \tag{6}$$

After substituting Eq.(3) to (5) into Eq.(6) and summation, we obtain

$$V_j=\sum_{i=1}^{N}C_{ij}q_i,\ i,j=1,2,3,...,N \tag{7}$$

where

$$C_{ij}=\frac{1}{4\pi\varepsilon_0}\sum_{k=1}^{M}\frac{k/M}{[(x_j-x_i')^2+(y_j-y_i)^2+(z-z')^2]^{1/2}} \tag{8}$$

Where (x_j, y_j, z_j) are coordinate of the jth field point chosen on the toroidal surface and j designate the resultants line charge (i=1,2,3,..,N). In the above expression,

$$x_i' = x_{oi} + a_i \cos(\frac{2\pi k}{M})$$

$$y_i' = y_{oi} + a_i \sin(\frac{2\pi k}{M})$$

$$z_i' = z_{oi}$$

where (x_{Oi}, y_{Oi}, z_{Oi}) are coordinates of the center of the ith ring charge which has radius a_i.

Application of Eq.(7) to the N rings of charge results in a system of N linear equations:

$$\begin{bmatrix} C_{11} & & \\ & \ddots & \\ & & C_{NN} \end{bmatrix} \begin{bmatrix} q_1 \\ \vdots \\ q_N \end{bmatrix} = \begin{bmatrix} V_1 \\ \vdots \\ V_N \end{bmatrix} \tag{9}$$

Rearrangement of Eq.(9) yields the solution for the unknown charges:

$$\begin{bmatrix} q_1 \\ \vdots \\ q_N \end{bmatrix} = \begin{bmatrix} V_1 \\ \vdots \\ V_N \end{bmatrix} \begin{bmatrix} C_{11} & & \\ & \ddots & \\ & & C_{NN} \end{bmatrix}^{-1} \tag{10}$$

The solution to Eq.(10) has been performed on a high speed personal computer using C/C^{++} computer language. Once the q_j are identified, the electric potential at any point outside the toroidal can be calculated by applying Eq.(7) to numerically calculate the potential due to the set of ring charges.

Similarly, the electric fields are

$$E_x = -\frac{dv}{dx}, E_y = -\frac{dv}{dy}, E_z = -\frac{dv}{dz}$$

$$E_x = -\sum_{k=1}^{M} \frac{q}{2\pi\varepsilon_0 M} \frac{x\text{-}x_0 - a\cos(\frac{2\pi k}{M})}{[(x\text{-}x_0 - a\cos(\frac{2\pi k}{M}))^2 + (y\text{-}y_0 - a\sin(\frac{2\pi k}{M}))^2 + (z\text{-}z_0)^2]^{3/2}} \quad (11)$$

$$E_y = -\sum_{k=1}^{M} \frac{q}{2\pi\varepsilon_0 M} \frac{y\text{-}y_0 - a\cos(\frac{2\pi k}{M})}{[(x\text{-}x_0 - a\cos(\frac{2\pi k}{M}))^2 + (y\text{-}y_0 - a\sin(\frac{2\pi k}{M}))^2 + (z\text{-}z_0)^2]^{3/2}} \quad (12)$$

$$E_z = -\sum_{k=1}^{M} \frac{q}{2\pi\varepsilon_0 M} \frac{z\text{-}z_0}{[(x\text{-}x_0 - a\cos(\frac{2\pi k}{M}))^2 + (y\text{-}y_0 - a\sin(\frac{2\pi k}{M}))^2 + (z\text{-}z_0)^2]^{3/2}} \quad (13)$$

2). Trajectories simulations

The position of the charged particle in an electric field is often affected by the electric forces and other external forces exerted on the particle. In order to study the motion of a charged particle in the electric field of a toroidal ring, the equations are given

$$m\frac{d^2x}{dt^2} + \frac{3\pi\eta d}{c}\frac{dx}{dt} = qE_x \cos wt \quad (14)$$

$$m\frac{d^2y}{dt^2} + \frac{3\pi\eta d}{c}\frac{dy}{dt} = qE_y \cos wt \quad (15)$$

$$m\frac{d^2z}{dt^2} + \frac{3\pi\eta d}{c}(\frac{dz}{dt} - v_{air}) = qE_z \cos wt + mg \quad (16)$$

where η--- viscosity of medium,

d ---the diameter of particle

m---mass of the particle

q---charge of the particle

c---cunningham correction factor

E_x, E_y, E_z---electric field of x, y, z axis respectively

mg---weight of the particle

v_{air}---air velocity

The first term on the left hand side of Eq.(14) is the particle acceleration, the second term is the drag force, the third term is the AC force. In Eq.(15) and (16), the terms are equivalent except the fourth is the gravitational force in Eq.(16). Then, velocity on the x axis is expressed as

$$v_{x_i} = v_{x_{i-1}} + \frac{d^2x}{dt^2}\Delta t \tag{17}$$

and $$x_i = x_{i-1} + v_{x_i}\Delta t + \frac{1}{2}\frac{d^2x}{dt^2}(\Delta t)^2 \tag{18}$$

Similarly, we can obtain

$$v_{y_i} = v_{y_{i-1}} + \frac{d^2y}{dt^2}\Delta t \tag{19}$$

and $$y_i = y_{i-1} + v_i\Delta t + \frac{1}{2}\frac{d^2y}{dt^2}(\Delta t)^2 \tag{20}$$

$$v_{z_i} = v_{z_{i-1}} + \frac{d^2z}{dt^2}\Delta t \tag{21}$$

and $$z_i = z_{i-1} + v_{z_i}\Delta t + \frac{1}{2}\frac{d^2z}{dt^2}(\Delta t)^2 \tag{22}$$

3). Methods to determine the charged particle properties

The equation of motion of a charged aerosol particle in an oscillating electric field with respect to rectangular coordinate (x, y, z) are shown in Eq.(14) to (16). Let the position of the particle x, y and z be expressed as

$$x = X + \xi, \quad y = Y + \nu, \quad z = Z + \gamma \tag{23}$$

where X, Y, Z represent the position of the slowly moving center of oscillation, while ξ, υ, γ represent the relatively small oscillating particle motion around the center of motion. Inserting Eq.(23) into Eq.(14), and expanding $E_X(x, y, z)$ in a Taylor's series, one obtains the following equation of motion in the x-direction:

$$m\frac{d^2X}{dt^2}+\frac{3\pi\eta d}{c}\frac{dX}{dt}+m\frac{d^2\xi}{dt^2}+\frac{3\pi\eta d}{c}\frac{d\xi}{dt}$$
$$=q[E_{xo}+\xi(\frac{\partial E_x}{\partial X})_o+\nu(\frac{\partial E_x}{\partial Y})_o+---]\cos\omega t+F_x \tag{24}$$

where the suffix o refers to the position of the center of oscillation. Neglecting the higher terms of ξ and υ under the assumption that they remain to be small enough, the following linear equation for the x-component of oscillation results from Eq.(24), as a first approximation:

$$m\frac{d^2\xi}{dt^2}+\frac{3\pi\eta d}{c}\frac{d\xi}{dt}=qE_{xo}\cos wt \tag{25}$$

The solution of Eq.(25) gives for steady state oscillation in the x-direction:

$$\xi=CE_{xo}\cos(\omega t-\psi) \tag{26}$$

where $C=\dfrac{q}{m\omega^2\sqrt{1+(3\pi\eta d/m\omega)^2}}$ (27)

and

$$\psi=\pi-\tan^{-1}(3\pi\eta d/m\omega) \tag{28}$$

Similarly, one obtains the steady state solution oscillation for the y and z direction:

$$\nu=CE_{yo}\cos(\omega t-\psi) \tag{29}$$

$$\gamma=CE_{zo}\cos(\omega t-\psi) \tag{30}$$

Putting Eq.(26), (29) and (30) into Eq.(24) and neglecting the terms containing ξ, υ and γ, the following linear equation of motion for the center of oscillation in x-direction can be obtained.

$$m\frac{d^2X}{dt^2}+\frac{3\pi\eta d}{c}\frac{dX}{dt}=-(1/4)m\omega^2C^2(\frac{\partial E^2}{\partial X})_o+F_x \tag{31}$$

where $E=\sqrt{E_x^{\,2}+E_y^{\,2}+E_z^{\,2}}$ (32)

Eq.(27), (28) and the trap distance can be used to imply particle size, charge and mass.

4). Experimental methods

Numerical computation using above method has been made to analyze the trajectories of charged particle motion at any place near the center over the ring electrode. A toroidal electrode with radius of 1cm and 1 mm thickness of the wire was selected for the simulation. An alternating potential with peak voltage of 10,000 V (relative to ground) was applied to the ring. Calculation were made at the frequency of 100 Hz, surface charge of 25.4 $\mu C/m^2$ and for several particle size. The two dimensional trajectories of particle motion are given in Figures 4 to 7. All four examples show that the charged particles will be caught some where below the z=0 plane. The trajectories are different due to different size of particles.

A real time imaging system based on a standard video camera to view and record the motion of a charged particle need to be developed. A diagram of the apparatus will be set up (Fig.8). Test aerosol particles will be produced by a aerosol generator. The generator will be fitted with an induction cap to which a voltage can be applied to control the charge on the aerosol droplets. The particle motion can be recorded by a video camera. The particle diameter, charge and mass can be determined by analyzing the phase lag between particle motion trajectory and electric field, oscillating amplitude and trap position.

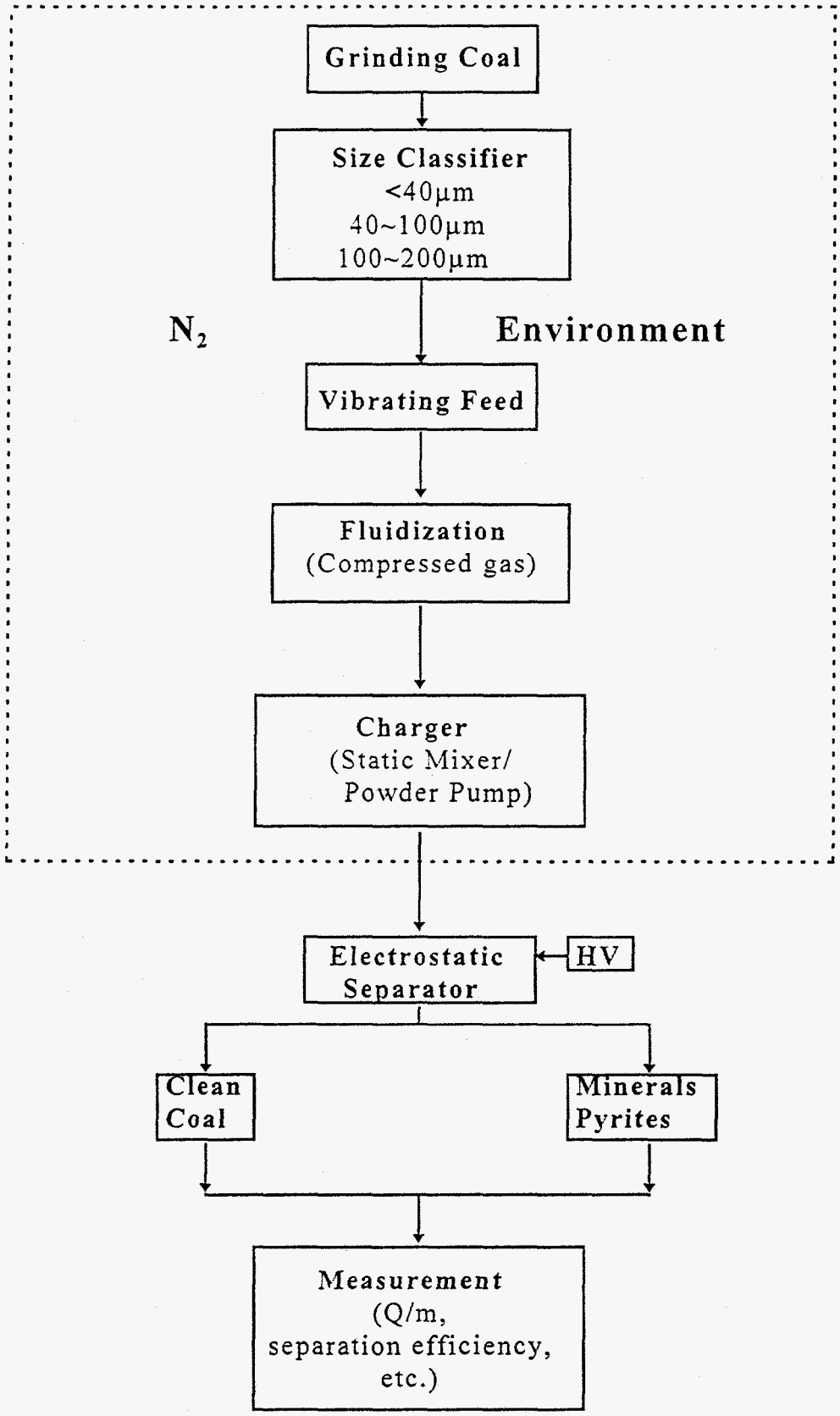


Fig. 1 Block diagram of experiment for separating the coal particles at nitrogen environment

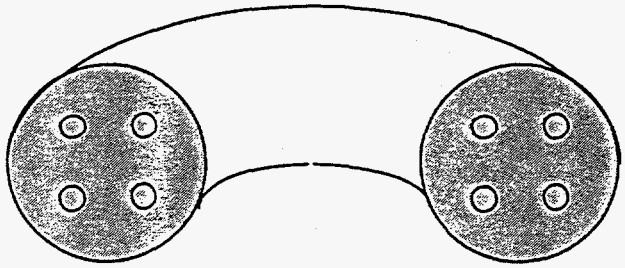


Fig.2 Cross section of the toroidal ring

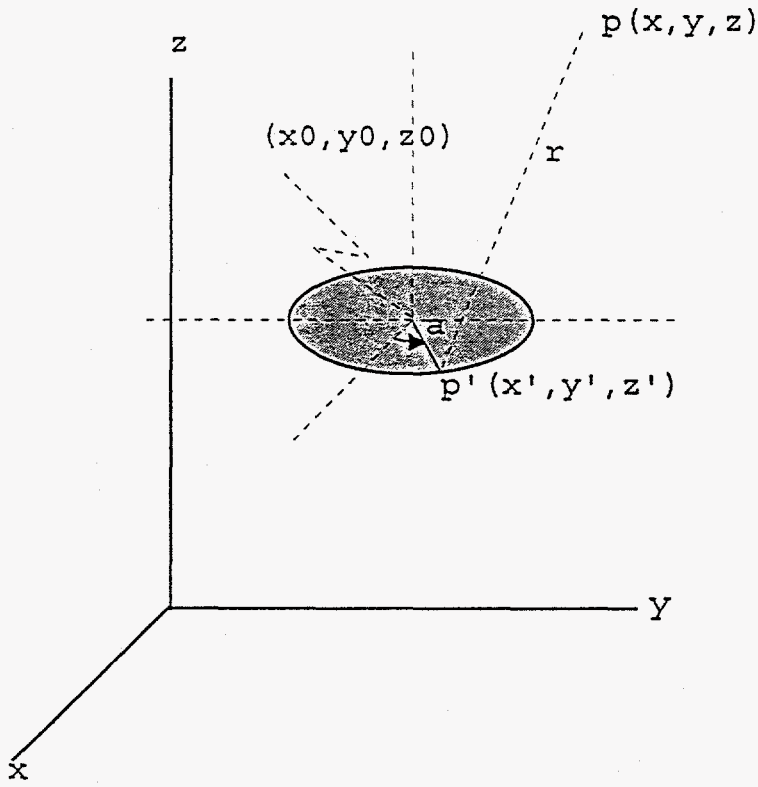


Fig.3 Ring lies in x-y plane

Fig.4 Particle motion in an AC toroidal electrode (V=10000sin(100*2pi*t))

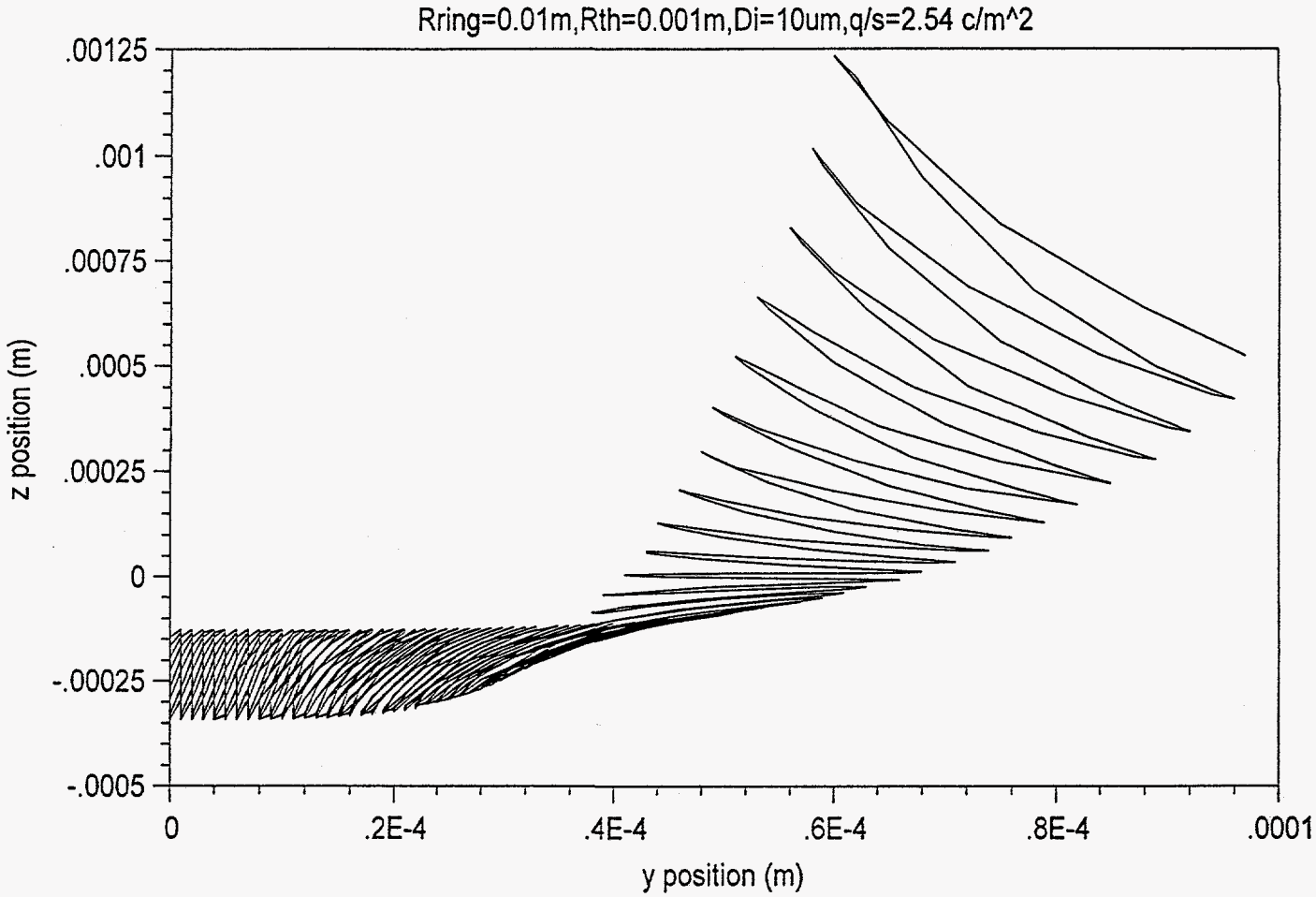


Fig.5 Particle motion in an AC toroidal electrode (V=10000sin(100*2pi*t))

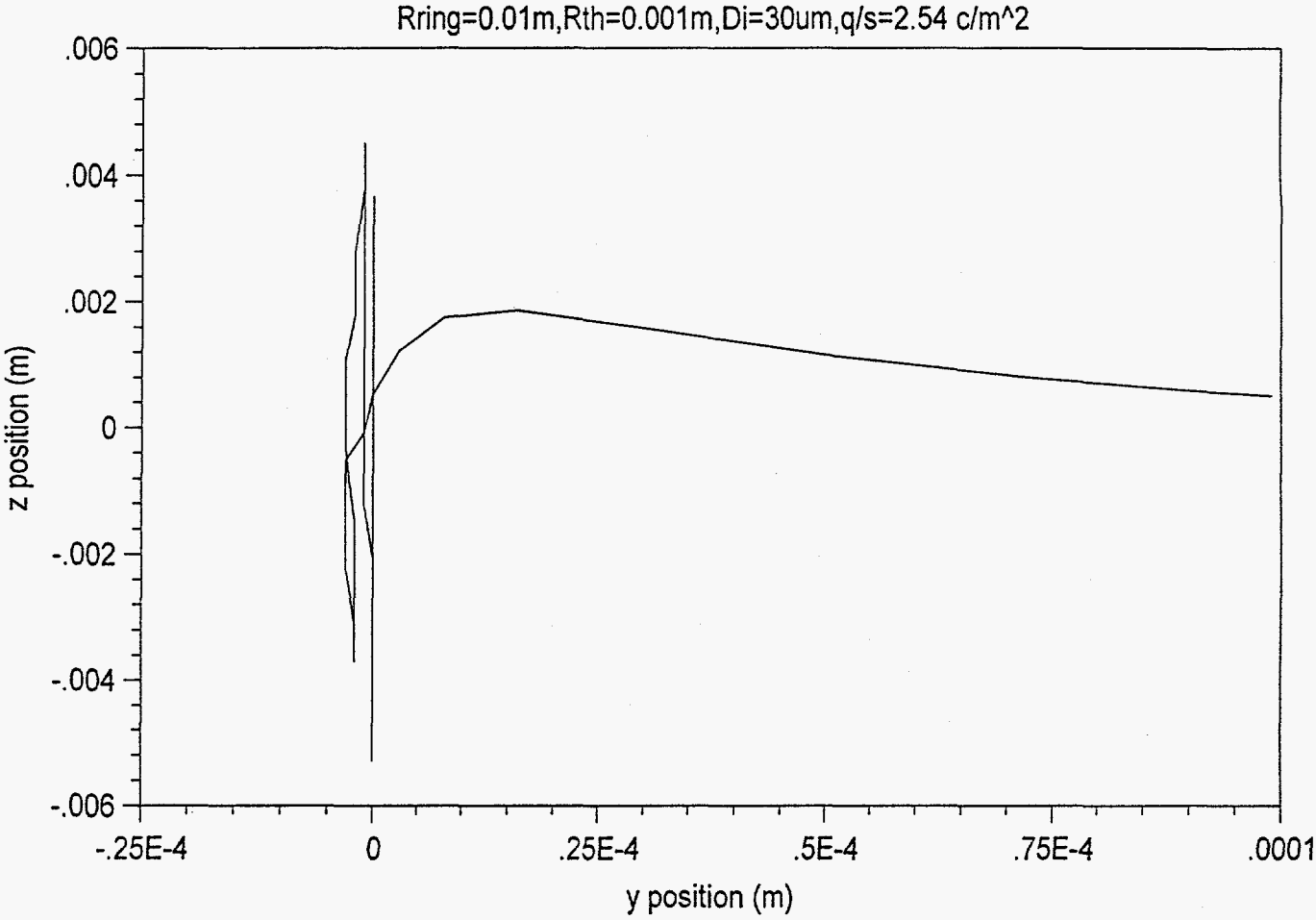


Fig.6 Particle motion in an AC toroidal electrode (V=10000sin(100*2pi*t))

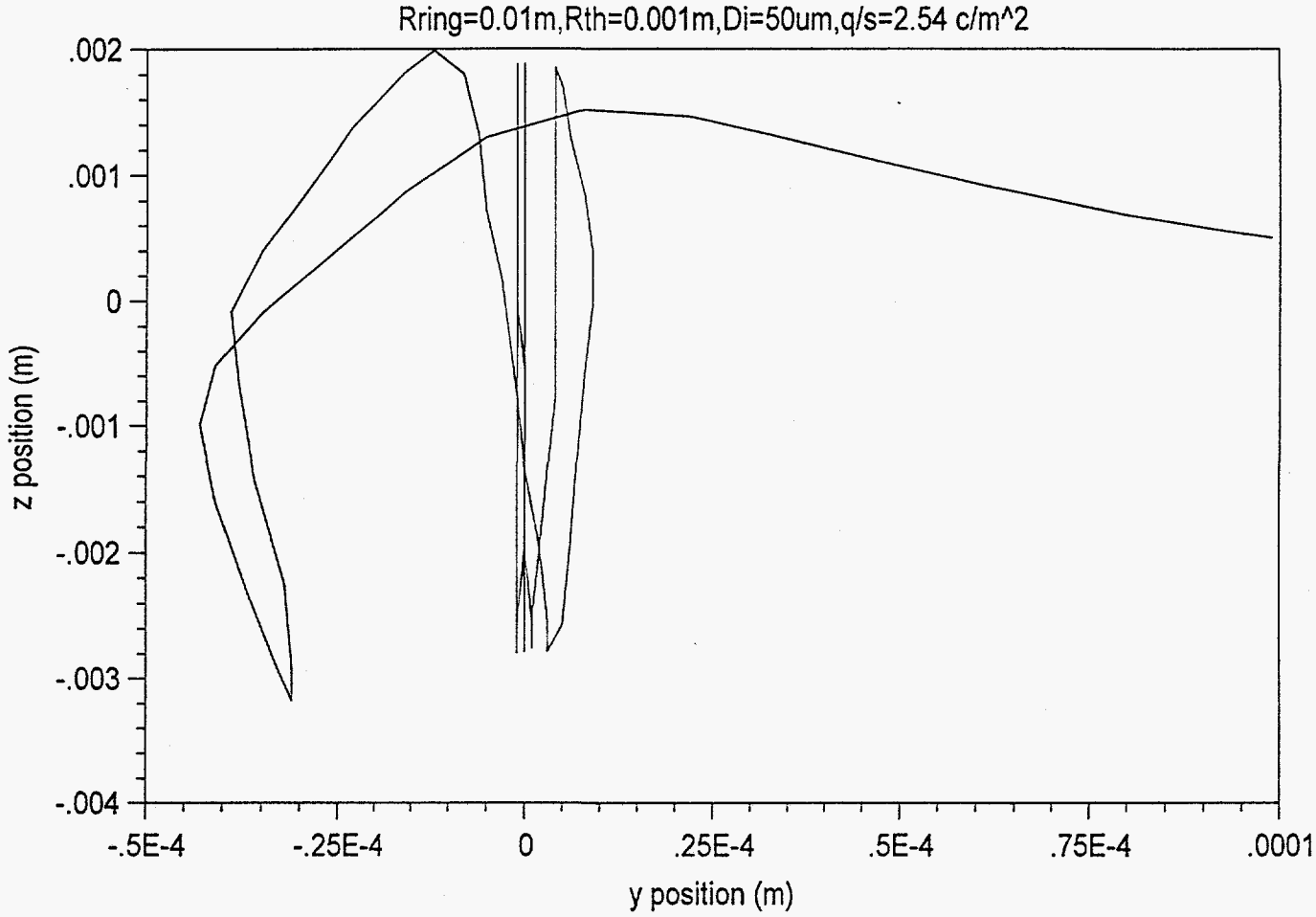
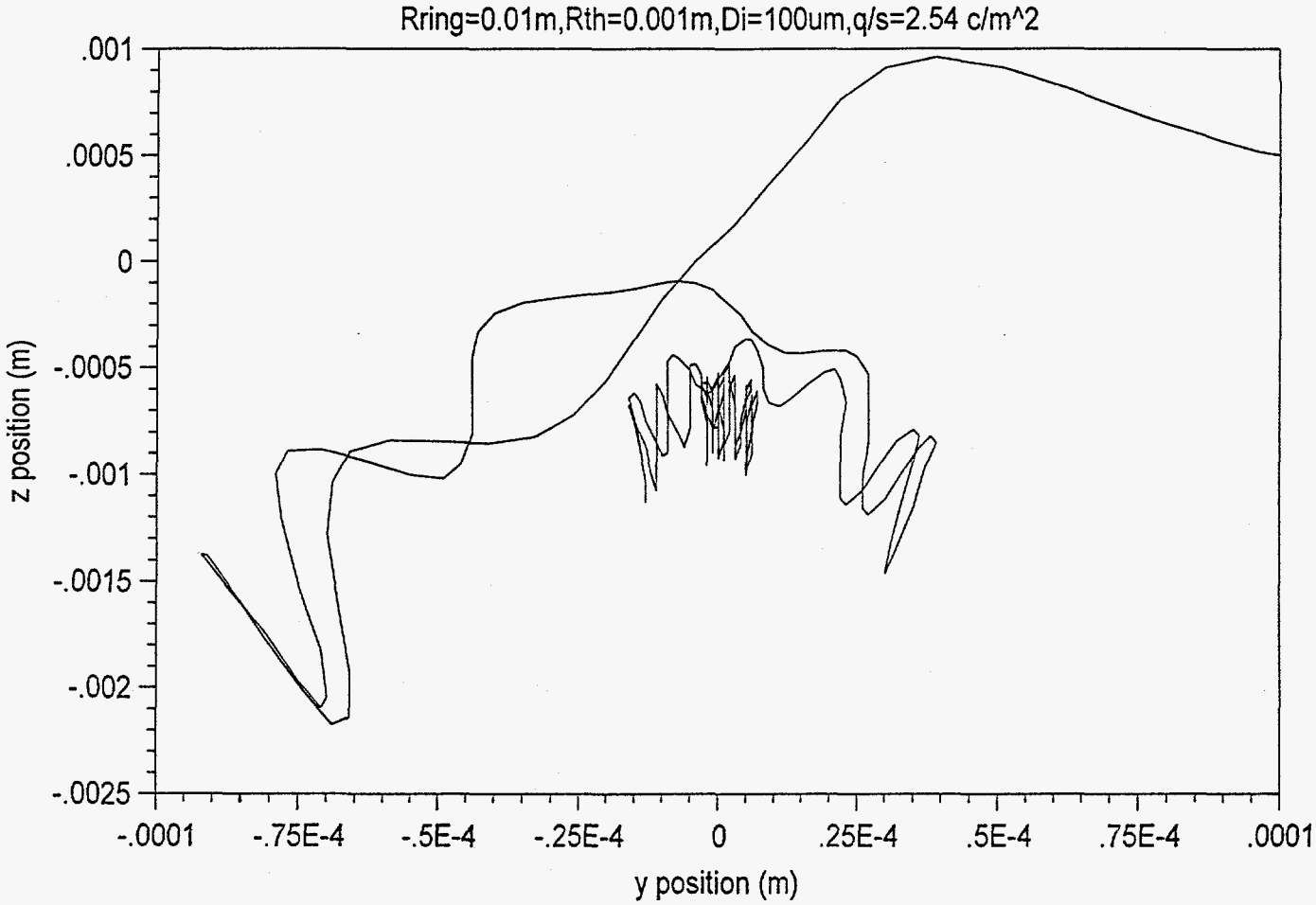


Fig.7 Particle motion in an AC toroidal electrode (V=10000sin(100*2pi*t))



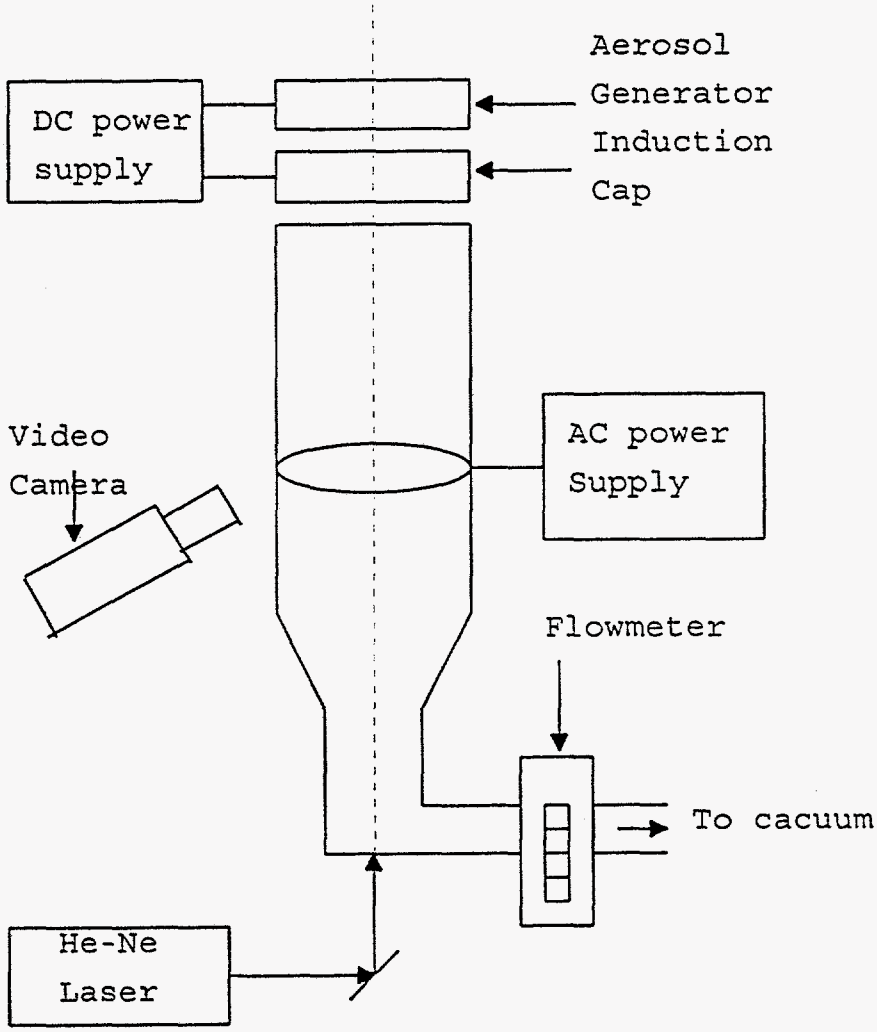


Fig. 8 Experiment Setup