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Preliminary Design of an Electrostatic Seperator for Micropulverized Lignite

Willie Nester

Preliminary Design of an Electrostatic Separator for Micropulverized Lignite

A Technical Report

by

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Appreciation is hereby expressed for partial support for the conduct of this project to the Mississippi Minerals Resources Institute.

Thanks are also due Dr. L. D. Flippin for his advice concerning electrostatic field distributions.

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NOMENCLATURE

A	Head loss coefficient	$\frac{ft.\ lbs}{Ibm}$ *
B	Head loss coefficient	$\frac{ibf.sec^2}{ft^2.ibm}$
C	Head loss coefficient	$\frac{Ibf.sec.^2}{ft^5.Ibm}$
E	Electrical Field	Volt/ft
f	Darcy-Weisbach friction factor	—
F_E	Electrical Force Acting on Particle	lbf.
F_d	Drag Force Acting on Particle	ibf
h_f	Head loss	$\frac{ft\text{-}lbf}{Ibm}$
κ	Head loss coefficient	—
M	Mass of fluid displaced by particle	Kg, Ibm
Mp	Mass of particle	Kg, Ibm
n	Power of Head loss term	—
Q	Volume Flow Rate of Fluid	ft^3/sec
r	Radius, Measured from the point 4 feet below the separator section	ft
t	Time	sec
σ	Velocity of the particle	ft/sec
VF	Velocity of the Fluid	ft/sec
$\overline{V}$^R	Velocity of Particle relative to Fluid	ft/sec
W	Weight of particle	lbf
S	Angle measured to the right from the center of the separator section	degrees
Õ	Electrical Potential	volts

NOMENCLATURE - Continued

Φ	Φ minus voltage of electrodes plates	volts
θ	Angle to the left of the positive electrodes plates	degrees
v	Kinematic Viscosity of Fluid	ft^2/sec

ABSTRACT

The ever growing need for available and affordable energy to lessen our dependence on foreign oil has led this country to increase its use of coal and lignite as fuel for power plants. One drawback to the use of coal and lignite is the polluting exhaust gas that results from burning. This project examines electrostatic separation as one possible method which could possibly improve this problem.

INTRODUCTION.

Electrostatic separation is the process where finely ground particles of lignite are triboelectrically charged and carried by a fluid through an electrical field produced by two high voltage electrodes on opposite sides. The particles are drawn to the electrode of opposite charge and are thus separated. A collecting device collects the separated flow as it comes out of the electrostatic section with the hope that cleaner burning lignite will be the results at one of the electrodes.

Some work on electrostatic separation of coal has been done in Canada and some details and results are given in Inculet, Bergougnou and Brown (1) and Inculet, Quigley, Bergougnou and Brown (2). It was the objective of this project to make a preliminary design of a small scale model to use on Mississippi lignite and to do a flow analysis and particle trajectory predictions on the design.

DESIGN

Figure 2.1 shows the electrostatic separator that is the subject of this report. A description of the separator component is given below.

Nitrogen gas is the fluid chosen to be used in this system. The reasons for its being chosen were its availability, its easy handling, and its non-combustible nature. The last reason is especially important since, with the high voltage in the separator section a significant amount of oxygen as found in air could possibly cause an explosion. The nitrogen is to be fed into the mixing tank by three nozzles equally spaced 120° apart, tilted upward at an angle of about 10° from the horizontal. They are also at an angle of about 30° to the left of the center of the tank, so that there would be a swirling motion resulting from the entrance of the nitrogen into the mixing tank. Figure 2.2 shows the position and direction of the nozzles. A pressure regulator is to be used with the N^ tank to control the flow. Each nozzle should be able to create a jet velocity of 3-10 fps with a combined mass flow rate at about 0.0225 to 0.0375 lbm/sec or about 0.3 to 0.5 ft^3/sec at atmospheric pressure.

The mixing tank, where the powdered lignite is placed, is a plastic container of 1.5 to 2 ft^3 in volume. It is to be filled about 1/3 full with the finely ground lignite. The tank is to be sealed except for a 2 inch plastic pipe discharge at the top. This is the area where most of the triboelectrification occurs. Triboelectrification can be described as follows: particles of different

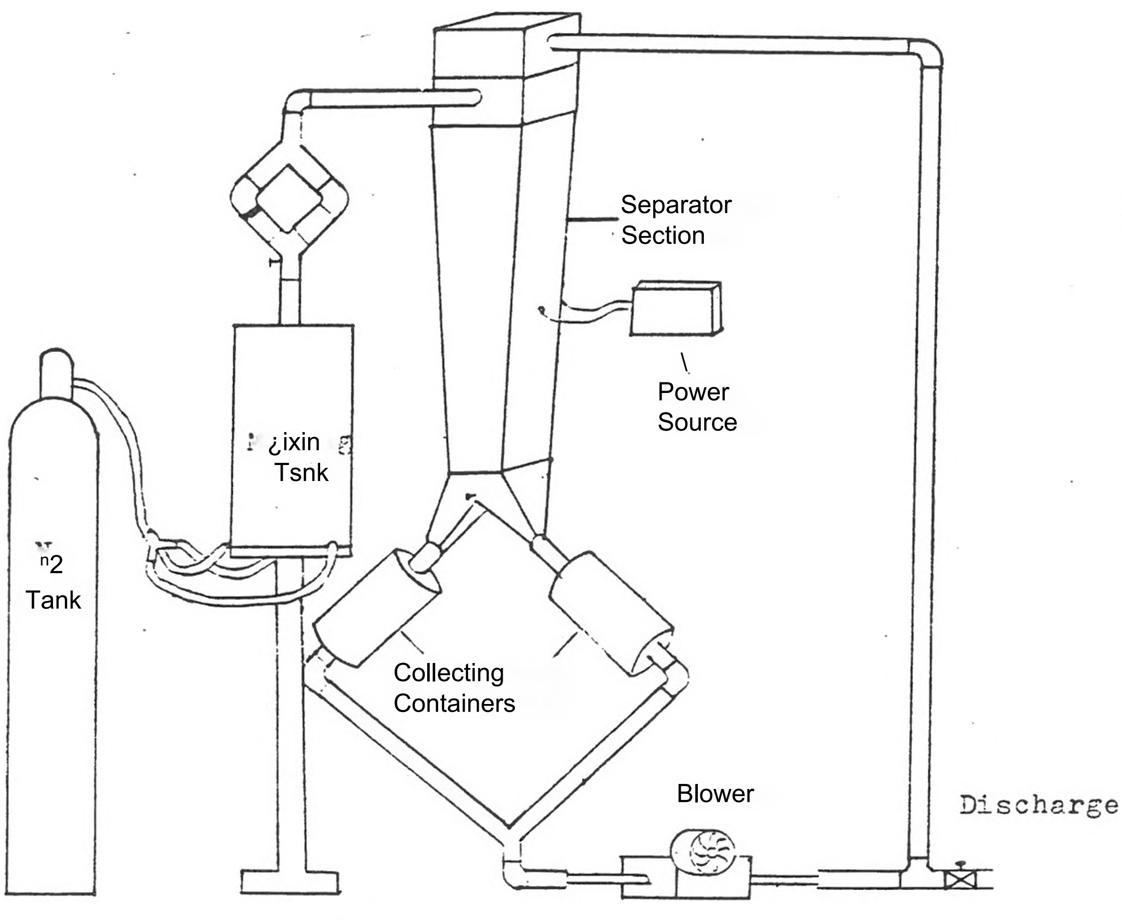
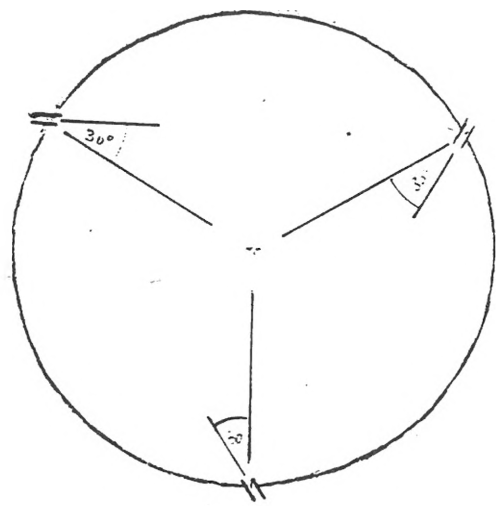


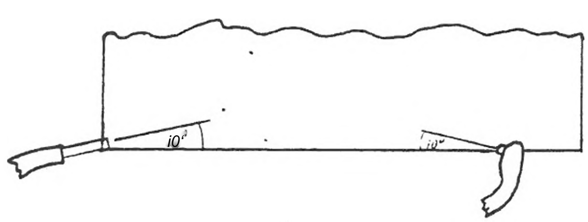
Figure 2.1 The Slectostatic Separator

composition or structure, which are being forcibly blown by the fluid, collide with one another transferring electrical charge. One particle becomes positively charged and the other negatively charged, and the magnitude of their charge depends on the conductivity and the length of contact. Charging should take a few minutes, therefore, a switching valve is located above the mixing tank requiring the flow to go through a filter. This will hold back the lignite while it is charging and also allows the nitrogen to start flowing through the loop which will purge the air from the separator section. After a few minutes, the valve will then be switched to allow the lignite to flow into the separator section. The mixing tank and all the pipes are made of plastic to prevent the particles from losing their charge as they collide with the wall. The switching valve should either be made of plastic or should be coated on the inside with a non-conducting material to prevent a loss of charge.

The separator section is shown in Figure 2.3. The flow from the mixing tank enters the separator and is introduced into the flow by the turning vanes. The turning vanes are used to distribute the lignite flow as evenly as possible in a line parallel to the two electrode plates, thus allowing greater exposure of the particle to the electric field. As the lignite particles fall between the electrode plate, they are drawn to a plate of the opposite charge. The plates are metal (such as steel or copper) rectangles of 8" by 24" and placed at an angle of about 2.386° from the vertical. The purpose of angling the plates is to slightly accelerate the flow so



(a) View from Top



(b) View from Side

Figure 2.2 Nozzle Placement

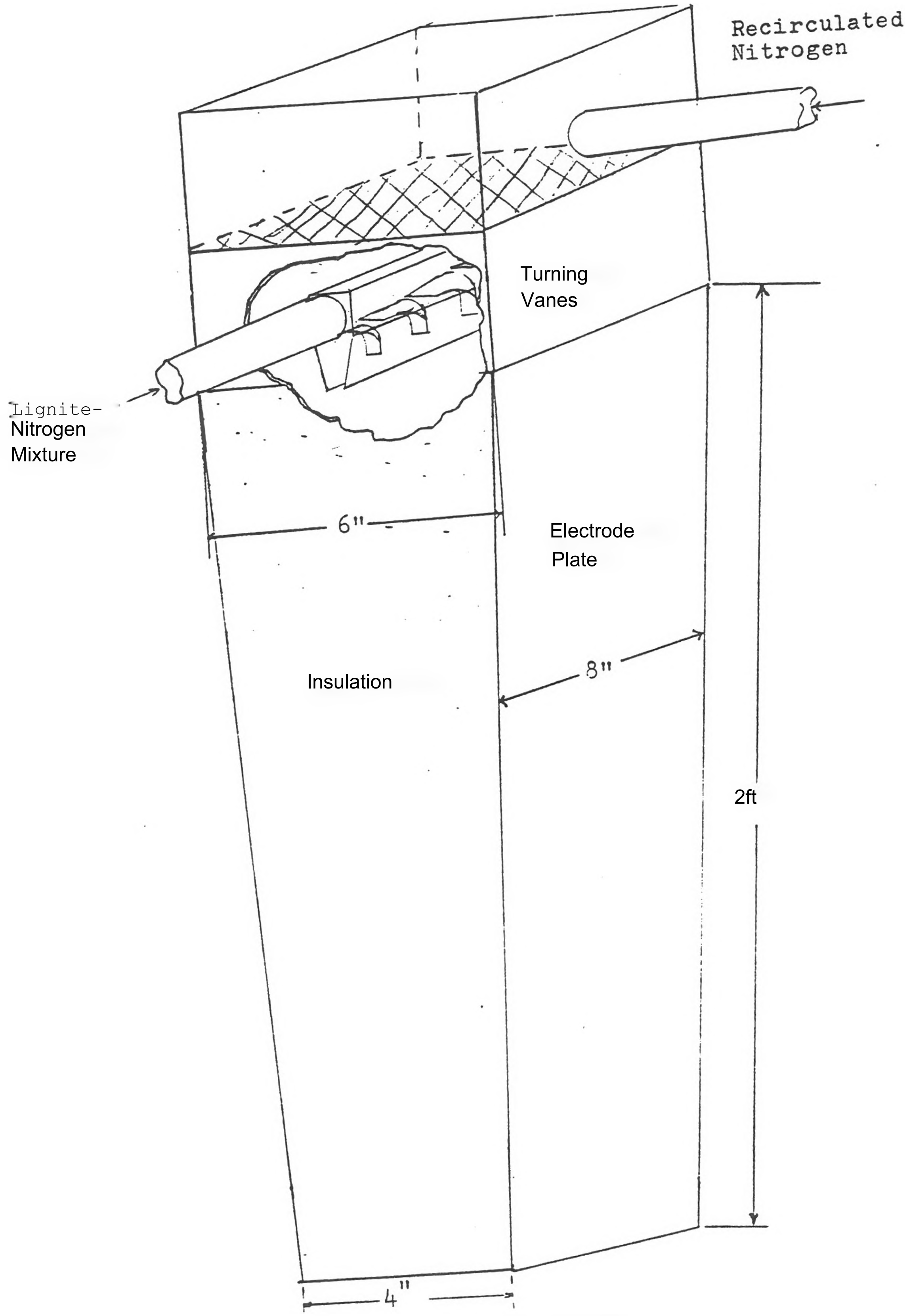


Figure 2.3 The Separator Section

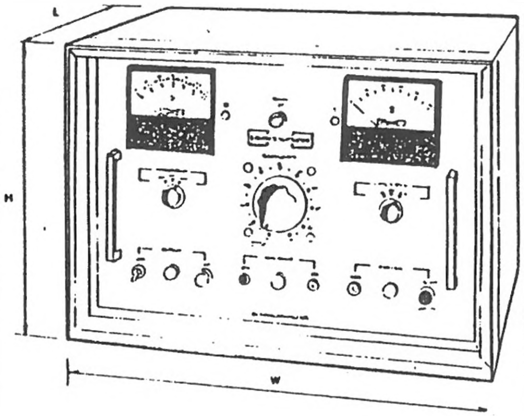
that it remains as laminar as possible. The plates are separated by insulation 6 inches wide at the top and 4 inches at the bottom. The power source that is used to create the voltage on the plates is the Hipotronics HV/DC Insulation tester, model 260, shown in Figure 2.4 which has a range of 0-60 KV output. It is connected to the plate by a heavy duty wire welded to the center of the plates. A problem that might arise is that the particles may collect on the electrode plate. They would either have to be continuously shaken loose by a process known as rapping or a liquid could be flushed down the sides of the plates. The latter would require some alteration to the system.

The particles are divided by a flow separator at the bottom of the separator section. The flow separator is adjustable to allow different amounts of flow to be separated. The lignite particles are collected in the two filter containers shown in Figure 2.1 below the separator section. These containers consist of about a foot long plastic pipe 6” to 8" in diameter with the lower end sealed off with a filter such as vacuum clean bags. The containers each have a hole, covered by plastic or glass, near the top so an observer, by visual inspection, could determine when the containers are nearly full. The nitrogen flows out through the filter container in 2” pipes that join back together into a single 2" pipe. This pipe is reduced into a 1” pipe that returns to a 0.5 hp blower. Leaving the blower, some of the nitrogen escapes through the valve shown at the lower right hand of the system in Figure 2.1, while the remainder of the nitrogen is recirculated through the loop. The amount of flow recirculated or exhausted is dealt with in the next section of this report.

Figure 2.3 The Power Source

HV/DC Insulation Testers

Model Nos. 25, 210, 220, 230
250, 260, 275



INFORMATION CHART

MODEL	2s	210	??>	230	I' 50	260	* 275
INPUT	115 VOLT O) Hi	i:5 VCII 60 M/	115 VOLT 60 HI	115 VOI T X' MI	1.5 vól т (HI hl	»15 VOI 1 6U Hf	' HS VOLT 60 Hf
OUTPUT VOLTAGE	0 5KVDC	0 10 KVDC	0 20 KVDC	0 30 KVDC	[illegible]	OLJ KVDC	0-75 «VDC
CURRENT	10 MA	10 MA	10 MA	10 MA	ЮMA	Ю MA	IO MA
INSULATIOM	OU	OU	OU	ou	ou	OU	OU
M V. SECTION	NONE	NONE	NONE	NONE	NONE	NONE	14 (355 6) OIA П (279 4) HIGH
44" (114)mm) KV METER	0 1'?$ 5	0 2 5'5'10	04 6'20	0 6/12'30	D 10'25'50	0 12'30 60	0 IS'3/SOS
44' (114 Jnm) CURRENT METER	0-105U4' Ima/I0»na	0 IOOua/ Ima'ICma	OIOOuB' 1ma/)0ma	0 IOOuV Inta'Kima	0 IOOııA' Ын/Юта	O-ЮOи»' Ima'IOm·	OIOOua' Ima'Юта
SIZES (INCHES) W ■ H ■ D	il .-.rs »rs .	21V a IS » 19 V	21.»15»I9V	2i'.;»is · 19 .	2 iv. HS a 19/	21.'a IS* a 19 /	21'.· »IS a 19V
CM M.) WaMiL	Mt.MI. O6	MI.MI.4J6	MI »MI »4J6	541 »MI »436	MI.MI.4M	MI. MI.4M	MI*MI.4M
APPROX. WEIGHT (LOS)	65	• 65	IS	7$	75	TS	•0
WEIGHT (Kς)	14S0	145 0	167 3	ICT 3	167 3	167 3	176 4

Specifications: Dimensions i weights are subject to change without notice
Warranty: Hipotronics Inc warrants this imit from defects in material and workmanship for one year.

DESCRIPTION HV/DC INSULATION TESTERS	Hipotronics
MODEL NOS. 25, 210, 220, 230 25Ü, 260, 275	**HIPOTRONICS INC.** P.O. Drawer A, Brewster, N.Y. 10509 (914) 279-8091 TWX 710-574-2420
Da,e **11/79** No. **IT3-W1**	

CO

The recirculated nitrogen returns to the separator section at the top. A filter covers the cross sectional area of the separator section just under the entrance of the recirculated nitrogen. The purpose of this filter is to create a somewhat evenly distributed laminar flow going down into the separator section. Therefore, this filter should be only sufficiently porous to create a slight pressure drop.

Various meters or measuring devices are to be placed throughout the system to carefully monitor its operation. A pressure gauge should be placed in the mixing tank to insure that the pressure does not exceed design limits. The pressure regulator can be adjusted to maintain a reasonable pressure in the tank. Next, flow meters should be placed in the pipe entering the separation section and in the pipe out of valve at the lower right hand of Figure 2.1. Finally, an oxygen detector should be used to closely monitor the amount of oxygen inside the separator section. If oxygen is detected, then the electrical power should be shut off immediately to prevent danger of an explosion.

FLOW ANALYSIS

To obtain an estimate of how much flow should be recirculated back into the separator section, an analysis of the flow loop in the electrostatic separator was developed using the generalized Hardy Cross method as described in Hodge (3).

The generalized Hardy Cross equation is written as

$$\Delta Q = -\frac{\sum_i \{K_i Q_i |Q_i|^{n_i-1} + SGN(Q_i)A_i + B_i Q_i |Q_i|\}}{\sum_i \{K_i n_i |Q_i|^{n_i-1} + 2B_i |Q_i|\}} \qquad (3\text{-}1)$$

where the pipe Loss is in the form of $h_L = K_i Q_i^{n_i}$ and losses from devices in the flow, such as filters and pumps (negative head loss for pump and blowers) are written as $h_L = A_i - B_i Q_i$. Figure 2.1 shows the Hardy Cross diagram for the loop with each loss identified.

The first step was to calculate the coefficients and exponential for the pipes and devices head loss terms. The nitrogen, due to the relatively slow velocities expected in the electrostatic separator, was considered to be incompressible at a density of 0.093 $\frac{lbm}{ft^3}$ (corresponding to a pressure of 20 psi). The friction factor for the pipes was calculated from the equation suggested by Haaland (3) which is given as:

$$f = \frac{0.3086}{\left\{\log\left[\frac{6.9}{Re} + \left(\frac{E}{3.7D}\right)^{1.11}\right]\right\}^2} \qquad (3\text{-}2)$$

where E was taken to be 0.00015 (same as for smooth pipes) and the Reynolds number was calculated for different flow rates inside the

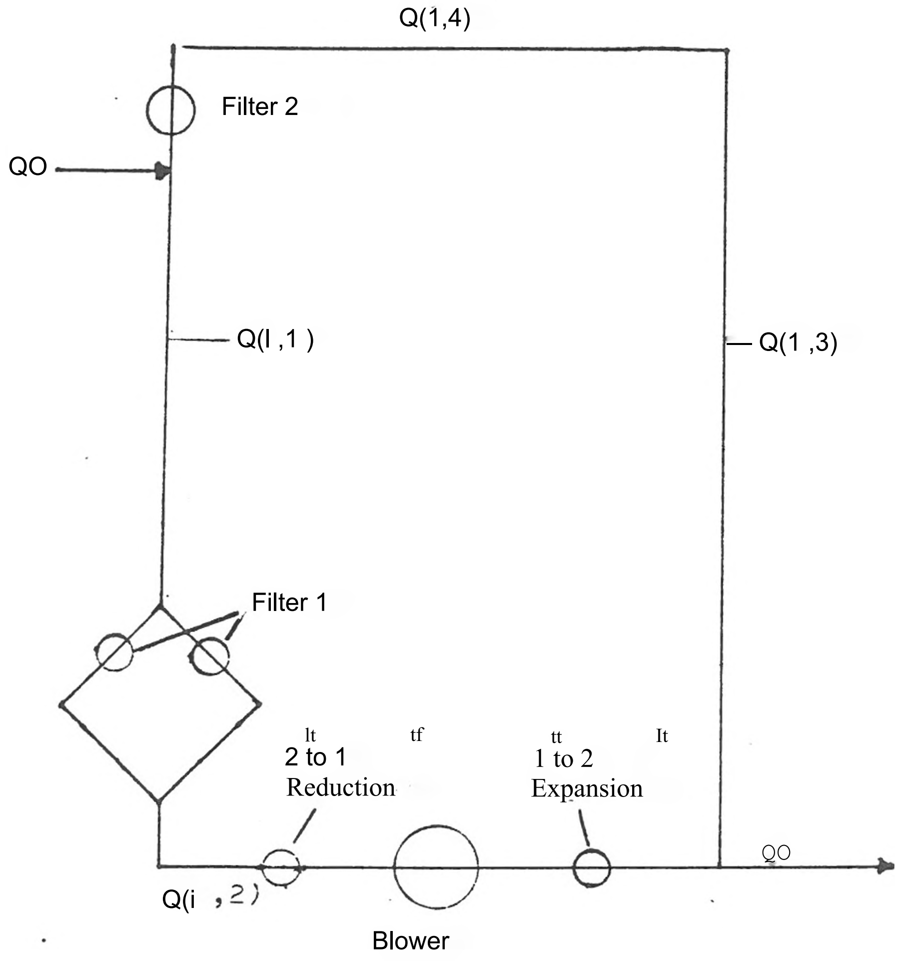


Figure 3.1 Hardy-Cross Diagram of the Electrostatic Separator

pipe. From these values the head loss was calculated from

$$h_f = f/D((^\wedge),) \quad \frac{2}{HD^{1}} \tag{3-3}$$

Several points of hf versus Q were calculated and curve fitted to obtain the head loss in the form of $hf = LKQ^n$ where L is the length of the pipe. For the 2" pipe, the results were K = 3.99 and η = 1.72 while for the 1" pipe K = 140.6 and n = 1.82.

The blower's head was evaluated at

$$hf = -\frac{2957.0}{Q} \frac{ft\text{-}lbs}{lbm} \tag{3-4}$$

which was to be put in the form of

$$hf = A + BQ$$

To find the value of A and B, a curve fit for head loss was plotted over a chosen range of flow rates (0.05-2.0 ~~A~~) and then the $\frac{f\text{-}lbf}{lbm}$ Hardy Cross program, using this data, was run to find an approximation of Q_{pump}. The curve fit was then plotted over a smaller range of points about Q_{pump} and inserted back into the program to find a new Q_{pump}. This was repeated for a few iterations until the solution converged to a value of $Q = A - BQ_{pump} \frac{2957.0}{Q_{pump}}$. The final values were A = -5451.9 and B = 2407.6. The values for the filter's head losses were unknown and therefore several runs with the computer program were made using varying values of loss coefficient for the filters, which were in the form of

$$Hf = CQ^2$$

where C was the loss coefficient. Other losses came from the elbows, sudden reduction in area and the sudden expansion in area. These are taken from Figure 2-2 and 2-3 which are found in Hodge (4). Assuming the average value of fT = 0.028, the loss for the elbows was calculated from

$$h_{f_{elbow}} = 30\, f_T \left(\frac{L}{D}\right) \frac{V^2}{2g_c} = 27.4\, Q^2 \quad \frac{\text{ft-lbf}}{\text{lbm}} \tag{3-5}$$

This value was also used for the Y-joint joining the two pipes below the separator section together. For the sudden contraction in the area, the following equation was used to find the loss coefficient.

$$K = \frac{0.5(1-\beta^2)\sqrt{\sin\theta/2}}{\beta^4} \tag{3-6}$$

where $\beta = \frac{d}{D} = 0.5$ and $\Theta = 180°$. K was calculated to be K = 6 which resulted in the head loss

$$h_f = K \frac{(4Q/\pi D^2)^2}{2g_c} = 195.7Q^Z \quad \frac{\text{ft-lbf}}{\text{Ibm}} \tag{3-7}$$

For the sudden expansion K was computed to equal

$$K = \frac{(1-\beta^2)^2}{\beta^4} = \frac{(1-(0.25)^2)^2}{(0.25)^4} = 9 \tag{3-8}$$

which led to the head loss as being

$$h_f = 294.9Q^Z \tag{3-9}$$

All of these losses were substituted into equation 3-1 and an initial set of flow rates were chosen as a starting approximation. The AQ term was calculated and added to the flow rates, with the process being repeated until AQ was less than 0.001. This was executed by the computer program shown in Appendix A. As mentioned earlier, several runs were made with various values of head losses for the

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• **"K" FACTOR TABLE—SHEET I of 4**

Representative Resistance Coefficients (K) for Valves and Fittings

PIPE FRICTION DATA FOR CLEAN COMMERCIAL STEEL PIPE WITH FLOW IN ZONE OF COMPLETE TURBULENCE

FORMULAS FOR CALCULATING "K" FACTORS FOR VALVES AND FITTINGS WITH REDUCED PORT

• Formula 1

$$K_2 = \frac{0.8 \sin\frac{\theta}{2}(1-\beta^2)}{\beta^4}$$

• Formula 2

$$K_2 = \frac{0.5(1-\beta^2)\sqrt{\sin\frac{\theta}{2}}}{\beta^4}$$

• Formula 3

$$K_2 = \frac{2.6 \sin\frac{\theta}{2}(1-\beta^2)^2}{\beta^4}$$

• Formula 4

$$K_2 = \frac{(1-\beta^2)^2}{\beta^4}$$

• Formula 5

$$K_2 = \frac{K_1}{\beta^4} + \text{Formula 1} + \text{Formula 3}$$

$$K_2 = \frac{K_1 + \sin\frac{\theta}{2}\left[0.8(1-\beta^2) + 2.6(1-\beta^2)^2\right]}{\beta^4}$$

• Formula 6

$$K_2 = \frac{K_1}{\beta^4} + \text{Formula 1} + \text{Formula 4}$$

$$K_2 = \frac{K_1 + 0.5\sqrt{\sin\frac{\theta}{2}}(1-\beta^2) + (1-\beta^2)^2}{\beta^4}$$

• Formula 7

$$K_2 = \frac{K_1}{\beta^4} + \beta(\text{Formula 2} + \text{Formula 4}) \text{ when } \theta = 180^\circ$$

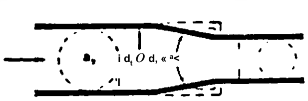
$$K_2 = \frac{K_1 + \beta\left[0.5(1-\beta^2) + (1-\beta^2)^2\right]}{\beta^4}$$

$$\beta = \frac{d_1}{d_2}$$

$$\beta^2 = \left(\frac{d_1}{d_2}\right)^2 = \frac{a_1}{a_2}$$

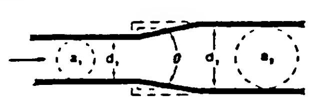
Subscript 1 defines dimensions and coefficients with reference to the smaller diameter.
Subscript 2 refers to the larger diameter.

SUDDEN AND GRADUAL CONTRACTION



If: $\theta \leq 45^\circ$ .... K_2 = Formula 1
$45^\circ < \theta \leq 180^\circ$. K_2 = Formula 2

SUDDEN AND GRADUAL ENLARGEMENT



If: $\theta \leq 45^\circ$ .... K_2 = Formula 3
$45^\circ < \theta \leq 180^\circ$ .. K_2 = Formula 4

Figs.3.2 · Crane Company Loss Coefficients

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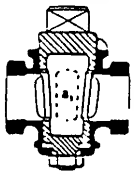
"K" FACTOR TABLE— SHEET 4 of 4

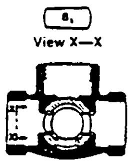
Representative Resistance Coefficients (K) for Valves and Fittings

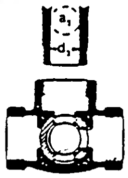
(for formuloi ond friction dota, too pogo A-26)

PLUG VALVES AND COCKS

Straight-Way **3-Way**







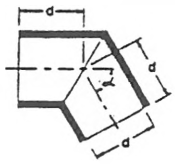
If: 3-1
K.- i8/r

If: 3- t.
K. - jo/r

If: 3 - 1.
Ki - go f_T

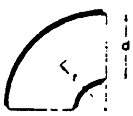
If: *0 < i.. .Kt-* Formula 6

MITRE BENDS



α	K
0°	2 *l,*
15'	4 fr
30'	8 *h*
45'	15 *l,*
40'	25 f,
75'	40 I,
90*	40 *l,*

90* PIPE BENDS AND FLANGED OR BUTT-WELDING 90' ELBOWS



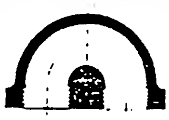
'l/d	K	r/d	K
1	20 f.	10	30 fr
2	12 f.	12	34 f.
3	12 fr	14	38 f_r
4	U *h*	16	42 *f,*
ó	17 *f,*	18	46 fr
8	24 *1,*	20	50 f,

The resistance eocllicicnt. *K/:.* for pipe bends other than go[0] may be determined as follows:

$$K_{n} \cdot (n-i) \left(0.25 \pi f_T \frac{r}{d} + 0.5 K\right) + K$$

n — number of 'XI* Ix-nd*
K — toistanee coefficient loi <нх· 'XI IvmJ (|x< table'

CLOSE PATTERN RETURN BENDS

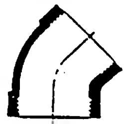


$K = 50 f_T$

STANDARD ELBOWS

90' **45'**

K-Jo/r



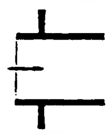
K - ib Jr

STANDARD TEES

Flow thru run................*K - io fi*
Flow thru branch .../<- 6o $/_7$

PIPE ENTRANCE

Inward Projecting

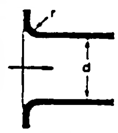


K - o.;S

'fd	K
0.00*	0.5
0.02	0.28
0.04	0.24
0.06	0.15
0.10	0.09
0. Ì 5 à up	0.04

'Shofp-edged

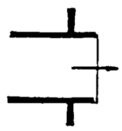
Flush



For *K.* see table

PIPE EXIT

Projecting

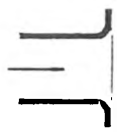


K = 1.0

Sharp-Edged

K = 1.0

Rounded



K = 1.0

Figs. 3.3. · Continued

filters assumed. These values are listed at the top of each output of the Hardy-Cross program in Appendix A.

The results of the Hardy-Cross program are given in the following table with Q_o, the flow entering the loop at the upper left hand

Loss Coeff. for Filterl lbf-s2 / ft?-1bm	Loss Coeff. for Filter^ W-s^2 / ft^y-lbm	Flow in Separator Section f^s	Recircu-lated Floy f^3/s
500.0	200.0	1.348	0.943
1000.0	500.0	1 .241	0.841
2000.0	1000.0	1.107	0.707
3000.0	1000.0	1 .037	0.637
5000.0	2000.0	0.905	0.505

Table 3.1 Results from the Hardy-Cross Program

corner and exhausting through the valve at the lower right hand corner, set equal to 0.4 $\frac{ft^3}{sec}$.

For the last case given, the velocity entering the separator region would be 2.715 f/s and the velocity leaving it would be 4.0775 f/s. This is about as fast as should be allowed in the separator section since a high velocity would cause turbulence and also cause the lignite to be carried through the electrical field in the separator too quickly. If the velocity in the separator region is too fast, then, either the filter loss should be increased or a smaller hp pump should be used.

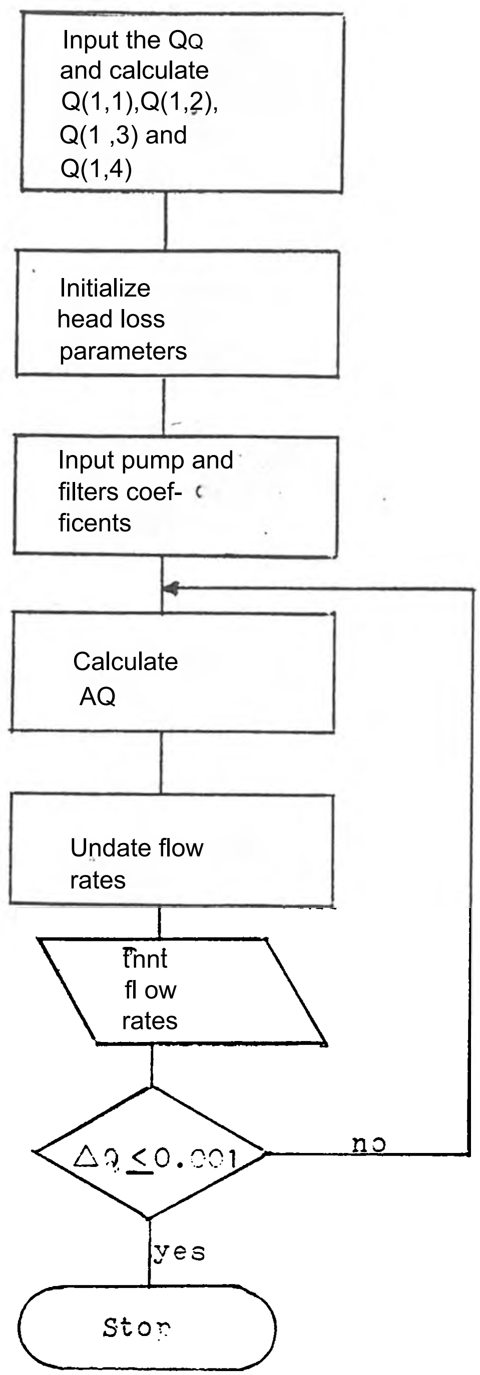


Figure 3*4 Flov; Chart for Hardy-Cross Program

PARTICLE TRAJECTORY

The final analysis for this project is the prediction of particle trajectory of a lignite particle going through the electrostatic section of the separator. This was accomplished by summing all the forces acting on the particle over a small time interval and finding the displacement resulting from these forces. This was repeated until the particle either reached the wall or passed through the separator section. The exact procedure is now given with the results for the particle trajectory computer program given at the end of this chapter and in Appendix B.

The first step was to find the electrical forces acting on the particles due to the high voltage electrodes. In order to do this, the electric field in between the two electrodes had to be evaluated. The figure below shows the electrode plates with the boundary conditions imposed.

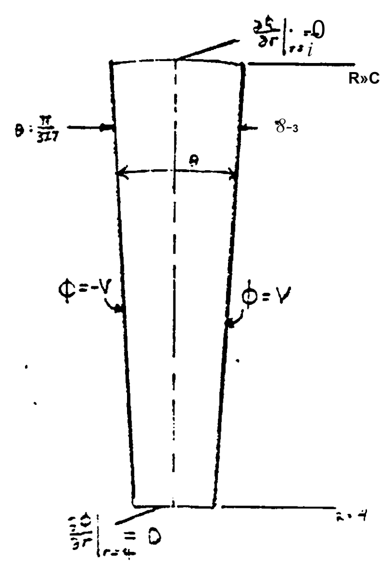


Figure 4.1. Boundary Conditions on Electrical Field Between Electrodes Plates.

The system is in polar coordinate, therefore the polar Laplace's equation is used to describe the electrical field. It is given as

$$\frac{\partial^2 \phi}{\partial r^2} + \frac{1}{r}\frac{\partial \phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \phi}{\partial \phi^2} = 0 \qquad (4\text{-}1)$$

substituting ф = ф—v into the equation (1) yields

$$\frac{\partial^2 \Phi}{\partial r^2} + \frac{1}{r}\frac{\partial \Phi}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \Phi}{\partial \theta^2} = 0 \qquad (4\text{-}2)$$

with the following boundary conditions

Φ (r,0) = O $\quad \frac{\partial \Phi}{\partial r}(8,4) = 0$

ф(r , 37^-) —2v $\quad \frac{\partial \phi}{\partial r}(\theta,6) = 0$

Using separation of variables with = R(r)ip (θ) yields the following two equations

$$\frac{d}{dr}\left(r\frac{dR}{dr}\right) + \frac{\lambda^2}{r}R = 0 \qquad \frac{dR(4)}{dr} = 0 \qquad \frac{dR(6)}{dr} = 0 \qquad (4\text{-}3)$$

$$\frac{d^2\Psi}{d\theta} - \lambda^2\Psi = 0 \qquad \Psi(0) = 0 \qquad (4\text{-}4)$$

The solution to equation (4-3) is

$$R = C_1\cos(\lambda \ln r) + C_2\sin(\lambda \ln r). \qquad (4\text{-}5)$$

Applying the boundary conditions of $\frac{dR}{dr}(4)=0$ gives

$$C_2 = C_1 \tan(\lambda \ln 4) \qquad (4\text{-}6)$$

while the boundary condition $\frac{dR(6)}{dr} = 0$ yields

$$\sin(\lambda \ln 6) - \tan(\lambda \ln 4)\cos(\lambda \ln 6) = 0$$

which is known as the characteristic equation from which values of λ are obtained.

The solution to equation (4-4) is

$\Psi = C_3 e^{\lambda\theta} + C_4 e^{-\lambda\theta}$ (4-7)

and applying the boundaries conditions yields

$C_4 = -C_3$

The electrical potential is now written as

$$\Phi(r,\theta) = \sum_{n=1}^{\infty} A_n[\cos(\lambda_n \ln r) + \tan(\lambda_n \ln 4)\sin(\lambda_n \ln r)](e^{\lambda_n\theta} - e^{-\lambda_n\theta}) \quad (4\text{-}8)$$

From ArpaCi (5) the solution to A_n given in the form of

$$A_n = \frac{\int w(r)\, f(r)\, \Phi_n(r)dr}{\int w(r)\, \Phi_n^2(r)dr} \quad (4\text{-}9)$$

where the weighing function, W(r) , is equal to $\frac{1}{r}$, f(r) = $\Phi(r,37.7\pi)$= -2v and Φ_n is the function on the right hand side of equation (4~8) that is multiplied by A_n. Solving for A_n gives

$$A_n = \frac{-2V\int_4^6 \cos(\lambda \ln r)d(\ln r) - 2V\tan(\lambda \ln 4)\int_4^6 \sin(\lambda \ln r)d(\ln r)}{(e^{37.7} - e^{-37.7})\int_4^6 [\cos(\lambda \ln r) + \tan(\lambda \ln 4)\sin(\lambda \ln r)]^2 d(\ln r)} \quad (4\text{-}10)$$

Integration of the numerator over the interval of R=4 to R=6 yields zero, thereby making A_n = 0. Therefore, the only solution to this problem is for λ=0. Substituting λ=0 into equation (4-3) and (4-4) yields R=C and Ψ= DΘ where C and D are constant. Φ is then written as Φ = B θ   Φ(r, 37.7π) = -2v

applying the boundary condition gives

Φ= -24.055V θ

or

Φ = -24.055V θ-V (4-11)

The electric field is defined as the negative of the gradient of the scalar potential Φ , as present in Jackson (6). This yields

E = - vφ = - -^-Ur - i r θθ (4-12)

where U_r and üθ are unit vectors. E is found to be

E = 24.255V / r (4-13)

Jackson (6) also states that the force acting on a particle with a charge q, inside the electric field is

F = qE = 24,055^ E 4 r (4-14)

It is desired to have the force in X and Y component where the Y-axis is at 9 π/75.4 = (which is directly in the center between the two electrode plates) and X-axis runs through the point where r=0. The X and Y components are

F_x = qEcosß (4-15a)

Fy = qEsinß (4-15b)

where ß = tan-l (x/y)

The charge of the particle is unknown and therefore several assumed charges will be examined.

Other forces acting on the particle are drag force, added mass (due to the accelerating flow) and the weight of the particle. The drag force on a solid sphere moving through a viscous imcompressible fluid was studied by Rayleigh (7). He approximated the drag force to be

$$F_d = -4.5 M \nu \bar{V}/a^2 \quad (4\text{-}16)$$

Although the fluid being examined for this problem is Nitrogen gas, it is, as mentioned earlier, assumed imcompressible due to the low velocity flow through the electrostatic separator. The term above is known as the steady state drag force. If the flow is accelerating as particles travel through it (and it is due to the converging separator section), then there is another term to add to the drag force known as the added mass term. Rayleigh (7) gives the added mass term for spheres as

$$F_{da.m.} = -0.5M \frac{d\bar{V}}{dt} \quad (4\text{-}17)$$

This is added to equation (4-16) to obtain the total drag force. The only other force applied to the particle is its weight. The forces then can be used to write the equation of motion in the X and Y direction as X-direction:

$$M_p A_x = -4.5 M \nu V_x/a^2 - 0.5M \frac{d\bar{V}_x}{dt} + F_x \quad (4\text{-}18)$$

Y-direction:

$$M_p A_y = -4.5 M \nu V_y/a^2 - 0.5M \frac{d\bar{V}_y}{dt} + F_y - W \quad (4\text{-}19)$$

These equations are not readily amenable to analytical solutions and therefore were approximated numerically on a digital computer. This was accomplished by the computer program shown in Appendix B.

The particle velocity was calculated from

$$U_{x2} = U_{x1} + \frac{1}{M_p}[-4.5MVVx/a-0.5M(VX2-VX_1)/DT + FxJDT \quad (4\text{-}20a)$$

and

$$U_{y2} = U_{y1} + \frac{1}{M_p}["4.5MVVy/a -0.5M(Vy_2- Vy1) /DT + Ey-W]DT \quad (4\text{-}20b)$$

The first two terms inside the bracket were equal to zero for the first iteration due to the fact that the particle and fluid were assumed to be at the same velocity entering the separator section. From those equations the new X and Y position were calculated by

$$X_2 = X_1 + (U_{x2} + U_{x1})*DT/2.0 \quad (4\text{-}21a)$$

$$Y_2 = Y1 + (U_{y2} + Uyl)*DT/2.0 \quad (4\text{-}21b)$$

The electrical force and fluid velocity corresponding to the new X and Y were obtained from subroutines. The fluid velocity was assumed to be a function of the radius r, where r = ^^*+7" . It is given as

$$VF = -0.82034Vor+ 2.5Vo \text{ (in m/s)} \quad (4\text{-}22)$$

and the X and Y components are

$$VF_x = VFsins \quad (4\text{-}23a)$$

and $$VF_y = VFcosB \quad (4\text{-}23b)$$

The new relative velocities were calculated from

$$VR_X = U_{x2} - VF_X \quad (4\text{-}24a)$$

and $$VRy = Uy_2- VFy \quad (4\text{-}24b)$$

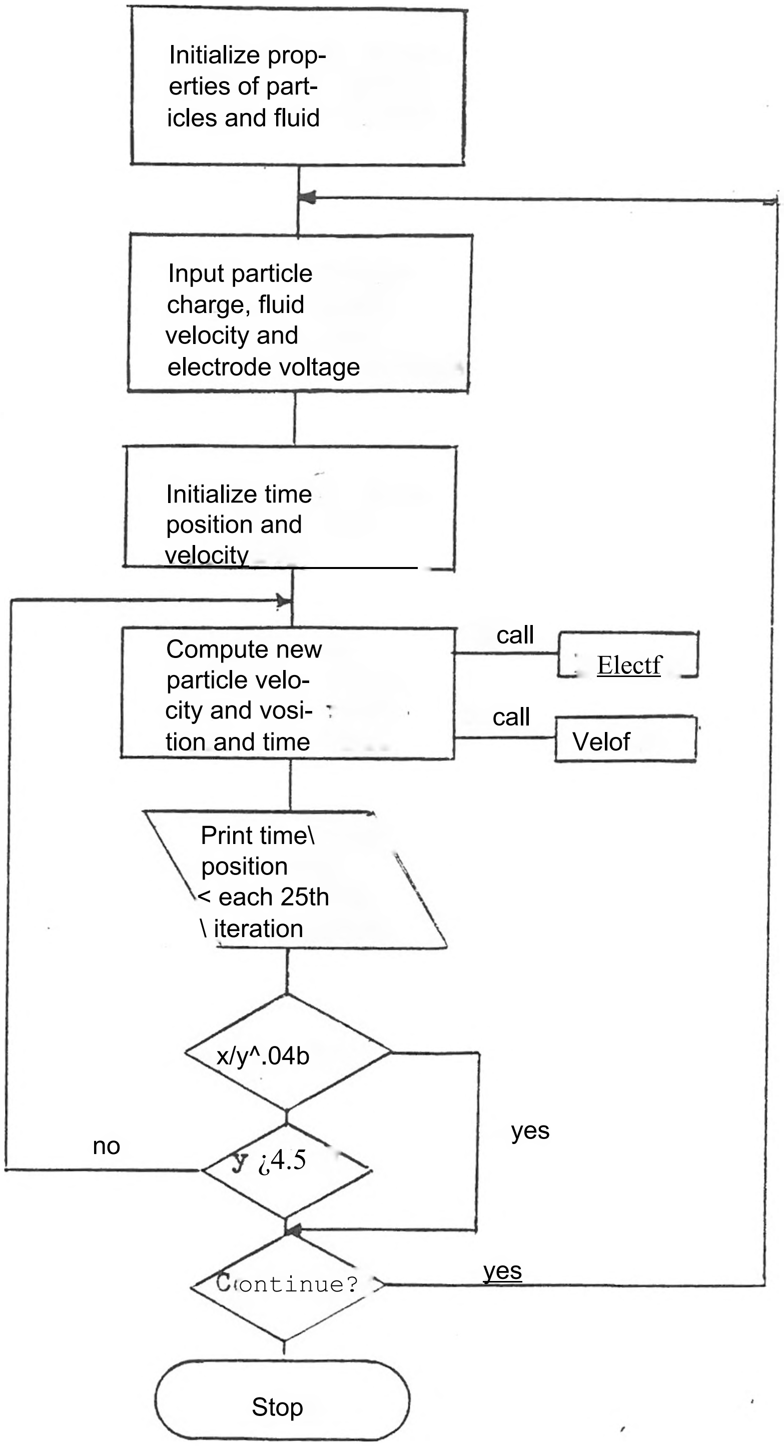


Figure ¿+.2 Flow Chart for Particle Trajectory Program

These values were then substituted back into equations (4-20 a and b) to obtain new values of X and Y. This was then iterated until the particle reached the wall (X/Y =0.04ilg) or the particle left the separator section ($\lambda < 4.0$ ft).

The particle trajectory program used metric units in the computing process due to the compatibility of metric unit to Electrical notation. However, the input and output is in English units.

The particle considered in this program had a diameter of 40 μm and a mass of 4.6914×10^{-11} Kg (density = 1.4g/cc). The kinematic viscosity of the nitrogen was taken to be 1.44×10^{-5} m^2/s while the mass of the fluid displaced by the particle was 4.0883×10^{-13} Kg (density = 1.203 Kg/m^3). The charge of the particle, the velocity of the fluid entering the separator section and the voltage of electrode plates were varied to determine how each affected the separation process. Because increasing the voltage and increasing the charge of the particle has the same effect, only the charge of the particle was varied while the voltage was maintained at 10,000 volts. The results are shown graphically in Figure 4.3» 4·4 and 4*5·

It should be pointed out that the analysis in this section was done on a single particle in the separator section. In reality, there will be many particles in the separator section at once and this will cause charge density in the electrical field. This would cause different results than were obtained for the single particle. However, the particle trajectory analyses presented herein were made in order to obtain an estimate of the separation process.

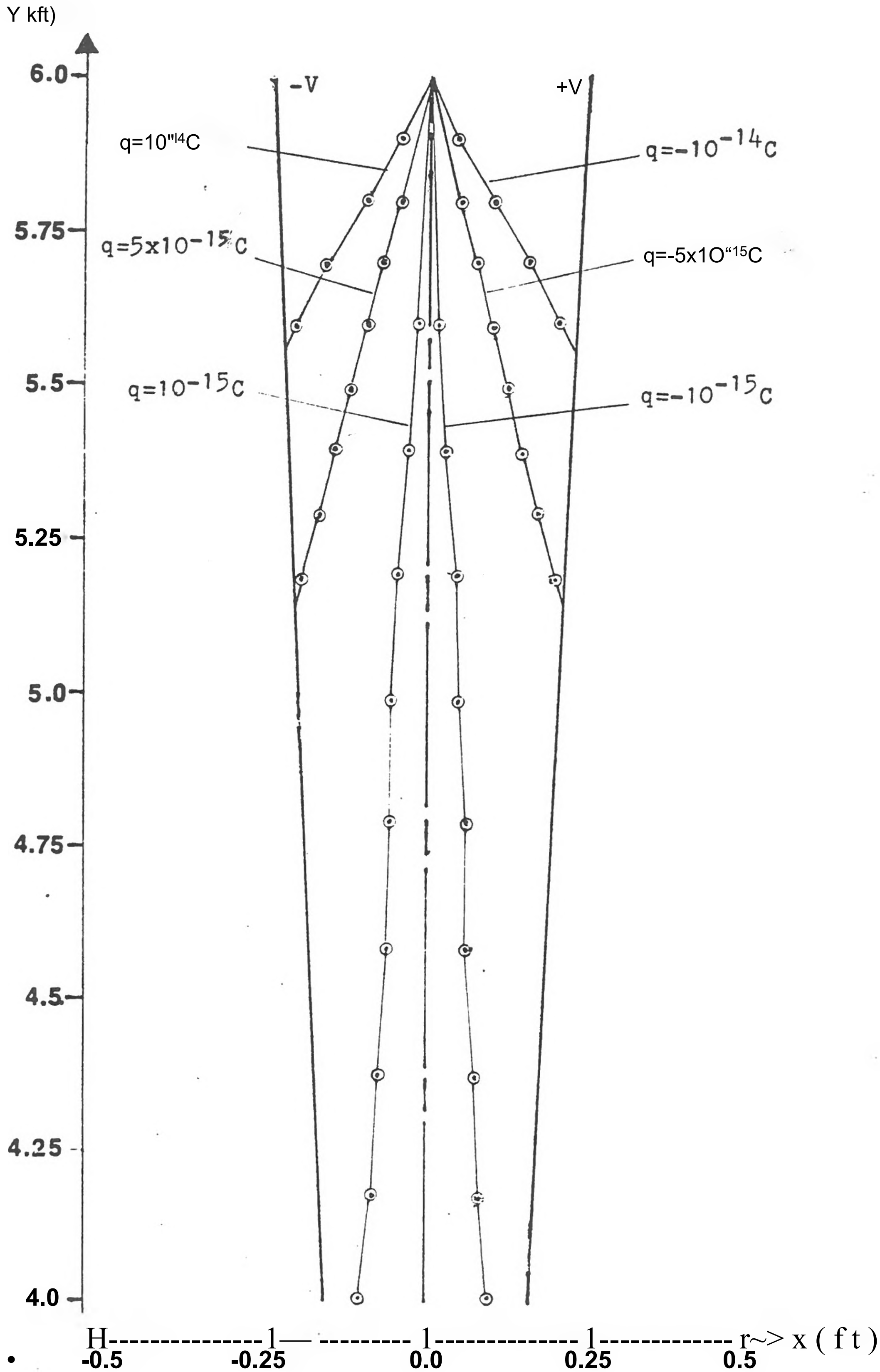


Figure 4.3 Particle Trajectory for Initial Velocity = -1.0 f/s

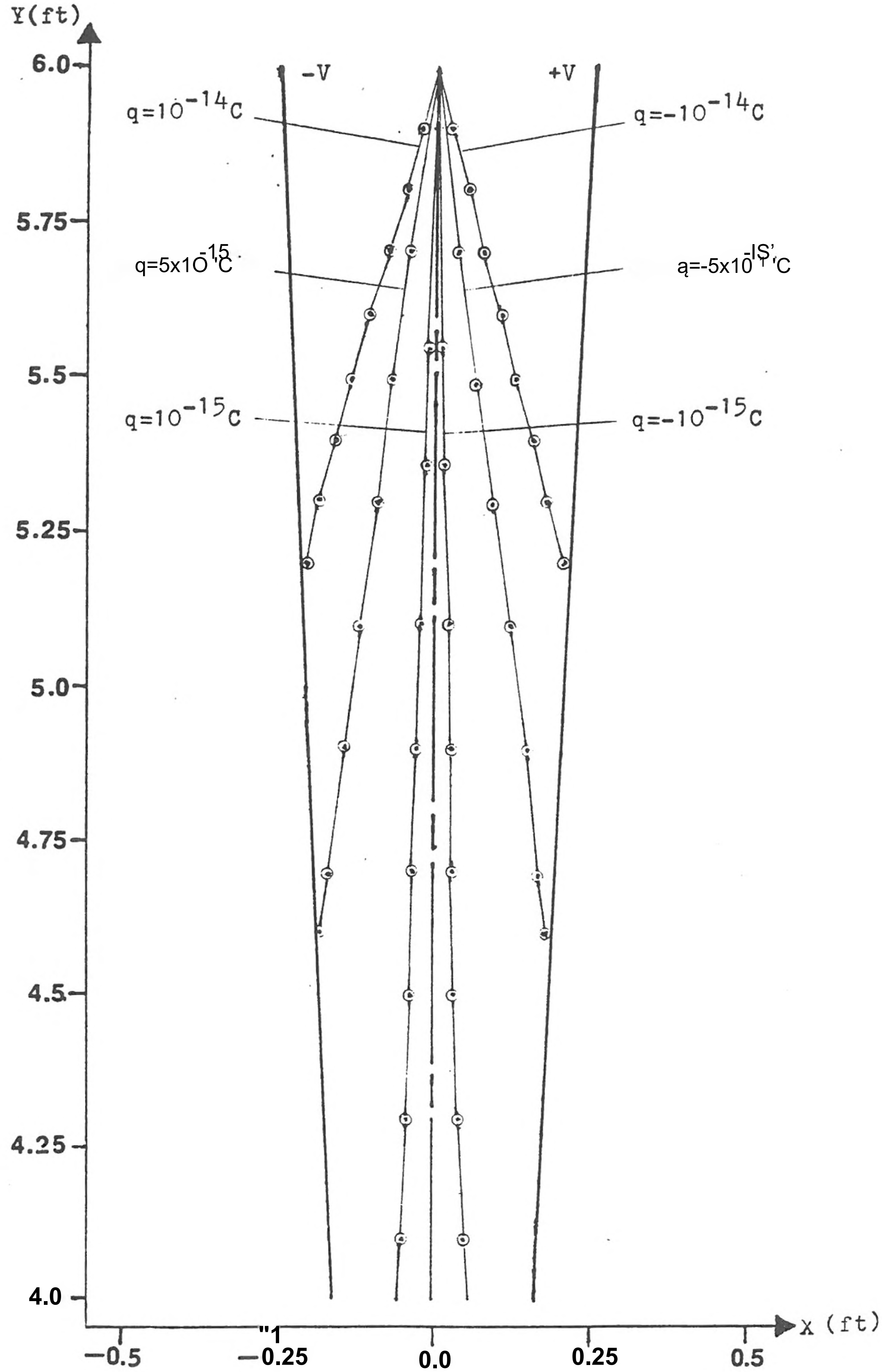


Figure 4.4 Particle Trajectory for Initial Velocity=-2.0 f/s

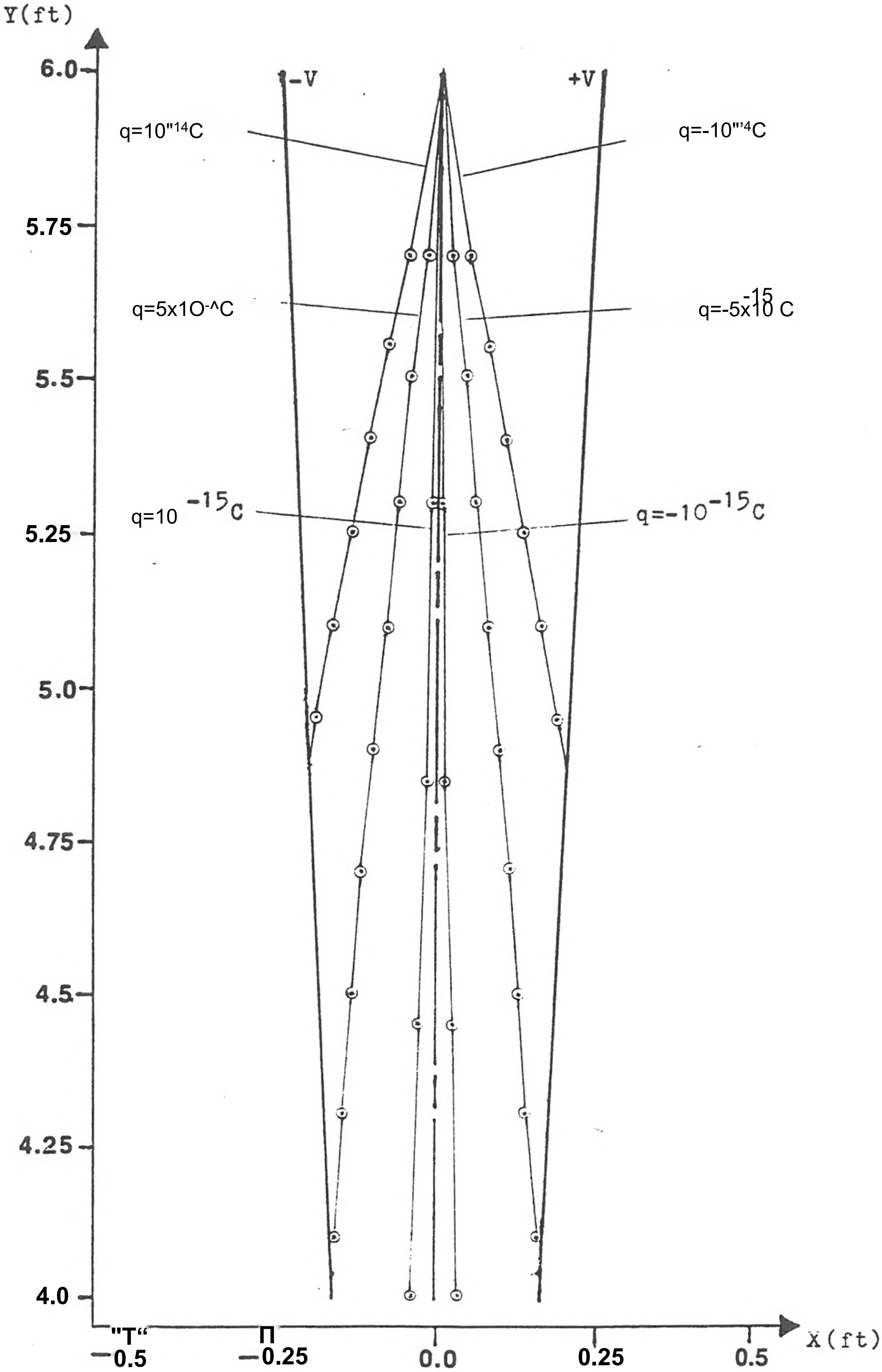


Figure 4.5 Particle Trajectory for Initial Velocity=-3.0 f/s

SUMMARY AND RECOMMENDATIONS

The preliminary design for an electrostatic separator has been presented. Analyses of flow and particle trajectories have been made and presented in this report. In the event that a working model can be constructed in the near future, these analyses will serve as a starting point in the detailed design. There are many unanswered questions about the performance of the separator that can only be answered experimentally. Based on the preliminary design presented herein, it is recommended that an experimental model be constructed and tested in order to ascertain the effectiveness of separating ash from Mississippi lignite.

APPENDICES

Appendix A

Hardy-Cross Computer Program and Output for a Flow Analysis of the h'i trogen Flow Loop

```
C               THIS PROGRAM USED THE HARDY CROSS METHOD TO DO A FLOW 32
C               ANALYSIS ON THE ELECTROSTATIC SEPARATOR»
                DIMENSION 0(5,5),A(5,5),B(5,5),C(5,5)
                REAL K1,K2,N1, N2,LI,L2,L3,L4,L5,NUMI,NUM2
                QO=O»4                                              ;
                WRITE(5,1)
      1        FORMAT(1XINPUT    THE    INITIAL    GUEST    FOR    0(1,5)    AND    LUN',)
                ACCEPT*,0(1,5),LUN
                0(1,1)=0(1,5)+00
                0(1,2)=0(1,1)
                0(1,3)=Q(1,1              )-00
                0(1,4)=0(1,3)
                LI  =  3♦0/0  »  707-1  ♦  0
                L2=0.5
                L3=2.0
                L4=6»5
                L5=3.0
                KI=3»99
                K2=140»6
                NI=I»72
                N2=I»82
                D1=N1-1♦     0
                D2=N2-I»0
                CL1=27»4
                CL2=27»4
                CL3=195»7
                CL4=294 » 9
                WRITE(5,3)
    3 FORMAT(IX,'INPUT THE PUMP COEFFICIENTS A AND B')
                ACCEPT*,A(1,2),B(1,2)
                WRITE(5,4)
    4           FORMAT(IX,'INPUT THE FILTERS COEFFICIENTS CI AND C2')
                ACCEPT*,C(1, 1) ,C(1,5)
                WRITE < LUN , 6 ) C ( 1 ,1. ),C(1,5)
    6           FORMAT(1XCOEFF♦ FOR FILTERS 1=',F7♦2,5X,'AND FILTER 2=',F7.2,/          '/ )
    5          NUM1=2♦0*(L1*K1*0(1,1)/2,*ABS(0(1 ,1)/2.)**D1
       C +C(1,1)*Q(1,1 )*ABS(Q(1, 1 )/4 ») + (CL 1+CL2)*0(1,1)*ABS(
       C 0(1,1)/4♦)) +(CL1+ CL3)*0(1,1)*ABS(Q(1,1) )+L3*K2*0(1,2)*
       C ABS(0(1,2))**D2 + A(1,2)+B(1,2)*0(1,2)+CL4*Q ( 1,2)                  *
       C *ABS(0(1,2))+CLI*Q(1,3)*ABS(Q(i,3))+(L4+L5)*K1*Q(1,3)*ABS(Q(1,3)
       C )**D1+CL1*0(1,3)*ABS(0(1,3))+C(1,5)*0(1,5)*ABS(0(1,5))
                DEN1=2 » *(L1*N1*K1 *ABS(0(1,1)/2»)**DI+2♦ *C( 1 , 1 )*ABS(0(1,1)
       C /2»)+2♦*(CL 1+ CL2)*ABS(0(1,1)/2, ))+2♦*(CL1+CL3)*ABS(0(1,1 ) )+L3
       C *K2*N2*ABS(0(1,2))**D2 + B(1,2)+2 »*CL4*ABS(0(1,2))
       C + 2 »*CL1*ABS(0(1,3))+N1 *(L4 + L5)*K1 *ABS(0(1,3))**D1 +
       C 2 ♦ *CL1*ABS(0(1,3))+2.*C(1,5)*ABS(Q(1,5))
                DEL1=-NUM1/DEN1
                Q(1,1)=Q(1,1)+DEL1
                0( 1,2)=0(1,2)+DEL1
                Q(1,3)=0(1,3)+DEL1
                Q(1,4)=Q(1,4)+DEL1
                Q(1,5) = Q(1,5)+DELI
                DO 10 1=1,5
                WRITE(LUN,100)I,0(1,1)
    10 CONTINUE
                WRI TE(LUN,102)DEL 1
                IF(ABS(DEL1)» GT » 0 » 001)GO TO 5
                STOP
  100          FORMAT(IX,'O(1,',I1,')=',P6»3,/)
  102          FORMATdX,'DEL1 = ',F6»3,///)
                END
```

Q(1,1)= 1.377

Q(1,2)= 1.377

Q(1,3)= 0.977

Q(1,4)= 0.977

Q(1,5)= 0.977

DEL1= 0.577

Q(1,1)= 1.352

Q(1,2)= 1.352

Q(1,3)= 0.952

Q(1,4)= 0.952

Q(1,5)= 0.952

DEL1=-0.025

Q(1,1)= 1.348

Q(1,2)= 1.348

Q(1,3)= 0.948

Q(1,4)= 0.948

Q(1,5)= 0.948

DEL1=-0.003

Q(1,1)= 1.348

Q(1,2)= 1.348

Q(1,3)= 0.948

Q(1,4)= 0.948

Q(1,5)= 0.948

DEL1= 0.000

COEFF. FOR FILTERS 1 = 1 O O O <· O O AND FILTER 2= 500»00

Q(1,1)= 1.239

Q(1,2)= 1.239

Q(1,3)= 0.839

Q(1,4)= 0.839

Q(1,5)= 0.839

DEL1= 0.439

Q(1,1)= 1.241

Q(1,2)= 1.241

Q(1,3)= 0.841

Q(1,4)= 0.841

Q(1,5)= 0.841

DEL1= 0.003

Q(1,1)= 1.242

Q(1,2)= 1.242

Q(1,3)= 0.842

Q(1,4)= 0.842

Q(1,5)= 0.842

DEL1= 0.000

COEFF. FOR FILTERS 1=2000»OO AND FILTER 2 = 1000 »00

Q(1,1)= 1.076

Q(1,2)= 1.076

Q(1,3)= 0.676

Q(1,4)= 0.676

Q(1,5)= 0.676

DEL1= 0.276

Q(1,1)= 1.100

Q(1,2)= 1.100

Q(1,3)= 0.700

Q(1,4)= 0.700

Q(1,5)= 0.700

DEL1= 0.024

Q(1,1)= 1.105

Q(1,2)= 1.105

Q(1,3)= 0.705

Q(1,4)= 0.705

Q(1,5)= 0.705

DEL1= 0.005

Q(1,1)= 1.106

Q(1,2)= 1.106

Q(1,3)= 0.706

Q(1,4)= 0.706

Q(1,5)= 0.706

DEL1= 0.001

COEFF. FOR FILTERS 1=3000.00 AND FILTER 2=1000.00

Q(1,1)= 0.995

Q(1,2)= 0.995

Q(1,3)= 0.595

Q(1,4)= 0.595

Q(1,5)= 0.595

DEL1= 0.195

Q(1,1)= 1.026

Q(1,2)= 1.026

Q(1,3)= 0.626

Q(1,4)= 0.626

Q(1,5)= 0.626

DEL1= 0.031

Q(1,1)= 1.034

Q(1,2)= 1.034

Q(1,3)= 0.634

Q(1,4)= 0.634

Q(1,5)= 0.634

DEL1= 0.008

Q(1,1)= 1.036

Q(1,2)= 1.036

Q(1,3)= 0.636

Q(1,4)= 0.636

Q(1,5)= 0.636

DEL1= 0.002

```
Q(1,1)= 1.037

Q(1,2)= 1.037

Q(1,3)= 0.637

Q(1,4)= 0.637

Q(1,5)= 0.637

DEL1= 0.001
```

COEFF. FOR FILTERS 1=5000.00 AND FILTER 2=2000.00

Q(1,1)= 0.878

Q(1,2)= 0.878

Q(1,3)= 0.478

Q(1,4)= 0.478

Q(1,5)= 0.478

DEL1= 0.078

Q(1,1)= 0.897

Q(1,2)= 0.897

Q(1,3)= 0.497

Q(1,4)= 0.497

Q(1,5)= 0.4[illegible]

DEL1= 0.019

Q(1,1)= 0.903

Q(1,2)= 0.903

Q(1,3)= 0.503

Q(1,4)= 0.503

Q(1,5)= 0.503

DEL1= 0.006

Q(1,1)= 0.904

Q(1,2)= 0.904

Q(1,3)= 0.504

Q(1,4)= 0.504

Q(1,5)= 0.504

DEL1= 0.002

Appendix B

Computer Program for Particle Trajectory Prediction in an Electrostatic Separator

```
C               THIS PROGRAM DOES A PARTICLE TRAJECTORY OF A LIGNITE PARTICLE
C              IN AN ELECTROSTATIC SEPARATOR WITH THE PARTICLE CHARGE, THE
C              ELECTRIC FIELD, AND THE FLUID VELOCITY VARYING*
               REAL MP y M
               MP = 4 ♦ 6914E-11
               W==MP*9*8
               M = 4 .0883E-14
               VIS=1»44E-5
               A=2*0E-5
    4 WRITE(5,1)
       1 FORMAT('1'y'INPUT THE PARTICLE CHARGE, THE ENTERING FLUID'
         C ' VELOCITY, THE VOLTAGE OF THE SEPARATOR PLATE AND THE LUN')
               ACCEPT*yQyUOy V y LUN
               WRITE(LUN y 5)QyUOy V
     5 FORMAT('1THE CHARGE OF THE PARTICLE IS 'y El 1 * 5y'COULOMB'y/y
         C ' THE ENTERING FLUID VELOCITY IS 'yF7♦2 y'FT/SEC'y/y
         C ' THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 'y E11♦5 y 'VOLTS'y//)
               DT = O *001
               T = 0.
             • IS = 0
               №0
               U0=U0/3*28
               X = 0*0
               Y== 1*8293
               VRX=0*0
               VRY = 0* 0
               UX=O * 0
               UY = UO
               CALL ELECTF(X y Y yQy V y EX yEY)
               UX1=UX4-1 * 0/MP*EX*DT
               UY1=UY+1♦O/MP*(EY-W)*DT
               X1=X+(UX1+UX)/2♦O*DT
               Y1= Y +(UY1+UY)/2 »O*DT
               T=T+DT
    9          N=0
   10 CALL VELOF(XI yYlyUOyVFXyVFY)
               VRX1=UX1-VFX
               VRY1=UY1-VFY
               CALL ELECTF(X1 y Y1 y O y V y EX y EY)
               UX2=UX1+1.0/MP*(-M*4.5*VIS*VRX1/(A*A)-0»5*M*(VRX1-VRX)/DT+EX)*DT
               UY2 = UY1 + 1*/MP*(-M*4* 5*VIS*VRYI/(A*A)-*5*M*(VRY1-VRY)/DT+EY-W)*DT
               T=T+DT
               X2=X1+(UX2+UX1)/2♦O*DT
               Y2 = Y1 + (UY2 + UY1)/2♦O*DT
               TH=X2/Y2
               IF(ABS(TH)♦GE♦0♦04166)IS=1
               IF(Y2*LE*1.2195)13=2
               IF<IS♦GT♦0)GO TO 90
               X1 = X2
               Y1=Y2
               UX1=UX2
               UY1=UY2
               URX=VRX1
               VRY=VRY1
               N = N+1
               IF(N*LT*25)G0 TO 10
               XP=X2*3*28
               YP=Y2*3*28
               WRITE(LUN y100)TyXPyYP
               GO TO 9
   90          XP=X2*3*28
               YP=Y2*3*28
               WRI TE(LUN y 100)T yXPyYP
               IF(IS EQ 2)GO TO 91
```

```
      WRITE(LUN,102)
102 FORMAT(//,IX, 'THE PARTICLE IS AT THE WALL',///)
       GO TO 200
 91      WRI TE(LUN,98)
 98      FORMAT(//,IX,'THE PARTICLE              HAS  EXITED              THE SEPARATOR SECTION')
200      WRITE(5,150)
150      FORMAT(IX,'WANTTO CONTINUE?              O-NO     1-YES')
          ACCEPT*,K
          IF(K»EQ*1)GO TO 4
          STOP
 100 FORMAT(IX,'TIME=',FÓ»3,'SEC',5X,'X-POSITION=', F6♦4, 'FT ' ,5X,
     C 'Y-POSITION=',F7♦5,'FT',/)
         END
         SUBROUTINE VELOF(X,Y,UO,VFX,VFY)
         R=SQRT(X*X+Y*Y)
         THETA=ATAN(X/Y)
         V=-0*82034*U0*R+2♦5*U0
         VFX = V*SIN(THETA)
         OFY=V*COS(THETA)
         RETURN
         END
         SUBROUTINE ELECTF(X,Y,Q,U,EX,EY)
         R=SQRT(X*X+Y*Y)
         TH=ATAN(X/Y)
         E~24>055*V/R
         EX=-Q*E*COS<TH)
         EY=G*E*SIN(TH)
         RETURN
         END
```

THE CHARGE OF THE PARTICLE IS 0♦10000E-14C0ULOMB
THE ENTERING FLUID VELOCITY IS -I.OOFT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0,10000E + 05VOLTS

>

TIME- 0*026SEC	X-POSI TI ON = - ♦ OO 13FT	Y-FOSITION-5,96964FT
TIME- 0*051SEC	X-POSITI0N=-♦0029FT	Y-POSITI ON-5,93884FT
TIME- 0*076SEC	X-POSITION--,0045FT	Y-POSITION-5,90789FT
TIME- 0*101SEC	X-POSITI0N=-,0062FT	Y-POSITION-5♦87681 FT
TIME- 0,126SEC	X-POSITION--*0078FT	Y-POSITION-5♦84558FT
TIME- 0*151SEC	X-POSITION = -.0094FT	Y-POSITION-5♦81423FT
TIME- 0*176SEC	X-FOSITI0N=-♦0111FT	Y-POSITION-5 *78273FT
TIME- 0,201SEC	X-POSITI0N=-♦O127FT	Y-POSITION-5♦75109FT
TIME- 0*226SEC	X-POSITION--♦0144FT	Y-FOSITION-5,71931 FT
TIME- 0*251SEC	X-POSITION--.0160FT	Y-POSITION-5,68738FT
TIME- Ö.276SEC	X-POSITION--,0176FT	Y-FOSITION-5♦65531 FT
TIME- 0,301SEC	X-POSITION--♦0193FT	Y-POSITI ON-5.62308FT
TIME- 0♦326SEC	X-POSITION--»0209FT	Y-POSITION=5 ,59070FT
TIME- 0,351SEC	X-POSITION--*0226FT	Y-POS ITION-5 » 55817FT
TIME- 0,376SEC	:X-POSITION=- .0242FT	Y-FOSITI ON-5♦52547FT
TIME- 0.401SEC	X-POSITION—.0259FT	Y-POSITI ON-5,49262FT
TÍME- 0,426SEC	X-P0SITI0N=-*0275FT	Y-POSITI ON-5,4 5960FT
TIME- 0.451SEC	X-POSITION--*0292FT	Y-POSITION-5,42642FT
TIME- 0.476SEC	X-POSITION=-*0308FT	Y-FOSI TION-5,39307FT
TIME- 0.501SEC	X-POSITION—»0325FT	Y-POSITION=5,35955FT
TIME- 0.526SEC	X-POSITION--*0341FT	Y-FOSITION-5.32585FT
TIME- 0>551 SEC	X-POSITION--,0358FT	Y-POSITION-5,29197FT
TIME- 0,576SEC	X-POSITION--*0374FT	Y-FOSITION-5,25791FT
TIME- 0*601 SEC	X-POSITION--* 0391FT	Y-POSITION-5,223Ó7FT
TIME- 0*626SEC	X-POSITION--* 0408FT	Y-FOSITION-5,18924FT
TIME- 0*651SEC	X-POSITI ON--,0424FT	Y-POSITION-5,15462FT
TIME- 0*676SEC	X-P0SITI0N=-*0441FT	Y-FOSITION-5,11980FT
TIME- 0»701SEC	X-POSITION--♦0457FT	Y-POSITI ON-5♦08478FT
TIME- 0*726SEC	X-POSITION--,0474FT	Y-POSITION-5♦04956FT
TIME- 0*751SEC	X-POSITION--,0490FT	Y-POSITION-5 * 01413FT

TIME =	0,801SEC	X-POSITION=- .0523FT	Y-P0SITI0N=4>942Ó4FT
TIME =	0.826SEC	X-POSITION=- .0540FT	Y“P0SITI0N=4♦90656FT
TIME =	0»851SEC	X-POSITION=- .0557FT	Y-POS IT10N = 4.87026FT
TIME =	0 » 876SEC	X-POSITION=- ♦0573FT	Y-POSITI0N=4♦83374FT
TIME =	0 ♦ 901SEC	X-POSITION=- ♦0590FT	Y-P0SITI0N=4♦79697FT
TIME =	0»926SEC	X-POSITION=- .0Ó06FT	Y-P0SITI0N=4♦75997FT
TIME =	0*951SEC	X-POSITION=- »0623FT	Y-P0SITI0N=4♦72273FT
TIME =	O.976SEC	X-POSITION=- ♦0639FT	Y-P0SITI0N=4♦68523FT
TIME =	1 »001SEC	X-POSITION=- .0656FT	Y-P0SITI0N=4»64748FT
TIME =	1♦026SEC	X-POSITION=- .0672FT	Y-POSITI0N=4♦60946FT
TIME =	1♦051SEC	X-POSITION=- ♦0689FT	Y-P0SITI0N=4*57118FT
TIME =	1»07ÓSEC	X-POSITION=- .0705FT	Y-P0SITI0N=4♦53262FT
TIME =	1♦1O1SEC	X-POSITION=- ♦0721FT	Y-P0SITI0N=4♦49379FT
TIME =	1♦126SEC	X-POSITION=- ♦0738FT	Y-POSITI0N=4♦454Ó6FT
TIME =	1 ,151SEC	X-POSITION=- ♦0754FT	Y-POSITI0N=4♦41524FT
TIME =	1♦176SEC	X-POSITION=- ♦0770FT	Y-POSITI0N=4♦37551FT
TIME =	1»2O1SEC	X-POSITION=- ♦0787FT	Y-P0SITI0N=4♦33548FT
TIME =	1♦226SEC	X-POSITION=- ♦0803FT	Y-POSITI0N=4♦29512FT
TIME =	1 .251SEC	X-POSITION=- .0819FT	Y-POSITI0N=4♦25444FT
TIME =	1.276SEC	X-POSITION=- .0835FT	Y-POSITI0N=4♦21342FT
TIME =	1.301SEC	X-POSITION=- .0851FT	Y-POSITI0N=4♦17206FT
TIME =	1 »326SEC	X-POSITION=- ♦0867FT	Y-POSITI0N=4♦13034FT
TIME =	1♦351SEC	X-POSITION=- ♦0884FT	Y-POSITI0N=4♦08826FT
TIME =	1»376SEC	X-POSITION=- .0899FT	Y-P0SITI0N=4♦04579FT
TIME =	1 ♦ 401SEC	X-POSITION=- ♦0915FT	Y-POSITI0N=4♦00294FT
TIME =	1 » 403SEC	X-POSITION=- »0917FT	Y-P0SITI0N=3♦99950FT

THE PARTICLE HAS EXITED THE SEPARATOR SECTION

THE CHARGE OF THE PARTICLE IS 0 ♦ 1OOOOE-14COULOMB
THE ENTERING FLUID VELOCITY IS -2,00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0.10000E + 05V0LTS

TIME= 0»026SEC	X-POSITION = -» 0013FT	Y-P0SITI0N = 5» 94355FT
TIME= 0«051SEC	X-POSITI0N=-♦0029FT	Y-POSITI0N=5»8873ÓFT
TIMÈ= 0»07óSEC	X-POSITION —♦0045FT	Y-P0SITI0N=5.83066FT
TIME= 0.101SEC	X-POSITI0N=-♦0062FT	Y-P0SITI0N=5.77346FT
TIME= 0.126SEC	X-POSITION=-♦0078FT	Y-POSITI0N№5 ♦ 7157 4FT
TIME = 0»151SEC	X-POSITI0N=-♦0094FT	Y-P0SITI0N=5»65750FT
TIME= 0*176SEC	X-POSIT10N=-» 0111FT	Y-POSIT 10N = 5♦59871 FT
TIME- 0»201SEC	X-P0SITI0N=-.0127FT	Y-POSITI0N=5♦53937FT
TIME= 0»226SEC	X-POSITION=-♦0144FT	Y-POSITI0N=5·47944FT
TIME = 0.251SEC	X-POSITI0N=-♦0160FT	Y-POSI T10N = 5 .41892FT
TIME= 0.276SEC	X-P0SITI0N=-»0176FT	Y-POSITI0N=5.35778FT
TIME= 0»301SEC	X-POSITI0N=-♦0193FT	Y-POSITI0N=5♦29601FT
TIME- 0»326SEC	X-POSITION=-»0209FT	Y-POSIT10N = 5 »23358FT
TIME- 0.351SEC	X-POSITION=-♦0226FT	Y-POSIT 10N = 5» 17047FT
TIME- 0.376SEC	X-POSITI0N=-♦0242FT	Y-POSITI ON-5 »10665FT
TIME- 0»401SEC	X-POSITION=-♦025ĐFT	Y-POSIT I0N = 5.0421 OFT
TIME- 0»426SEC	X-POSITI0N=-»0275FT	Y-POSIT10N = 4♦97680FT
TIME- 0.451SEC	X-POSITI0N = -♦0291 FT	Y-POSIT10N = 4.91070FT
TIME- 0»476SEC	X-POSITION=-,0307FT	Y-POSIT 10N=4.84379FT
TIME- 0.501SEC	X-POSITI0N=-»0323FT	Y-POSIT I0N = 4.776 03FT
TIME- 0»526SEC	X-POSITION = - .0340FT	Y-POSITI0N = 4» 7 07 3 8FT
TIME- 0.551SEC	X-POSITI0N=-♦035ÓFT	Y-POSIT10N = 4.6 3781 FT
TIME- 0»576SEC	X-P0SITI0N=-»0372FT	Y-POSITI0N№4 ♦ 56727FT
TIME- 0.601SEC	X-POSITION=-»0388FT	Y-POSITI0N=4♦49573FT
TIME- 0*626SEC	X-POSITI0N=-♦0404FT	Y-P0.SITI0N = 4.4 2312FT
.TIME- 0»651SEC	X-POSITI0N=-♦0420FT	Y-POSI TION№4 ♦ 349 41 FT
TIME- 0.676SEC	X-POSITI0N=-♦0435FT	Y-POSIT I0N = 4 » 27 45 4FT
TIME- 0»701SEC	X-POSIT10N = -♦0451 FT	Y-P0SITI0N=4.19845FT

THE PARTICLE HAS EXITED THE SEPARATOR SECTION

THE CHARGE OF THE PARTICLE IS O ♦ 10000E-14C0ULOMB
THE ENTERING FLUID VELOCITY IS -3*00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05V0LTS

TIME = 0*026SEC	X-POSITION=-♦0013FT	Y-P0SITI0N=5♦9174OFT
TIME-·-0,051SEC	X-POSITION=-♦0029FT	Y-POSITI0N = 5 »83554FT
TIME= 0»076SEC	X-POSITION=-♦0045FT	Y-P0SITI0N=5,75257FT
TIME= 0.101SEC	X-POSITION=-.0062FT	Y-P0SITI0N=5♦66848FT
TIME = 0»126SEC	X-POSITION=- .0078FT	Y-P0SITI0N=5♦58322FT
TIME= 0.151SEC	X-POS ITION = - ♦ 0094FT	Y-POSITI0N=5♦49674FT
TIME= 0,176SEC	X-POSITION=-♦0111FT	Y-POSITI0N=5♦40898FT
TIME = 0.201SEC	X-POSITION=-♦0127FT	Y-P0SITI0N=5♦31988FT
TIME= 0»226SEC	X-POSITION=-♦O144FT	Y-POSITI0N=5♦22936FT
TIME^ 0.251SEC	X-POSITION = - .0160FT	Y-P0SITI0N=5♦13737FT
TIME= 0*276SEC	X-POSITION=-♦0176FT	Y-POSITI0N=5♦04382FT
TIME= 0»301SEC	X-POSITION = -♦0192FT	Y-POSIT10N = 4 »94863FT
TIME= 0.326SEC	X-POSITION=-♦0209FT	Y-POSITI0N=4♦85170FT
TIME= 0»351SEC	X-POSITION = - ♦ 0225FT	Y-POSITI0N=4♦75293FT
TIME- 0*376SEC	X-POSITION = -♦0241 FT	Y-POSITI0N = 4♦65221 FT
TIME = 0M01SEC	X-POSITI0N=-♦0257FT	Y-POSITI0N=4♦54941FT
TIME= 0M26SEC	X-POSITI0N=-♦0273FT	Y-POSITI0N=4♦44440FT
TIME = 0»451SEC	X-P0SITI0№-»0288FT	Y-POSIT10N = 4♦33701 FT
TIME = 0»476SEC	X-POSITION=-»0304FT	Y-P0SITI0N=4♦22708FT
TIME = 0.501SEC	X-POSITI0N=-♦0319FT	Y-P0SITI0N=4.11440FT
TIME = 0»526SEC	X-POSITION=-*0335FT	Y-P0SITI0N=3♦99876FT

THE PARTICLE HAS EXITED THE SEPARATOR SECTION

THE CHARGE OF THE PARTICLE IS -♦ 10000E-1 3COULOMB
THE ENTERING FLUID VELOCITY IS -1*OOFT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05V0LTS

TIME- 0*026SEC	X-POSITION-O♦0127FT	Y-P0SITI0N-5 ♦ 96963FT
TIME- 0*051SEC	X-POSITION-O»0290FT	Y-P0SITI0N-5 .93879FT
TIME- 0*076SEC	X-POSITION-O♦0453FT	Y-POSITION-5♦90775FT
TIME- O*1O1SEC	X-POSITION-O♦0616FT	Y-POSITION-5♦87653FT
TIME- 0*126SEC	X-POSITION-O♦0780FT	Y-POSITION-5 » 84513FT
TIME- 0*151SEC	X-POSITION-O.0944FT	Y-POSITION-5♦81354FT
TIME- 0*176SEC	X-POSITION-O.1108FT	Y-POSITION-5♦78177FT
TIME- 0*201SEC	X-POSITION-O♦1271 FT	Y-POSITION-5♦74980FT
TIME- 0*226SEC	X-P0SITI0N-0.1436FT	Y-POSITION-5♦71764FT
TIME- 0.251SEC	X-FOSITI0N№0tl600FT	Y-P0SITI0N-5♦68529FT
TIME- 0*276SEC	X-POSITION-O♦1764FT	Y-POSITION-5♦65274FT
TIME- 0*301SEC	X-POSITION-O.1928FT	Y-P0SITI0N-5♦61998FT
TIME- 0*326SEC	X-POSITION-O »2093FT	Y-POSITION-5♦58701FT
TIME- 0*351SEC	X-POSITION-O »2258FT	Y-POSITION-5♦55384FT
TIME- 0*359SEC	X-P0SITI0N-0.2310FT	Y-POSITION-5*54318FT

THE PARTICLE IS AT THE WALL

THE CHARGE OF THE PARTICLE IS 0 ♦ 1OOOOE-13COULOMB
THE ENTERING FLUID VELOCITY IS -2*00FT/SEC UQ
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0 ♦ 10000E + 05V0LTS

TIME = 0»026SEC	X-POSITION«-	» 0127FT	Y-POSIT10N = 5 ♦ 94354FT
TIME« 0»051SEC	X-POSITION«-	.0290FT	Y-P0SITI0N = 5♦88731 FT
TIME= 0<076SEC	X-POSITION«-	♦0453FT	Y-P0SITI0N=5*83052FT
TIME= 0.101SEC	X-POSITION«-	.0617FT	Y-POSITI0N=5♦77318FT
TIME« 0»126SEC	X-POSITION«-	♦0781FT	Y-P0SITI0N=5♦71527FT
TIME« 0.151SEC	X-POSITION«-	,0944FT	Y-POSITI0N=5♦65680FT
TIME = 0»176SEC	X-POSITION«-	♦ 1108FT	Y-P0SITI0N=5*59772FT
TIME« 0.201SEC	X-POSITION«-	♦ 1272FT	Y-POSITI0N=5♦53803FT
TIME« 0»226SEC	, X-POSITION«-	» 1436FT	Y-POSIT10N = 5♦4 7771 FT
TIME« 0.251SEC	X-POSITION«-	♦ 1600FT	Y-POSITI0N=5·41673FT
TIME« 0.276SEC	X-POSITION«-	.1764FT	Y-POSITI0N=5♦35508FT
TIME« 0>301SEC	X-POSITION«-	♦ 1927FT	Y-POSITI0N=5♦29273FT
TIME« 0.326SEC	X-POSITION«-	.2091FT	Y-POSITI0N=5♦22966FT
TIME« 0.338SEC	X-POSITION«-	.2170FT	Y-P0SITI0N=5♦19912FT

THE PARTICLE IS AT THE WALL

THE CHARGE OF THE PARTICLE IS 0 ♦ 1 0000E-13COULOMB
THE ENTERING FLUID VELOCITY IS -3.00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05V0LTS

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TIME = 0.02ÓSEC	X-POSITION=-	♦0128FT	Y-POSITI0N=5.91739FT
TIME = 0.051SEC	X-POSITION=-	♦0290FT	Y-POSITI0N=5♦83548FT
TIME = 0.076SEC	X-POSITION=-	♦0454FT	Y-POSITI0N=5♦75242FT
TIME = 0.101SEC	X-POSITION=-	♦0617FT	Y-P0SITI0N=5♦66820FT
TIME = 0.126SEC	X-POSITION=-	♦0781FT	Y-POSITI0N=5♦58274FT
TIME = 0.151SEC	X-POSITION=-	♦0945FT	Y-POSITI0N=5♦49602FT
TIME = 0.176SEC	X-POSITION=-	♦1108FT	Y-POSITI0N=5♦40795FT
TIME = 0.201SEC	X-POSITION=-	.1272FT	Y-POSITI0N=5♦31849FT
TIME = 0.226SEC	X-POSITION=-	♦1435FT	Y-POSITI0N=5♦22755FT
TIME= 0.251SEC	X-POSITION=-	♦1598FT	Y-POSITI0N=5. 13508FT
TIME= 0.276SEC	X-POSITION=-	.1761FT	Y-POSITI0N=5♦04097FT
TIME= 0.301SEC	X-POSITION=-	.1923FT	Y-POSIT10N = 4» 94515FT
TIME= 0.318SEC	X-POSITION=-	♦2033FT	Y-POSITI0N=4♦87896FT

THE PARTICLE IS AT THE WALL

THE CHARGE OF THE PARTICLE IS O♦50000E-14C0UL0MB
> THE ENTERING FLUID VELOCITY IS -I.OOFT/SEC 5O
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05V0LTS

TIME = 0.026SEC	X-POSITION = -.0064FT	Y-P0SITI0N=5.96961FT
TIME = 0.051SEC	X-POSITI ON«-» 0145FT	Y-P0SITI0N=5.93872FT
TIME= 0.076SEC	X-POSITION«-.0226FT	Y-POSITI0N=5♦90759FT
TIME = 0.101SEC	X-POSITION«-♦0308FT	Y-P0SITI0N=5♦87626FT
TIME = 0.126SEC	X-POSIT ION«- . 0390FF	Y-POSITI0N=5.84472FT
TIME = 0.151SEC	X-POSITION«-.0472FT	Y-P0SITI0N=5.81298FT
TIME = 0.176SEC	X-POSITION«-♦0554FT	Y-POSITI0N=5♦78102FT
TIME = 0.201SEC	X-POSITION«-♦0636FT	Y-POSITI0N=5.74885FT
TIME = 0.226SEC	X-POSITION=-♦0718FT	Y-POSITI0N=5.71646FT
TIME-" 0.251SEC	X-POSITI ON«-♦0800FT	Y-P0SITI0N=5♦68387FT
TIME = 0.276SEC	X-POSITION=-♦0882FT	Y-POSITI0N=5♦65105FT
TIME« 0.301 SEC	X-POSITION«-.0964FT	Y-POSITI0N=5♦61802FT
TIME« 0.326SEC	X-POSITION«-♦1046FT	Y-POSITI0N=5♦58476FT
TIME« 0.351SEC	X-POSITION«-. 1129FT	Y-P0SITI0N=5.55129FT
TIME« 0.376SEC	X-POSITION«-.1211FT	Y-POSITI0N=5♦51759FT
TIME« 0.401SEC	X-POSITION«-.1293FT	Y-POSIT10N = 5» 48367FT
TIME= 0.426SEC	X-POSITION«-♦1376FT	Y-POSITI0N=5♦44953FT
TIME« 0.451SEC	X-POSITION«-♦1458FT	Y-POSITI0N=5.41515FT
TIME« 0.476SEC	X-POSITION«-.1540FT	Y-POSITI0N=5.38055FT
TIME« 0.501SEC	X-POSITI0N=-.1623FT	Y-POSITI0N=5.34571FT
TIME« 0.526SEC	X-POSITION«-♦1705FT	Y-POSITI0N=5.31065FT
TIME« 0.551SEC	X-POSITION«-.1788FT	Y-POSITI0N=5♦27535FT
TIME« 0.576SEC	X-POSITION«-.1870FT	Y-POSITI0N=5♦23981FT
TIME« 0.601SEC	X-POSIΓION«-.1953FT	Y-POSITI0N=5.20403FT
TIME« 0.626SEC	X-POSITION«-.2035FT	Y-POSITI0N=5♦16802FT
TIME« 0.651SEC	X-POSITION«-.2118FT	Y-POSITI0N=5.13177FT
TIME« 0.Ó57SEC	X-POSITION«-.2138FT	Y-POSITI0N=5♦12303FT

THE PARTICLE IS AT THE WALL

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THE CHARGE OF THE PARTICLE IS O♦ 50000E-1 4C0UL0MB
THE ENTERING FLUID VELOCITY IS -2.00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0 ♦ 10000E + 05V0LTS

TIME« 0.026SEC	X-POSITI ON«-.0064FT	Y-POSITI0N=5♦94346FT
TIME« 0.051SEC	X-POSITION«-♦OI45FT	Y-P0SITI0N=5♦88696FT
TIME« 0.076SEC	X-POSITION«-.0227FT	Y-POSITI0N = 5♦82971 FT
TIME« O.1O1SEC	X-POSITION«-.0308FT	Y-POSITI0N=5♦77172FT
TIME« 0.126SEC	x-POSITION=-,0390FT	Y-POSITI0N=5♦71300FT
TIME« 0.151SEC	X-POSITION«-♦0472FT	Y-POSITI0N=5♦65353FT
TIME« 0.176SEC	X-POSITION«-.0554FT	Y-POSITI0N=5♦59330FT
TIME« 0.201SEC	X-POSITION«-.0636FT	Y-POSITI0N=5.53231FT
TIME« 0.226SEC	X-POSITION«-♦0718FT	Y-POSITI0N=5♦47053FT
TIME« 0.251SEC	X-POSITION«-♦0800FT	Y-POSITI0N=5♦40797FT
TIME« 0.276SEC	X-POSITION«-.0881FT	Y-POSITI0N=5♦34461FT
TIME« 0.301SEC	X-POSITI ON«-♦ 0963FT	Y-POSITI0N=5♦28045FT
TIME« 0.326SEC	X-POSITION«-.1045FT	Y-P0SITI0N=5♦21546FT
TIME« 0.351SEC	X-POSITION«-♦1126FT	Y-POSITI0N=5♦14964FT
TIME« 0.376SEC	X-POSITION«-.1208FT	Y-POSITI0N=5.08299FT
TIME« 0.401SEC	X-POSITION«- . 1289FT	Y-POSITI0N=5♦O1548FT
TIME« 0.426SEC	X-POSITION«- .1371FT	Y-P0SITI0N=4.94711FT
TIME« 0,451SEC	X-POSITION«-♦1452FT	Y-POSITI0N=4♦87786FT
TIME« 0.476SEC	X-POSITION«-.1533FT	Y-POSITI0N=4♦80773FT
TIME« 0.501SEC	X-POSITION«-. 1614FT	Y-POSITI0N=4♦73671FT
TIME« 0.526SEC	X-POSITION«- . 1694FT	Y-POSITI0N=4♦66477FT
TIME« 0.551SEC	X-POSITION«- . 1774FT	Y-POSITI0N = 4.59191 FT
TIME« 0.576SEC	X-POSITION«- . 1355FT	Y-POSITION«4.51812FT
TIME« 0.583SEC	X-POSITION«-.1877FT	Y-POSI T I 0N = 4.4 9729FT

THE PARTICLE IS AT THE WALL

THE CHARGE OF THE PARTICLE IS - ♦ 50000E-14C0UL0MB
THE ENTERING FLUID VELOCITY IS -3.00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05V0LTS

TIME- 0.026SEC	X-POSITION-O♦0064FT	Y-POSITION-5♦91722FT
TIME- 0.051SEC	X-POSITION = O♦0145FT	Y-POSITION-5♦83470FT
TIME- 0.076SEC	X-POSITION-O.0227FT	Y-POSITI ON-5♦75059FT
TIME- 0.101SEC	X-POSITION-O.0309FT	Y-POSITION-5♦66488FT
TIME- 0.126SEC	X-POSITION-O.0390FT	Y-POSITION=5.57755FT
TIME- 0.151SEC	X-POSITION-O.0472FT	Y-POSITI ON-5♦48856FT
TIME- 0.176SEC	X-POSITION=0 .0554FT	Y-POSITI ON-5♦39788FT
TIME- 0.201SEC	X-POSITION-O.0635FT	Y-POSITI ON-5♦30548FT
TIME- 0.226SEC	X-POSITION-O♦0717FT	Y-POSITION=5.21133FT
TIME- 0.251SEC	X-POSITION-O.0798FT	Y-POSITION-5♦11538FT
TIME- 0.276SEC	X-POSITION-O.0879FT	Y-POSITION-5♦OI7Ó2FT
TIME- 0.301SEC	X-POSITION=0.0960FT	Y-POSITION-4♦91799FT
TIME- 0.326SEC	X-POSITION-O.1041FT	Y-POSITI ON-4♦81Ó48FT
TIME- 0.351SEC	X-POSITION-O♦1Í21FT	Y-POSITION-4.71303FT
TIME- 0.376SEC	X-POSITION-O♦1201FT	Y-POSITION-4.60762FT
TIME- 0.401SEC	X-POSITION-O♦1281FT	Y-POSITI ON-4.50021 FT
TIME- 0.426SEC	X-POSITION-O♦1360FT	Y-POSIT I ON-4♦390 75FT
TIME- 0.451SEC	X-POSITION-O♦1438FT	Y-POSITION-4.27920FT
TIME- 0.476SEC	X-POSITION-O.1516FT	Y-POSITI ON-4.16553FT
TIME- 0.501SEC	X-POSITION-O »1593FT	Y-POSITION-4 »04 9 70FT
TIME- 0.512SEC	X-POSITION-O <1627FT	Y-POSITION-3.99803FT

THE PARTICLE HAS EXITED THE SEPARATOR SECTION

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THE CHARGE OF THE PARTICLE IS 0 ♦ 1 0000E-1 3COULOMB
THE ENTERING FLUID VELOCITY IS -2.00FT/SEC
THE VOLTAGEÍ+ AND -) OF THE ELECTRODES IS 0 ♦ 10000E + 05VOLTS

TIME= 0»026SEC	X-POSITION=-♦0127FT	Y-POSIT10N = 5 ♦ 94354FT
TIME = 0.051SEC	X-POSITION=-♦0290FT	Y-POSITI0N = 5♦8 8731 FT
TIME= 0*076SEC	X-POSITION=- ♦0453FT	Y-P0SITI0N=5♦83052FT
TIME= 0.101SEC	X-POSITION=- .0617FT	Y-POSITI0N=5.77318FT
TIME= 0»126SEC	X-POSITION=- ♦0781FT	Y-POSITI0N=5♦71527FT
TIME = 0.151SEC	X-POSITION=- ♦O944FT	Y-POSITI0N = 5♦65680FT
TIME= 0»176SEC	X-POSITION=- ♦ 1108FT	Y-POSITI0N=5*59772FT
TIME = 0.201SEC	X-POSITION=- ♦1272FT	Y-POSITI0N=5♦53803FT
TIME = 0*226SEC	. X-POSITION№- ♦ 1436FT	Y-POSIT10N = 5♦47771 FT
TIME= 0.251SEC	X-POSITION=- ♦1600FT	Y-POSIT10N = 5 » 41673FT
TIME= 0.276SEC	X-POSITION=- ♦1764FT	Y-POSITI0N=5♦35508FT
TIME= 0»301SEC	X-POSITION=- ♦1927FT	Y-POSITI0N=5 »29273FT
TIME = 0.326SEC	X-POSITION=- .2091FT	Y-POSITI0N=5»22966FT
TIME= 0»338SEC	X-POSITION=- .217FT	Y-POSITI0N=5♦19912FT

THE PARTICLE IS AT THE WALL

THE CHARGE OF THE PARTICLE IS O ♦ 10000E-13COULOMB
THE ENTERING FLUID VELOCITY IS -3.00FT/SEC
THE VOLTAGEU AND -) OF THE ELECTRODES IS 0 ♦ 10000E+05V0LTS

TIME = 0.026SEC	X-POSITION=-	♦0128FT	Y-POSITI0N=5♦91739FT
TIME = 0.051SEC	X-POSITION=-	♦0290FT	Y-P0SITI0N=5♦83548FT
TIME = 0.076SEC	X-POSITION=-	♦0454FT	Y-P0SITI0N=5♦75242FT
TIME« O,1O1SEC	X-POSITION=-	♦0617FT	Y-P0SITI0N=5»66820FT
TIME = 0.126SEC	X-POSITION=-	♦0781FT	Y-P0SITI0N=5♦58274FT
TIME« 0.151SEC	X-POSITION«-	♦0945FT	Y-POSITI0N=5.49602FT
TIME« 0.176SEC	X-POSITION=-	♦1108FT	Y-POSITI0N=5.40795FT
TIME« 0.201SEC	X-POSITION=-	.1272FT	Y-P0SITI0N=5♦31849FT
TIME« 0.22ÓSEC	X-POSITION=-	♦1435FT	Y-POSITI0N=5♦22755FT
TIME= 0,251SEC	X-POSITION=-	. 1598FT	Y-P0SITI0N=5♦13508FT
TIME= 0.276SEC	X-POSITION=-	♦1761FT	Y-POSITI0N=5.O4097FT
TIME« 0.301SEC	X-POSITION=-	.1923FT	Y-POSITI0N=4♦94515FT
TIME= 0.318SEC	X-POSITION=-	♦2033FT	Y-POSITI0N=4.87896FT

THE PARTICLE IS AT THE WALL

* THE CHARGE OF THE PARTICLE IS O ♦ 50000E-1 4COULOMB
* THE ENTERING FLUID VELOCITY IS -1,OOFT/SEC

THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0 ♦ 10000E + 05V0LTS

TIME = 0»026SEC	X-POSITION»-♦0064FT		Y-POSITI0N=5♦96961FT
TIME= 0,051SEC	X-POSITION»-	♦0145FT	Y-P0SITI0N=5♦93872FT
TIME= 0»076SEC	X-POSITION»-	.0226FT	Y-POSITI0N=5♦90759FT
TIME = 0»101SEC	X-POSITION»-	♦0308FT	Y-P0SITI0N=5♦87626FT
TIME= 0*126SEC	X-POSITION»-	.0390FF	Y-P0SITI0N=5♦84472FT
TIME= 0.151SEC	x-POSITION=-	♦0472FT	Y-POSITI0N=5♦81298FT
TIME= 0»176SEC	X-POSITION»-	♦0554FT	Y-POSITI0N=5♦78102FT
TIME = 0>201SEC	X-POSITION»-	♦063ÓFT	Y-P0SITI0N=5»74885FT
TIME= 0»226SEC	X-POSITION=-	♦0718FT	Y-POSITI0N=5♦71646FT
TIME- 0*251SEC	X-POSITION»-	♦0800FT	Y-P0SITI0N=5♦68387FT
TIME = 0>276SEC	X-POSITION»-	♦0882FT	Y-POSITI0N=5♦65105FT
TIHE» 0.301SEC	X-POSITION=-	.0964FT	Y-POSITI0N=5♦61802FT
TIME» 0*326SEC	X-POSITION=-	♦ 1046FT	Y-POSITI0N=5♦58476FT
TIME» 0.351SEC	X-POSITION=-	, 1129FT	Y-POSITI0N=5.55129FT
TIME» 0,376SEC	X-POSITION=-	♦ 1211FT	Y-POSITI0N=5♦51759FT
TIME» 0.401SEC	X-POSITION=-	. 1293FT	Y-POSITI0N=5♦48367FT
TIME» 0M26SEC	X-POSITION=-	♦ 1376FT	Y-POSI T10№5»44953FT
TIME» 0,451SEC	X-POSITION=-	. 1458FT	Y-POSITI0N=5♦41515FT
TIME» 0.476SEC	X-POSITION=-	♦1540FT	Y-POSITI0N=5♦38055FT
TIME» 0»501SEC	X-POSITION=-	»1623FT	Y-POSITI0N=5♦34571FT
TIME» 0.526SEC	X-POSITION=-	♦1705FT	Y-P0SITI0N=5.31065FT
TIME» 0.551SEC	X-POSITION=-	♦ 1788FT	Y-POSITI0N=5♦27535FT
TIME» 0.576SEC	X-POSITION=-	♦ 1870FT	Y-POSITI0N=5♦23981FT
TIME» 0,001 SEC	X-POSITION=-	. 1953FT	Y-POSITI0N=5♦20403FT
TIME» 0»626SEC	X-POSITION=-	.2035FT	Y-POSITI0N=5♦16802FT
TIME» 0»651SEC	X-POSITION=-	♦2118FT	Y-POSITI0N=5♦13177FT
TIME» 0,657SEC	X-POSITION=-	♦2138FT	Y-POSITI0N=5♦12303FT

THE PARTICLE IS AT THE WALL

J

THE CHARGE OF THE PARTICLE IS 0 *50000E-14C0UL0MB
THE ENTERING FLUID VELOCITY IS -2*00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05V0LTS

TIME« 0*026SEC	X-POSITI ON«-♦0064FT	Y-POSIT10N = 5 »94346FT
TIME« 0*051SEC	X-POSITION«-♦0145FT	Y-P0SITI0N=5♦88696FT
TIME« 0*076SEC	X-POSITION«-♦0227FT	Y-POSITI0N = 5♦82971 FT
TIME« 0.101SEC	X-POSITI ON«- .0308FT	Y-P0SITI0N=5* 77172FT
TIME« 0*126SEC	X-POSITION«-♦0390FT	Y-POSIT10N = 5* 71300FT
TIME« 0.151SEC	X-POSITION«- .0472FT	Y-POSITI0N=5♦65353FT
TIME« 0*176SEC	X-POS ITI ON«-♦ 0554'FT	Y-POSITI0N=5*59330FT
TIME« 0*201SEC	X-POSITION«-♦0636FT	Y-POSITI0N=5*53231FT
TIME« 0.226SEC	X-POSITION«-♦0718FT	Y-POSITI0N=5*47053FT
TIME [illegible]SEC	X-POSITION«- .0800FT	Y-P0SITI0N=5♦40797FT
TIME« 0*276SEC	X-POSITION«-♦0881FT	Y-POSIT10N = 5* 34 461FT
TIME« 0.301SEC	X-POSITION«- .0963FT	Y-POSITI0N=5♦28045FT
TIME« 0*326SEC	X-POSITI ON«-♦1045FT	Y-POSITI0N=5*21546FT
TIME« 0*351SEC	X-POSITION«-♦1126FT	Y-POSITI0N=5♦14964FT
TIME« 0*376SEC	X-POSITION«-♦1208FT	Y-POSITI0N=5♦08299FT
TIME« 0»401SEC	X-POSITION«-♦1289FT	Y-POSIT10N = 5♦01548FT
TIME« 0*426SEC	X-POSITION«-*1371FT	Y-P0SITI0N = 4 * 94711FT
TIME« 0*451SEC	X-POSITION«-♦ 1452FT	Y-POSIT10N = 4♦877 86FT
TIME« 0.476SEC	X-POSITION«-♦ 1533FT	Y-P0SITI0N = 4 .80773FT
TIME« 0*501SEC	X-POSITION«-♦1614FT	Y-POSIT10N = 4♦73671 FT
TIME« O*52ÓSEC	X-POSITION«-*1694FT	Y-POSITI0N = 4 * 6 64 77FT
TIME« 0*551SEC	X-POSITION«-♦1774FT	Y-POSITI0N=4♦59191FT
TIME« 0*576SEC	X-POSITION«-*1855FT	Y-P0SITI0N = 4 *51812FT
TIME« 0.583SEC	X-POSITION«-♦1877FT	Y-POSITI0N = 4 * 4 9729FT

THE PARTICLE IS AT THE WALL

THE CHARGE OF THE PARTICLE IS - ♦ 50000E-14C0UL0MB
THE ENTERING FLUID VELOCITY IS -3»00FT/SEC
THE VOLTAGE(+ AND -) OF THE ELECTRODES IS 0♦10000E+05VOLTS

TIME = 0»026SEC	X-POSITION=O♦0064FT	Y-POSITI0N=5♦91722FT
TIME= 0»051SEC	X-POSITION = O♦0145FT	Y-P0SITI0N=5♦83470FT
TIME= 0«076SEC	X-POSITION=O♦0227FT	Y-POSITI0N=5♦75059FT
TIME= 0.101SEC	X-POSITION=O♦0309FT	Y-POSITI0N=5♦66488FT
TIME= 0*126SEC	X-POSITION=O♦0390FT	Y-P0SITI0N=5»57755FT
TIME = 0»151SEC	X-POSITION = O »0472FT	Y-POSITI0N=5♦4885ÓFT
TIME= 0»176SEC	X-POSITION = O »0554FT	Y-POSITI0N=5♦39788FT
TIME= 0»201SEC	X-POSITION=O♦0635FT	Y-POSITI0N=5♦30548FT
TIME = 0*226SEC	X-POSITION=O♦0717FT	Y-P0SITI0N=5♦21133FT
TIME= 0.251SEC	X-POSIT10N = 0 »0798FT	Y-P0SITI0N=5*11538FT
TIME= 0»276SEC	X-P0SITI0N=0♦0879FT	Y-POSIT10N = 5♦017Ó2FT
TIME= 0.301SEC	X-POSITI0N=0.0960FT	Y-POSITI0N=4♦91799FT
TIME= 0.326SEC	X-P0SITI0N=0.1041FT	Y-P0SITI0N=4♦81Ó48FT
TIME= 0»351SEC	X-P0SITI0N=0*1121FT	Y-POSITI0N=4♦71303FT
TIME= 0»376SEC	X-POSITION=O♦1201FT	Y-POSIT I0N = 4♦60762FT
TIME= 0»401SEC	X-P0SITI0N=0.1281FT	Y-POSIT10N = 4.50021 FT
TIME = 0.426SEC	X-POSITION=O♦1360FT	Y-POSI T 10N = 4♦39 075FT
TIME= O.451SEC	X-POSITION=O.1438FT	Y-P0SITI0N=4♦2792OFT
TIME= 0»476SEC	X-POSITION=O»1516FT	Y-POSITI0N=4♦16553FT
TIME= 0»501SEC	X-POSITION=O»1593FT	Y-POSITI0N=4♦04970FT
TIME= 0*512SEC	X-POSITI0N=0♦1627FT	Y-POSI T 10N = 3♦998 03FT

THE PARTICLE HAS EXITED THE SEPARATOR SECTION

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5. Arpaci, V.S., Conduction Heat Transfer, Addison-Wesly, Reading, Massachusetts, 1966.

6. Jackson, J.D., Classical Electrodynamics, Wiley, New York, 1962.

7. Lord Rayleigh, "On the motion of solid bodies through viscous liquid," Philosophical Magazine, June, 1911, p. 704.