are quite volatile at ionizer temperatures As the refractory metals are oxidized, vaporization of their oxides will cause continuous erosion Hence, the requirement for low oxygen-cesium appears to be mandatory

As we have emphasized, the corrosion resistance of metals and potential degradation of the ionizer is influenced by the oxygen content of the cesium Unfortunately, adaptation of analytical methods used for determining oxygen in other alkali metals has not yet proved entirely satisfactory for cesium Thus, it is difficult to evaluate fully the effect of oxygen concentration at this time

In conclusion, the most important problem with which we are faced in the use of cesium propellant for ion engines is the production and maintenance of high purity cesium with a low oxygen content

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Charged Aerosol Energy Converter

A MARKS* AND E BARRETO†
Marks Polarized Corporation, Whitestone, N Y
AND
C K CHU‡
New York University, New York, N Y

The charged aerosol energy converter is an electrohydrodynamic unit which operates more efficiently than other electrohydrodynamic devices By using charged aerosol particles in a dense gas the mobility is reduced so that slip velocities become negligible A theoretical model is discussed and the solution of the equations indicates that constant gas velocity or constant thermodynamic state operation is possible The experimental results show excellent agreement with the theoretical model, hence verifying the assumptions made It is demonstrated both experimentally and theoretically that the only limitation to the generator is electric breakdown At present the operation is confined to high velocity due to difficulties in producing the aerosol

Introduction

THE conversion of kinetic energy to electrical energy by making use of the retarding force exerted by an electric field on either ions or charged particles is an old concept[1 2] which has recently been revived as a way of producing electricity in a system without moving parts

In one method under current investigation,[3] the particles are produced in an expansion through a supersonic nozzle into a vacuum chamber; thus, high kinetic energy is imparted to particles of very high mobility The system, however, is not susceptible to staging, and coulomb beam spreading and space charge limitations are to be expected

In another method presently being investigated, the particles are immersed in a fluid, to which kinetic energy is imparted For successful operation this requires negligible slip velocity of the particles as compared to the velocity of the carrier fluid If ions are used, they may be suspended in an insulating liquid[4 5] resulting in very small mobilities This type of approach is very fruitful for high voltage generation, but high wall frictional losses reduce its capacity as a power source

Still another method,[6] which results in low slip velocity and frictional losses, is to increase particle size and suspend the particles in a gas This method can result in high charge densities, and permits staging of several units Since the kinetic energy of a gas can easily be obtained from an expansion originated by the addition of heat, it is possible to use this approach for the conversion of heat to electrical energy This paper is devoted to the last approach just mentioned

Theoretical Model

Our theoretical model comprises a one-dimensional frictionless steady flow of aerosol through a nozzle whose shape is part of the problem The aerosol particles are assumed uniform in size Figure 1 depicts the situation: aerosol particles become charged instantaneously at a ground reference position x_1 and they give up their charge to a collector placed downstream at position x_2 The collector is connected through a load resistor R to ground The space between the charging and collector planes constitutes the region where flow energy converts into electrical energy Excellent but unnecessarily complicated theoretical analysis of the fundamental set of equations governing the conversion process has been made[7–9] Here it is assumed at the start that the charged particles have negligible slip velocity (zero mobility) and that they do not affect the gas thermodynamically Under these assumptions, which later will be seen to be justified from the experimental results, the general formulation of the problem is given by standard laws as follows:

$$\delta v A = \text{const} = M \qquad \text{(conservation of mass)} \quad (1)$$

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* President

† Scientific Director; presently at Curtiss-Wright Corporation, Woodridge, N J

‡ Associate Professor of Aeronautics; presently at Columbia University

$$\rho v A = \text{const} = I \quad \text{(conservation of charge)} \quad (2)$$

$$j = \rho v \quad \text{(transport of charge)} \quad (3)$$

$$\delta v \frac{dv}{dx} + \frac{dP}{dx} - \rho E = 0 \text{ (conversion of momentum)} \quad (4)$$

$$\delta v \frac{d}{dx}\left[c_p T + \left(\frac{1}{2}\right) v^2\right] - jE = 0 \quad (5)$$

(conservation of energy)

$$P = \delta R T \quad \text{(ideal gas law)} \quad (6)$$

$$\frac{dE}{dx} = \frac{\rho}{\epsilon} \quad \text{(Gauss' law)} \quad (7)$$

A close look at the system of equations reveals that the charge-to-mass ratio ρ/δ and the entropy are constants; hence, the energy equation integrates immediately, yielding

$$c_p T + (\tfrac{1}{2}) v^2 + (I/M)\varphi = \text{const} \quad (8)$$

Two particular solutions have special significance to power conversion: 1) conversion at constant thermodynamic state, and 2) conversion at constant velocity

1 Conversion at Constant Thermodynamic State

For constant thermodynamic state, the electrical energy originates from a decrease in kinetic energy of the gas We seek then a configuration $A(x)$ that gives $P = P_1$; $\delta = \delta_1$, and $T = T_1$ This is consistent with constant entropy $S = S_1$. Since the ratio of the charge-to-mass density is in general a constant, it follows that the charge density is also constant and Poisson's equation immediately integrates to a parabolic potential distribution The constants of integration are evaluated by using the boundary conditions $\varphi(0) = 0$, and $d\varphi(\lambda)/dx = 0$ Where λ is the conversion space length One then obtains

$$\varphi(x) = \rho_1 \frac{\lambda^2}{2\epsilon}\left(\frac{2x}{\lambda} - \frac{x^2}{\lambda^2}\right) \quad (9)$$

Equation (9) gives the potential distribution The output voltage is given by $\varphi(\lambda)$,

$$\varphi(\lambda) = \rho_1 \frac{\lambda^2}{2\epsilon} \quad (10)$$

Using Eq (10), one may rewrite the potential distribution as the potential for a parallel plate capacitor, plus a correction term dependent on the charge density and length of the conversion space That is,

$$\varphi(x) = \varphi(\lambda)\frac{x}{\lambda} + \rho_1 \frac{\lambda^2}{2\epsilon}\left(\frac{x}{\lambda} - \frac{x^2}{\lambda^2}\right) \quad (9a)$$

Combining (10) with Ohm's law, the maximum output voltage is obtained with an optimum conversion length, λ_{max}, which is a function of the load resistor and the geometry of the nozzle:

$$\lambda_{max} = [2\epsilon A(x_2) v(x_2) R]^{1/2} \quad (11)$$

Combining Eqs (8–10 and 2), the nozzle configuration, for constant thermodynamic state energy conversion, can be

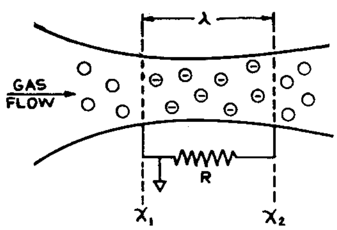

Fig 1 Theoretical model

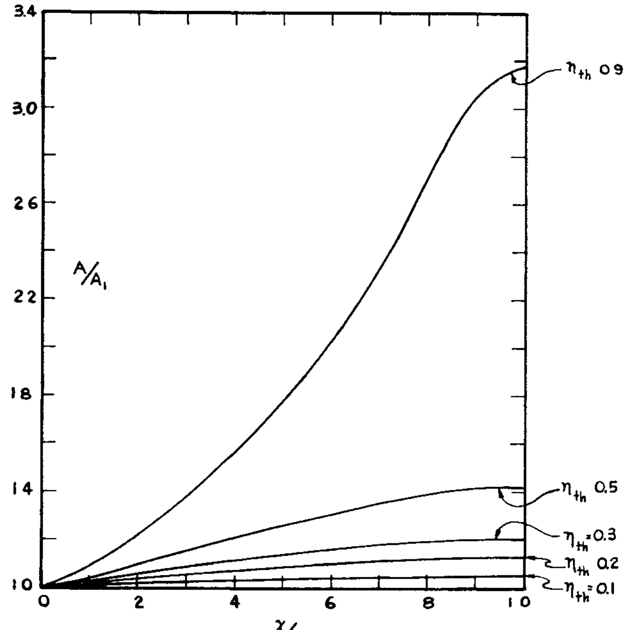

Fig 2 $A(x)$ for constant thermodynamic state conversion

computed as

$$\left(\frac{A_1}{A}\right)^2 = 1 - \eta_{th}\left(\frac{2x}{\lambda} - \frac{x^2}{\lambda^2}\right) \quad (12)$$

η_{th} on Eq (12) is defined as the ratio of output electrical power to the total kinetic power input which is called the conversion ratio

$$\eta_{th} = [\varphi(\lambda)_{max} I]/(\tfrac{1}{2}\dot{M} v_1^2) \quad (13)$$

Figure 2 shows a plot of (A/A_1) vs x/λ for different conversion ratio values It shows that for constant thermodynamic state operation, divergent nozzles should be used whose area rate of change with position increases for higher conversion ratios

2 Constant Velocity Energy Conversion

Under constant velocity operation, one may cancel terms involving velocity position derivatives of the basic set of Eqs (1–7) The thermodynamic changes can then be computed as functionals of the electric field After some lengthy algebraic manipulation, and using the fact that $c_p - c_v = R$, one finds that for constant velocity energy conversion

$$(P/P_1) = \xi \quad (14)$$

$$(T/T_1) = \xi^{(\gamma-1)/\gamma} \quad (15)$$

$$(\delta/\delta_1) = (j/j_1) = (A_1/A) = \xi^{1/\gamma} \quad (16)$$

where

$$\xi = 1 + (\epsilon/2P_1)(E^2 - E_1^2) \quad (17)$$

and γ is the ratio of the specific heat capacities Equations (14–16) give the change in pressure, temperature, and the nozzle shape as functionals of the electric field intensity If the electric field is obtained explicitly in terms of position, one will be able to specify completely the change in thermodynamic variables The equation to be solved is given by Eq (16) and Gauss' law as

$$\begin{aligned} dE/dx &= (\rho_1/\epsilon)\xi^{1/\gamma} \\ &= (\rho_1/\epsilon)[1 + (\epsilon/2P_1)(E^2 - E_1^2)]^{1/\gamma} \end{aligned} \quad (18)$$

Even without an explicit solution of (18), the presence of the charged aerosol in the conversion space indicates that $E_1 > E$; hence: $-1 < (\epsilon/2P_1)(E^2 - E_1^2) < 0$ and by looking at

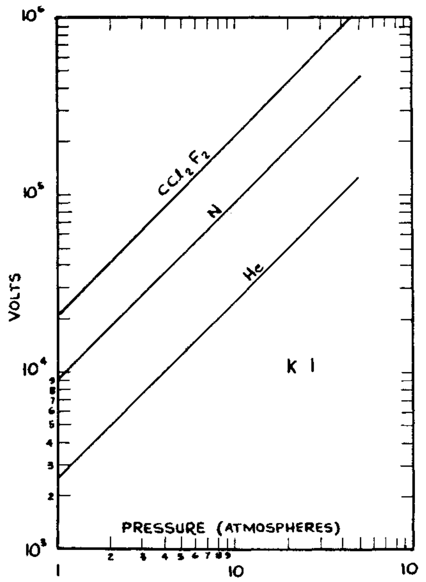

Fig 3 Maximum output voltage vs operating pressure

the forementioned equations, one can see that there is a pressure and temperature drop and that the area must increase for constant velocity energy conversion However, since no friction is assumed, the pressure and temperature drops are the ones contributing to the output electrical energy A similar but much more complicated analysis involving mobility effects[7] can be shown to yield Eqs (14–18) by letting the mobility value approach zero

For air at standard conditions $E^2 - E_1^2$ is of the order of 10^{13} v²/m² It follows that

$$|\theta| = |(\epsilon/2P_1)(E^2 - E_1^2)| \approx 10^{-4} \ll 1 \qquad (19)$$

The maximum value E can have is at the entrance to the conversion space (E_1) and limited by the breakdown value for the given temperature and pressure For most substances, the breakdown field strength above one atmosphere can be taken to be linear with density; hence, for constant temperature, linear with pressure $\theta \ll 1$ would hold up to an operating pressure of 100 atm; and Eqs (14–16) can be approximated by a linear expansion for ξ:

$$(\Delta P/P_1) = -\theta \qquad (20)$$

$$(\Delta T/T_1) = -[(\gamma - 1)\gamma]\theta \qquad (21)$$

$$(\Delta A/A) = \theta/\gamma \qquad (22)$$

where $\theta = (\epsilon/2P_1)(E_1^2 - E^2)$

Another important implication of inequality (19) is that for all practical purposes Eq (18) reduces to the case presented in the previous section for constant charge density The solutions obtained for the potential and the field are then still valid, to a first-order approximation, for the case of constant velocity, and we may therefore compute the thermodynamic change as a function of position

Maximum Output Values

It has been shown that for either constant velocity or constant thermodynamic state it suffices to approximate the charge density as a constant The solution for the potential distribution is then given by Eq (9), the maximum output voltage by Eq (10), and the best conversion space length by Eq (11)

The only limitation to output voltage is electric breakdown; hence, the maximum charge density possible is given by the value which would produce breakdown field intensity E_b at the entrance of the conversion space ($x = 0$)

From Eq (9) one obtains

$$E_b = -(d\varphi/dx)_{x=0} = -\rho_{\max}(A_2 v_2 R/\lambda + \lambda/2\epsilon) \qquad (23)$$

$$\rho_{\max} = -E_b\lambda[A_2 v_2 R + \lambda^2/2\epsilon]^{-1} \qquad (24)$$

Substituting Eqs (11) and (24) into (10), one obtains the maximum output voltage as limited by breakdown This value times the current [Eq (2)] gives the maximum power output, $\dot{W}_{\max}$:

$$\dot{W}_{\max} = (\tfrac{1}{2})\epsilon E_b^2\, v_2 A_2 \qquad (25)$$

As previously mentioned, at constant temperature, the breakdown electric field intensity can be taken to be linear with pressure A most convenient way to express this relationship is to write

$$E_b = K b_s P_A \qquad (26)$$

where b_s is the electric breakdown field intensity at standard conditions for a given gas, and it varies with gas composition; K is a constant for any given set of conditions, its value depends on temperature and the influence of the aerosol and gas velocity on breakdown; and P_A is the ratio of operating pressure to atmospheric pressure

Substituting Eq (26) into (25) one obtains

$$\dot{W}_{m\ x} = (\tfrac{1}{2})\epsilon(K b_s P_A)^2\, vA \qquad (27)$$

The subscript on the vA product can be dropped without ambiguity since ρ is taken to be a constant Equation (27) indicates that the output power varies parabolically with density, or with pressure at constant temperature Since the input pneumatic power to the generator is only linear with pressure, it follows that the efficiency of the generator is proportional to the input pressure

Combining Eqs (9) and (26) one finds that

$$\rho_{\max}\lambda/\epsilon = Kb\, P_A = |E_b| \qquad (28)$$

Combining this relationship with Eqs (9, 10, and 26), the maximum charge density and output voltage can be obtained as functions of v and P_A The results are plotted in Figs 3–7 using $\lambda = 6 \times 10^{-3} m$ and b_s as given in the literature [10]

The gases were chosen so as to cover a wide range of density and breakdown values The velocity effect is displayed by considering three different Mach numbers Note that although the power density for a given gas decreases, the efficiency increases as evidenced by the conversion ratio behavior (constant thermodynamic state operation) The

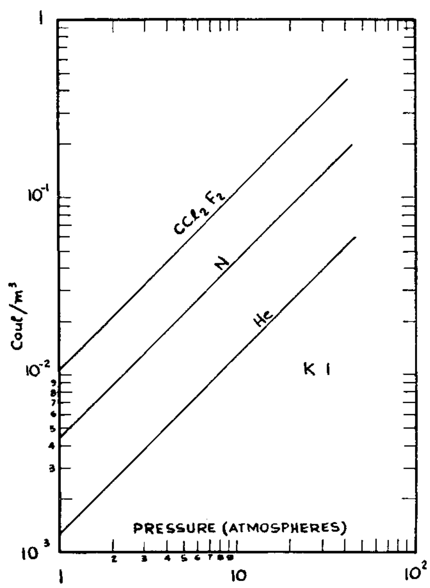

Fig 4 Maximum charge density vs operating pressure

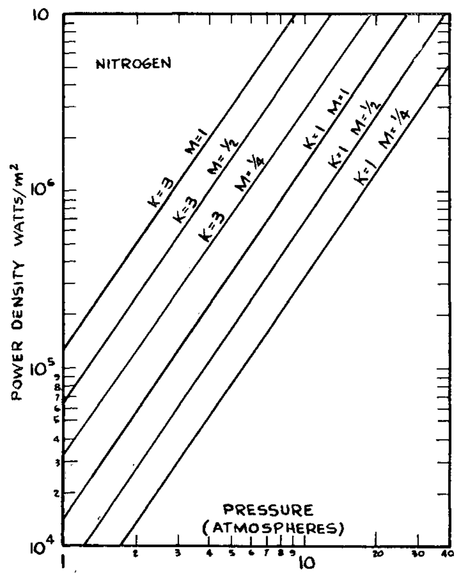

Fig 5 Power density vs operating pressure

value of K is taken to be one in all the curves with the exception of Figs 5 and 6 This assumes that the aerosol has no influence on the electrical breakdown characteristics of the gas

Mobility and Charge Density Limitations

It has been assumed that mobility values for the aerosol droplets are so low that their slip velocity u can be neglected when compared to the gas velocity v This section will justify the low mobility assumption By definition, the mobility of a charged aerosol droplet k is given by

$$k = qu/F = u/E \tag{29}$$

F represents the external force on the droplet and q the charge per droplet Both q and u are functions of the particle size

Three markedly different approaches exist to predict the maximum charge per droplet:

1) Rayleigh's limit[11]: the maximum charge value is obtained by balancing surface tension forces with electrical repulsion

$$q_1 = 8\pi(\gamma\epsilon)^{1/2}r^{3/2} \tag{30}$$

where γ is the surface tension coefficient, newtons/m and r is the particle radius, m

2) Infinite conductivity[12]: the maximum charge obtained by a droplet when placed in a region of infinite monopolar conductivity

$$q_2 = 16\epsilon\mu\ Tr^2/(el) \tag{31}$$

where μ is the Boltzman's constant, joules/°K; T is the absolute temperature, °K; e is the electronic charge, coul; and l is the mean free path, m

3) Infinite conductivity plus external electric field[13]: the maximum charge value allows for an induced dipole moment on the droplet

$$q_3 = 12\pi\epsilon Er^2 \tag{32}$$

Since field charging is possible along with diffusion charging, the values predicted by diffusion alone can be considered as a lower limit On the other hand, the maximum charge a droplet can hold without breaking is given by Rayleigh's limit which is considered an upper limit

Table 1 shows the accepted formulas for the force acting on a particle of radius r, moving through a medium of viscosity ν, with a slip velocity u The values $A = 0\ 87$ and $B = 1\ 1$ come from Millikan's work for free droplets in the atmosphere [14]

For a given particle radius, one can select the appropriate formulas to determine mobility There is little overlapping except when the droplet is the same order of magnitude as the mean free path for the gas molecules Figure 8 shows a plot of particle size vs mobility at standard conditions and for different charging modes according to Eqs (30–32) At higher pressures and for gases denser than air, mobility values will be even lower The curve with a negative slope describes the situation for singly charged droplets Because one electronic charge is the minimum charge per particle, the dotted portion of the curves, which corresponds to less than one electronic charge, represents statistical mean values The criterion for neglecting mobility is chosen so that the ratio of the slip velocity of the droplets to the gas velocity is smaller than or equal to 0 01 If the gas velocity is as low as Mach $\frac{1}{4}$, with air at standard conditions, this criterion predicts a mobility value which is at most 3×10^{-7} m²/v-sec

Comparison to Fig 8 indicates that such a situation is met by particles as large as 1 μ in radius, charged by diffusion plus the effect of an external field Particles charged to the maximum possible value (Rayleigh's limit) have a very high mobility value and cannot be used However, particles with such a high charge density could not be allowed by break-

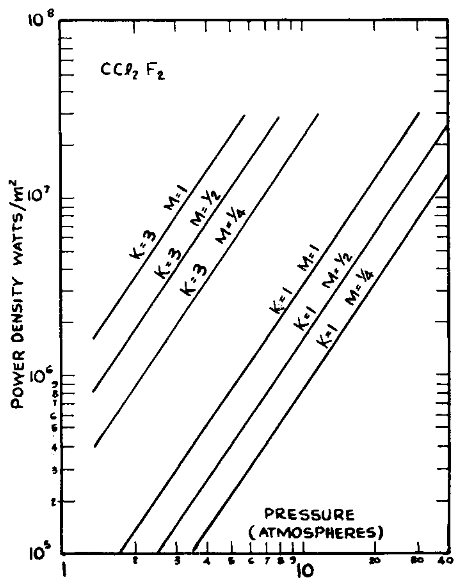

Fig 6 Power density vs operating pressure

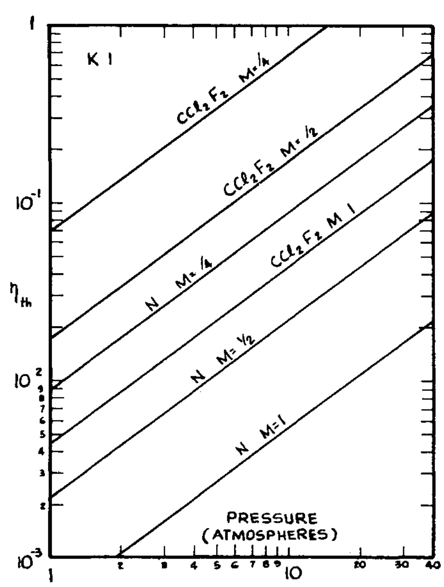

Fig 7 Conversion ratio vs operating pressure (constant thermodynamic state)

Table 1

Physical law	Size range, μ	Equation	Error, %
Stoke	$8 < r < 15$	$F = 6\pi\nu r u$	1
	$0\ 8 < r < 35$		10
Stoke Cunningham	$0\ 1 < r < 8$	$F = 6\pi\nu r u/(1 + Al/r)$	1
	$0\ 05 < r < 8$		10
Solid elastic	$10^{-3} < r < 2 \times 10^{-3}$	$F = 6\pi\nu r^2 u/(Bl)$	1

down limitations One concludes then that for particles as large as 1 μ in radius, and operation at a gas velocity as low as $\frac{1}{4}$ Mach number, the slip velocity effects can be neglected The question arises as to whether particles as large as 1 μ can produce a suitable charge density value Figure 9 shows a plot of particle size vs charge density for a concentration of 10^{17} particles per cubic meter This last value is given as the largest probable for a stable aerosol [15] Our recent work shows a value computed as 2×10^{17} 1/m^3 Particle concentration changes little due to Brownian motion effects ($1\mu > r > 0\ 01\mu$) For a uniform sized aerosol, 1-μ particles yield a charge density value around 0 5 coul/m^3 This compares favorably to the breakdown limited value of $4\ 5 \times 10^{-3}$ coul/m^3, for standard conditions, (Fig 4) Although arguments for neglecting mobility effects are carried through for standard conditions and air, they would hold even better if the pressure and density increase

Experimental Results

Experimentally the aerosol formation and charging proved to be a problem The methods generally used to produce high charge density aerosols gave a wide size distribution and the methods used to produce uniformity of size involved low flow velocities and charging became difficult We developed a method which produced both uniformity of size and high charge density but is limited by high velocity operation An undersaturated mixture of air and water is led to a convergent nozzle at the throat of which a corona discharge is maintained between a fine wire and a ring (Fig 10) The shape of the nozzle is chosen so that supersaturation conditions are reached at the throat where a high ion density is maintained Condensation occurs and a uniform sized charged aerosol is produced Experimentally the production and charging of the aerosol took place in a length equal to the diameter of the nozzle (at its throat), and the operation was optimized by making this region part of the annular electrode for the corona discharge The downstream face of this electrode is considered the entrance of the conversion section When the Mach number at the entrance of the conversion section is higher than about 0 75, the ions are trapped and carried away by the droplets with such a high efficiency that the input electrical power to the unit is negligible compared to the output

The collector was first made as a hollow cylinder whose inside diameter matched the nozzle; a length of 7 5 cm was sufficient to completely discharge the droplets from a 6-mm-throat diameter nozzle Recently the collector has been modified to be a metal rod at the center of the aerosol stream It works more efficiently than the hollow tube, and prevents conduction through the nozzle walls The mechanism taking place will make part of a future paper

Because of the small conversion ratio on the experimental model, one cannot readily distinguish between operation at constant velocity or constant thermodynamic state

The effect of the collector's field on the aerosol droplets is to produce a pressure drop, due to electrical phenomena across the conversion space [5] If slip velocities are negligible, the power represented by the electrical pressure drop must be very close to the output electrical power An experiment was set up to verify this assumption The pressure drop across the nozzle when the electric field was turned on was measured by a manometer connected between the entrance and the exit of the nozzle The ratio of the output electrical power to the flow times the electrical pressure drop is shown in Fig 11 plotted against the nozzle pressure ratio It is seen that it reaches a peak value of 83% This peak value corresponds within experimental error to just choked operation

Equation (11) predicts that as the conversion section length is varied, it should show a peak value Experimentally, the conversion section length could be varied by using a movable collector The predicted value using $R = 3 \times 10^8$ ohms; $M = 1$, and a 5 mm throat area nozzle is $\lambda_{max} = 5\ 96 \times 10^{-3}$m Figure 12 shows a plot of the experimental result, the conversion section length is plotted against the ratio $W/Q(\Delta P)_{t\,t\,l}$ $(\Delta P)_{tot\,l}$ is the total pressure drop across the conversion section including frictional effects

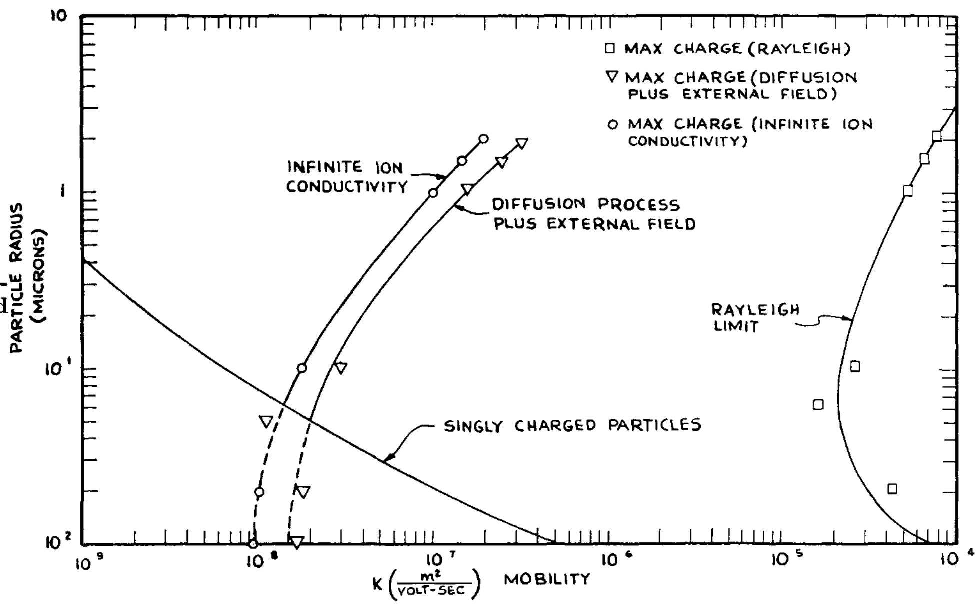

Fig 8 Particle radius vs mobility for singly charged and multiply charged particles

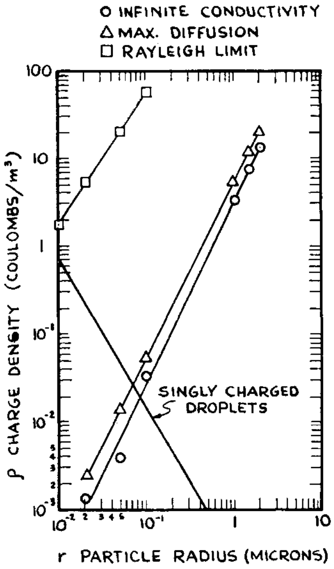

Fig 9 Particle radius vs charged density (particle density 10^{17} 1/m^3)

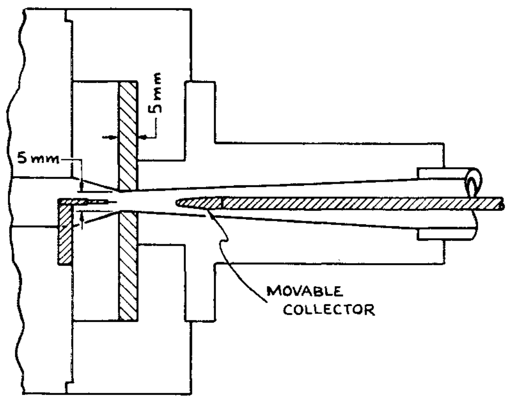

Fig 10 Experimental model

The peak does seem to occur at $\lambda = 6\ 00$ mm hence showing the one-dimensional approach to be adequate

To gain an understanding of the phenomena, simple starting conditions were chosen Hence the experimental work has been conducted exclusively with air-water and air-ethanol aerosols The theory can be checked with charged aerosols formed from these two substances The equations developed predict, at constant temperature, a linear variation of output voltage and current with operating pressure The power output should vary parabolically with pressure Figures 13 and 14 show a plot of experimental results The current and voltage are straight lines just as expected Power output is shown compared to the values predicted by Eq (27) The pressure marked on the graph is input pressure to the nozzle Since the nozzle is choked, the actual operating pressure at the throat is 0 53 times the value indicated The agreement between theory and experiment is remarkable The fact that the output power is slightly higher than the predicted value can be ascribed to K exceeding 1 A test was conducted to verify this possibility by measuring the effect of aerosol velocity on breakdown It was observed that the values are higher as the velocity increases thus confirming our suspicion A preliminary estimate yielded a value of about 1 5

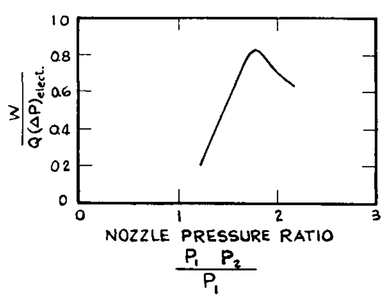

Fig 11 Ratio of electrical power output to electrical power loss across the nozzle vs nozzle pressure ratio

Discussion

Up to now little has been said about the efficiency of the process We have introduced the conversion ratio [Eq (13)] as the output electrical power divided by the kinetic power input This is not a suitable efficiency except in the case of constant thermodynamic state conversion, since it neither accounts for the total energy supplied nor for the friction Our main concern at the moment is the converter's performance and not the cycle efficiency which involves the pump work and heat added Consequently, one defines the generator's efficiency η_G as

$$\eta_G = \frac{\text{generator output}}{\text{generator isentropic work}} = \frac{I\varphi(\lambda)}{W_{isen}}$$

η_G measures the effects of friction, shocks, inefficient diffusion, and particle-molecule interaction losses The isentropic work W_{isen} is evidently given by

$$W_{isen} = c_p\dot{M}(T_1 - T_{2isen}) = c_p\dot{M}T_1[1 - (P_2/P_1)^{\gamma-1/\gamma}] \quad (33)$$

Assuming that $(P_1 - P_2)/P_1$ is small compared to unity, Eq (33) can be expanded by the binomial formula Keeping two terms of the expansion and using the fact that $c_p = \gamma R/(\gamma - 1)$ one obtains

$$W_{isen} = Q(P_1 - P_2) + Q(P_1 - P_2)^2/2P_1\gamma \quad (34)$$

where Q is the volume flow Experimentally, we always found the second term on (34) to be considerably smaller as compared to the first term Hence we are justified to use the incompressible fluid expression,

$$\eta_G = I\varphi(\lambda)/Q(\Delta P)_{total} \quad (35)$$

The pressure difference $(P_1 - P_2)$ in Eq (35) is denoted as $(\Delta P)_{total}$ This is done in order to differentiate between the drop in pressure due to the aerodynamic effects alone, $(\Delta P)_{aero}$, and the additional drop in pressure caused by the electrical process taking place, $(\Delta P)_{elect}$ Obviously,

$$(\Delta P)_{total} = (\Delta P)_{aero} + (\Delta P)_{elect} \quad (36)$$

The efficiency for the electrical process alone can be defined as

$$\eta_e = I\varphi(\lambda)/Q(\Delta P)_{elect} \quad (37)$$

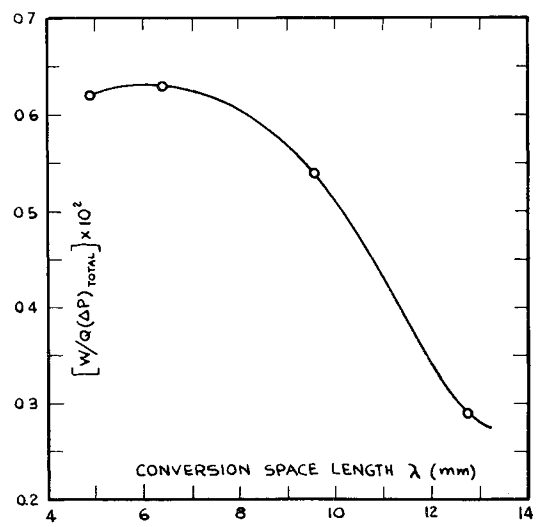

Fig 12 Ratio of electrical power output to total power loss across the nozzle vs conversion space length

As discussed in the experimental section, measurements of η_G and η_e yielded values of 1% and 83%, respectively The 1% value for η_G indicates large frictional and shock losses due to high velocity operation, $[(\Delta P)_{\text{aero}} \gg (\Delta P)_{\text{elect}}]$ However, the 83% value for η_e indicates that the electrodynamic process is very nearly isentropic Mobility effects are truly negligible and the measured value of η compares favorably with corresponding values for either a turbine or a magnetohydrodynamic generator[7] If frictional losses are reduced to a negligible value by low velocity operation $[(\Delta P)_{l\ \ t} \gg (\Delta P)_{\ \ o}]$, then the generator's efficiency η_G will approach values around 80%, or higher if the particle size can be arranged to make the process 100% isentropic

Conclusions

Experimental verification of the fact that slip velocity can be neglected for an electrohydrodynamic generator using charged aerosols has been obtained by the close agreement between predicted and observed values Our present measured generator efficiencies per stage (nozzle) are around 1%; however, since we have only worked with high velocities, the small efficiency is mainly due to high frictional losses We have demonstrated that the isentropic energy conversion process in one experiment is by itself 83% efficient, and that the operation at high velocity is not essential to the generator performance, but is merely due to particle size effects which are not controlled in our present experimental setup Estimated generator efficiency values per stage, if operating at Mach 0 25 for air, are certainly above 60% Since the system is readily staged this would allow for attractive cycle efficiencies in a small number of stages The values of charge density, power density, and output voltage presently obtained are very encouraging particularly because they are accurately predicted: $\rho_{\max} = 0\ 03$ coul/m³; $\dot{W}_{\max}/A = 2\ 5 \times 10^5$ w/m²; $\varphi_{\max} = 5\ 0 \times 10^4$ v

If instead of air we use CCl_2F_2 at an operating pressure level of 40 atm we would obtain ($K = 1$): $\rho_{\max} = 0\ 4$ coul/m³; $\dot{W}_{\max}/A = 3\ 0 \times 10^7$ w/m²; $\varphi_{\max} = 10^6$ v

As predicted we have observed that the only limitation to output voltage is due to electrical breakdown This is governed by the gas used and to a certain extent to the effects of velocity of the gas and of the droplets (K factor) Future work would be directed to the investigation of the effect of the K factor and to the construction of units which would operate with different gases and under different thermodynamic conditions If the experimental verification of the theory is as successful as at present, our generator would be a most attractive unit for a wide variety of uses

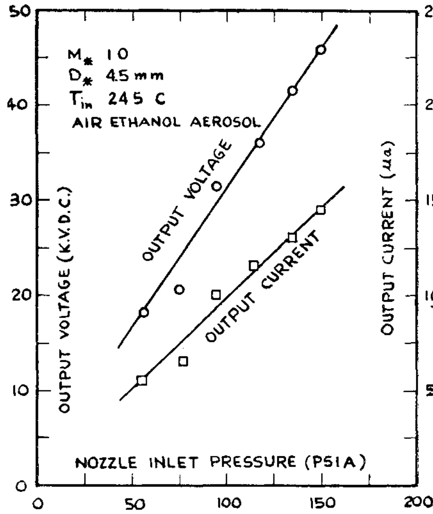

Fig 13 Output voltage and current vs nozzle inlet pressure

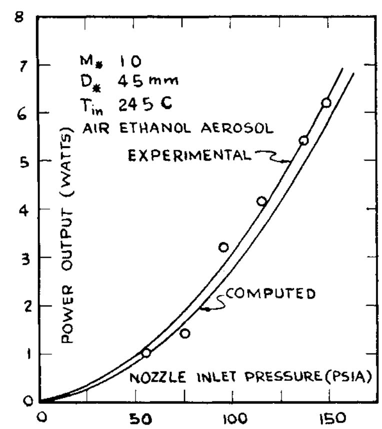

Fig 14 Electrical output vs nozzle inlet pressure

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