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Triboelectric Effects on Polyethylene Methane Drainage Pipelines

By A. A. Campoli, J. Cervik, and R. L. King

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	lb	pound weight
°C	degree Celsius	lbf/in^2	pound force per square inch
deg	angular degree	m	meter
°F	degree Fahrenheit	µm	micrometer
ft	foot	mg/m^3	milligram per cubic meter
ft/min	foot per minute	min	minute
ft^3/d	cubic foot per day	mL	milliliter
ft^3/min	cubic foot per minute	mm	millimeter
g	gram	$MMft^3$	million cubic feet
g/min	gram per minute	$MMft^3/d$	million cubic feet per day
hp	horsepower	m^3	cubic meter
in	inch	m^3/s	cubic meter per second
kg	kilogram	pct	percent
kV	kilovolt	rad	radian
kPa	kilopascal	V	volt
kW	kilowatt		

TRIBOELECTRIC EFFECTS ON POLYETHYLENE METHANE DRAINAGE PIPELINES

By A. A. Campoli,[1] J. Cervik,[2] and R. L. King[3]

ABSTRACT

The Bureau of Mines performed laboratory experiments to evaluate the triboelectric effect of particulate-laden gas streams on polyethylene pipe at various velocity, humidity, dust-size, and dust-load conditions. Charges in excess of 10 kV were produced on the outside and inside surfaces of laboratory pipe samples, when exposed to 40 pct relative humidity (RH) gas stream containing coal dust. However, no charges were produced in laboratory tests that duplicated the over 75 pct RH and dust-free gas streams found in working underground pipelines. Bare copper wire, which is wound around the polyethylene pipe in a 1-ft (31-cm) spacing and grounded, eliminated the charge on the outside surface of the pipe, but not on the inside of the pipe surface.

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INTRODUCTION

The Bureau of Mines estimates that as much as 766 trillion cubic feet ($7.12\times10^{10}m^3$) of coalbed gas, predominantly methane, is contained in the coalbeds of the United States (1).[4] This gas is both a natural resource and a hindrance to mining. Methane drainage systems have been employed in most major coal regions of the United States to remove gas from the coalbed prior to mining and/or capture the coalbed gas for fuel.

Methane drainage systems employ horizontal, vertical, and cross-measure boreholes. Vertical borehole systems (2) consist of holes drilled from the surface into the gas-bearing coal strata. The boreholes are cased with metal pipe, which provides the conduit for the flow of gas from the gas-bearing strata to the surface. Horizontal (3) and cross-measure (4) systems require the drilling of boreholes into the coalbed or associated strata from underground locations. The boreholes are connected to an underground pipeline that carries the gas to the surface.

Methane, which is piped through mine passageways in quantities sufficient to contaminate large areas of the mine, justifies caution and concern in the design, installation, protection, and maintenance of the underground pipeline. Both the Bureau (5) and the Mine Safety and Health Administration (MSHA), U.S. Department of Labor (6), outlined procedures for the safe operation of underground methane drainage pipelines. These reports should be consulted for a general overview of pipeline protection requirements.

The Bureau study (5) provided the basis for the pipeline material selection. Polyethylene pipe best meets the design criterion because of its superior resistance to corrosion and impact forces. It also is attractive to mine operators because it is lightweight, easy to install, and significantly cheaper than metal piping.

In an attempt to negate any hazard produced by the triboelectrification of polyethylene pipe, MSHA recommends that a grounded bare copper wire be spirally wound around all polyethylene piping. The recommendation was incorporated in many of the methane drainage systems now in place across the United States. The objectives of this study were to obtain a better understanding of the triboelectrification process as it relates to the underground polyethylene methane drainage pipeline and to evaluate the recommended grounding safety procedure.

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STATIC ELECTRICITY AND GAS-PIPING SYSTEMS

To the average person the words, "static electricity," mean the shock experienced when touching a doorknob after walking across a carpeted floor, noise in a radio receiver, or the tendency for clothes to cling or stick tightly. Nearly everyone recognizes that these phenomena are more intense when weather is dry. In most situations, static electricity is simply an annoyance.

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[4] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

The term "electricity" is derived from the ancient Greek word "electron" meaning "amber," because it was with this substance that the phenomenon of electrification was first observed. For centuries, the term meant only what is now called static electricity, the property exhibited by some substances after being rubbed with material like silk or wool of being able to attract or repel lightweight objects. Mechanization produced stronger electrification that was first observed about 300 years ago (7), and in comparatively recent times, the properties of "flowing" electricity were discovered; the word "static" then came into use as a means of distinguishing the two forms. The implication that static electricity is always at rest is erroneous, because such electricity causes the most concern when it ceases to rest.

For the sake of simplicity, one may imagine electricity to be a weightless and indestructible fluid that can move freely through some substances, such as metals, that are called conductors, but can flow with difficulty or not at all through or over the surface of a class of substances called nonconductors or insulators. This latter group includes gases, glass, rubber, amber, resin, sulfur, paraffin, most dry petroleum oils, and many plastic materials such as polyethylene pipe. When electricity is present on the surface of a nonconductive body, where it is prevented from escaping, it is called static electricity. Electricity on a conducting body that is in contact only with insulators is also prevented from escaping and is therefore nonmobile or static. In either case, the body on which this electricity is evident is said to be charged (7).

Static charges on polyethylene gas distribution pipelines have long been a concern to natural gas utilities and pipe manufacturers (8-9). Of primary concern is the "bell hole" fire caused by static electricity. A "bell hole" is dug around a damaged section of a buried gas transmission pipe to provide access for repair. Sparks from the pipe can ignite explosive mixtures of the narural gas and air when the worker enters the "bell hole" with a tool to squeeze off the plastic pipe.

In the preceding example, charges were generated by the extremely high velocity gas flow through a rupture. Charges also occur at lower velocities by the addition of a particulate matter (9). Whether generated by rupture leaks or dust-laden gas flows, the static charges are the result of triboelectrification. Gas molecules and particulates vigorously rub the surface of the pipe causing a transfer of electrons to the nonconductive pipe. Conductive pipe used in the same application would not change the charging process; however, it would provide a path for the triboelectricity to ground.

The "wet-rag" technique is accepted as the basic safety procedure for removal of static electricity prior to repair of polyethylene gas pipelines. Wet rags are wrapped around the pipe to increase the surface conductivity. This increase in conductivity caused by the addition of moisture does not eliminate the charge-generation mechanism; it only provides a path to ground for the static elecricity. The technique is quite effective in removing the charge from the outside surface (9). However, its effectiveness in removing charges from the inside surface is adversely effected by pipe wall thickness. Table 1 shows that as wall thickness increases, the wet-rag technique becomes less effective in removing static charges from the inside surface of the pipe (9). Most methane drainage pipelines are 4 in (10 cm) or larger. Although no data are presented on the 4 in

TABLE 1. - Effect of wall thickness on reduction of internal charge using wet-rag technique

Pipe size, in	Wall thickness, in	Internal discharge, pct
1-1/4...........	0.16	64
2...............	.23	51
3...............	.33	27
4...............	.40	NA
6...............	.58	NA
8...............	.76	NA

NA Not available.

(10 cm) or larger pipe sizes, the general trend is a reduction in effectiveness of outside grounding in removing inside surface charges.

The polyethylene pipe employed in coal mine methane drainage is the same as the pipe used by the natural gas industry; however, the gas flow velocities and pipeline environment are different. Coalbed methane drainage systems utilize the natural coalbed pressure to move the gas, and pipeline pressures are generally 5 lbf/in^2 (34 kPa) or less compared with more than 30 lbf/in^2 (207 kPa) in natural gas transmission systems. Consequently, much higher velocities and the possibility of extreme velocities due to pinhole leaks exist in natural gas systems. The particular matter of concern in natural gas systems is rust scale that is carried from metal lines into polyethylene lines. Rust is not a concern in coalbed methane drainage because the pipe is all plastic. However, coal dust from horizontal boreholes or rock particles from cross-measure boreholes are a possibility. Finally, the polyethylene pipe is buried in natural gas systems and is exposed in methane drainage applications. Thus, electrostatic hazards are paramount in repair situations only in natural gas systems, but could be a concern throughout the life of a pipeline used for coalbed methane drainage.

LABORATORY EQUIPMENT

Laboratory apparatus was assembled to simulate a variety of velocity, dust concentration, and humidity conditions in and around polyethylene pipe samples. A 50-hp (37-kW), 740-ft^3/min (0.35-m^3/s) water-ring vacuum pump was used to generate the airstream through the pipe samples. Gas-stream velocities were measured with a pitot tube (fig. 1), and relative humidity and temperature were measured with psychrometers (fig. 2). Pipe samples were connected to the pump with 6-in (15-cm) flexible suction tubing. Particulates were hand-fed into the inlet end of the pipe samples.

Four types of medium-density polyethylene pipe used for gas transission were tested: DuPont type 2, Drisco type 2, Drisco type 3, and Plexco type 3. Type 2 pipe is orange. Type 3 is black owing to the addition of carbon black, which prevents the development of brittleness when the pipe is exposed to ultraviolet light. Thus, care must be taken in the storage of the type 2 pipe because structural degradation may result. Owing to the proprietary nature of the chemical consist of polyethylene pipe, no further information could be obtained regarding the composition of the pipe samples.

The particulates used in the laboratory tests were crushed coal from the Pittsburgh and Coalburg Coalbeds, limestone rock dust, iron filings, and sand. Table 2 shows the proximate and ultimate analysis of the two crushed coal samples.

A rectangular wooden frame, 8 by 8 by 24 ft (2.4 by 2.4 by 7.3 m), was covered with clear plastic to provide for a variable humidity environment (fig. 3).

FIGURE 1. - Pitot tube being used to measure gas-stream velocity.

Steam and air were drawn into the chamber by the partial vacuum generated by the pump. The steam and air intake for the chamber were located at the far corner from the pipe sample intake. The humidity and temperature inside and surrounding the pipe sample were identical during operation (fig. 3).

The rock dust is blown into return airways in coal mines to render loose coal dust incombustible. To determine if rock dusting procedures could impart a static charge to a polyethylene methane drainage pipeline, a 2- by 2- by 8-ft (0.6- by 0.6- by 2.4-m) chamber was constructed to simulate such procedures (fig. 4). The chamber provided for the movement of rock dust over and around the pipeline. Velocity within the chamber was measured with a vane anemometer. A door was located on the top panel of the rock dust chamber (not shown on figure 4) to provide access to the chamber for surface charge measurement. Static charge measurements were made with a high-impedance (5×10^{15}-ohm) voltmeter (fig. 5). The meter is voltage operated.

TABLE 2. - Coal analysis, percent

Analysis	Coalburg	Pittsburgh
Proximate:		
Moisture.........	3.2	2.9
Volatile matter..	27.0	35.7
Fixed carbon.....	39.4	53.7
Ash..............	30.4	7.7
Total.........	100.0	100.0
Ultimate:		
Hydrogen.........	4.0	5.3
Carbon...........	54.5	75.5
Nitrogen.........	.8	1.5
Sulfur...........	.1	1.1
Oxygen...........	10.2	8.9
Ash..............	30.4	7.7
Total.........	100.0	100.0

FIGURE 2. - Relative humidity and temperature being measured with psychrometers.

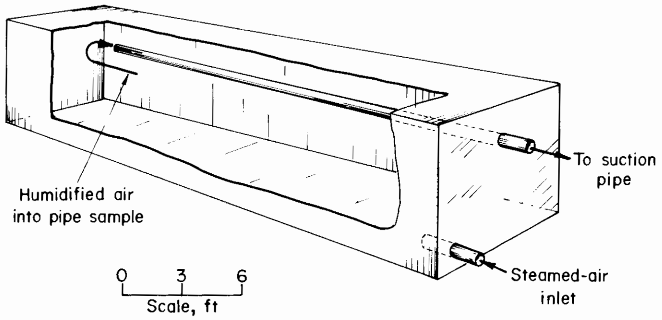

FIGURE 3. - Humidity chamber.

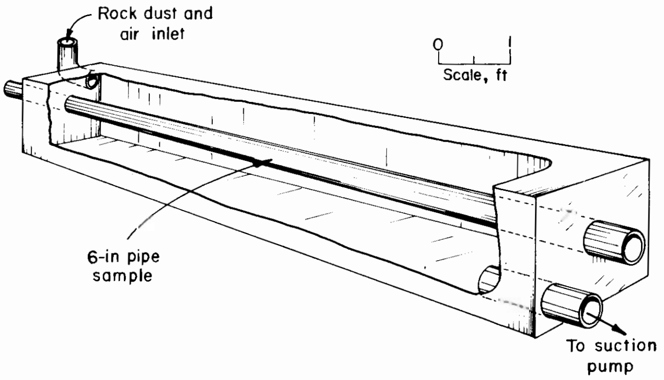

FIGURE 4. - Rock-dust chamber.

ELECTROSTATIC TEST PROCEDURES

Even though the electrostatic voltmeter consumed very little current due to its high impedance, a charge collection device was required to provide sufficient charge to activate the instrument. Initially, tests were performed with a 4-in (10-cm) wide, 1/64-in (0.4-mm) thick aluminum band wrapped around the pipe (fig. 5). Aluminum was selected for its low cost and ease of handling; however, copper or any other highly conductive metal could have been used. During the testing, we found that the bands behaved as charge sinks. They gave erroneously high readings at the point of measurement. Thus, a probe was put in contact with the pipe sample after it was charged (fig. 6). An insulated handle at least 3 ft (0.9 m) long insured that the person taking the reading did not come close enough to the pipe to disturb the electric field. The probe heads were fashioned from aluminum sheeting, 1/64 in (0.4 m) thick, and solid copper wire, 3/16 in (4.8 mm) in diameter. They were shaped to cover one-half of the circumference of the pipe over a 4-in (10-cm) wide band. The heads were then glued into 4-in (10-cm) long sections of 2-in (5-cm) round solid polyvinyl chloride. An insulated wire, recommended by the voltmeter manufacturer, was connected directly from the probe head to the grounded voltmeter.

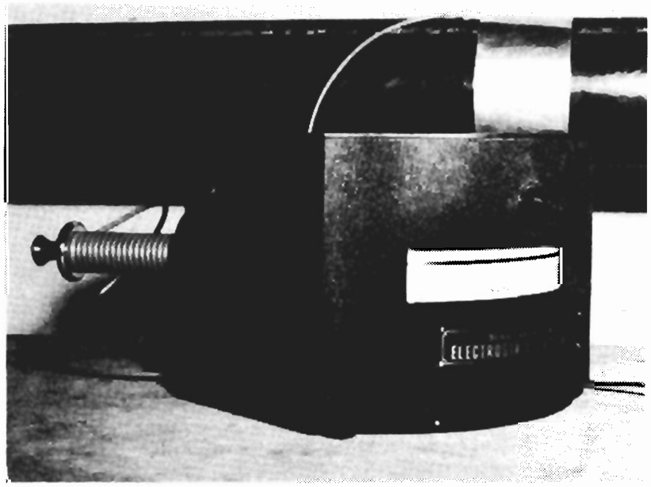

FIGURE 5. - Multirange electrostatic voltmeter.

A similar probe was built for internal charge measurement. The probe was constructed of the same material as the probe described earlier (fig. 6) and contacted a 4-in-wide half cylinder on the inside surface of the 6-in-diameter pipe samples.

The general procedure for the laboratory experiments was initiated by establishing the gas-stream velocity, along with the temperature and relative humidity of the gas stream and of the ambient air. Dust was then hand-fed into the inlet of the pipe sample as consistently as possible over a predetermined time of exposure. Measurement of the static charge was accomplished by placing the probe head on the pipe immediately after the flow was shut off. The probe was removed from the pipe and grounded to eliminate any bias on subsequent measurements. Subsequent measurements were made individually. The total elapsed time between the final measurement and when the fan was shut off was no more than 2 min for all the tests. At the conclusion of each test, the internal and outside surfaces of the pipe sample were "wet ragged," and a charge measurement was made to insure that no charge remained on the pipe prior to the next test.

All tests were repeated three times, and the results were then averaged. Figure 7 shows three separate tests conducted under identical conditions. The static charge generally decreases from the inlet to the exhaust end of the pipe for each test. Variations between test

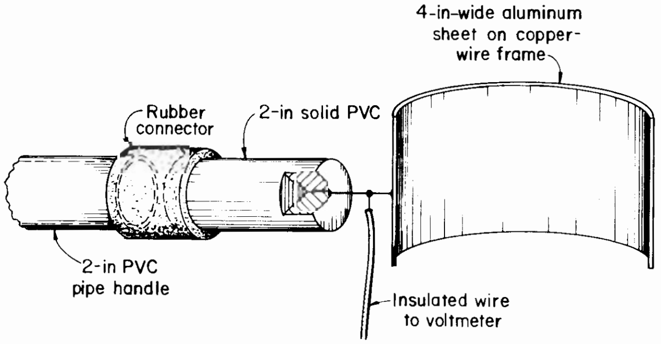

FIGURE 6. - General configuration of probe.

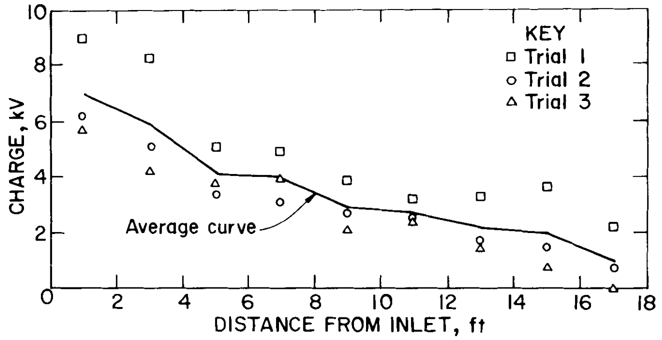

FIGURE 7. - Averaging data for three electrostatic tests. Velocity = 5,000 ft/min, temperature = 65° F, relative humidity = 48 pct, Pittsburgh Coalbed dust, DuPont type 2 pipe, exposure time = 3 min, dust concentration = 5,500 mg/m^3, dust size = minus 200 mesh.

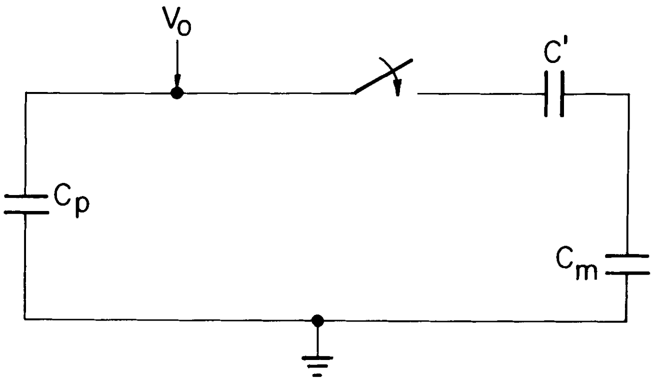

FIGURE 8. - Model of capacitance of measurement system.

runs range to 4 kV; the causes for those variations are not known.

Measuring electrostatic charge on an object is a difficult task due to the effects of the capacitance of the measurement equipment. It is a well-known scientific principle that the electrostatic charge is stored in the electric field of the system's capacitance (C). Therefore, when a measuring device is brought into the vicinity of the object of interest, an effect on the electric field can be detected. This effect is a function of the relative size of the capacitances and the configuration of the electric circuit after the measuring device is connected.

In the case of measuring the electrostatic voltage on a methane drainage pipeline, the following circuit relationships can be derived from the test setup. Assuming that the pipeline is isolated from ground, the actual voltage to which the pipeline is charged is as follows:

$$V_o = Q_o / C_p,$$

where V_o = the actual pipeline voltage,

Q_o = the charge stored in the pipeline's capacitance,

and C_p = the capacitance of the pipeline.

To make an actual measurement, the pipeline is isolated and a quantity of particulate material is driven through the pipeline by a certain velocity airstream. The measuring system is then brought into contact with the inside surface of the pipeline to make a measurement. Figure 8 shows that the measuring circuit contains two capacitors, one for the capacitance of the probe (C') and the other for the capacitance of the meter (C_m). Because the charge will redistribute itself between the three capacitors when the switch is closed (i.e., a measurement taken), the equation relating the reading on the meter (V_m) with the actual voltage (V_o) that was initially on the pipeline is as follows:

$$V_o = V_m \left[1 + \frac{C'C_m}{(C+C_m)C_p} \right].$$

This equation shows that if the capacitance of the object being measured (C_p) is much greater than the capacitance of the measuring circuit (C' and C_m), the meter reading is equivalent to the actual voltage (V_o). Second, if the measuring circuit does have an effect on the actual reading, the error will be such that the recorded reading is less than the actual reading. Therefore, if all of the capacitances were either measured or calculated, a means to correct the readings for the effect of the measuring circuit could be made. However, because the capacitance of the pipeline was large with respect to the measuring circuit and because the purpose of the project was not to ascertain actual voltage numbers but relative ones, the fabricated measuring circuit was deemed suitable for the project.

LABORATORY RESULTS

Clean, dry air equivalent to 1 MMft^3/d (0.33 m^3/s) was put through a 2-in-diam (5-cm) Dupont type 2 pipe sample at a velocity of 33,000 ft/min (168 m/s). This velocity is 22 times the maximum velocity measured in underground methane pipelines. The temperature and relative humidity of the gas stream were 63° F (17° C) and 22 pct, respectively. While the temperature is normal for an underground coal mine, the humidity is very low. No charge was detected over a 3-h operating period. Thus, even at low humidities, gas streams free of particulate matter have no static charge potential.

Six-foot (1.8-m) long sections of 6-in (15-cm) diam Dupont type 2, Drisco type 2, Drisco type 3, and Plexco type 3 were compared for their charge susceptibility. Pittsburgh Coalbed dust, minus 28 mesh (600 µm) (table 3), was fed into a 5,000-ft/min (25-m/s) airstream. Each sample was exposed to a 5,500-mg/m^3 dust concentration for 2 min. The temperature and the relative humidity of the gas stream were 59° F (15° C) and 40 pct, respectively. Figure 9 shows that the type 2 pipe charged to a greater voltage than did the type 3 pipe, which contains carbon black.

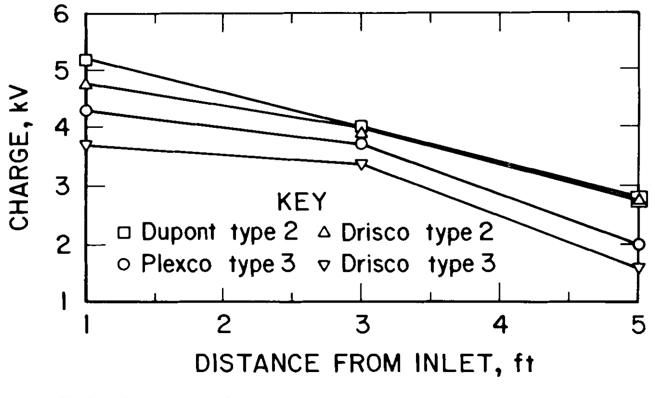

FIGURE 9. - Comparison of pipe data. Velocity = 5,000 ft/min, temperature = 59° F, relative humidity = 40 pct, Pittsburgh Coalbed dust, exposure time = 2 min, dust concentration = 5,500 mg/m^3, dust size = minus 28 mesh.

The effect of gas velocity on static charge generation was determined by feeding 2.6 lb (1,200 g) of dust into a pipe for 3 min. Figure 10 shows that a 5,000 ft/min (25 m/s), a maximum charge of 3.2 kV is generated close to the inlet of the pipe and decreases thereafter. At 2,500 ft/min (13 m/s), the charge builds to a maximum of 2.0 kV about 5 ft (1.5 m) from the inlet, and at 1,000 ft/min (5 m/s) a maximum charge of about 1.6 kV occurs about 11 ft (3.4 m) from the inlet. No measurable charge is detected along the first 11 ft (3.4 m) of the pipe when the gas velocity is 1,000 ft/min (5 m/s). Apparently at 1,000 ft/min (5 m/s) and to a lesser extent at 2,500 ft/min (13 m/s), the dust particles require more time to reach the velocity of the gas stream, and

TABLE 3. - Particle-size distribution of Pittsburgh Coalbed samples, percent

Pratice size, mesh	Minus 3/8 in	Minus 28 mesh	Minus 200 mesh
-3/8 in, +8...	31.0	NAp	NAp
-8, +28.......	39.7	NAp	NAp
-28, +48......	13.4	1.6	NAp
-48, +100.....	7.8	64.6	NAp
-100, +200....	4.3	26.7	NAp
-200..........	3.8	7.1	100.0

NAp Not applicable.

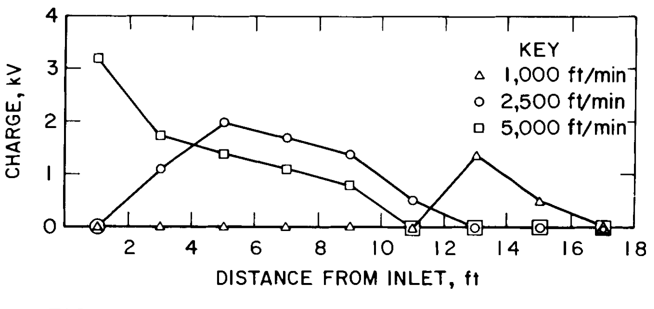

FIGURE 10. - Effect of velocity variation. Temperature = 67° F, relative humidity = 60 pct, Pittsburgh Coalbed dust, DuPont type 2 pipe, exposure time = 3 min, dust load = 400 g/min, dust size = minus 28 mesh.

consequently the charging process occurs further from the inlet.

Figure 11 shows that the magnitude of the static charge on the pipe increases as the exposure time to particles increases. Only about 13 ft (4.0 m) of the 20-ft (6.1-m) length of pipe is charged. Note that the pipe is not charged uniformly along its length. The charge is zero near the inlet, increases to a maximum at about 5 ft (1.5 m), and then decreases to zero. This is consistent with the 2,500-ft/min (13-m/s) velocity test (fig. 10).

Particle size has a marked effect on the magnitude of the static charge generated on polyethylene pipe (table 3). Figure 12 shows that minus 200 mesh (75 µm) dust produces a higher charge than does minus 28-mesh (600 µm) dust. Apparently, the finer dust has a larger surface area from which charges can be stripped. The charging characteristics of the Pittsburgh and Coalburg Coalbeds (table 2) were compared using minus 200-mesh (75 µm) dust. Figure 13 shows that the Coalburg Coalbed dust imparted a greater charge than did the Pittsburgh Coalbed dust over about the first 6 ft (1.8 m) of pipe downstream of the inlet and a lower charge downstream of the 9-ft (2.7-m) measurement point. Apparently, the difference in charging characteristics is due to the higher ash content of the Coalburg dust (table 2). Both tests compared equal weight dust samples.

Plexco type 3 pipe, 4-in (10-cm) diam, was assembled into a 24-ft (7.3-m) long, double 90° (1.57 rad) bend test section (fig. 14). The circled numbers represent the eight static charge measurement points. Pittsburgh Coalbed dust [minus

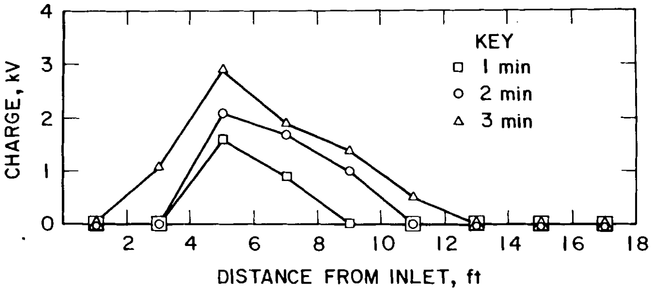

FIGURE 11. - Effect of exposure-time variation. Velocity = 2,500 ft/min, temperature = 60° F, relative humidity = 55 pct, Pittsburgh Coalbed dust, DuPont type 2 pipe, dust concentration = 32,000 mg/m^3, dust size = minus 28 mesh.

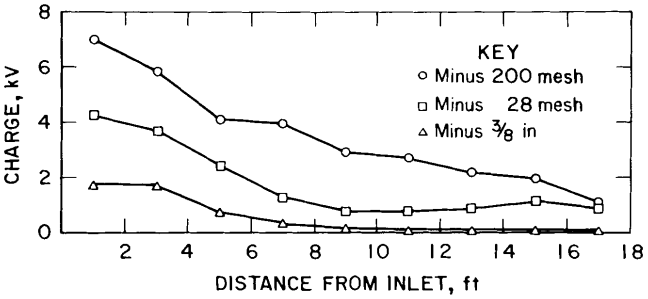

FIGURE 12. - Effect of dust-size variation. Velocity = 5,000 ft/min, temperature = 65° F, relative humidity = 48 pct, Pittsburgh Coalbed dust, DuPont type 2 pipe, exposure time = 3 min, dust concentration = 5,500 mg/m^3.

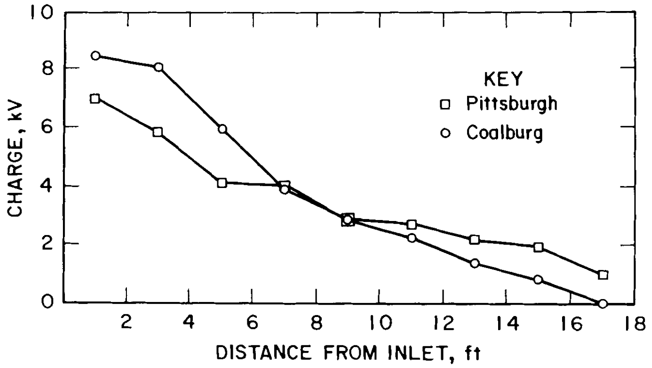

FIGURE 13. - Comparison of Pittsburgh and Coalburg Coalbeds. Velocity = 5,000 ft/min, temperature = 65° F, relative humidity = 48 pct, DuPont type 2 pipe, exposure time = 3 min, dust concentration = 5,500 mg/m^3, dust size = minus 200 mesh.

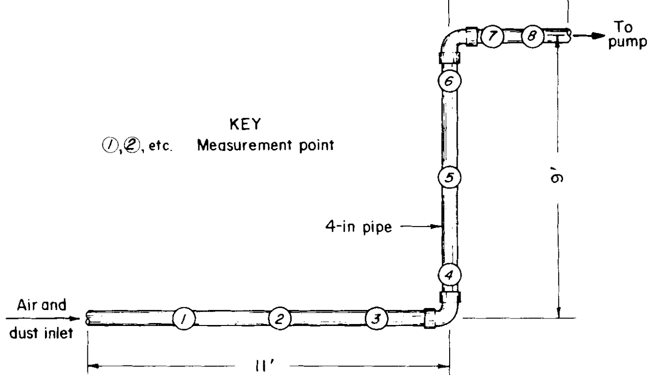

FIGURE 14. - Configuration for elbow test. (Plexo type 3 pipe.)

28 mesh (600 μm)], degreased iron filings [minus 40 mesh (425 μm)], and sand [minus 12 mesh (1.4 mm)] were fed to a 10,000-ft/min (51-m/s) velocity airstream. A 200-mL volume of coal dust, sand, and iron filings or 0.44, 0.60, and 1.12 lb (200, 270, and 510 g), respectively, was added over separate 3 min exposure time tests. Figure 15 shows that for coal dust, the maximum static charge occurred near the inlet (stations 1 and 2) and decreased toward station 3. At the elbows, the charge on the pipe increased (stations 4 and 7). Apparently, the elbows cause coal-particle degradation which exposes new surfaces to the electron exchange process. For the iron and sand particles, no charge occurred on the initial straight portion of the pipe (stations 1, 2, and 3) until the particles impacted the pipe at the first elbow (station 4). The charge was greatest at the elbow, and then decreased along the straight portion of the pipe (stations 5 and 6) until the next elbow was reached where the charge increased again (station 7). The sand and iron particles did not charge the first 10 ft (3.1 m) of the pipeline (stations 1, 2, and 3). These are much heavier than coal particles and may require a longer pipe length to reach the speed of the airstream on a much higher velocity airstream.

Experience shows that when the relative humidity is low inside a building, walking across a carpeted floor can generate static charges of considerable magnitude, but when the relative humidity is high, the static charge annoyance is minimal or eliminated. Similar results have been observed for polyethylene pipe. A 20-ft (6.1-m) length of pipe was placed in a chamber (fig. 2), and steam was injected to control humidity. Figure 16 shows that when the relative humidity of the airstream is increased from 38 to 80 pct, the static charge on the pipe decreased dramatically. Thus, the relative humidity of the airstream is an important factor controlling the static charge on the pipe.

Generally, bare copper wire is spirally wound on polyethylene pipe, and at intervals of about 500 ft (152 m), the copper wire is connected to a buried copper ground rod. Laboratory tests were conducted to evaluate the effectiveness of this grounding procedure on the static charges on the inside and the outside of the pipe. Figure 17 shows that when no ground wire is present, the charge on the inside surface of the pipe ranges from about 10 kV near the inlet to 6 kV about 7 ft (2.1 m) from the inlet. When the copper wire is spirally wound in 1-ft (30-cm) or 2-ft (61-cm) spacing, the static charge on the inside surface is reduced but not eliminated. On the outside surface of the pipe, no charge is measured when the pipe is spirally wound with bare copper wire in a 1-ft (30-cm) spacing. For a 2-ft (61-cm) spacing, a static charge of about 2 kV is measured between the winds of copper wire. Thus,

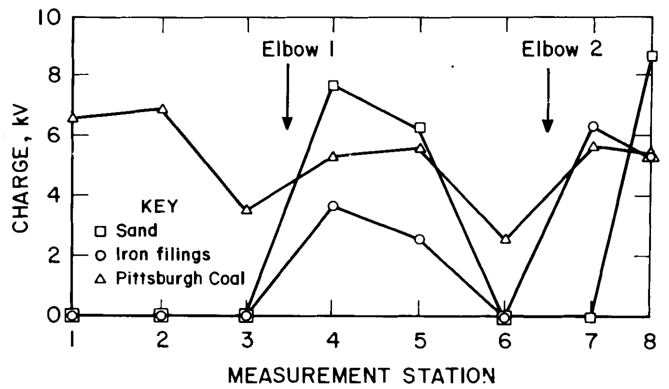

FIGURE 15. - Results of elbow test. Velocity = 10,000 ft/min, temperature = 68° F, relative humidity = 46 pct, exposure time = 2 min, contaminate volume = 200 mL.

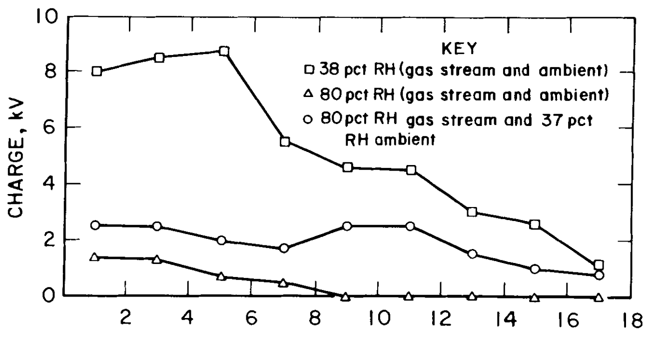

FIGURE 16. - Effect of humidity variations. Velocity = 5,000 ft/min, temperature = 69° F, Coalburg Coalbed dust, DuPont type 2 pipe, exposure time = 2 min, dust concentration = 11,000 mg/m^3, dust size = minus 200 mesh.

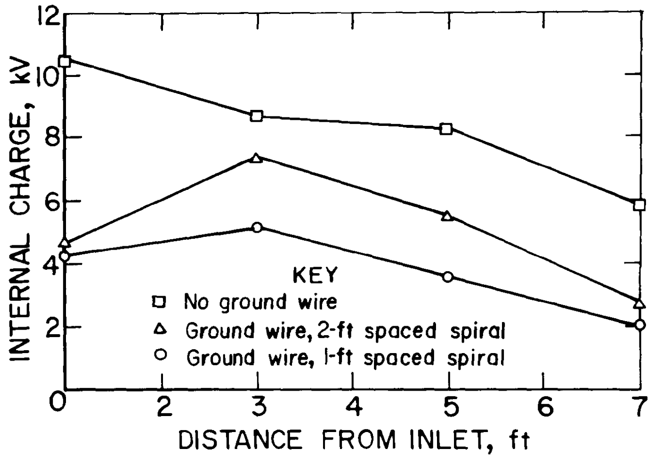

FIGURE 17. - Results of grounding evaluation. Velocity = 5,000 ft/min, temperature = 62° F, relative humidity = 40 pct, Coalburg Coalbed dust, DuPont type 2 pipe, exposure time = 2 min, dust concentration = 11,000 mg/m^3, dust size = minus 200 mesh.

a spirally wound, grounded copper wire is effective in reducing the charge on the outside and inside surfaces of the pipe.

Underground methane pipelines are located in return airways, which are rock dusted periodically using forced air to blow the rock dust into the entry. This procedure was simulated in the laboratory to determine the static-charge effect of the rock dust particles on the pipeline (fig. 4). Air velocity around the pipe in the dust chamber was about 200 ft/min (1 m/s) and over a 5-min period, 25 lb (11 kg) of rock dust was drawn over the pipe (table 4). Rock dust coated the pipe, and no measurable static charge was detected on the outside surface of the pipe. However, a static charge of about 2 kV was measured on the inside surface of the pipe (fig. 18). The relative humidity during the test was about 30 pct, which is low compared with an underground environment and may have contributed to the generation of static charge.

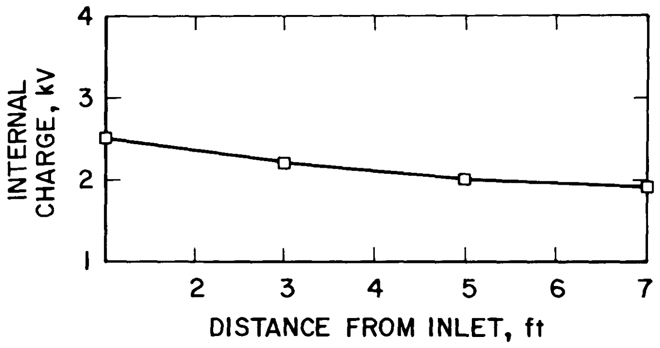

FIGURE 18. - Results of rock-dusting test. Velocity = 210 ft/min, temperature = 57° F, relative humidity = 30 pct, limestone dust, dust weight = 25 lb, DuPont type 2 pipe, feed time = 5 min.

TABLE 4. - Rock dust analysis, percent

CaO..........	91.5	Fe_2O_2........	1.2
S_1O_2.........	4.8	MgO..........	1.1
Al_2O_3........	1.3	S............	.1

FIELD TESTS

Three underground pipelines were dismantled and examined for contamination. Table 5 shows that the volume of methane transported by these pipelines ranged from 100 million to 400 million ft^3 (2.8 million to 11.3 million m^3). No discoloration, scarring, or deposits of dust or dirt were found. One of the pipelines was used in a cross-measure system, which is more prone to produce dust because of strata movement.

TABLE 5. - Dust contamination data for methane drainage pipelines

Site	Drainage system	Pipe material	CH_4 transported, $MMft^3$	Evidence of contamination
Beckley Mining Co.: Beckley Mine	Horizontal...	Polyethylene	200	None
BethEnergy Mines Inc.:				
Cambria 33 Mine...............	Cross-measure	...do.......	100	None
Marianna Mine.................	Horizontal...	Metal.......	400	None

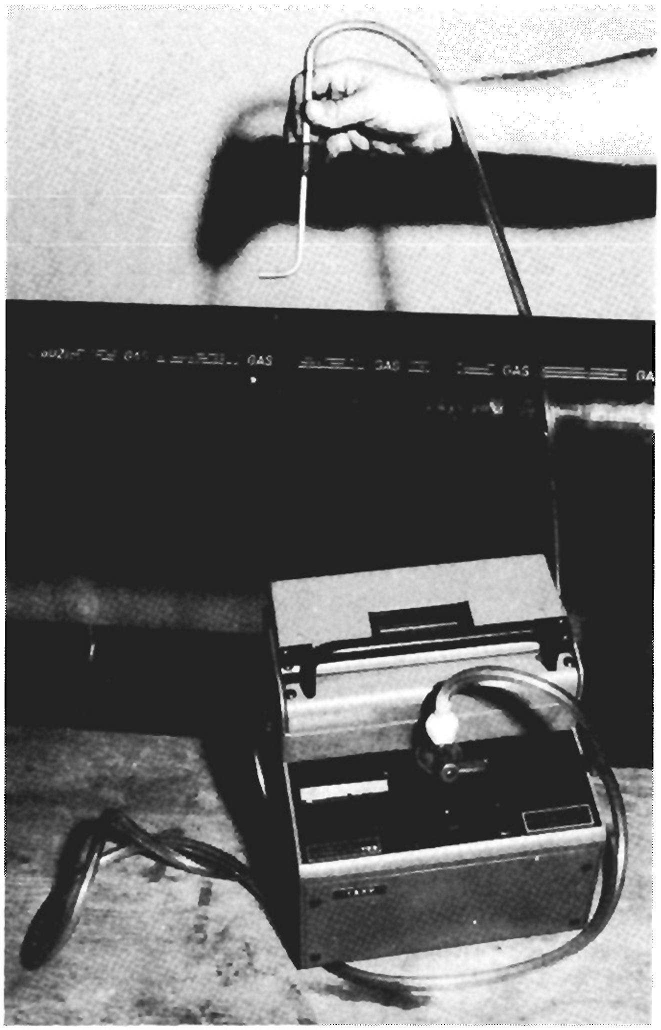

FIGURE 19. - Real-time aerosol monitor.

To further investigate the dust levels in working methane drainage systems, a cross-measure surface borehole and two vertical gob boreholes were inspected. A real-time aerosol monitor (fig. 19) was used to measure the concentration of minus 20-µm dust particles in the methane-air gas flows from the three boreholes. The measured dust levels were comparable to levels in a clean air environment, which produced no static charge on the pipe in the laboratory tests even though the velocity of the gas stream was 33,000 ft/min (168 m/s) and relative humidity was low (22 pct).

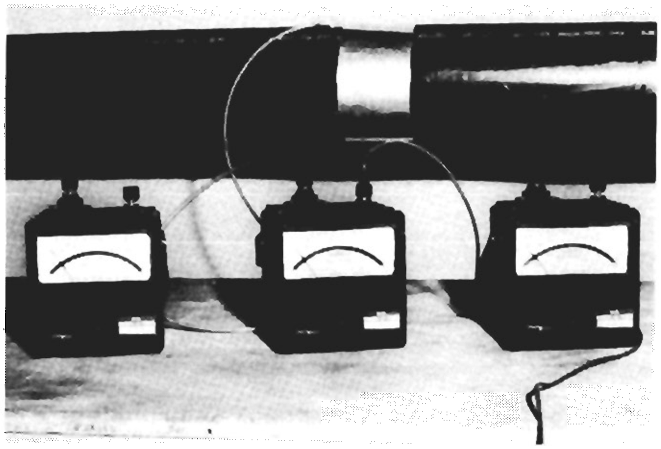

FIGURE 20. - Single-range electrostatic voltmeter.

TABLE 6. - Results of real-time evaluation of methane drainage pipelines

	Jim Walter No. 5 Mine	Beckley Mine
Gas stream:		
Velocity......ft/min..	1,450	1,040
Dust conc......mg/m^3..	0.06	0.05
Relative humidity, pct:		
Gas stream...........	100	78
Entry................	98	83
Methane conc.......pct..	100	97
Temperature.........°F..	77	63
Charge measured......V..	0	0

Static-charge measurements were conducted on two underground methane drainage pipelines (table 6). A 4-in (10-cm) wide band of aluminum was wrapped around each pipeline to collect static charges and a 0- to 300-V electrostatic voltmeter was used to measure the static charge (fig. 20). For both pipelines, the relative humidity of the gas stream and the entry containing the pipeline were 78 pct or greater. Dust concentrations in the gas streams were comparable to a clean air environment. No static charge was detected on the two pipelines.

SUMMARY AND CONCLUSIONS

Velocities up to 33,000 ft/min (168 m/s) in polyethylene pipe produced no static charges when the gas stream was free of particulate matter. When particulate matter is present, the magnitude of static charge is directly proportional to the gas-stream velocity and dust concentration and inversely proportional to size of the dust particles and relative humidity.

Type 2 polyethylene pipe charged to a greater magnitude than did type 3, which contains carbon black and is presumably more conductive than type 2.

Field measurements showed that the relative humidity of the gas transported in underground methane drainage pipelines is 78 pct or greater, and the dust concentration is negligible (0.06 mg/m^3). No static charge was measurable on the underground pipelines under these conditions. In laboratory tests where the relative humidity was 78 pct or greater and dust concentrations were 11,000 mg/m^3, a static charge of only 2 kV was generated. Where relative humidity was 22 pct and particulate concentrations were negligible, no measurable static charge was generated even though gas-stream velocity was as high as 33,000 ft/min (168 m/s). Thus, relative humidity and dust concentration conditions would have to change radically for the development of sizable static charges on underground methane pipelines.

The buildup of static charges on the outside surface of polyethylene pipe can be prevented by wrapping bare copper wire around the pipe in a 1-ft (30-cm) spacing. When a 2-ft (61-cm) spiral wrapping is used, static charges exist between the wraps. However, the static charge on the inside pipe surface is reduced but not eliminated for both the 1-ft (30-cm) and 2-ft (61-cm) spacings.

The low-velocity flow [200 ft/min (1 m/s)] of rock dust around polyethylene pipe generated a static charge of about 2 kV on the inside surface and no measurable charge on the outside surface, which was coated with rock dust. The relative humidity during the test was 30 pct compared with field measurement at 78 pct or greater, which would lower the static charge on the inside surface considerably.

Field measurements show that the relative humidities in the mine entry and the gas stream are high (78 pct or greater), and the level of particulate matter in the gas stream is comparable to that of a clean air environment. These conditions are not conducive to the development of static charges on underground polyethylene pipelines.

Because of the possibility of static-charge buildup on underground pipelines, the wet-rag technique should be employed to remove static charges from the outside pipe surface and to reduce the static charge on the inside surface before a polyethylene pipeline is repaired or dismantled.

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