Some electrostatic factors may cause gas explosion in coal mines

T T Wang, S M Liu, J C Zhang*, X Chen, Y G Zhang, M Zhang, Y Zhang, X X Ding, H Liu
Zhongyuan University of Technology, Zhengzhou, PR China, 450007
E-mail: zjc@zzti.edu.cn

Abstract. The human body capacitances vary greatly when miners leave a narrow tunnel. The human body electrostatic discharge energy is increased at the outlet of narrow tunnels. Thereby the possibility of detonating gas is greatly increased. Human body electrostatic half-life changes according to the dress of miner. Intense movements of human body will increase the static electricity produced in unit time. This can also increase the human body static electricity and cause gas explosion.

1. Introduction
Coal mine gas explosion is a serious threat to people's lives and property safety. Human body static is an important cause of coal mine gas explosion. The generation and discharge of human body static electricity is influenced by a number of factors. When there is too much human body static electricity, the discharge energy could cause gas explosion, resulting in significant harm.

2. Human body capacitance in narrow trench of coal mine
The human body capacitances of miners in uniform at different places of the narrow trench are tested with “the simulating device of mining narrow trench” (only parts of the data are listed in table 1).

Table 1. Human body capacitance at different positions of narrow trench a.

| No. | sex  | height (cm) | weight (kg) | capacitance (pF) | surface resistivity of antistatic boots (Ω) |
|-----|------|-------------|-------------|-----------------|------------------------------------------|
|     |      |             |             | outlet of the trench | inner | middle | back | left | right |
| 1   | male | 165         | 63          | 135             | 2720  | 2850   | 2730 | 2650 | 2690   | 2×10¹⁰ |
| 2   | male | 173         | 72          | 150             | 2400  | 2810   | 2800 | 2500 | 2610   | 2×10¹⁰ |
| 3   | male | 181         | 73          | 155             | 2710  | 3020   | 3000 | 2700 | 2700   | 2×10¹⁰ |
| 4   | male | 177         | 72          | 160             | 1700  | 1550   | 1520 | 1620 | 1300   | 2×10¹⁰ |

* Temperature: 19°C; Relative humidity: 45%

* To whom any correspondence should be addressed.
Results in table 1 show that the body capacitances of the miners at the outlet are less than one tenth of the inner.

“The simulating system of the human body electrostatic discharge detonating gas” consists of mixed gas chamber, the ignition device of human body ESD simulator, the control unit, gas measurement unit, oxygen measurement unit, temperature measurement unit, alarm screen, PC and gas supply devices. The schematic diagram is shown in figure 1. The gas concentration is measured with the system. The measured error of gas concentration is less than 0.1%.

With “the simulating system of the human body electrostatic discharge detonating gas”, discharge experiments are made, and the human body capacitances range from 100 pF to 2700 pF (the human body resistance is chosen as 350 Ω).

In experiments, the gas of concentration from 5% to 16% is filled into the chamber. The gas mixture is detonated by “the simulating system of the human body electrostatic discharge detonating gas”. The gas concentration, oxygen concentration and mixture temperature in time of the gas explosion are shown. In this way different human body ESD energy detonating gas and the easiest detonated gas concentration in different conditions of temperature and oxygen concentration can be verified. Human body leakage resistance, relative humidity, the discharge gap of the human body ESD model and the gas concentration are shown in table 2.

3. The human body discharge voltage detonating gas
Electrostatic discharge detonating gas must meet three conditions:
- Electrostatic discharge energy must be greater than the gas mixture’s minimum ignition energy 0.28 mJ.
- Field strength of the discharge voltage must be greater than 22 kV/cm, which is the breakdown field strength of the gas mixture.
- Gas concentrations must be in the explosive concentration limits of 5% -16%.

That is to say, discharge voltage ensures that the human body discharge energy should be greater than 0.28 mJ, and the discharge field strength should be greater than 22 kV/cm. To detonate gas mixture, the human body voltage not only must be greater than \((2W/C)^{\frac{1}{2}}\) but also must be greater than
\( E_0d \). \( W \) is the minimum ignition energy. \( C \) is the human body capacitance. \( E_0 \) is the breakdown field strength of gas mixture, and \( d \) is the discharge gap.

| No | Gas Concentration (%) | Oxygen Concentration (%) | Capacitance (pF) | Discharge gap (mm) | Leakage resistance (Ω) | Temperature (°C) | Relative humidity (%) |
|----|-----------------------|--------------------------|------------------|-------------------|----------------------|------------------|----------------------|
| 1  | 8.5                   | 20.9                     | 2700             | 0.2               | 350                  | 22               | 45%                  |
| 2  | 8.8                   | 20.2                     | 1800             | 0.3               | 350                  | 22               | 45%                  |
| 3  | 8.5                   | 20                       | 900              | 0.6               | 350                  | 22               | 45%                  |
| 4  | 8.5                   | 20                       | 500              | 0.6               | 350                  | 22               | 45%                  |
| 5  | 8.3                   | 20                       | 300              | 0.9               | 350                  | 22               | 45%                  |
| 6  | 8.5                   | 20                       | 280              | 1.2               | 350                  | 22               | 45%                  |
| 7  | 8.7                   | 20                       | 100              | 1.2               | 350                  | 22               | 45%                  |

4. The relationship between the human body discharge voltage and resistance

Take a Gaussian surface in the miner’s dress; the current and current density vector \( \vec{\delta} \) through the closed surface of the dress and the charge \( Q \) satisfy the following relationship.

\[
I = \int_s \vec{\delta} \cdot d\vec{S} = -\frac{dQ}{dt} \tag{1}
\]

Where

\[
\vec{\delta} = \vec{E} / \rho
\]

\[
\int_s \vec{E} \cdot d\vec{S} = \frac{Q}{\varepsilon_0 \varepsilon_r} \tag{2}
\]

\[
\int_s \rho \vec{\delta} \cdot d\vec{S} = -\rho \frac{dQ}{dt} \tag{3}
\]

\[
-\rho \frac{dQ}{dt} = \frac{Q}{\varepsilon_0 \varepsilon_r} \tag{4}
\]

\[
\frac{dQ}{Q} = -\frac{dt}{\varepsilon_0 \varepsilon_r \rho} \tag{5}
\]

The solution of the equation is

\[
Q = Q_0 e^{-\frac{t}{\varepsilon_0 \varepsilon_r \rho}} \tag{6}
\]

When the human body electrostatic voltage attenuates to half of the original, the required time is:

\[
\tau_{\frac{1}{2}} = 0.69 \varepsilon_0 \varepsilon_r \rho \tag{7}
\]

\( \tau_{\frac{1}{2}} \) is known as the electrostatic half-life.

If the charge is \( Q \) at a moment, from the charge attenuation formula (6), the decrease of electricity from \( t \) to \( t + dt \) is:

\[
-dQ' = \frac{1}{\varepsilon_0 \varepsilon_r \rho} Q dt \tag{8}
\]
If the electricity generated in unit time is \( P \), then the total electricity increased from \( t \) to \( t + dt \) is:

\[
\frac{dQ}{dt} = P - \frac{1}{\varepsilon_0 \varepsilon_r \rho} Q dt
\]  (9)

Based on \( Q = CU \), if the surroundings around miners doesn’t change, \( C \) is constant, therefore

\[
Q = \varepsilon_0 \varepsilon_r \rho P \left(1 - e^{-\frac{t}{\varepsilon_0 \varepsilon_r \rho}}\right)
\]  (11)

Therefore, electrostatic charge has a maximum value, and the maximum value is proportional to the electrostatic half-life and the electricity generation rate. The larger the electrostatic half-life is, the more the maximal static electricity on human body is. The larger the electricity generation rate is, the more the maximal static electricity on human body is.

In this paper, the human body capacitances in different places of narrow mine tunnel is discussed. The human body capacitance at the outlet of narrow tunnel is less than one tenth of that in the middle of the tunnel. So it is dangerous for miners to move out of a narrow tunnel. The human body electrostatic discharge voltage detonating gas and the relationship between the human body discharge voltage and resistivity of miners’ dress are also discussed. From the discussion it can be seen that the miners’ dress and intense movements of miners influence the maximal static electricity on human body. So miners’ dress should be selected strictly and intense movements of miners in coal mine should be forbidden.

Acknowledgments
This work is supported by the National Nature Science Foundation of China (NSFC) under contract No. 50977093 and 51077134.

References
[1] Mannan M S 1999 Chem. Process Saf. (AIChE, Chemical Process Safety). p 105
[2] Liu S and Wei G 1990 Static Theor. and Prot. (Beijing, Weapons Industry Press)
[3] Nabours R.E. 2003 Ind.I and Commer. Power Syst. (St. Louis, IEEE Technical Conference) p 66