CHEMICAL ENGINEERING TRANSACTIONS

VOL. 48, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Eddy de Rademaeker, Peter Schmelzer

ISBN 978-88-95608-39-6; **ISSN** 2283-9216

DOI: 10.3303/CET1648058

Determination of Material Resistivity of Fully Assembled Spiral Coiled Tubes by Measurements and Model Calculations

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In spiral coiled tubes electrostatic discharges – so called propagating brush discharges – have been observed during the pneumatic transfer of powders. Such discharges are rather energetic and may ignite most combustible powders. If the material in which the earthed metallic spiral coil is embedded is highly insulating, the charges resulting from friction between the powder particles and the inner tube wall cannot be quickly released to earth. As a consequence a high potential may be built-up on the inner wall giving rise to propagating brush discharges. Based on recent measurements of the charging current density and model calculations a safe upper limit of the resistivity of the material, in which the earthed coiled spiral is embedded, has been determined, below which no longer any propagating brush discharges will occur. The resistivity of a material can easily be determined from a sample in form of a cuboid or cylinder. This is however nearly impossible if the resistivity should be determined from a fully assembled spiral coiled tube without dismantling and destroying the whole tube. This paper gives guidance how this can be done by simple measurements and by interpreting the results with computer model calculations.

1. Introduction

It is well known that pneumatic transfer of powders or granules through pipes, tubes or hoses is one of the processes giving rise to the highest build-up of static electricity in process industry. As soon as either the product or the equipment is insulating, charge build-up is intrinsically related to the process and can hardly be avoided. In fixed installations usually metal pipes are used, which are reliably connected to earth. If highly insulating products are transferred through such pipes, the charge build-up on the pipes is immediately released to earth and no electrostatic ignition hazard related to any charge build-up on the pipes exists. The charged product is transferred into a receiving silo or container, where it may generate very high electrical fields and provoke brush and cone discharges, which have to be assessed separately.
If however, for reasons of handling and manipulating the transfer line must be flexible, often tubes or hoses mainly made from plastics are used. Many different constructions are presently on the market, where the insulating material is reinforced with an embedded metal coiled spiral. As mentioned in a recent publication by Fath et al. (2013) such tubes or hoses may give rise to propagating brush discharges, if the resistivity of the material embedding the metal coiled spiral is not sufficiently conductive as shown in Figure 1. The requirements which have to be met by the material of the tubes or hoses have been experimentally determined in the past and published at the last Conference on Loss Prevention and Safety Promotion by Glor et al. (2013a) and Glor (2013b). In the meantime these requirements have been incorporated into the planned new 2016 edition of the German Guidelines on the Avoidance of Ignition Hazards Due to Static Electricity Edition 2009, TRBS 2153 (2009).
Since the most important requirement is given in terms of a limit value for the resistivity of the material into which the metal coiled spiral is embedded, the question comes up, how can the resistivity of a fully assembled spiral coiled tube be reliably determined in industrial practice without dismantling and destroying the hose? In the following a simple method to perform resistance measurements on a fully assembled hose is given.

Please cite this article as: Glor M., 2016, Determination of material resistivity of fully assembled spiral coiled tubes by measurements and model calculations, Chemical Engineering Transactions, 48, 343-348 DOI:10.3303/CET1648058

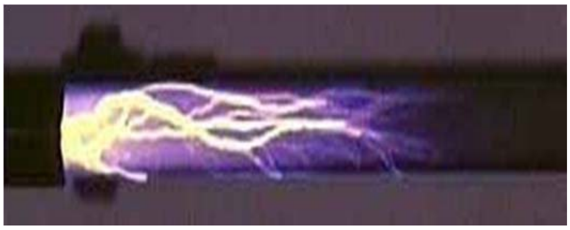


Figure 1: Propagating brush discharge and traces of propagating brush discharges in a transparent plastics pipe.

Depending on the construction type of the hose the material resistivity is calculated with simple equations or can be derived from computer simulations as shown in the following sections.

2. Experimental set-up for resistance measurement

In all cases a conductive filling compound like e.g. conductive foamed plastics must be introduced into the tube or hose over a length L. This filling compound must make good electrical contact with the inner wall of the hose and represents the first measuring electrode. In case of a tube with a homogeneous wall without a metal coiled spiral the second measuring electrode is an electrically conductive foil wrapped around the outer surface of the tube or hose over the length L opposite to the inner electrode and also making good electrical contact with the outer wall. In case of a hose with a metal coiled spiral this metal spiral represents the second electrode. It must be made sure that neither the conductive filling compound nor the conductive foil on the outside or the metal spiral makes electrical contact with the flanges of the hose. Then the total resistance R_{tot} between the two electrodes is measured with a Megohmmeter. Depending on this resistance a voltage of several 100 V should be applied

3. Results obtained with different models

3.1 Sliced tube with homogeneous wall material - cubical geometry

In case of a piece of sliced tube (outer radius r_o, inner radius r_i, length L and total resistance R_{tot} between the metal plates) put between two metal plates (electrodes) the resistivity ρ is calculated by Eq(1). Such an arrangement is shown in Figure 2.

$$\rho = R_{tot} L \frac{\pi(r_o + r_i)}{(r_o - r_i)} \qquad (1)$$

Figure 2: Sliced tube with homogeneous wall material and cubical geometry

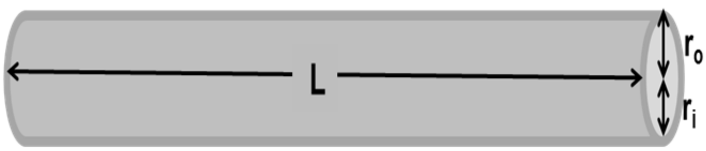
Example: With L=200 mm, r_o=80 mm, r_i=74 mm and R_{tot}=6.2 MΩ the resistivity ρ equals 10^8 Ωm.

3.2 Full tube with homogeneous wall material – cylindrical geometry

In case of a tube (outer radius r_o, inner radius r_i, length L and total resistance R_{tot} between outer and inner conductive surface) the resistivity ρ is calculated by Eq(2). Such an arrangement is shown in Figure 3.

$$\rho = R_{tot} \frac{2\pi L}{\ln(\frac{r_o}{r_i})} \qquad (2)$$

Figure 3: Full tube with homogeneous wall material and cylindrical geometry



Example: With L=200 mm, r_o=80 mm, r_i=74 mm and R_{tot}=6.2 MΩ the resistivity ρ equals $9.99 \cdot 10^7$ Ωm.

3.3 Cubical plate of homogeneous wall material with metal bars – simulation of sliced spiral coiled tube

In this case a simulation of a sliced spiral coiled tube or hose is made. The model is made by a cubically shaped plate of homogeneous material of resistivity ρ. One surface is connected with a conductive electrode simulating the conductive filling compound introduced into the tube or hose. On the opposite surface conductive stripes are deposited perpendicularly to the tube or hose axis simulating the metallic spiral within the tube or hose. Such an arrangement is shown in Figure 4.

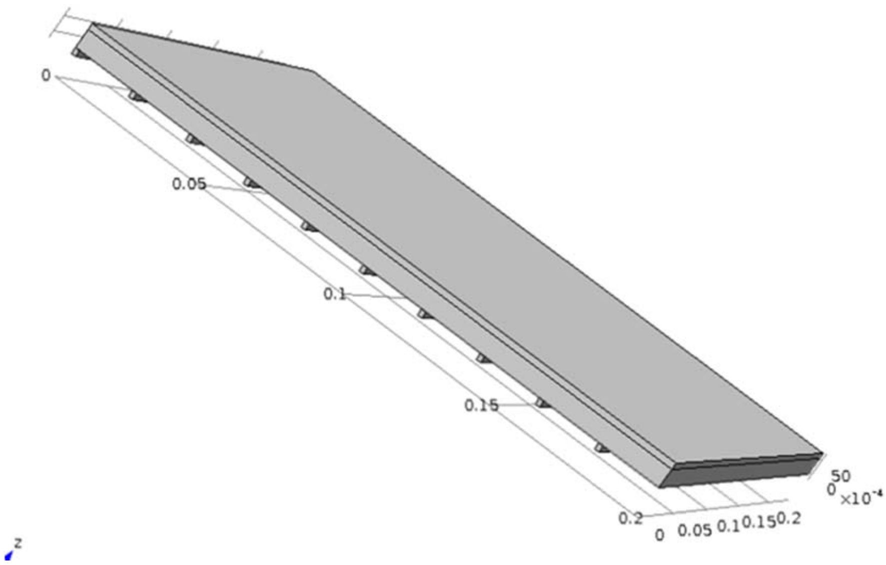


Figure 4: Simulation of a sliced spiral coiled tube or hose as described in the full text.

In the computer simulations the following assumptions have been made:

- L 200.0 mm Length of the conductive filling compound
- r_i 37.5 mm Interior radius
- d 6.0 mm Thickness of the tube or hose wall
- a 20.0 mm Distance between the conductive stripes (centre to centre)
- b variable Broadness of the conductive stripes
- ρ 10^6 Ωm Resistivity of the wall material
- A 0.05089 m^2 Resulting contact surface of conductive filling compound
- U_i 1000 V Potential of conductive filling compound
- U_o 0 V Potential of all conductive stripes

Based on these assumptions the computer simulations have been made with a 64 bit HP EliteBook 8460p Laptop with the software COMSOL Multiphysics® Version v4.3. The conductive electrode simulating the conductive filling compound introduced into the tube or hose was set to an elevated potential U. The potential of all conductive stripes deposited perpendicularly to the tube or hose axis on the opposite surface simulating the metallic spiral within the tube or hose was set to 0 V. The distribution of the current density on the conductive electrode was calculated and integrated over the total surface resulting in a total current I. The calculation of the total resistance R_{tot} was made by the simple formula $R_{tot} = U/I$.

In case the broadness of the conductive stripes is 20 mm the electrode arrangement corresponds to the arrangement described in section 3.1. If the broadness of the stripes is reduced and the resistivity of the wall material remains constant the total resistance R_{tot} increases. This is the result from the model calculations and is as well physically comprehensible. Figure 5 shows the relationship between the broadness of the stripes and the total resistance R_{tot}.

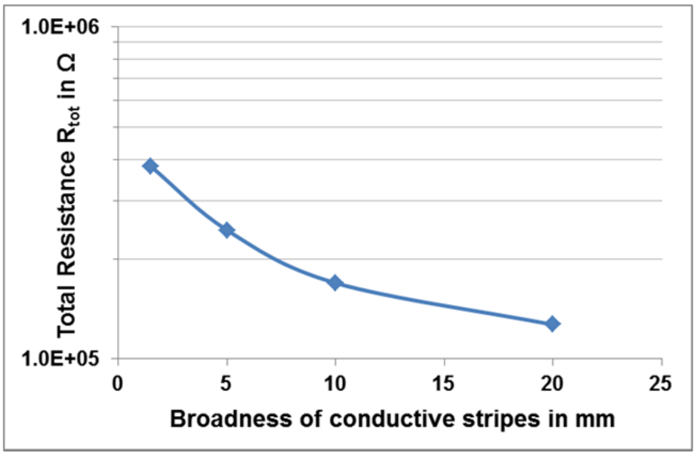


Figure 5: Relationship between the broadness of the stripes and the total resistance R_{tot} in case of a cubical plate of homogeneous wall material with metal bars (see Figure 4 for geometrical arrangement)

3.4 Fully assembled spiral coiled tube or hose - computer simulation

In this case a simulation of a fully assembled spiral coiled tube or hose is made as shown in Figure 6.

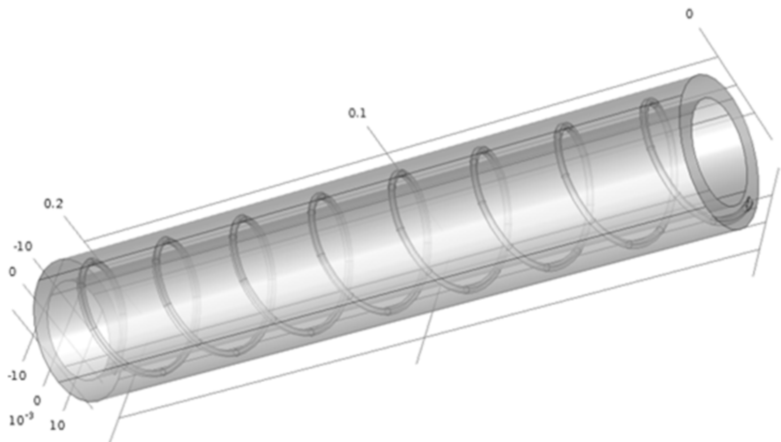


Figure 6: Simulation of a sliced spiral coiled tube or hose as described in the full text.

The significant parameters in this model are:

- L Length of the conductive filling compound
- RE External radius of the tube or hose
- TH Thickness of the tube or hose wall
- DT Distance between two turns of the spiral
- DWS Distance between inner surface of the tube or hose and surface of the spiral wire
- RS Radius of the spiral wire
- RSIS Resistivity of the wall material

With different parameter sets computer simulations have been made with a 64 bit HP EliteBook 8460p Laptop with the software COMSOL Multiphysics® Version v4.3. The conductive electrode simulating the conductive filling compound introduced into the tube or hose was set to a potential of 1000 V. The potential of the metallic spiral within the tube or hose was set to 0 V. The distribution of the current density on the conductive electrode was calculated and integrated over the total surface resulting in a total current I. The calculation of the total resistance R_{tot} was made by the simple formula $R_{tot} = U/I$.

Figures 7 to 11 show the influence on the total resistance R_{tot} when one of the following parameters is varied:

- Length of the conductive filling compound
- External radius of the tube or hose
- Distance between two turns of the spiral
- Distance between inner surface of the tube or hose and surface of the spiral wire
- Radius of the spiral wire

The total resistance R_{tot} is always directly proportional to the resistivity ρ of the wall material independent on all other parameters.

Figure 7: Total Resistance R_{tot} as a function of the length of conductive filling compound.

Parameters

L	*variable*
RE	*50 mm*
TH	*6 mm*
DT	*26 mm*
DWS	*2 mm*
RS	*1 mm*
RSIS	*10^6 Ωm*

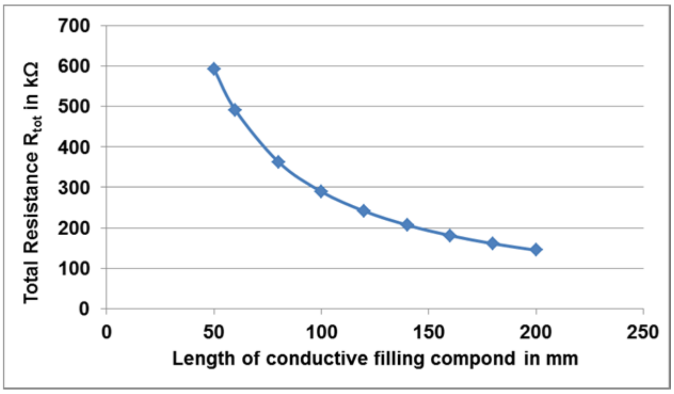


Figure 8: Total Resistance R_{tot} as a function of the radius of tube or hose.

Parameters

L	*100 mm*
RE	*variable*
TH	*6 mm*
DT	*26 mm*
DWS	*2 mm*
RS	*1 mm*
RSIS	*10^6 Ωm*

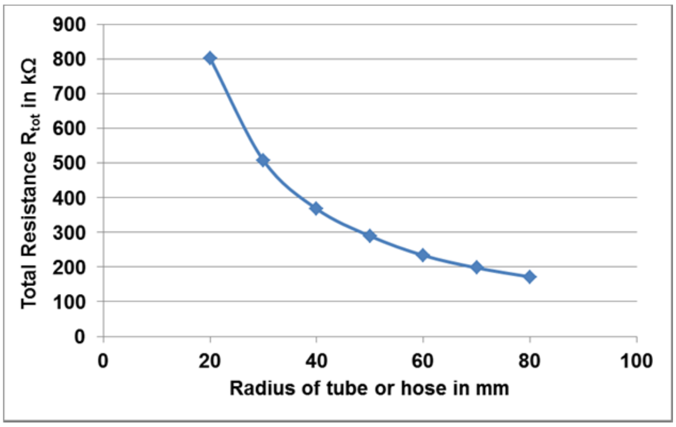


Figure 9: Total Resistance R_{tot} as a function of the height of one turn of the spiral.

Parameters

L	*100 mm*
RE	*40 mm*
TH	*6 mm*
DT	*variable*
DWS	*2 mm*
RS	*1 mm*
RSIS	*10^6 Ωm*

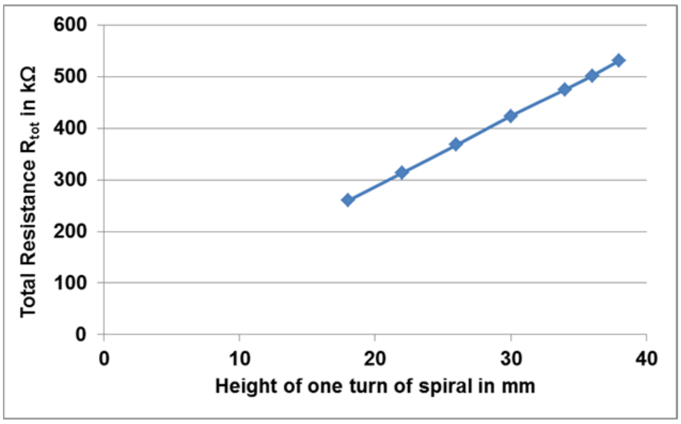


Figure 10: Total Resistance R_{tot} as a function of the distance of spiral to inner tube or hose surface.

Parameters

L	*100 mm*
RE	*40 mm*
TH	*6 mm*
DT	*22 mm*
DWS	*variable*
RS	*1 mm*
RSIS	*10^6 Ωm*

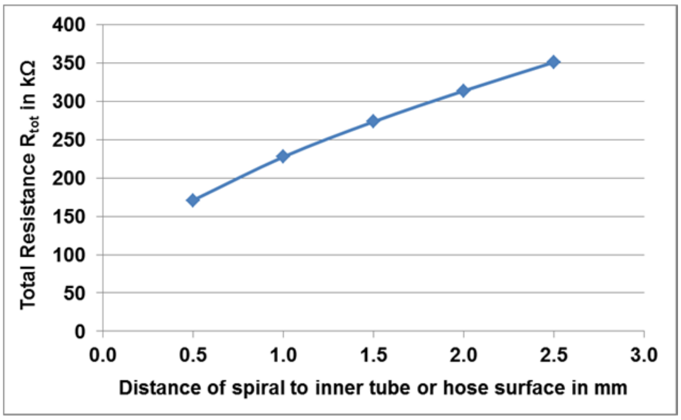
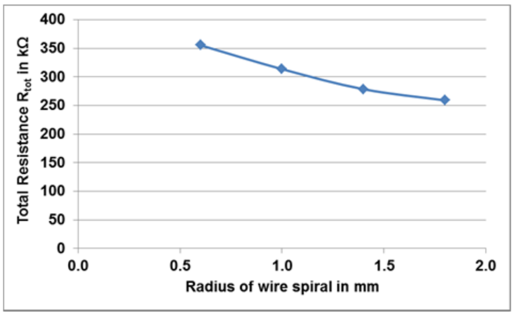


Figure 11: Total Resistance R_{tot} as a function of the radius of the wire spiral.
Parameters

L	*100 mm*
RE	*40 mm*
TH	*6 mm*
DT	*22 mm*
DWS	*2 mm*
RS	*variable*
RSIS	*10^6 Ωm*



How can now Figures 7 to 11 be used to calculate the material resistivity of the wall of a fully assembled spiral coiled tube or hose? This is explained in the following examples.

Example 1: The parameters of a fully assembled spiral coiled hose equal the parameters of Figure 7. With a conductive filling compound of length 100 mm a total resistance R_{tot} of about 60 MΩ is measured. This value is about 200 times higher than the total resistance R_{tot} in case of a hose with a resistivity of the wall material of 10^6 Ωm. Considering the fact that the total resistance R_{tot} is always directly proportional to the resistivity ρ of the wall material independent on all other parameters, the resistivity of the wall material is about $2{\cdot}10^8$ Ωm.

Example 2: The parameters of a fully assembled spiral coiled hose equal the parameters of Figure 10. The distance between the metal spiral surface and the inner wall surface is 2.5 mm. With a conductive filling compound of length 100 mm a total resistance R_{tot} of about 17.5 kΩ is measured. This value is about 20 times smaller than the total resistance R_{tot} in case of a hose with a resistivity of the wall material of 10^6 Ωm. Considering the fact that the total resistance R_{tot} is always directly proportional to the resistivity ρ of the wall material independent on all other parameters, the resistivity of the wall material is about $5{\cdot}10^4$ Ωm.

Example 3: The parameters of a fully assembled spiral coiled hose equal the parameters of Figure 9 except for the tube radius which is 80 mm instead of 40 mm. According to Figure 8 the radius difference changes the total resistance R_{tot} by about a factor of 2.15. This means that for the same total resistance R_{tot} a 80 mm radius hose has a 2.15 times higher resistivity than a 40 mm radius hose.

The height of one turn of the metal spiral is 36 mm. With a conductive filling compound of length 100 mm a total resistance R_{tot} of about 2 MΩ is measured. According to Figure 9 this value is about 4 times higher than the total resistance R_{tot} of 500 kΩ in case of a hose with a resistivity of the wall material of 10^6 Ωm. Thus, Considering only this latter difference and the fact that the total resistance R_{tot} is always directly proportional to the resistivity ρ of the wall material independent on all other parameters, the resistivity of the wall material would be about $4{\cdot}10^6$ Ωm. Considering in addition the factor of about 2.15 resulting from the radius difference, the resistivity of the wall material is about $8.6{\cdot}10^6$ Ωm.

The result of example 3, where two different parameters have to be adjusted, was validated with a computer simulation using the actual parameter set. The agreement was within 1%.

4. Conclusions

The procedure described in section 3.4 has proven to be very useful to calculate the resistivity of the wall material of fully assembled spiral coiled tubes or hoses without dismantling and destroying them, based on a simple resistance measurement.

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